

An Analysis of Spectral Selectivity on Edge Detection Algorithms for a
Non-invasive Identification of Skin Cancer

Dissertation Report

by

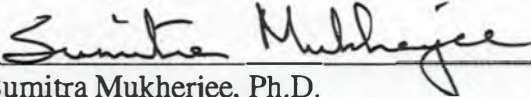
Gerald R. Williams

A dissertation proposal submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in
Computer Information Systems

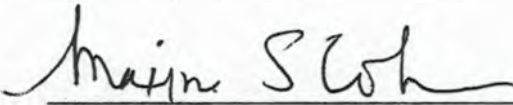
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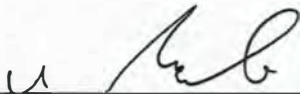
We hereby certify that this dissertation, submitted by Gerald R. Williams, conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirements for the degree of Doctor of Philosophy.


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Abstract

An Abstract of a Dissertation Submitted to Nova Southeastern University
in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

An Analysis of Spectral Selectivity on Edge Detection Algorithms for a
Non-invasive Identification of Skin Cancer

by
Gerald R. Williams

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Skin cancer is the number one form of cancer in humans today. Most moles or lesions are non-cancerous (defined as benign); however, a small percentage may actually be cancerous and can ultimately be fatal. A doctor has to draw from his or her own experience and manually inspect lesions for characteristics of skin cancer during a patient's medical exam to determine whether a lesion is cancerous or benign. Being able to make this distinction could prevent serious life-threatening conditions from going undiagnosed. A review of existing literature finds that most of the current research is now focused on using computer imagery to assist the doctor in this evaluation. The basic steps include capturing the image, defining the image (e.g., shape), performing any enhancements necessary to the image (e.g., hair removal), and finally analyzing and storing the characteristics of that image (e.g., asymmetry, border, dimensions, etc.). The image has a shape that will need to be defined and this is accomplished through a process known as edge detection. Edge detection algorithms identify and locate discontinuities in the pixel intensities of an image. The discontinuities are typically associated with abrupt changes in pixel intensity values that characterize the boundaries of the objects. Since current research depends so much on computer imagery and accurate edge detection, new research should focus on what can be done to enhance the image for edge detection analysis.

This dissertation focused on analyzing images of skin lesions with filtered light to determine if there were visible or non-visible characteristics of potentially cancerous lesions that the human eye could not see. This was accomplished by measuring the affect that different wavelength filters (spectral selectivity) had on lesion parameters. While this was only a small piece of the problem, it was an important building block necessary for an automated visual inspection system. Serious life threatening conditions could be better diagnosed if there was a certified visual inspection system that could distinguish benign lesions from cancerous lesions. This dissertation along with the existing body of

research established a foundation on which a future system could be designed and deployed that would aid patients as well as doctors by providing additional information that can result in an improved diagnosis.

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- 234. Lesion 473X Elongation Factor 351
- 235. Lesion 473X Compactness Factor 351
- 236. Lesion 473X Perimeter 352
- 237. Lesion 473X Heywood Circularity Factor 352
- 238. Lesion 473X Area 352
- 239. Lesion 474X Particles Found 353
- 240. Lesion 474X Elongation Factor 353
- 241. Lesion 474X Compactness Factor 353
- 242. Lesion 474X Perimeter 354
- 243. Lesion 474X Heywood Circularity Factor 354
- 244. Lesion 474X Area 354
- 245. Lesion 475X Particles Found 355
- 246. Lesion 475X Elongation Factor 355
- 247. Lesion 475X Compactness Factor 355
- 248. Lesion 475X Perimeter 356

- 249. Lesion 475X Heywood Circularity Factor 356
- 250. Lesion 475X Area 356
- 251. Lesion 476X Particles Found 357
- 252. Lesion 476X Elongation Factor 357
- 253. Lesion 476X Compactness Factor 357
- 254. Lesion 476X Perimeter 358
- 255. Lesion 476X Heywood Circularity Factor 358
- 256. Lesion 476X Area 358
- 257. Lesion 477X Particles Found 359
- 258. Lesion 477X Elongation Factor 359
- 259. Lesion 477X Compactness Factor 359
- 260. Lesion 477X Perimeter 360
- 261. Lesion 477X Heywood Circularity Factor 360
- 262. Lesion 477X Area 360
- 263. Lesion 479X Particles Found 361
- 264. Lesion 479X Elongation Factor 361
- 265. Lesion 479X Compactness Factor 361
- 266. Lesion 479X Perimeter 362
- 267. Lesion 479X Heywood Circularity Factor 362
- 268. Lesion 479X Area 362
- 269. Lesion 480X Particles Found 363
- 270. Lesion 480X Elongation Factor 363
- 271. Lesion 480X Compactness Factor 363

- 272. Lesion 480X Perimeter 364
- 273. Lesion 480X Heywood Circularity Factor 364
- 274. Lesion 480X Area 364
- 275. Lesion 481X Particles Found 365
- 276. Lesion 481X Elongation Factor 365
- 277. Lesion 481X Compactness Factor 365
- 278. Lesion 481X Perimeter 366
- 279. Lesion 481X Heywood Circularity Factor 366
- 280. Lesion 481X Area 366
- 281. Lesion 482X Particles Found 367
- 282. Lesion 482X Elongation Factor 367
- 283. Lesion 482X Compactness Factor 367
- 284. Lesion 482X Perimeter 368
- 285. Lesion 482X Heywood Circularity Factor 368
- 286. Lesion 482X Area 368

Chapter 1

Introduction

Problem Statement

Skin cancer is the most common form of cancer in humans today (Xu et al., 1999). The typical manifestation of skin cancer is the appearance of moles or the change of characteristics of existing moles. These moles are referred to as lesions. Most lesions are non-cancerous or benign, which is defined as no danger to one's health; however, a small percentage may actually be cancerous and can ultimately be fatal. Typically, a general practitioner has to draw from his own experience and manually inspect lesions for characteristics of skin cancer during a patient's medical exam. A problem exists in that it is very difficult to detect a benign lesion from a cancerous lesion. Being able to make this distinction could prevent serious life-threatening conditions from going undiagnosed. A review of existing literature found that most of the research is focused on using computer imagery to assist the doctor in this evaluation. The basic steps include capturing the image, defining the shape of the image, performing any enhancements necessary to the image such as hair removal, and finally analyzing and storing the characteristics of that image. The image has a shape that needed to be defined and this is accomplished through a process known as edge detection. Edge detection algorithms identify and locate discontinuities in the pixel intensities of an image. The discontinuities

are typically associated with abrupt changes in pixel intensity values that characterize the boundaries of the objects. Since current research depends so much on accurate edge detection, new research should focus on what can be done to enhance the image for edge detection analysis.

Goal

Most doctors may feel they are experienced enough based on the visual characteristics of skin cancer to make their own determination whether or not to extract a mole. Dr. Leon Cohen, a medical doctor in Florida with vast skin cancer experience, was asked his opinion about skin cancer detection. Dr. Cohen stated that it is sometimes difficult to determine if a lesion is malignant even when a biopsy is done. Sometimes a pathologist's analysis is inconclusive, and the sample is sent to a tertiary lab for further analysis. Unfortunately, this means the current visual inspection process can, and does, miss life threatening conditions involving malignant lesions (Noorzaie, et. al., 2004). So how can research and technology help a doctor in this endeavor? A review of existing literature found that most of the research involving visual inspection was focused on computer imagery using digital data. The basic steps were to capture an image, define the image (e.g., shape), perform any enhancements necessary to the image (e.g., hair removal), and finally to analyze and store the characteristics of that image (e.g., asymmetry, border, and dimensions, etc.).

This image also had a target or embedded shape that needed to be defined. This was accomplished through a process known as edge detection. Edge detection is an algorithm that is used to identify and locate discontinuities in the pixel intensities of an

image. The discontinuities are typically associated with abrupt changes in pixel intensity values that characterize the boundaries of the objects. Edge detection filters out irrelevant information and its goal is to significantly reduce the amount of data while preserving the important properties of an image (National Instruments, 2005).

Since current research depends so much on accurate edge detection, new research should focus on what can be done to enhance the image for edge detection analysis. The capture of an image is dependent on the reflectivity of the target. A person's skin, depending on their skin tone, will reflect different amounts of light. For this reason, color filters were used to enhance the image prior to image analysis. In addition, there could be characteristics outside the range of visible light to aid the edge detection algorithm.

As an analogy to help understand this concept, take the childhood experiment where an image with embedded words is not easily visible unless viewed through color filters. The lesson demonstrates the transmission and separation of color by filters. A transparent piece of glass transmits all wavelengths of light, while a red filter transmits red, a blue filter transmits blue, and a yellow filter transmits yellow. In other words, a filter transmits or passes one color while blocking out all others. If you are looking through a red filter then red and yellow objects are red and other colors (e.g., green) appear dark because their light is not transmitted through the filter (refer to Figure 1). A filter used to isolate a particular color or wavelength is known as spectral selectivity, which means to change the visibility of the image (NASA, 2006).

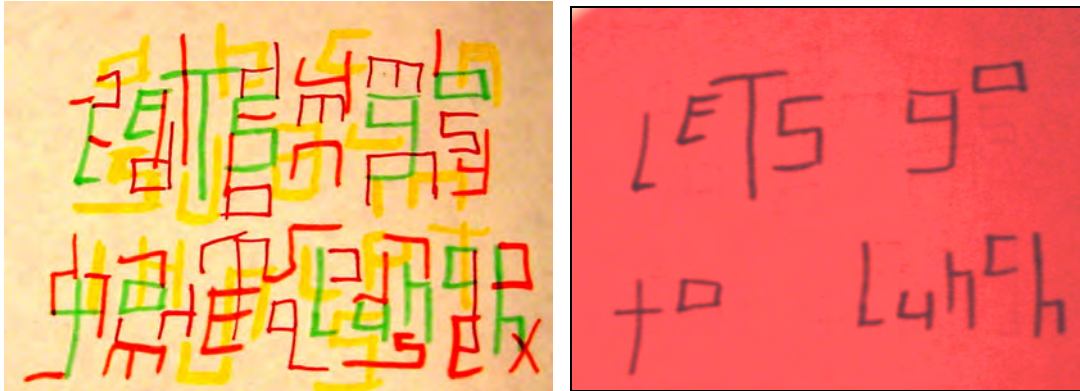


Figure 1. Message will show green as dark letters with a red filter (NASA, 2006)

This research examined the preliminary benefits provided by visual and non-visual spectral selectivity on edge detection. The analogy discussed above helped visualize how this research might ultimately reach this goal. Simply put, can different optical filters or the combination of optical filters aid in edge detection of skin lesions?

This was accomplished by answering the following questions:

1. Does spectral selectivity of visible light (color filtration) affect the results of an edge detection algorithm?
2. Does spectral selectivity of non-visible light (ultraviolet (UV), and infrared (IR)) affect the results of an edge detection algorithm?
3. Does spectral selectivity affect lesion parameter measurements (e.g., asymmetry, border, and dimension)?

While the goal of this research should be measurable, it was not practical to perform biopsies to verify whether a lesion was benign or malignant. The goal of this research was to analyze images of skin lesions with filtered light to determine if there were visible or non-visible characteristics of potentially cancerous lesions that the human eye could not see.

This was accomplished by measuring the affect of spectral selectivity on lesion parameters.

Relevance and Significance

According to the American Cancer Society, more than 700,000 new skin cancer cases are diagnosed annually in the United States (Xu et al., 1999). The three main types of skin cancer are basal cell carcinoma, squamous cell carcinoma, and melanoma (refer to Figure 2).

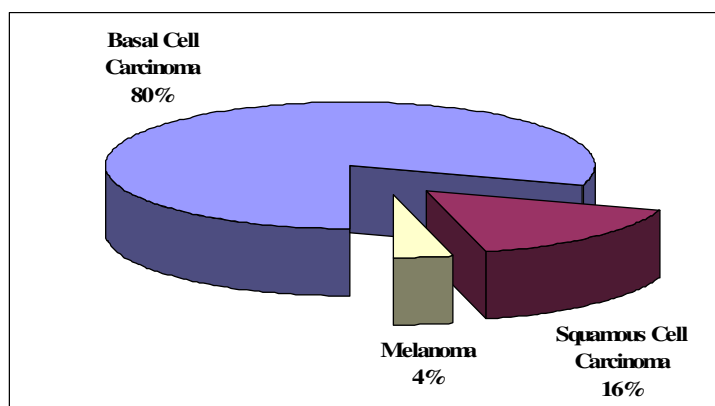


Figure 2. Skin Cancer by Type

Skin cancers are classified as either melanoma or non-melanoma. Non-melanoma (basal cell carcinoma and squamous cell carcinoma) can cause substantial illness and, if untreated, can cause considerable damage and disfigurement. These carcinomas have a cure rate of more than 90% if detected and treated early (Centers for Disease Control and Prevention (CDC), 2006). Where all three types are cancerous, melanoma is the most likely to metastasize to other organs. Melanoma accounts for about 4% of skin cancers diagnosed annually; however, the number of people developing melanoma is increasing faster than any other form of cancer. Melanoma also accounts for most of the mortality

from all skin cancers (Xu et al., 1999). The number of new melanomas diagnosed per 100,000 total population each year has more than doubled from 5.7 to 14.3 since 1973. In 2002 alone, 53,600 new melanomas were diagnosed in the United States and around 7,400 people died due to melanoma.

Surgical excision will typically cure melanoma if it is caught in its earliest stages and the five-year survival is better than 90%. However, if melanoma is diagnosed when it has penetrated the deeper levels of the skin or spread to other organs (e.g., bones, lungs, liver, brain, etc.) then the prognosis for survival is significantly reduced to only 6% (Gentry, 2003). Currently, the only way to know for sure whether a skin lesion is cancerous is to perform an incisional or core biopsy. A biopsy is a medical test where a small sample of living tissue is removed for microscopic examination (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005). This invasive approach next requires the tissue sample to be sent to and analyzed in a laboratory by a pathologist, which can take from three to 10 days (Sudha et. al., 2004). If the biopsy comes back positive, then a second procedure is performed called an excisional biopsy where the entire suspicious area is removed. The process is repeated until a safe margin of error is achieved around the area, which varies from 5 millimeters to 2 centimeters according to the depth of the cancerous cells. The purpose is to remove any cancer in the surrounding skin and to prevent it from growing back at the same site (Cancer Council Victoria, 2006).

Typically the patient will then have a Magnetic Resonance Imaging (MRI) and/or a Computed Tomography (CT Scan), originally known as Computed Axial Tomography (CAT scan), to determine if the melanoma has metastasized into other organs (Anderson

et al., 2005). The process discussed could be shortened significantly (in the event the lesion is malignant), or possibly completely avoided (if the lesion were benign) if there was a certified visual inspection system that could implement a non-invasive technique to detect skin cancer. This system could help save a patient's life.

Melanoma, while not as common as non-melanomas, account for most of the mortality from skin cancers. Therefore, the early detection of skin cancer, especially malignant melanoma considerably reduces morbidity and mortality. A questionnaire provided by the American Academy of Dermatology (AAD, 2005) can help determine your risk of skin cancer (refer to Appendix A). Scores less than 15 indicate a below average risk. While anyone can develop skin cancer, the following characteristics place some individuals at a higher risk (CDC, 2006):

- Lighter natural skin color
- Family history of skin cancer
- Personal history of skin cancer
- Constant exposure to the sun through work and play
- A history of sunburns early in life
- Skin that burns, freckles, gets red easily, or becomes painful in the sun
- Blue or green eyes
- Blond or red hair
- Certain types and a large number of moles

When cutaneous (relating to, or affecting the skin) melanoma is detected in its early stages and removed, there is a very high likelihood that the patient will survive. Clinical features of pigmented lesions, which suggest that melanoma may exist, are known as the ABCDs of melanoma: asymmetry, border irregularity, color variation, and diameter greater than 6 mm (Xu et al., 1999). Recent research have proposed that

the ABCD criteria be augmented by the addition of an E for evolving. The modified acronym is now referred to as the ABCDEs of melanoma: asymmetry, border irregularity, color variation, diameter, and evolving over time (Rigel, Friedman, Kopf, and Polsky, 2005). Image analysis techniques for measuring these features have been developed. This diagnostic technique requires that the lesions first be detected and localized in an image. The next critical step is to define the lesion boundaries of the image accurately so the asymmetry, irregularity of the boundary, color characteristics, and the maximum diameter can be computed. Various image segmentation methods have been developed to delineate lesion boundaries (Xu et al., 1999).

Non-melanoma skin cancers are rarely fatal but still should be taken very seriously. If left untreated, they can spread and cause other health problems. In 1994, 900,000 Americans were diagnosed with non-melanoma skin cancer, while only 1200 Americans died. The most common places for skin cancer to develop are on those body parts exposed to the sun such as the face, neck, ears, forearms, and hands.

The first type of non-melanoma skin cancers is basal cell carcinomas, which are tumors that usually appear as small, fleshy bumps or nodules on the head and neck, but can, occur anywhere on your skin. This type of skin cancer is the most common skin cancer found among fair-skinned people. Basal cell carcinoma does not grow quickly and rarely spreads to other parts of the body; however, it can penetrate below the skin to the bone and cause considerable local damage.

The second type of non-melanoma skin cancers is squamous cell carcinomas and it appears as nodules or as red, scaly patches. This type of skin cancer is the second most

common skin cancer found among fair-skinned people. Squamous cell carcinoma can develop into large masses, and unlike basal cell carcinoma, it can spread to other parts of the body, although this is rare.

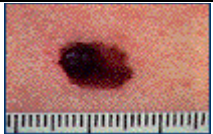
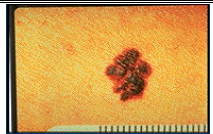
The last type of skin cancer is malignant melanomas, which may appear without warning as a dark mole or other dark spot in the skin. Melanoma is the most serious form of skin cancer and is one of the fastest growing types of cancer in the United States. Melanoma cases in the U.S. have almost doubled in the past two decades and the rise in melanoma cases and deaths in America is expected to continue (EHSO, 2005).

All three types of skin cancer can be curable if you detect them in their early stages. Recent research has shown certain moles are at a higher risk for changing into malignant melanoma; for example, moles that are present at birth and atypical moles have a greater chance of becoming malignant. In the early 1980s, New York University (NYU) developed a memorable paradigm to improve survival by enhancing the early detection of melanoma through the recognition of visible clinical features. At that time, physicians were asked why they thought a lesion was a melanoma, they invariably answered, "Because it looked like one." When these experienced physicians were displayed images of melanoma they were generally able to correctly identify them as melanoma; however, it was clear that a more objective reproducible criterion was needed for early diagnosis. The analysis of the NYU cooperative group database found that there were recognizable clinical features such as asymmetry, border irregularity, color variation, and a diameter greater than 6 mm that differentiated benign lesions from melanoma. These clinical features led to the creation of the ABCDE acronym, which has

subsequently been accepted as an aid in the early diagnosis of melanoma (Rigel, Friedman, Kopf, and Polsky, 2005).

The University of Maryland Medical Center (UMMC) developed an ABCD chart with examples of benign moles and melanoma to aid in the recognition and early detection of malignant melanoma. Melanomas vary greatly in appearance and some melanomas may show all of the ABCD characteristics while others may not (refer to Table 1) (UMMC, 2004).

Table 1. Distinguishing Benign Moles from Melanoma (UMMC, 2004)

Normal Mole	Melanoma	Sign	Characteristic
		<u>A</u> symmetry	When half of the mole does not match the other half
		<u>B</u> order	When the border (edges) of the mole are ragged or irregular
		<u>C</u> olor	When the color of the mole varies throughout
		<u>D</u> iameter	If the mole's diameter is larger than a pencil's eraser

While melanoma is the most life threatening skin cancer, all three types of skin cancers will benefit from this research, as all three share many common characteristics. The significance of this research is not only public awareness but also laying down a foundation for a non-intrusive skin cancer detection.

Barriers and Issues

Why the Goal Has Not Been Met

A new European system based on confocal imaging promises to improve cancerous lesion detection and diagnosis rates by 20 percent (Sheblee, 2005). While 20% is quite an improvement, it is also an indication of just how hard this goal is to achieve. Sheblee stated that their current project has ended, but they hope to develop another prototype in the next five years where they can take advantage of significant technology changes. Stoecker (2004) stated there have already been several trials of automated systems in the presence of human observers. As of today, it is unlikely that these systems will replace the skill and judgment of a trained physician. In addition, it is also unlikely that the Food and Drug Administration (FDA) would approve any system any time in the near future. The next logical step is to see if this technique can be used to give a physician further data in the ABCD identification and analysis.

Contributing Issues

Many issues contributed to the difficulty in completing this research. The most difficult was the location of human subjects with not only easily accessible skin lesions but who were also willing to be a human test subject. While this research used real test subjects, it was not the intent to determine whether a human subject's skin lesions were benign or cancerous.

Hardware / Software Acquisition

The acquisition of the software required to complete this research was an issue. The researcher elected to utilize the National Instrument's (NI) LabVIEW™ suite for this research. The NI LabView™ programming environment supports numerous hardware instruments that accommodated the frequent changes necessary to design and test a system of this complexity. In an effort to minimize the cost of this research, some hardware was borrowed from various sources.

Hair Interference

Human hair became an issue during image analysis. For this reason, the elimination of the hair prior to acquisition was desirable (refer to Figure 3). The image on the left is the source image. The image on the right is after the edge detection algorithm has defined a region of interest (ROI). As can be noted from the image, hair has a major impact on the edge detection algorithm. For this reason, volunteers with hair around a lesion of interest were asked to shave the ROI. If they could not or would not, then they were excluded from the research.

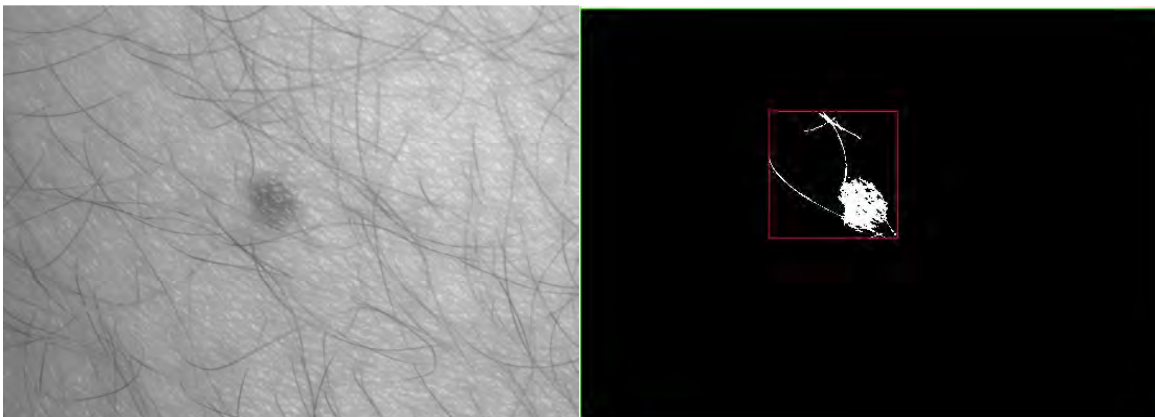


Figure 3. Hair Interference

Macro Photography Steadiness

The stability of the camera during data acquisition was identified as a potential issue during testing and experimentation. This research involves taking very close up images where the working distance from the end of the lens to the test subject is approximately eight inches. While a fixed focus was used, macro photography has a small focus window and an out of focus image is possible with movement of the camera or test subject. This issue was addressed by using a tripod, which provided a stable platform and therefore prevented any movement of the camera. In addition, for photography of human limbs the test subject was asked to place his or her limb on a stable surface to prevent any movement of the test subject.

Hypotheses

The job of research is to observe, describe, and explain the natural world through hypotheses and experimentation. Given the above framework and goal, the hypotheses that this paper attempted to address were:

1. The reflectivity of the skin will be different when spectral selectivity (filters) is used and this will impact the results of capturing the digital image.
2. Non-visible light imaging may offer advantages over selected bands of visible light for edge detection.
3. Spectral selectivity significantly affects the results of edge detection algorithms.

Limitation and Delimitation

Limitations

Factors that might have affected this study, but **were not** under control of the research were:

1. Limited ultraviolet sensitivity using a commercial off the shelf (COTS) camera due to budget constraints.
2. Limited ethnicity (skin tone) coverage based on sample size and/or geography.

Delimitations

Factors that might affected this study but **were** under control of the research were:

1. Ambient light at target location (note that flash will be the primary light source)
2. Quality of hair elimination will be variable since the subject will have to shave himself/herself

Summary

The number one form of cancer in humans today is skin cancer. While most skin lesions are non-cancerous or benign a small percentage may actually be cancerous and ultimately fatal. A doctor has to draw from his or her own experience and manually inspect lesions for characteristics of skin cancer during a patient's medical exam. Unfortunately, it is very difficult to detect a benign lesion from a cancerous lesion. Being able to make this distinction would help prevent serious life-threatening conditions from going undiagnosed. A certified visual inspection system, one that included an accurate edge detection methodology, could potentially help a doctor make a proper and accurate

determination. A future system could aid patients as well as doctors and help avoid situations where a judgment call is necessary by providing additional information that will result in an improved diagnosis.

Chapter 2

Review of the Literature

Research Literature

The purpose of this literature review was to establish the context for this dissertation, and to acknowledge the contributions of previous researchers. First, a survey paper by Suetens, Fua, and Hanson on the field of digital imagery, digital imagery definitions, and edge detection algorithms was presented. This was followed by a survey paper by Arman and Aggarwal on computer vision as a subset of the machine intelligence. Finally, significant contributions of other researchers in the field since 1993 were presented such as: mobile communications, optoelectronic biopsy, and Epiluminescence microscopy. Each source closed by establishing a relationship between the previously conducted investigations in the professional literature and the dissertation proposal. A brief discussion on these papers follows.

Suetens, Fua, and Hanson (1992) survey paper introduced the field of applied object recognition for the non-specialist as well as a detailed guide for those beginning research in this domain. Practical computational strategies for recognizing objects in digital imagery with a focus on mature techniques with explicit models and working applications were researched. The techniques were classified into groups according to the nature of the computational strategy used.

- Simplest strategies, which work on data appropriate for feature, vector classification.
- Methods that match models to symbolic data structures for situations involving reliable data and complex models.
- Approaches that fit models to the photometry and are appropriate for noisy data and simple models.
- Combinations of these strategies, which must be adopted in complex situations.

Representative examples of various methods were evaluated with respect to their appropriateness for particular applications.

In order to survey the papers objectively, some characteristics of an object recognition task needed to be defined. Object recognition is defined as the task of finding and labeling parts of a two-dimensional (2D) image of a scene that correspond to objects in the scene. For example, an aerial image of an industrial complex would require a human observer to recognize and label buildings and roads.

Photometry is typically defined as light intensities reflected from surfaces in a scene and recorded on camera film; however, sources such as ultrasound or x-ray absorption can also be used instead of light. A digital computer image of a scene is a 2D array of numbers called pixels whose values represent the scene's photometry, which simply stated is the strength of the signal or intensity information arriving at a particular point on the recording medium (e.g., film, digital sensor, etc.).

The first step in an object recognition task is to establish models or general descriptions of each object that needs identified. A model typically includes the shape, texture, and context knowledge about the object in a scene. The shape could be a mathematical description of a building while the texture might include colors or knowledge about the layout of a building's windows. There are several important

distinctions about the kind of information in a digital image. The syntactic information deals only with the pixel values themselves and not their meaning. In contrast, the semantic information deals with knowledge and meaning of the pixels in the image. Therefore, a syntactic image operation means that a procedure blindly applies an algorithm to the pixel values, for example, a procedure that assembles groups of adjacent pixels that have a high contrast with their other neighbors. A semantic operation uses models of the scene and the image production process that incorporate symbolic knowledge about the organization of the information, for example, parts may be laying on top of one another.

A closely related term that is frequently used is the term local, which refers to processes that look at a pixel and its very nearest neighbors but uses no information about the rest of the image; local processes are typically syntactic. On the other hand, the term global refers to context information from the entire image or scene and is usually semantic. In summary, object recognition is the process of drawing lines and outlining areas in an image that corresponds to the model that best represents it. In this paper, the authors restricted the scope of the research to object models that include knowledge of object structure such as shape or semantic context. In particular, models are not considered that rely strictly on local photometry or syntactic context (e.g., all contiguous pixels with an intensity value above 128). These restrictions, in effect, will focus on object recognition strategies such as locating single object instances, accurately determining object boundaries in an image, and choosing an object's best class membership from among many possibilities.

Object recognition is very a difficult process since a number of factors will be considered to identify objects. Ironically, a human will experience the same type of confusion that a computer system does if the context of the scene is not clearly understood. For example, given the context information that the image is an aerial image of a highway, an object such as an automobile is more easily recognized. Cultural context plays a central role in enabling us to interpret the scene. In other words, computer systems as well as humans need appropriate context models in order to carry out object recognition and scene interpretation. The simplest approaches to object recognition rely entirely on operators that analyze the photometric statistics of the image such as light intensities. Unfortunately, this method may fail since real objects are defined by geometric and semantic characteristics as well as their statistical properties. While not part of the author's research, it is important to understand the impact that local image statistics can have. For example, a simple parameter setting for an edge detector algorithm will produce so many edges that relevant information either cannot be perceived in the clutter or will fail to extract edges that are crucial for the interpretation process. Another example are region segmentation algorithms which either under-segment (combine semantically meaningful objects) or over-segment (break coherent objects into unrecognizable pieces). These errors are inevitable because statistical techniques fail to consider higher-level geometric and semantic knowledge. An example of these phenomena is shown below for the Canny edge detection algorithm and was computed with progressively lower-edge strength thresholds (refer to Figure 4 and Figure 5).



Figure 4. A source image of an aerial suburban scene



Figure 5. Canny edge images computed with progressively lower-edge strength thresholds (Canny, 1986)

As can be noted from this example, many object recognition approaches depend on the assumption that the outlines appearing in some images are defined by such methods that will correspond directly to objects such as buildings; however, this assumption is not always the case. In summary, the authors emphasized that the major task in the object recognition process is to outline areas in an image identifiable as model instances and that it is tempting to use one of the above edge detection or region segmentation methods by itself. Unfortunately, this generally does not work since there are no conceptual models; however, simple techniques can form a basis or starting point for a more sophisticated analysis. This example emphasizes how a small parameter change can have a large impact on the outcome of an edge detection algorithm. It is also important to note that Canny is a more sophisticated edge detection approach as compared to its predecessors such as: Differentiation, Gradient, Prewitt, Roberts, Sigma, or Sobel. While the authors successfully argued that local photometry does not fully

characterize objects in the real world and that effective object recognition procedures must incorporate model knowledge or context, this is outside the scope of this dissertation. This research will be keeping the edge detection parameters constant since the goal is to evaluate whether spectral selectivity has an affect on edge detection algorithms and not to determine whether an edge detection algorithm successfully segmented an image based on content.

Arman and Aggarwal (1993) paper surveys computer vision as a subset of the machine intelligence systems area. The goal of a computer vision system is to interpret the visual data to complete a task. Such tasks include (1) the navigation of autonomous vehicles, (2) the assembly or inspection of manufactured parts, and (3) the analysis of microscopic images and medical x-rays. A vision system must know the shape or geometry of the objects and sometimes information such as thermal and stress properties. A vision system, which makes use of an object model, is referred to as a model-based vision system. The general problem of identifying the desired object is defined as object recognition. Ideally, a model-based vision system should be able to locate objects in an image. To design such systems, models are necessary to provide prior knowledge of the vision system. This paper surveys published papers up to 1993 that addressed the problem of the model-based recognition of objects in 3D dense-range images. The survey paper discussed specific problems of model-based vision, 3D sensors, various low-level processing procedures, various representations used to describe the objects, modeling schemes such as computer-aided design (CAD), and matching strategies. While this survey paper covered several important topics, the author's research as it

applies to this dissertation was on the various low-level processing procedures necessary as a preliminary step to the description and recognition of objects (Arman and Aggarwal, 1993).

As mentioned above, the ideal vision system must be able to recognize arbitrarily shaped objects in an image. The system must be able to cope with possible partial occlusion from other objects in the scene. Prior to the calculation of most surface properties, the image must be smoothed to compensate for sensor inaccuracies and calibration errors. The next step involves the calculation of second-order partial derivatives that magnify the effects of any noise present. While many studies have been done on noise reduction for gray-scale images, most researchers have adapted noise reduction methods developed from gray-scale images. In addition, most studies assume the error to exist only in the z coordinate (the depth value) of the measurements (Arman and Aggarwal, 1993).

In Gaussian smoothing the data is convolved with the rotationally invariant Gaussian filter (refer to the equation listed below) (Marr and Hildreth, 1980).

$$G(u, v) = e^{-(u^2 + v^2)/2\sigma^2} \quad (1)$$

Where:

(u, v) is the intrinsic coordinate of each point in the data.

The variance σ is chosen such that the noise in the data is suppressed while the significant features of the data are preserved. Unfortunately, the larger σ becomes for effective noise reduction will result in too much blurring of the image and the loss of the

image details. As an alternative, the image can be convolved many times with a smaller operator such as:

$$\begin{bmatrix} 1 & 2 & 1 \\ 2 & 12 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

Using the central-limit theorem, this operation will approximate the Gaussian window with a standard deviation of $\sqrt{n}$, where n is the number of iterations.

In 1987, Hoffman and Jain investigated several smoothing techniques such as the median filter, nearest neighborhood smoothing, and maximum likelihood smoothing. In maximum-likelihood smoothing, a square neighborhood of each pixel is examined, and each pixel is replaced by the average of a subset of the neighborhood pixels. Using such an approach, Hoffman and Jain research on synthetic images reported that the standard deviation of the added noise dropped by a half using a 3×3 window. In 1988, Saint-Marc and Medioni presented an adaptive smoothing filter, which is applicable to intensity or range images. Once noise reduction processes are completed, many of the surface properties can be approximated using one of two general approaches. In the first approach, a mathematical function is fitted to the data, and then the necessary partial derivatives are solved at each point. The disadvantage of this approach is that the image must be partitioned prior to applying the mathematical function since no single function can approximate all areas of an image. The second approach uses a set of local window operators convolved with the image data points to calculate the partial derivatives at each point. The size of the operator is very important since small windows might not yield

good approximations to curvature and large windows may overlap areas that include surface discontinuities. This, in turn, will cause erroneous errors close to the boundary points; nevertheless, this approach is more computationally efficient and therefore more popular. Most vision systems data collected is represented using symbolic descriptions. Segmentation is the assignment of the pixels in a given image into one of many disjointed sets where each set shares a common property. The criterion used to assign each pixel to a set is dependent on the desired task, the desired description, and the scene. The authors' results were good on segmentation of several real-range images (Arman and Aggarwal, 1993).

In 1987, Hoffman and Jain segmentation researched noisy synthetic images using a clustering algorithm. The features used for the clustering are the 3D data points. The regions with less than a threshold number of pixels are merged with the one neighbor that shares the longest boundary. Next, the resulting patches undergo three statistical tests: trend test, curvature planarity test; and an Eigenvalue test. Eigenvalue is defined as a special set of scalars associated with a linear system of equations that are sometimes also known as characteristic roots, characteristic values (Hoffman and Kunze, 1971), proper values, or latent roots (Marcus and Minc, 1988). Finally, the combined results yield a final segmentation and classification. The more common approach is that pixels with similar properties are grouped together to form the desired partitions; however, an alternative approach is to detect dissimilarities among data points and to partition them accordingly. In 1990, Fan and his colleagues used the outputs of three segmentation methods to detect discontinuities in the curvature of the input data to partition dense-

range images. In the first segmentation method, Gaussian smoothing is performed with four different variances and the results from the four directions are merged. In the second segmentation method, the images are Gaussian smoothed, and the extrema and zero crossings are computed. The third segmentation method combines two processes. The first process consists of adaptively smoothing the input image using the first derivatives followed by calculating the curvature extrema. In the second process, the Canny edge operator (Canny, 1986) detects surface discontinuities. The results of the three segmentation methods are then combined with good segmentation results. This research also utilized the Canny edge detection algorithm and evaluated whether spectral selectivity has an affect on this algorithm as well as some of the predecessors to Canny. In addition, this survey paper focused on segmenting complex images and while this might be applicable for overlapping lesions for future research, the focus of this dissertation was identifying the edge of one lesion in an image for evaluation and analysis (Arman and Aggarwal, 1993).

John Canny (1986) defined a computational approach for edge detection. The success of this approach depended on a comprehensive set of goals for the computation of edge points. Canny specified three issues that an edge detector must address to be optimum. These are:

- **Error rate** - the edge detector should respond only to edges, and should find all of them; no edges should be missed.
- **Localization** - the distance between the edge pixels as found by the edge detector and the actual edge should be as small as possible.
- **Response** - the edge detector should not identify multiple edge pixels where only a single edge exists (Parker, 1996).

According to Canny, the optimal filter that meets all three criteria above can be efficiently approximated using the first derivative of a Gaussian function. While spectral selectivity will be evaluated against several other edge detection algorithms, Canny offers a more sophisticated edge detection approach and is more commonly recognized.

Schindewolf et. al (1994) evaluated different image acquisition techniques for a computer vision system that would be used in the diagnosis of malignant melanoma. The characteristics of the lesions were computed for over 700 lesions. Some of the lesions were from slides used for medical reports, teaching, and research in dermatology. While the rest of the images were acquired directly from patients utilizing new technologies such as small high-resolution digital cameras with charge coupled device (CCD) sensors. These new technologies have made it possible to digitize skin lesions directly from the patient. The advantage of this is that the image can be stored directly to a computer as a digital image and analyzed. The research was motivated by the work Cascinelli and his colleagues completed in 1987 where digital imaging for the diagnosis of malignant melanoma was deemed feasible. Since the fact was established that digital image analysis was found to be a useful tool for preoperative diagnosis of melanocytic lesions, this research investigated which kind of image acquisition technique is more appropriate for digital image analysis. This research used six different image classifiers for establishing standardized image size and color features. Standardization of the size between measurements proved to be very challenging. The only way to alleviate this issue was by acquiring images directly from patients at a fixed distance. This dissertation also acquired images at a fixed distance, otherwise there is a degree of inaccuracy even

though technology exists that could calculate and adjust the image size. Schindewolf and his colleagues also identified 20×20 mm as an ideal size area size for sufficient feature extraction. This dissertation research was based on a 35mm camera and used a similar resolution of 28×42 mm. While a smaller area might provide better resolution, a larger area allowed for feature extraction of the surrounding skin. Another noteworthy fact identified by Schindewolf was that it is very difficult to train a classifier and that the classifiers produced different results. This really comes as no surprise since a repeatable and accurate methodology for feature extraction still does not exist and is why this technology is not used or is not found in every doctor's office today.

Green et al. (1994) goal was to develop a computer image analysis system that has potential use as an adjunct to clinical distinction of melanoma from less serious pigmented lesions. Cutaneous melanoma is unique among other cancers in that it contrasts with the surrounding skin as well as being easily accessible. As compared to breast cancer where a system only has to detect a tumor, the goal of this system is to differentiate melanoma from benign lesions. According to the authors, many early melanomas are excised with the diagnosis being unsuspected. This raises the question, how many invasive melanomas may be unsuspected but are not excised in this early more treatable stage. The software developed for this system had the goal of objectively distinguishing melanomas from less serious pigmented lesions on the skin such as nevi, freckles, pigmented basal cell carcinomas, and seborrheic keratoses. Some of the characteristics for diagnosis include color, variegation, shape, size, regularity of outline, and distinctness of the boundary with the surrounding skin. The algorithm used for

segmentation was adapted from a gray scale thresholding to use red, green, and blue (RGB) level intensities. The system consists of a hand-held device that incorporates a video camera and color frame grabber. The analysis software extracted features relevant to the size, color, shape, and boundary of each lesion. The features extracted were correlated with clinical and historical characteristics on which standard diagnosis of skin tumors are based. The results showed that computer image analysis has the potential to provide valuable diagnostic data that could enable the health care industry to make specific diagnosis of early curable melanoma. The motivation for this research stems from the difficulty of differentiating early melanoma from benign pigmented lesions since both have a similar clinical appearance. The researchers showed that the most powerful discriminate was first the size, and second the color variegation. While size is an important consideration, the melanoma might have already metastasized into other organs before the size is considered suspicious. While this research also measured the size of a lesion, it examined the more subtle characteristics such as asymmetry and border as well.

Seidenari, Burrioni, Dell'Eva, Pepe, and Belletti (1995) evaluated the usefulness of a videomicroscope with polarized light. Dermatologists are now faced with a rising incident rate of malignant melanoma. In recent years, there has been an increasing effort in the early diagnosis of malignant melanoma. A breakthrough was accomplished in the early diagnosis of malignant melanoma with the introduction of vivo epiluminescence (ELM). This non-invasive technique employs oil immersion and thus makes the subsurface structures of the skin more accessible. The study examined 114 images of

benign pigmented skin lesions and compared the data recorded with polarization and oil modes. The polarization enables the recognition of subsurface structures such as pigment networks and capillaries. The red and blue components in the image are more pronounced with this technique. However, green components are more pronounced in green oil images. Videomicroscopes are now cheap and readily available thus enabling a quick examination of skin area. The authors' research demonstrated that the polarized mode allowed for a computerized epiluminescence where a rapid screening of numerous patients and lesions is necessary. Now decisions can be made on diagnostic criteria of features that would otherwise not be visible to the naked eye. While ELM was not being examined in this dissertation, this research examined light outside the visible light spectrum.

Xu et al. (1999) addresses the experiences the authors faced with the segmentation of images of skin cancer and other pigmented lesions. Their approach starts by reducing a color image into an intensity image and segmented in what the authors call "intensity thresholding." The image is then refined using the segmentation of image edges. The authors call the next step "double thresholding" and it is used to focus on an image area where a lesion boundary potentially exists. An elastic curve is fitted around the initial circumference of the image and is locally shrunk or expanded to approximate the edges in the area of focus. Their research of 20 randomly selected images showed an average error that was approximately the same as that obtained by four experts manually segmenting the images. Thresholding will also be used in this research to isolate the area of interest in the image.

Zhou, Li, and Aggarwal (2004) examine the challenging task of extracting object boundaries in thermal images that lack sharp boundaries. In the past, classical edge-based segmentation methods have had the drawback of not connecting edge segments to form a distinct and meaningful boundary. There have been numerous approaches to extract object boundaries, which include changes of the topology and the presence of corners. Previous researcher's methodology has included image gradients, edge strengths, area minimization and region intensity. The approach used by the authors uses both the edge direction and the gradient magnitude to overcome the problems resulting from weak edges. This research also experienced weak edges especially with images outside the visible light spectrum.

Zouridakis, Doshi, Duvic, and Mullani (2005) presented a new methodology for early detection of skin cancer based on the analysis of a pair of cross-polarization and side-transillumination images to examine surface pigmentation and vascularization characteristics of a lesion. In the early stages of skin cancer, the cure rate in most cases is very high; therefore, it is paramount to screen patients frequently who have skin pigmentations. Their approach involves the use of cross-polarization epiluminescence imaging (ELM) (XLM) as well as side-transillumination ELM (TLM) cross-polarization (ELM). Side-transillumination ELM (TLM) is a new imaging technique in which light is directed from a ring around the periphery of a lesion towards its center at an angle of 45 degrees. This forms a virtual light source around the focal point of the image about 1 cm below the surface of the skin making it translucent. According to the author, TLM has a big advantage since it is sensitive to increased blood flow and vascularization. In

addition, TLM also has the ability to visualize the subsurface pigmentation in a nevus. Nevus refers to different, usually benign, pigmented lesions of the skin (e.g., birthmarks) (Anderson, D., Anderson, K., Anderson, L., and Glanze, 2005). This technique is the basis for the development of a prototype device called Nevoscope that can produce cross-polarization ELM (XLM) as well as TLM images. Their procedure involves ingesting both images and automatically segmenting them using three separate procedures. The most accurate results are selected by a scoring stage. The final step classifies a lesion as malignant or benign by measuring the amount of hypervascularity around the pigmented area. The goal of this research was the early detection of skin cancer (Zouridakis et al., 2005).

Noorzaie, Aslandogan, and Celebi (2004) examines the use of mobile communications devices capable of acquiring high-resolution images and whether they are technically feasible to conduct remote screening of various medical conditions. The authors present a system that supports remote acquisition of images and similarity retrieval from a centralized database after automatic content analysis. The system introduced by the authors was a prototype for the remote screening of skin lesion images that supported remote image acquisition by a device such as a digital cell phone, wireless Personal Digital Assistant (PDA), digital camera, or communication via the Internet. A user starts by first submitting an image query through a web interface. The system goes through an automated analysis procedure and produces an interactive report containing similar images and a risk analysis. Ultimately, the goal of this research was to produce an automated analysis report.

Westerhoff, McCarthy, and Menzies (2000) examine whether primary care physicians (PCP) or general practitioners could improve melanoma diagnosis using surface microscopy after a short education session on the technology involved. Skin surface microscopy (e.g., oil epiluminescence microscopy, dermoscopy, and dermatoscopy) has been shown to increase the diagnostic accuracy of detecting malignant melanoma; however, all of these studies to date have been in an expert setting.

Dermoscopy, dermatoscopy and epiluminescence microscopy are terms that describe the use of an incident light magnification system to examine skin lesions with immersion oil at the skin-microscope interface. The most commonly used surface microscopes are hand-held instruments that allow a fixed magnification of $\times 10$ (e.g., EpiscopesTM, Welch Allyn Inc., Skaneateles Falls, NY, U.S.A.; DermatoscopeTM, Heine Ltd, Herrsching, Germany). Surface microscopy allows the epidermis to become translucent, and therefore permits a detailed examination of the pigmented structures. The result is the visualization of morphological features that are not visible with the naked eye. This allows for early clinical diagnosis of nearly all pigmented lesions including invasive melanoma. The authors asked seventy-four practicing PCPs to complete a pretest of 50 melanomas and 50 atypical non-melanoma pigmented skin lesions. Next, the PCPs were randomized between two groups: one group that was educated on surface microscopy and a control group. The group that received the training showed a significant improvement in both clinical melanoma diagnosis (63% versus 55%) and surface microscopy melanoma diagnosis (76% versus 58%) while the control group showed no notable difference was found between pretest and post-test. An improvement was recorded in the diagnosis of

melanoma with surface microscopy. This increased accuracy should help reduce the number of needless excisions while ensuring actual melanoma is identified early. While the instrument for this research was a specialized camera, it is similar to epiluminescence microscopy, dermoscopy, and dermatoscopy methodologies.

Ganster et al. (2001) developed a system for the computerized analysis of images obtained from Epiluminescence microscopy (ELM). This system was developed to enhance the early recognition of malignant melanoma. Malignant melanoma is one of the leading cancers among many white-skinned populations around the world. A change of recreational behavior together with the increase in ultraviolet radiation has caused a dramatic increase in the number of melanomas diagnosed. The incident rate increase in the United State was first noticed in 1930, where one person out of 100 000 per year suffered from skin cancer. The incident rate increased to six people out of 100,000 in 1985 and 13 people out of 100,000 in 1991. The incident rate increase is comparable to rates observed in Europe. In Austria the incidence of melanoma increase 51.8 % in the ten-year period between 1985 and 1995. On the other hand, investigations have shown that the curability of skin cancer is nearly 100% if it is recognized early and treated surgically. This is quite an improvement since the mortality rate caused by melanomas in the early sixties was about 70%. Since there is now a higher incidence rate for malignant melanoma, researchers are concerned more and more with the automated diagnosis of skin lesions. Ironically, despite a vast amount of research into automated melanoma recognition by an image processing system, an integrated dermatological image analysis system is rarely found in clinical use, nor have these systems been tested on a significant

number of real-life samples. ELM has proven to be an important tool in the early recognition of malignant melanoma. In ELM, halogen light is projected onto the object, thus rendering the surface translucent and making subsurface structures visible. First, a binary mask of the skin lesion is determined by several segmentation algorithms combined with a fusion strategy. Next, a set of features containing shape and radiometric features are calculated to describe the malignancy of a lesion. While the initial research showed positive results, new parameters have to be derived and included in the feature sets in order to achieve better classification results. These new parameters need to better describe the lesion boundary as well as the texture for future research. The system presented here is currently undergoing comprehensive tests at the Department of Dermatology at the Vienna General Hospital. While the goal of this system was the same as this research, the approach was different since this research was based on ELM (Ganster et al., 2001).

Sudha and Palnivelu (2004) propose an optoelectronic biopsy that employs a light source and optical fibers. The reflectance imaging system permits imaging of the tissue to discriminate the cancerous ones without removal of tissues for analysis. This system is based on the principle of backscattering of laser radiation from tissue and promises to be a low cost, accurate and fast tool for detection of skin cancer. The goal of this research was ultimately the same, to analyze tissue without its removal.

Summary

The field of computer imagery is the backbone in reaching the ultimate goal of an automated melanoma recognition system. The summary of what is known is vast, yet an

approved system has yet to be fielded and tested. The existing research has focused on computer aided image analysis, research data description, segmentation, feature calculation, and classification. Narrowing the focus even further to edge detection, which typically falls under segmentation research for image analysis, there is a void on how spectral selectivity affects these algorithms. With an increase in computational computer power, the Canny edge detection algorithm brought a more sophisticated approach as compared to its predecessors such as: Differentiation, Gradient, Prewitt, Roberts, Sigma, and Sobel. While there is existing literature on IR, UV, as well as ELM, none of these approaches specifically addressed how spectral selectivity affects edge detection algorithms. This gap in research needs to be filled if the ultimate goal of a non-invasive identification of skin cancer is ever to be achieved.

Research Contribution

The review of the literature has shown that the existing body of research has laid a foundation for this work. This literature demonstrates the complexity involved in being able to detect a benign lesion from a cancerous lesion. The ultimate goal of the existing research as well as this research was to be able to prevent serious life-threatening conditions from going undiagnosed. While there is a large body of research on edge detection, this research held different edge detection algorithms as a constant parameter and altered the filters or wavelengths input to the edge detection algorithms inside and outside the visible light spectrum. This research was another step that added to the existing body of research by determining whether spectral selectivity as it applies to edge

detection can be used for the automated recognition of melanoma by image processing in the future.

Chapter 3

Methodology

Background

The overall approach was to design a system capable of capturing filtered images, analyzing the image, and producing a report that shows the properties for that image (e.g., centroid, area, circumference, circularity, eccentricity, perimeter, etc.). The next step was to find volunteers with easily accessible skin lesions. Once located, the volunteers were briefed on the research and asked to sign a release form (refer to Appendix B). Then several pictures were taken of a volunteer's lesion at a fixed distance using a variety of spectral selectivity filters, including color, non-visible ultraviolet (UV), and infrared (IR). Next, some of the data had to be preprocessed to separate the RGB channels into separate files. The final step was to analyze the output for each filter statistically to compare the images to the baseline to determine whether the filters produce a statistically significant variance.

To expand further on this approach, this chapter is organized as follows: a description of how the human eye works; a description and background of digital optics and photography; camera, lens, filter and lighting specifications for this research; digital storage and data compression that laid a foundation for the investigation of skin lesions.

The Human Eye

To understand how the data in a digital picture was processed there needs to be a basic understanding of how the human eye operates. A camera has a flat image plane that gives it a reasonably constant response and resolution. The human eye is quite different from a camera and is comprised of a lens and iris diaphragm (refer to Figure 6). The retina is a thin layer of nerve cells that is partially composed of light sensor cells. This retina layer makes up the majority of the inside chamber of the eye and accounts for our wide angle of peripheral vision. The eye has the flexibility to adapt to a wide range of illumination colors and levels. The eye's fovea is where the sensors associated with this system are located.

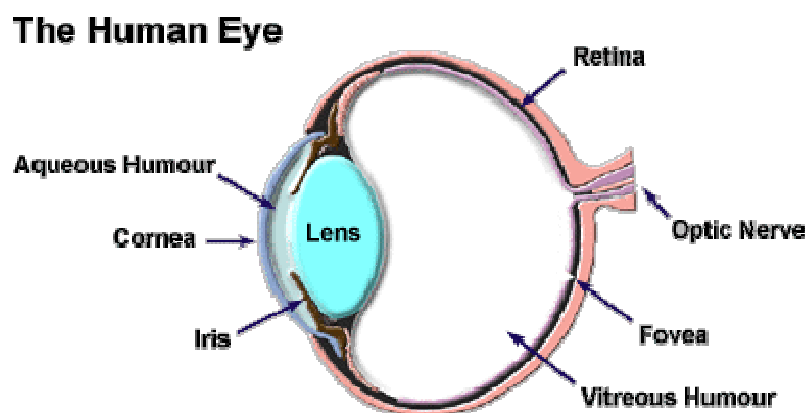


Figure 6. The Human Eye (Scott et al., 2006)

The eye's rods are light sensor cells capable of working over wide illumination levels and providing quick response to changes. The eye's cones are light sensor cells that provide

high-resolution color imaging. The cones are localized in the area of the fovea and the rods are spread throughout the retina (refer to Figure 7).

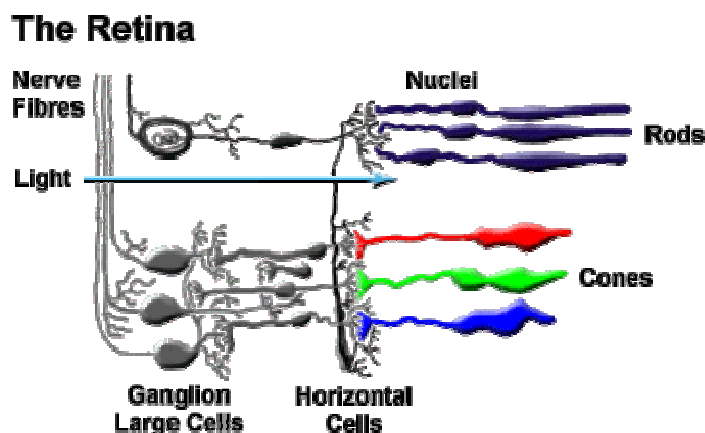


Figure 7. The Retina (Scott et al., 2006)

The cones in the human eye have the ability to sense three different portions of the spectrum: red, green and blue (RGB). The rods in the human eye provide the luminance information (Scott et al., 2006). Luminance is defined as the brightness information in the image (National Instruments, 2005). The human brain and nervous system performs the processing of the rod and cone outputs in order to generate an image. The eyes have peak sensitivities at certain light frequencies, for example, red (580 nanometers), green (540 nanometers) and blue (450 nanometers). Light in the visual spectrum range of 400 to 700 nanometers will excite one or more of these three types of sensors. The color we see is determined by the combination of sensors that are excited and by how much. Typically, the Greek letters Rho (red), Gamma (green), and Beta (blue) denote the RGB sensors. The sensitivity of each RGB sensor in our eyes determines the intensity of the colors we perceive for the wavelengths in the visual spectrum (refer to Figure 8). This

research examined the wavelength characteristics inside and outside the visual spectrum range (Scott et al., 2006).

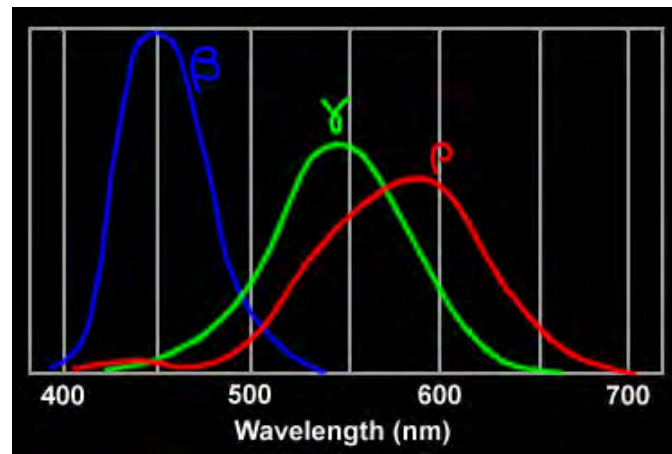


Figure 8. Wavelength (Scott et al., 2006)

Digital Images

A digital image is a 2D array of values representing light intensity, $f(x, y)$ where f is the brightness of the point (x, y) , and x and y represents the spatial coordinates of a picture element, or pixel. The spatial reference of the pixel with the coordinates $(0, 0)$ is located at the top, left corner of the image (refer to Figure 9).

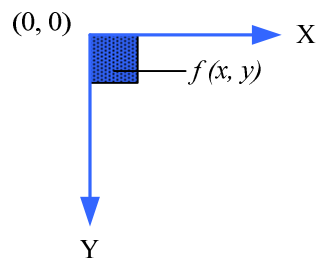


Figure 9. Spatial Reference of the $(0, 0)$ Pixel

A digitized image has three basic properties: resolution, definition, and number of planes. The number of rows and columns of pixels determine the spatial resolution of an image. The columns (m) and rows (n) determine the resolution of an image ($m \times n$). The number

of shades that you can see in the image is the bit depth. Each pixel has a depth of n , which means that a pixel can have 2^n different values. If n equals 16 bits, a pixel can have 65,536 different values ranging from 0 to 65,535 or from $-32,768$ to $32,767$. The type of encoding depends on the nature of what you plan to do with the image. For example, 8-bit encoding is sufficient if you need to obtain the shape information of objects in an image; however, 16-bit or floating-point encoding is necessary to measure the light intensity of an image precisely.

The number of planes in an image directly correlates to the number of arrays of pixels that compose the image. For example, a grayscale or pseudo-color image is composed of one plane; while a true-color image is composed of three planes—one each for the red component, blue component, and green component. In true-color images, the color component intensities of a pixel are coded into three different values that are a combination of three arrays of pixels corresponding to the red, green, and blue components in an RGB image (National Instruments, 2005). The evolution of digital images was instrumental in making digital photography the industry standard.

Digital Photography

Photography has been around for over two centuries now and there has been a wealth of invention and innovation aimed at capturing a realistic and pleasing full-color two-dimensional representation of a scene. Lyon and Hubel (2002) look back at the historical milestones of color photography and bring into focus a fascinating parallelism between the evolution of chemical based color imaging starting over a century ago, and the evolution of electronic photography, which continues today. Film achieved this by

using three layers of emulsion to capture full color at every point in the image. The technology that made digital photography a reality was the Charged Couple Device (CCD) image sensors. CCDs, developed approximately 30 years ago, were instrumental in ushering in the era of digital photography (refer to Figure 10).

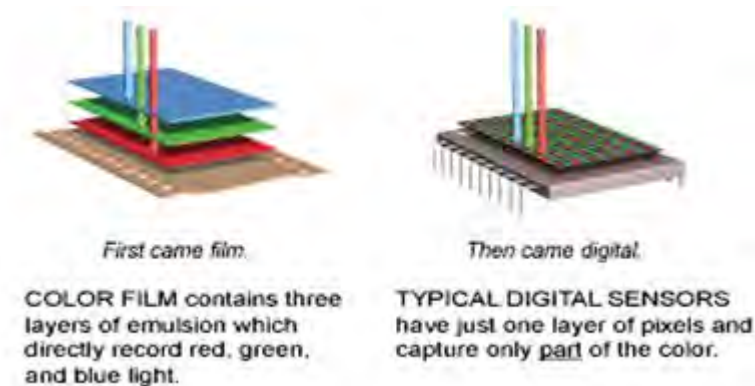


Figure 10. Film and Image Sensor (Foveon, 2005)

Bayer-Pattern Image Sensors

The sensor that made digital photography a reality was the Bayer-Pattern Image Sensor. This color CCD sensor, introduced by Bryce Bayer in 1976, used mosaic patterns of filters (Lyon, 2002). Dr. Bayer, of the Eastman Kodak Company, is also responsible for the less expensive alternative known as the Bayer Color Filter Array (CFA) that fueled the recent explosion of digital image capture devices in both the DSC (Digital Still Camera) and the cell phone markets. The Bayer CCD and CFA are made of a repeating array of red, green, and blue filter material deposited on top of each pixel in an array (refer to Figure 11) (Guttosch, 2004).

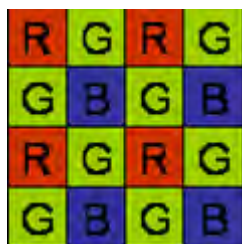


Figure 11. Bayer Sensor Composition (Guttosch, 2005)

Unfortunately, the new digital cameras were not capable of the rich, warm tones and detail of color film that the world came to expect. The reason for this was that CCD digital image sensors were only capable of recording just one color at each point in the captured image instead of the full range of colors at each location (refer to Figure 12) (Foveon, 2005).



Figure 12. Bayer Sensor Decomposition (Guttosch, 2005)

The Bayer CFA improved the state-of-the-art of color image capture while simultaneously reducing the cost. Unfortunately, the drawback was the sharpness of the images. The Bayer CFA represents an inefficient use of silicon area and imposes three constraints that the digital camera designer must overcome due to the sparse nature of the sampling. The first constraint to overcome is the interpolation of the missing color data in order to create three complete color image planes (R, G, and B). Second, the image has to be sharpened in order to account for the inherent reduction in the sharpness of the luminance and chrominance. Finally, the color aliasing artifacts that result from the

incomplete sampling in the image plane and the phase offsets of the color channels need to be suppressed. This is accomplished with the use of an optical blur filter, also known as an Anti-Aliasing filter, or an optical low-pass filter (OLPF) (refer to Figure 13).

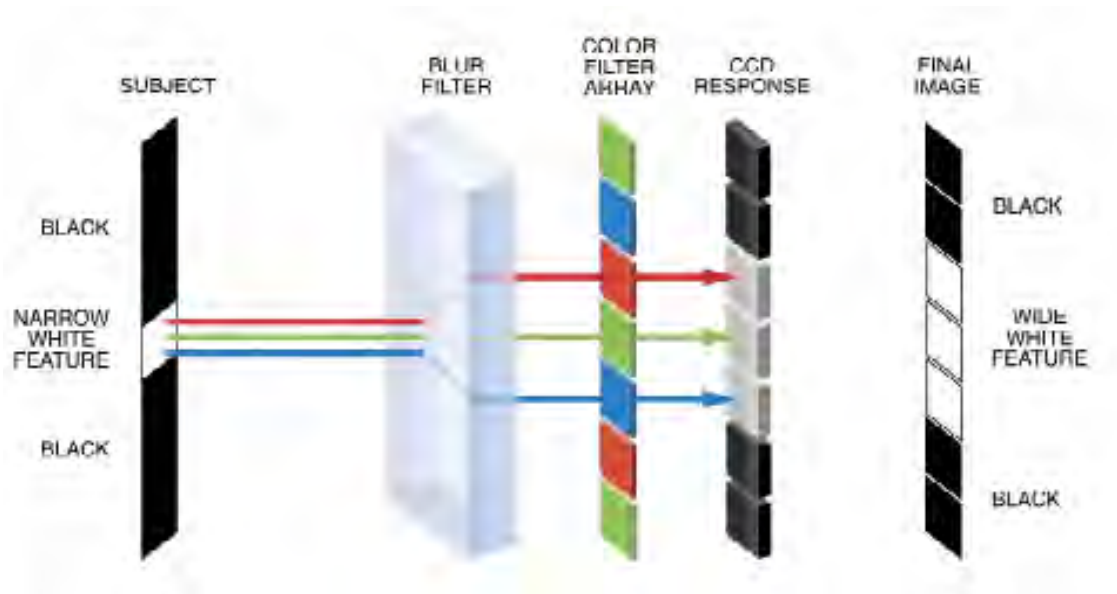


Figure 13. CCD sensor blurs color to suppress false color artifacts

Blur filters are used to reduce the color aliasing artifacts caused by spatial phase differences among the color channels (i.e., the red, green, and blue filters are placed next to each other). Consumer and professional digital cameras typically place two blur filters in the optical path: one to blur in the horizontal direction, the other in the vertical. The blur filters reduce color aliasing caused by the sensor design but at the expense of image sharpness (Guttosch, 2004). These issues are what add error to our current edge detection algorithms and what must be avoided in future research; this is now possible with introduction of a new sensor technology.

Foveon X3® Direct Image Sensors

The technical deficiencies of the CCD sensor were finally resolved with the introduction of Foveon's innovative design of the three layer X3 direct image sensor. The new Foveon X3 image sensor has three layers of pixels and is similar to the layers of chemical emulsion used in color film (Guttosch, 2005). The layers of pixels are stacked vertically and take advantage of the ability of silicon to absorb different wavelengths of light at different depths in silicon (Hubel, 2005) (refer to Figure 14).

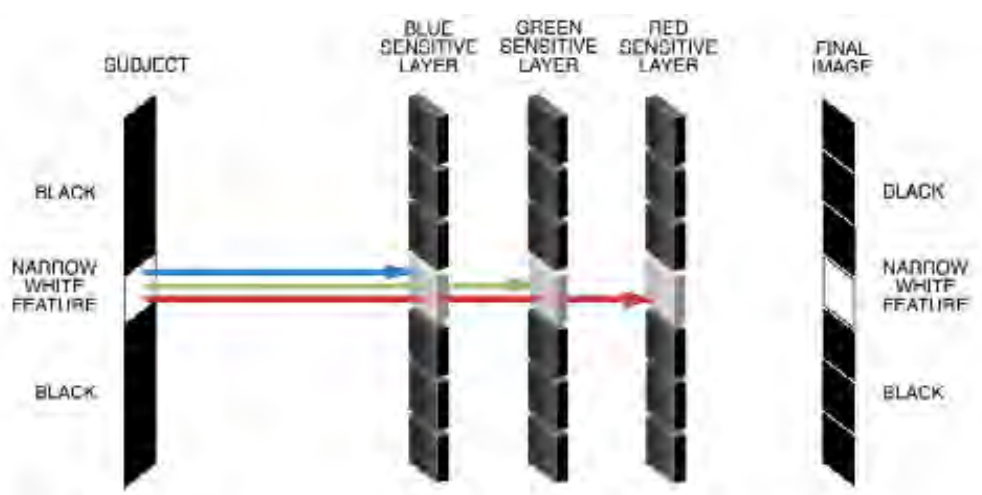


Figure 14. X3 sensor does not need to blur color so images are sharper

This is the first and only image sensor that captures red, green, and blue light at every point of the image (refer to Figure 15) (Guttosch, 2005).

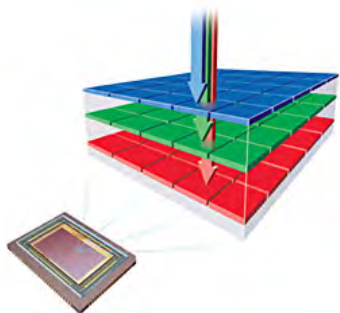


Figure 15. Foveon X3® Direct Image Sensors (Foveon, 2005)

The Foveon X3 sensor had an inherent luminance-chrominance behavior, which resulted in higher image quality using fewer image pixels (Lyon, 2002). This new CMOS sensor technology with three layers of photodiodes can also function well in the near ultraviolet and infrared bands. Ultraviolet sensitivity is the result of the close proximity of the top (blue) photodiode junctions to the surface of the silicon and the lack of any significant UV-absorbing materials above them. The IR extends deep into the sensor to the (red) photodiodes (Gilblom, 2003). This research exploited the UV and IR capabilities of this sensor.

Camera Basics

The basics of exposure are the same for film or digital cameras. The variables are shutter speed, lens aperture (f -stop), and film speed or sensor sensitivity. Exposure is the cumulative effect of light on a photosensitive surface and is controlled by a combination of shutter speed and lens opening. The first variable is the shutter, which acts like a curtain that keeps light out of the camera except during exposure. When a picture is taken, the shutter opens for a specified period of time. This time is measured in fractions of a second to seconds for 'time' exposures. The second variable is the 'iris diaphragm', which controls the size of the lens opening just like the iris of the human eye controls the pupil size. Simply stated, the diaphragm reduces the diameter of the lens. The diaphragm has no effect when the lens is wide open. As the lens closes, the quantity of light that can pass through the lens per unit of time is reduced. These lens openings or apertures are measured by ' f -stops'. An f -stop is a number that indicates the ratio of

focal length of the lens to its diameter. For example, a typical 50 mm lens that has a maximum opening of f 1.4. The following is the order of f -stops for this lens:

1.4 2.0 2.8 4 5.6 8 11 16 22

For this research, an 80mm lens was used which has the following f -stops:

5.6 8 11 16 22 32

While the numbers may appear arbitrary, they do make sense. As you go up the scale, each number represents a lens opening that lets in $\frac{1}{2}$ the amount light of the previous number. The amount of light admitted is halved each time you increase the f -stop, for example, from f 1.4 to f 2.0. Therefore, the amount of light that passes through the aperture is directly proportional to the area of the opening. The f -stops are related to the area of the lens opening which in turn is related to diameter by the following formula:

$$A = \pi \left[\frac{d}{2} \right]^2 \quad (2)$$

Using our 50 mm lens example, at f 2 the diameter of the lens is $50/2 = 25$ mm. Using the equation above the area of a 25 mm circle is approximately 490 mm^2 . At f 2.8, the diameter is $50 \text{ mm}/2.8 = 17.9$ mm and the area is approximately 251 mm^2 . Changing the lens opening by one f -stop higher number halved the area of the lens opening. As the shutter speed is doubled, the lens opening increases by one f -stop to maintain the same exposure. In other words, $1/10 \text{ sec. @ } f 22 = 1/20 \text{ sec @ } f 16 = 1/40 \text{ sec @ } f 11 = 1/80 \text{ sec @ } f 8 \text{ etc.}$ (Syosset Camera Club, 2004).

Sigma SD10 Digital Single-Lens Reflex (DSLR) Camera

The visible light band is at 400-700 nanometers. Seeing outside this range is typically an undesirable characteristic of a camera and therefore it is typically blocked.

The Sigma SD10 camera was chosen since this research wanted to exploit the area outside the visible light range. This camera used the Foveon X3 sensor and was ideally suited for this application for the following reasons:

1. The Foveon X3 sensor had three unique attributes that made it ideally suited for this application:

- Unlike conventional color sensors, the Foveon X3 measures three color channels at each pixel location instead of a single color. For monochrome applications, the three channels can be summed, differenced or sampled individually. For color applications, this means color is measured without requiring color matrix demosaicing, which may interfere with edge detection as most color reconstruction algorithms have their own edge detection/enhancement logic.
- It does not have an optical anti-aliasing filter in the path between the sensor and the lens. Such filters, used with most color mosaic cameras, reduce color aliasing by spreading the light among multiple pixels.
- The sensor is sensitive to both near-UV and near-IR light.

2. The camera was simply modified to remove the internal UV/IR blocking filter thus enabling the full range of sensitivity.

- The camera was modified by removing the dust protector behind the lens. The dust protector is also the Infrared and UV blocking filter when the camera is used for normal color photography. The removal of this dust protector expanded the spectral selectivity (refer to Figure 16).
- A B+W 403 (or Schott UG1) filter was used, enabling the “blue” channel to detect most of the near-UV light and the “red” channel to detect most of the near-IR light passed by this filter.

3. The camera is portable and self-contained.

- The camera is battery powered, relatively small, and saves data to standard Compact Flash memory cards.
- The camera can be brought to locations convenient for the subjects.

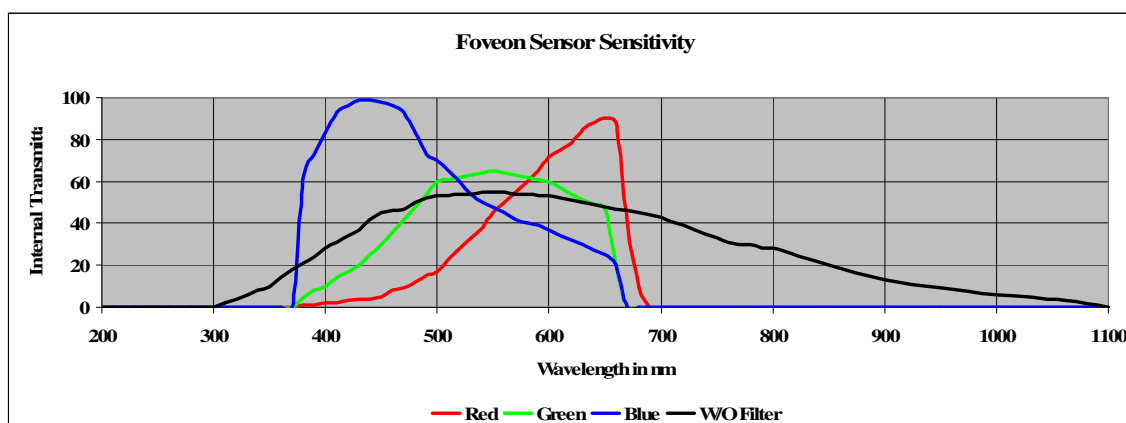


Figure 16. Foveon Sensor Sensitivity

Lenses

The lens projected for this research is the Nikon El-Nikkor 80mm f/5.6 enlarging lens. This lens is color corrected for light in the range from 380 nanometers (near UV) to 750 nanometers (IR). In addition, due to their simpler construction (fewer elements and groups) and less sophisticated coatings these lenses pass more UV light than modern multicoated camera lenses. An enlarging lens does not have a focusing mechanism, so focus was achieved using a Pentax Bellows II focusing rail. The bellows attached to the camera via an SA-M42 adapter. The lens was attached to the bellows via a M39 to M42 adapter. Focus was set for a fixed distance from the subject to provide a 1-2 reproduction ratio. Since some filters are visually opaque, attached to the front of the bellows was a metal distance and framing guide. This was used for correct positioning of the system relative to the target feature.

Lighting

The overall lighting conditions for this research were very important. Lighting conditions varied since this research involved photographing lesions at a place of convenience for the volunteer. To ensure consistent lighting, a Sunpak DX-8R electronic flash ring light was used. This flash attached in front of the lens and provided an even as well as shadowless light at close distances. Unfortunately, an electronic flash is a strong UV and IR light source; therefore, the exposure settings for the camera were pre-calculated based on the camera ISO setting and the filter strength and were controlled by varying the flash output power.

Image Storage

Understanding how a grayscale image is stored as compared to a color image and how to manipulate the information mathematically was a crucial part of this research. Spatial resolution is defined as the number of pixels horizontally and vertically in a digital image. Color images are encoded in memory as a red, green, and blue (RGB) image or a hue, saturation, and luminance (HSL) image. Hue represents the dominant color of a pixel, saturation is the amount of white added to a pure color, and luminance is the brightness information in a picture. A grayscale image is composed of a single plane of pixels, each comprised of 4 bytes (refer to Table 2) (National Instruments, 2006).

Table 2. Bytes per Pixel

Image Type	Number of Bytes per Pixel Data
Grayscale	 32-bit for the grayscale intensity
RGB Color	 8-bit for the alpha value (not used) 8-bit for the red intensity 8-bit for the green intensity 8-bit for the blue intensity
HSL Color	 8-bit (not used) 8-bit for the hue 8-bit for the saturation 8-bit for the luminance

Every image file has a header that is followed by pixel values. Depending on the file format, the header contains information about the horizontal and vertical resolution, pixel definition, calibration, pattern matching templates, overlays, and the original palette. The following are common image file formats:

- Bitmap (BMP)
- Tagged image file format (TIFF)
- Portable network graphics (PNG) – Capable of storing image information about spatial calibration, pattern matching templates, and overlays
- Joint Photographic Experts Group format (JPEG)

Standard formats for grayscale and RGB color images are BMP, TIFF, PNG and JPEG.

While there are pros and cons of every format, the format for this research was TIFF, which provides the most information (National Instruments, 2005).

Image Data Compression

As can be noted above, digital images can utilize a large amount of drive space. Each raw image is approximately 5 megabytes in size. The Sigma SD10 supports writing the Foveon .X3F file format, which consists of:

- Camera settings
- Image settings
- Preview thumbnail
- Raw 12 bits x 3 channels of data, losslessly compressed

Notice that the file is compressed using the lossless data compression algorithm.

Lossless data compression allows the exact original data to be reconstructed from the compressed data. On the other hand, a lossy data compression is an algorithm that involves deliberately discarding information that is not visually or diagnostically important. The lossy data compression also has a drawback called generation loss when a file is repeatedly compressed and decompressed in that the file will progressively lose quality (Clunie, 2000). This research restricted itself to losslessly compressed data for the raw images (.X3F) as to not add any unknown variables to the edge detection algorithms. In other words the more pixels the better. The raw losslessly compressed images (.X3F) were converted to an 8 bit tagged image file format (TIFF) where the uncompressed file size jumped to approximately 10 megabytes (e.g., 2267 pixels x 1513 pixels x 3 bytes or 10.3 megabytes). The file size was even larger for 16 or 32 bit TIFFs. This research utilized 8 bit TIFFs since most of the algorithms in the Nation Instrument's Vision library are 8 bit.

Research Method

Edge Detection Fundamentals

After an image is captured, the next step is to find the edges in the region of interest, a process known as edge detection. Edge detection is a fundamental tool used in most image processing applications. This process detects outlines of an object and boundaries between objects and the background in the image (Parker, 1996). Edge detection algorithms are based on standard mathematical knowledge about directional derivatives and differential geometry. The large amount of literature on edge detection makes it clear why it is the most important tool for image analysis. While the goal of this research was not to investigate edge detection algorithms, a basic understanding was necessary. The computational limitations in the 1960's and 1970's introduced several crude approximation algorithms such as the Roberts, Prewitt, and Sobel filters. During the 1980's, researchers began to realize the importance of a more structured approach. Granlund introduced a filter design that clearly showed two key concepts: scale and orientation. Marr and Hildreth proposed the use of Gaussian derivative operators, which is based on their similarity to simple detectors in the human visual system (Van Ginkel, 2002). Marr and Hildreth felt that no single filter could be optimal at all scales, so an approach had to be sought that dealt separately with changes occurring at different scales (Marr and Hildreth, 1980). Researchers then began applying more complex derivative-based operations to the image analysis problem, such as second order directional derivatives. One of these was Canny, who showed that the Gaussian regularization kernel is not only theoretically important, but is also very close to optimal with respect to

a number of sensible criteria for a variety of edge shapes and noise models (Van Ginkel, 2002).

Edge Detection Search Methodologies

An edge is defined as a significant change in the grayscale values between adjacent pixels in an image. In the National Instruments Vision software, edge detection works on a one-dimension (1D) or two-dimension (2D) profile of pixel values along a search region. The 1D search region can take the form of a line, the perimeter of a circle or ellipse, the boundary of a rectangle or polygon, or a freehand region. The software analyzes the pixel values along the profile to detect significant intensity changes. An edge detection algorithm identifies discontinuities in the pixel intensities of an image. The abrupt changes characterize the boundaries of objects in a scene. These algorithms work well when there is little noise in the image and there is a distinct demarcation between the foreground and the background (refer to Figure 17) (National Instruments, 2005).

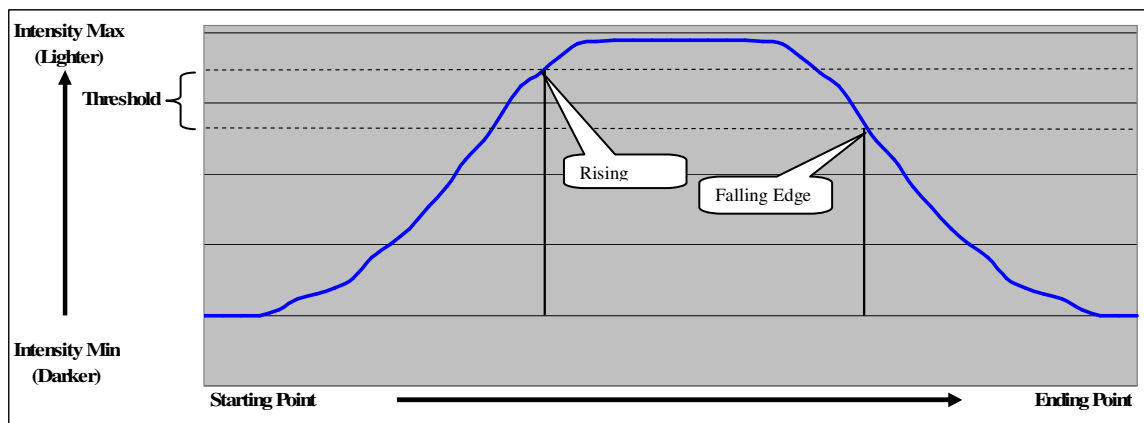


Figure 17. Simple Edge Detection Algorithm (National Instruments, 2005)

If the image has background noise, then a more suitable technique would be to use the advanced edge detection algorithm. This algorithm allows some flexibility in that you can set the steepness and width parameters, for example, the size of the width parameter can be increased to compensate for background noise. This algorithm computes the edge strength at each pixel location and, if the contrast is greater than a user-set value, then that point is stored for further analysis. Edge strength is defined as the minimum difference in the grayscale values between the background and the edge. The edge strength is sometimes referred to as edge contrast. An edge is defined where the difference between the start and end edge locations is greater than or equal to 90% of difference between maximum and minimum contrast (refer to Figure 18) (National Instruments, 2005). For this research, a more complex 2D search methodology was necessary.

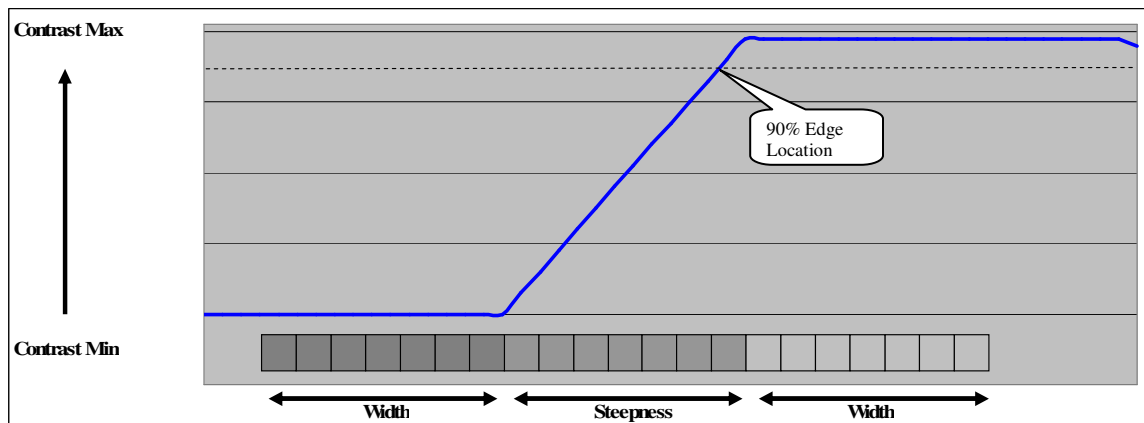


Figure 18. Advanced Edge Detection Algorithm (National Instruments, 2005)

More complex search methodologies are spoke and concentric rake. The spoke algorithm works on an annular search region along search lines that are drawn from the center of the region to the outer boundary (refer to the dashed line in Figure 19). The

number of search lines can be set by specifying the angle between each line. While the search direction can also be controlled, this research lent itself to search from the center outward. A variation of the spoke edge detection algorithm is the concentric rake edge detection algorithm (refer to the dotted line in Figure 19). This algorithm uses concentric circles instead of spokes. The user can control the number of concentric search lines by specifying the radial distance between the concentric lines in pixels (National Instruments, 2005).

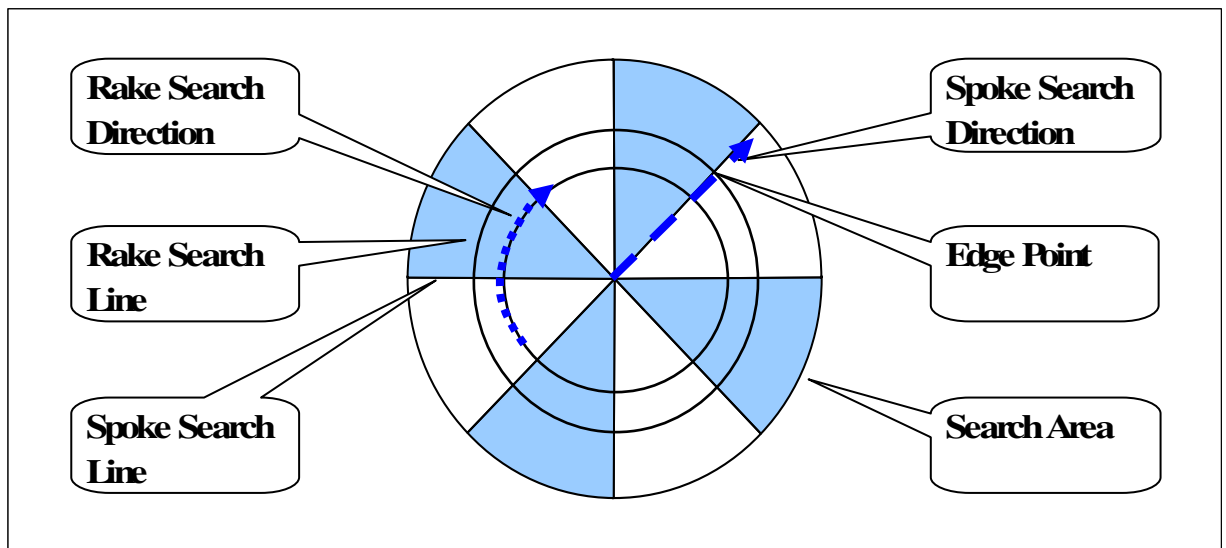


Figure 19. Spoke and Concentric rake Edge Detection (National Instruments, 2005)

While both of these search methodologies would work, the spoke was more suitable for this research since the outer boundary of a lesion is not necessarily circular. Once the search methodology was known, an edge detection algorithm could be utilized on the region of interest.

Image Filtering

Filters are divided into two types: linear and nonlinear. A linear filter sometimes referred to as a convolution filter, is an algorithm that consists of recalculating the value of a pixel based on its own pixel value and the pixel values of its neighbors weighted by the coefficients of a convolution kernel. The new pixel value is derived from the sum of this calculation divided by the sum of the elements in the kernel. Convolutions are divided into four families: gradient, Laplacian, smoothing, and Gaussian. This grouping is determined by the convolution kernel contents or the weight assigned to each pixel. Filters serve a variety of purposes, such as detecting edges along a specific direction, contouring patterns, reducing noise, and detail outlining or smoothing so information can be extracted. Nonlinear filters are used to extract the contours (edge detection) or remove the isolated pixels.

Edge detection algorithms typically use a convolution kernel, which is a 2D filter that can be applied to a grayscale image. The coefficients of the convolution kernel determine the filtered value of each pixel in the image. A convolution kernel is used when a grayscale image needs filtering to enhance the quality of the image. Filters are used to smooth an image, remove noise from an image, enhance the edge information in an image, etc. The convolution kernel is a structure whose coefficients define how the filtered value at each pixel is computed. The filtered output for each pixel is a weighted combination of its original value and the values of its neighboring pixels. The size of the convolution kernel determines the number of neighboring pixels that will be included in the filtering process (refer to Figure 20). In the case of a 3×3 kernel the value of the

central pixel (center pixel shown in blue) is derived from the values of its eight surrounding neighbors (surrounding pixels shown in yellow).

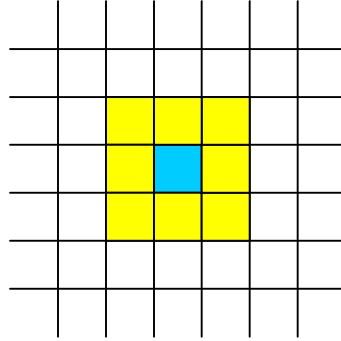


Figure 20. 3 x 3 Convolution Kernel

A filtering operation on an image involves moving the kernel from the top left pixel in the image to the bottom right pixel in the image. A new value is computed with the kernel at each pixel location (National Instruments, 2005).

The size of the convolution kernel can be either a square or rectangular, for example: 3×3 , 5×5 , 5×7 , 9×3 , etc. While NI Vision allows for user defined convolutional kernels, this research used the default kernel size for a particular algorithm (e.g., Roberts 2×2 , Prewitt 3×3 , etc.). The default kernel size was used because the goal of this research was to see if spectral selectivity had an affect on a fixed edge detection algorithm, in other words, the edge detection was as a constant. In addition, the larger the kernel, the thicker the edges. This was an undesirable affect for this research (refer to Figure 21) (National Instruments, 2005).

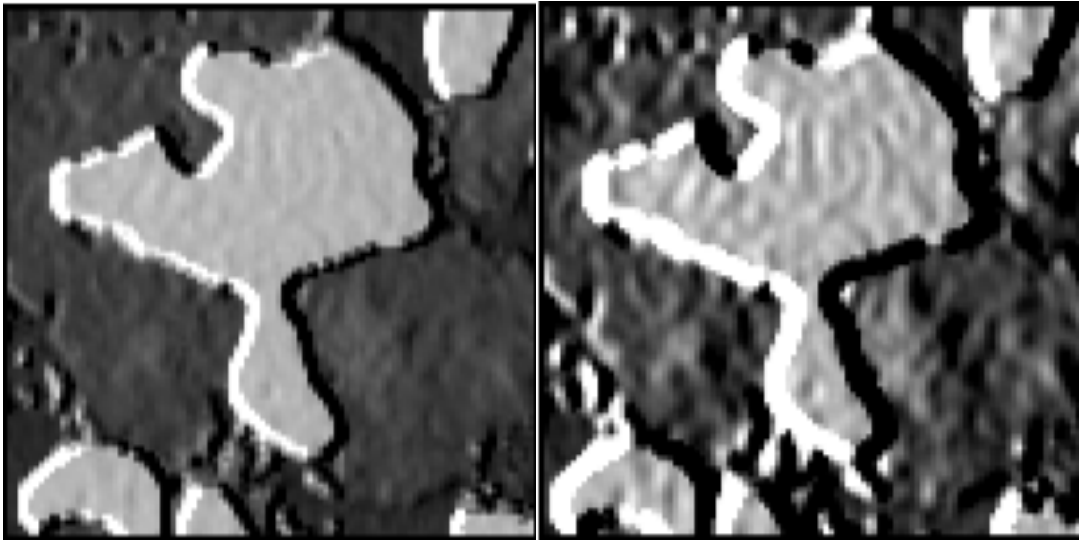


Figure 21. Gradient 3×3 (left) and 5×5 (right) (National Instruments, 2005)

Contour Extraction Filters

The NI Vision™ has seven different methods that can be used for contour extraction: Canny, Differentiation, Gradient, Prewitt, Roberts, Sigma, or Sobel. The Canny Edge Detection filter is a specialized edge detection method that locates edges accurately, even under low signal-to-noise conditions in an image. Filters alter pixel values with respect to variations in light intensity in their neighborhood. The neighborhood of a pixel is defined by the size of a matrix centered on the pixel itself.

Filters fall into two categories:

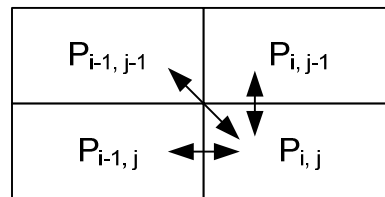
- High-pass filters emphasize significant variations of the light intensity typically around the boundary of objects. These filters can isolate abruptly varying patterns that correspond to sharp edges.
- Low-pass filters attenuate variations of the light intensity. These filters help emphasize gradually varying patterns and have the tendency to smooth images by eliminating details and blurring edges (refer to Table 3) (National Instruments, 2005).

Table 3. Edge Detection Filter Types

Filter	Gradient	Laplacian	Smoothing	Gaussian	Roberts	Sobel	Prewitt	Differentiation	Sigma	Median	Nth Order	Lowpass	Canny
Linear High-pass	✓	✓											
Linear Low-pass			✓	✓									
Nonlinear High-pass				✓	✓	✓	✓	✓	✓				
Nonlinear Low-pass										✓	✓	✓	
Specialized													✓

Since this research focused on the boundary of objects (edge detection), only nonlinear high-pass filters were discussed as well as used.

Differentiation is a nonlinear high-pass filter used in edge detection that produces continuous contours by highlighting each pixel where an intensity variation occurs between itself and its three upper-left neighbors (refer to Figure 22 and Equation 3) (National Instruments, 2005).

**Figure 22. Differentiation Matrix**

$$P(i, j) = \max[|P_{(i-1,j)} - P_{(i,j)}|, |P_{(i-1,j-1)} - P_{(i,j)}|, |P_{(i,j-1)} - P_{(i,j)}|] \quad (3)$$

Gradient is a nonlinear high-pass filter used in edge detection that highlights the variations of light intensity along a specific direction, which has the effect of outlining

edges and revealing texture (refer to Figure 23 and Equation 4) (National Instruments, 2005).

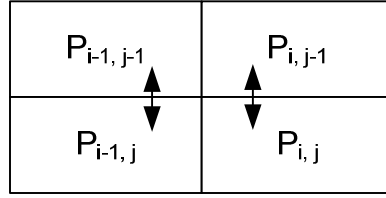


Figure 23. Gradient Matrix

$$P(i, j) = \max[|P_{(i,j-1)} - P_{(i,j)}|, |P_{(i-1,j-1)} - P_{(i-1,j)}|] \quad (4)$$

Roberts filter is a nonlinear high-pass filter used in edge detection that outlines the contours in grayscale that highlight pixels where an intensity variation occurs along the diagonal axis (refer to Figure 24 and Equation 5) (National Instruments, 2005).

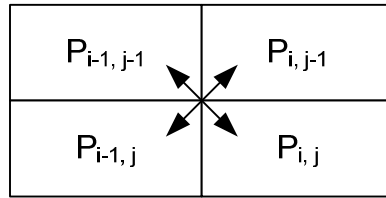


Figure 24. Roberts Matrix

$$P(i, j) = \max[|P_{(i-1,j-1)} - P_{(i,j)}|, |P_{(i,j-1)} - P_{(i-1,j)}|] \quad (5)$$

Prewitt is a nonlinear high-pass filter used in edge detection that extracts the contours in gray-level values using a 3×3 filter kernel. The Prewitt filter is better suited for curved contours (refer to Equation 6 and Figure 25) (National Instruments, 2005).

$$P(i, j) = \max[|P_{(i+1,j-1)} - P_{(i-1,j-1)} + P_{(i+1,j)} - P_{(i-1,j)} - P_{(i+1,j+1)} - P_{(i-1,j+1)}|, \\ |P_{(i-1,j+1)} - P_{(i-1,j-1)} + P_{(i,j+1)} - P_{(i,j-1)} - P_{(i+1,j+1)} - P_{(i+1,j-1)}|] \quad (6)$$

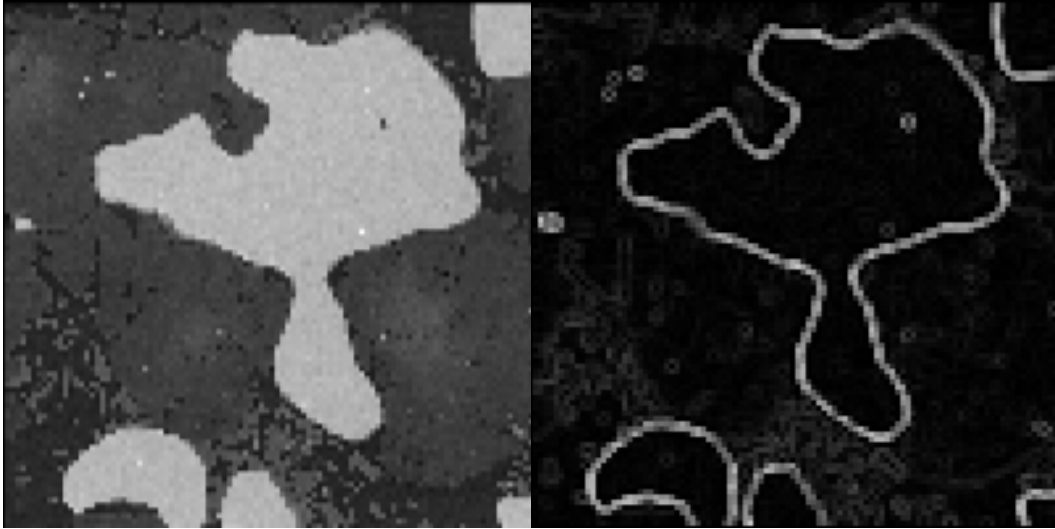


Figure 25. Prewitt - Image (left) and after filtering (right) (National Instruments, 2005)

Sigma is a nonlinear high-pass filter used in edge detection that outlines edges. A Sigma filter outlines contours and details by setting pixels to the mean value found in their neighborhood if the deviation from this value is not significant (refer to Equation 7 and Figure 26) (National Instruments, 2005).

$$\begin{array}{ll}
 \text{If} & P_{(i,j)} - M > S \\
 \text{Then} & P_{(i,j)} = P_{(i,j)} \\
 \text{Else} & P_{(i,j)} = M
 \end{array} \quad (7)$$

Each pixel $P(i, j)$ is set to the mean value M if it falls inside the range $[M - S, M + S]$.

Where:

S = standard deviation

M = mean value of $P(i, j)$ and its neighbors

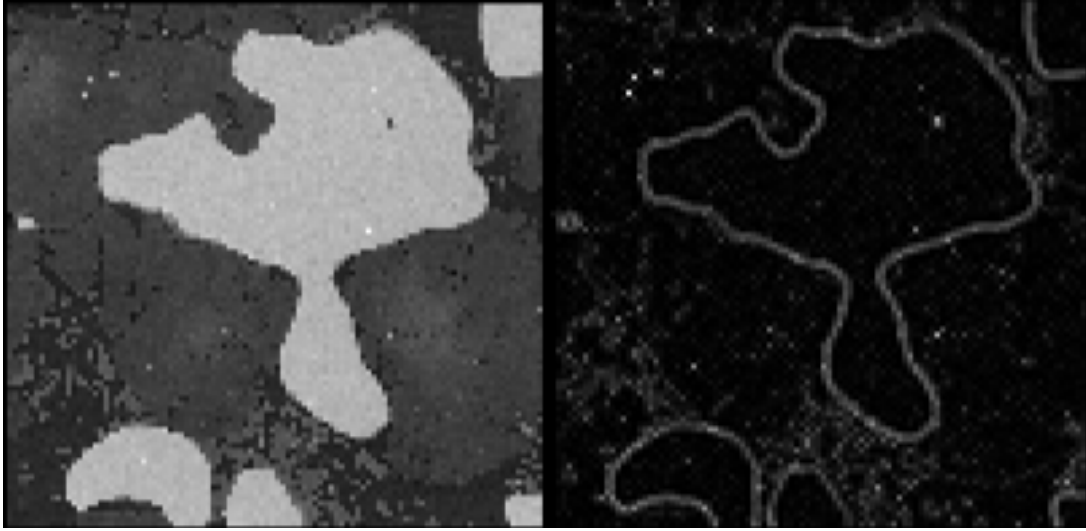


Figure 26. Sigma - Source image (left) and after filtering (right) (National Instruments, 2005)

Sobel is a nonlinear high-pass filter used in edge detection that extracts the contours in gray-level values using a 3×3 filter kernel. The Sobel filter is better suited for squared contours (refer to Equation 8 and Figure 27) (National Instruments, 2005).

$$P(i, j) = \max[|P_{(i+1, j-1)} - P_{(i-1, j-1)} + 2P_{(i+1, j)} - 2P_{(i-1, j)} - P_{(i+1, j+1)} - P_{(i-1, j+1)}|, \\ |P_{(i-1, j+1)} - P_{(i-1, j-1)} + 2P_{(i, j+1)} - 2P_{(i, j-1)} - P_{(i+1, j+1)} - P_{(i+1, j-1)}|] \quad (8)$$

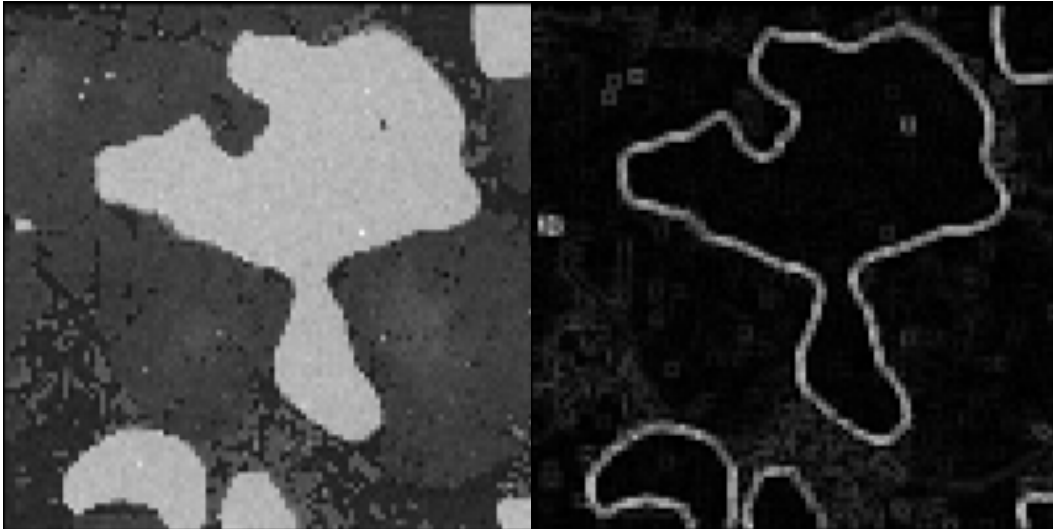


Figure 27. Sobel - Source image (left) and after filtering (right) (National Instruments, 2005)

Canny is a nonlinear high-pass filter used in edge detection that extracts the contours in gray-level images (refer to Equations 9 and 10).

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (9)$$

$$\frac{\partial G(x, y)}{\partial x} \alpha x e^{-\frac{x^2+y^2}{2\sigma^2}} \quad \frac{\partial G(x, y)}{\partial y} \alpha y e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (10)$$

First, the image is smoothed with the Gaussian filter. Next, the gradient of the image is found by feeding the smoothed image through a convolution operation with the derivative of the Gaussian in both the vertical and horizontal directions (refer to Equation 11 for the 2-D convolution operation).

$$\begin{aligned} I'(x, y) &= g(k, l) \otimes I(x, y) \\ &= \sum_{k=-N}^N \sum_{l=-N}^N g(k, l) I(x-k, y-l) \end{aligned} \quad (11)$$

Where:

$g(k, l)$ = convolutional kernel

$I(x, y)$ = original image

$I'(x, y)$ = filtered image

$2N + 1$ = size of convolutional kernel

The non-maximal suppression stage finds the local maxima in the direction of the gradient and suppresses all others. The local maxima is found by comparing the pixel with its neighbors along the direction of the gradient, which helps maintain a single pixel thin edge. The Canny algorithm then uses hysteresis thresholding, which adapts to the local content of the image. There are two threshold levels, the high (t_h) and the low (t_l) and pixel values above the t_h value are immediately classified as edges. By tracing the

edge contour, the neighboring pixels with values less than t_h can still be marked as edges as long as they are above t_l . This process identifies strong edges while preserving the relevant weak edges in addition to maintaining some level of noise suppression. The performance of the Canny algorithm depends heavily on the adjustable parameters, σ , which is the standard deviation for the Gaussian filter, and the threshold values, t_h and t_l . σ also controls the size of the Gaussian filter. As σ increases so does the size of the Gaussian filter which in turn implies more blurring. In addition, the larger the scale of the Gaussian, the less accurate is the localization of the edge. Smaller values of σ imply a smaller Gaussian filter that limits the amount of blurring while maintaining finer edges in the image (Neoh, 2004).

Spectral Selectivity

Spectral selectivity is a technique for capturing images that intentionally uses limited ranges of radiation in the ultraviolet, visible or infrared portions of the spectrum. While this technique is used in artistic photography, it is the scientific possibilities we plan to exploit in this research. In the past, photographers had to work around the inherent spectral sensitivity limitations of the photographic materials available. Today, modern digital photographic materials are available to a wide portion of the spectrum, ranging from 250 nanometers (ultraviolet) to 925 nanometers (infrared) while our human vision system is only capable of detecting a range of light spectrum from about 400 nanometers (violet) to 700 nanometers (red). This range of light wave frequencies is perceived by our visual system as a varying rainbow of colors (refer to Figure 28).

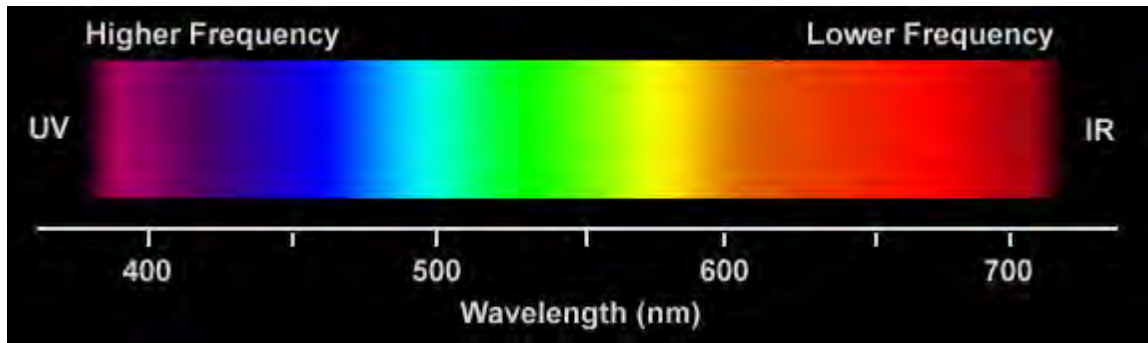


Figure 28. Typical Human Eye Visual Spectrum (Scott et al., 2006)

The selective use of this spectrum lends itself to many applications; using specific light wave frequencies, certain characteristics of an image can be emphasized or eliminated by limiting the range of spectrum used. The primary tool for selective use of spectrum with conventional photography is a camera filter (Scott et al., 2006). Camera filters are defined as transparent or translucent optical elements that alter the properties of light entering the camera lens for the purpose of improving the image being recorded. Filters are capable of affecting contrast, sharpness, highlight flare, color, and light intensity, either individually, or in various combinations (Tiffen, 2006). The example below is an example of an ultraviolet filter. The intention is to show that a filter is capable of removing extraneous information that is above and beyond what is necessary to see (refer to Figure 29).



Figure 29. Image Comparison Without and With a UV Lens (Kodak, 2006)

For the purposes of our discussion, note how the UV filters remove useless information and allow the human eye to see more clearly what is already there.

In the next example, a dual filter (Infrared and Ultraviolet) is used. The top image is from the red channel and contains mostly IR (e.g., veins visible). The bottom picture, extracted from the blue channel, contains most of the UV light (e.g., sun block visible). This demonstrates how information that is invisible to the naked eye can be converted to a spectrum that is visible using spectral selectivity (refer to Figure 30). Next, this filter as well as several others to cover the entire spectrum for this research will be discussed.

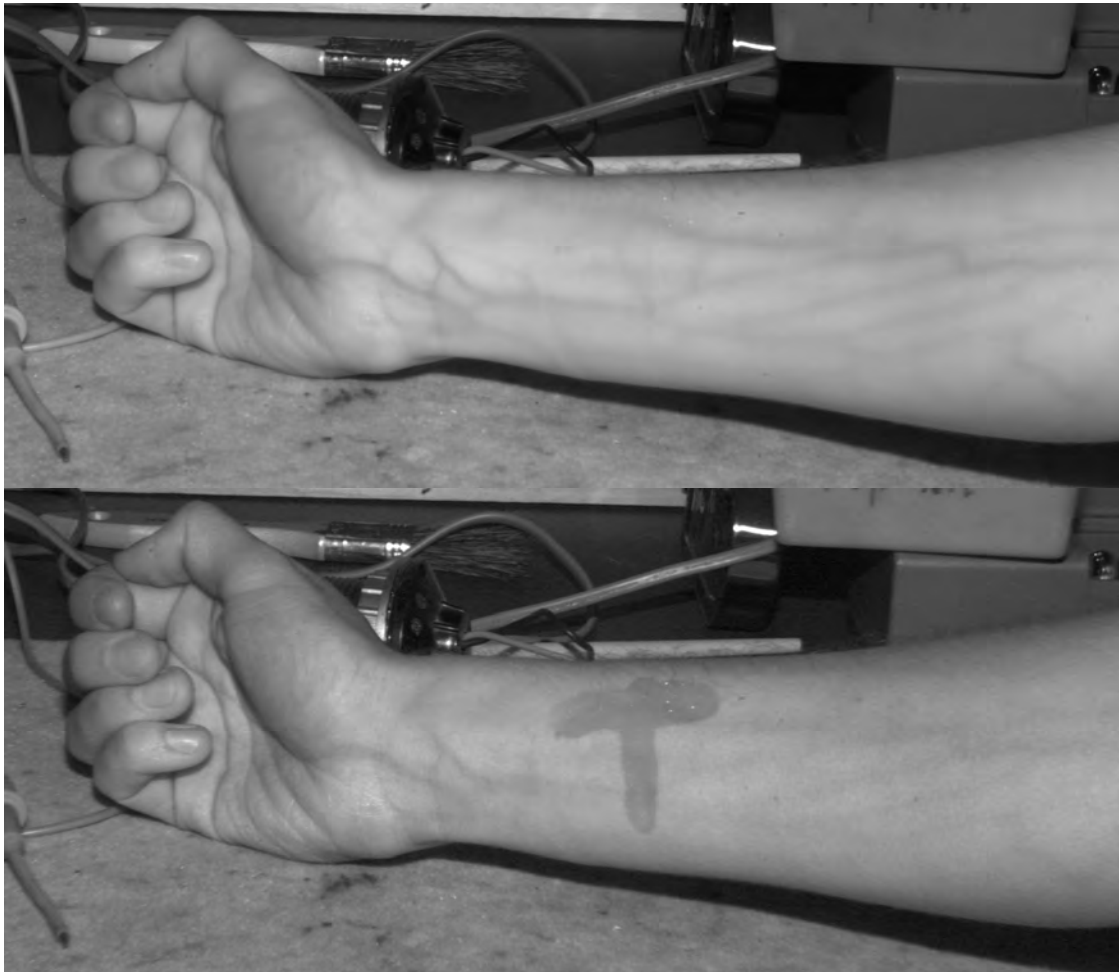


Figure 30. IR (top) and UV (bottom) Images – Pictures courtesy of Dominic Gross

Image Analysis

Once the edge of the image is defined, some basic analytic analysis measurements will be needed to determine any variance between the images. The first measurement will be to determine the area (A) of the image in pixels where $a = 1/2 E_{2a}$ and $b = 1/2 E_{2b}$ (refer to Equation 12 and Figure 31).

$$A = \pi ab \quad (12)$$

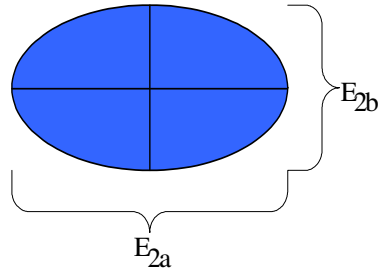


Figure 31. Ellipse Major/Minor Axis Definition

Second, the center of mass is located. The center of mass is defined as the mathematical center of the area outlined by the edge detection process. This point represents the average position of the total particle mass, which assumes every point in the image has a constant density. The x-coordinate and y-coordinate for the image center of mass are calculated based on the formulas in Equations 13 and 14 respectively (National Instruments, 2005).

$$x = \frac{\sum x}{A} \quad (13)$$

$$y = \frac{\sum y}{A} \quad (14)$$

Once this point is located then other calculations can be made such as the radial distance. Finally, the orientation (O) can be determined using the angle (a) of the line that passes through the image's Center of Mass about which the particle has the lowest moment of inertia. This orientation might be necessary in order to position or normalize the images prior to analysis (refer to Equation 15).

$$O = \frac{1}{2} a \tan \left(\frac{2\Sigma_{xy}}{\Sigma_{yy} - \Sigma_{xx}} \right) \quad (15)$$

The equations listed above will be the foundation of other equations used to analyze the asymmetry, the border, the color, and the dimension, otherwise known as the ABCDs of melanoma.

Asymmetry

The 'A' in the ABCD chart stands for asymmetry and was the first image characteristic that was examined. Asymmetry, as it applies to the characteristics of moles, is defined where half of the mole does not match the other half (UMMC, 2004). The radial distance from the center of mass can be determined by scanning the image from the centroid until there is an intersection with the image edge. Each radial scan is compared to its 180-degree counterpart for equivalency. Whether or not a mole has asymmetrical characteristics can be determined by processing the circumference of the image (refer to Figure 32).

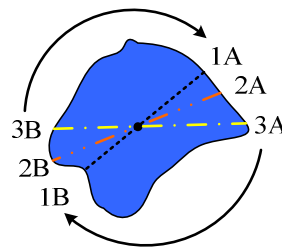


Figure 32. Asymmetry Algorithm

Unfortunately, this is a complex algorithm in which a mathematical algorithm would have had to be derived and written for NI Vision. As an alternative, the asymmetry of the image was analyzed using the elongation factor and the compactness factor (National Instruments, 2005). The maximum Feret diameter (F) is the distance

between the maximum Feret diameter start and the maximum Feret diameter end (refer to Equation 16).

$$F = \sqrt{(F_{y2} - F_{y1})^2 + (F_{x2} - F_{x1})^2} \quad (16)$$

The equivalent rectangle short side (Feret) (RFb) is calculated using the shortest side of the rectangle with the same area as the image (A_{ch}) or area of the image convex hull, and longest side equal in length to the maximum Feret diameter (refer to Equation 17).

$$RF_b = \frac{A_{CH}}{F} \quad (17)$$

Then the elongation factor (E) is determined by dividing the maximum Feret diameter by the equivalent rectangle short side (Feret). The more elongated the shape of a particle, the higher its elongation factor (refer to Equation 18).

$$E = \frac{F}{RF_b} \quad (18)$$

In addition to the elongation factor (E), the compactness factor (C) gave us some indication of the asymmetry. The compactness factor (C) is calculated dividing the Area (A) by the product of the bounding rectangle width (W) and bounding rectangle height (H). This parameter will give an indication of whether the lesions have protrusions outside or indentations inside the circumference of a round or circular lesion (refer to Figure 33).

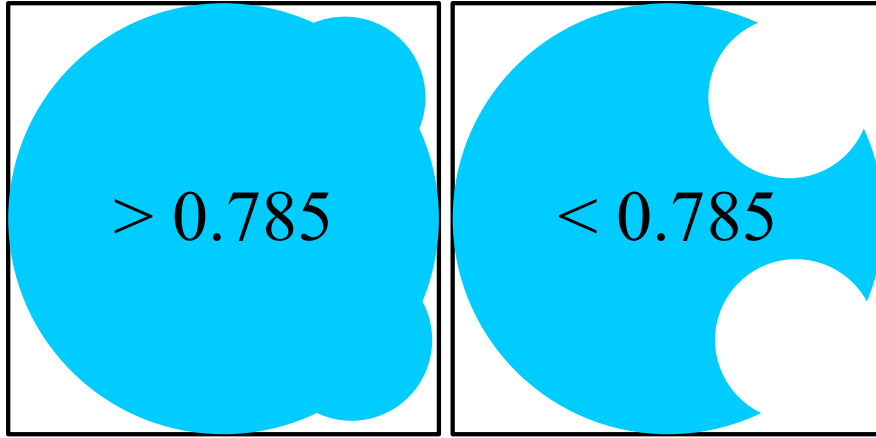


Figure 33. Compactness Factor, Circle protrusions (left) and indentions (right)

The compactness factor belongs to the interval $[0, 1]$ (refer to Equation 19) (National Instruments, 2005).

$$C = \frac{A}{W H} \quad (19)$$

Border

The 'B' in the ABCD chart stands for border and was the second image characteristic that was examined. Border as it applies to the characteristics of a mole is defined where the border or edge of the mole is ragged or irregular (UMMC, 2004). This change in angle along the border can be used to determine whether the image has ragged or irregular characteristics. The length of the outer boundary of the image is called the perimeter (P) (refer to Equation 20).

$$P = \pi \sqrt{2(a^2 + b^2)} \quad (20)$$

In addition to the perimeter (P), the Heywood circularity factor was used to analytically evaluate an image's border. The Heywood circularity factor (H) uses the perimeter (P) of the image divided by the circumference of a circle with the same area (A). The closer the shape of the lesion is to a circle then the closer the Heywood circularity factor (H) is to one (1). The border of the image was analyzed using the perimeter as well as the Heywood circularity factor (refer to Equation 21) (National Instruments, 2005).

$$H = \frac{P}{2\sqrt{\pi A}} \quad (21)$$

Color

The 'C' in the ABCD chart stands for color and was the third image characteristic. Color as it applies to the characteristics of a mole is defined where the color of the mole varies throughout (UMMC, 2004). While this is an important attribute in the identification of skin cancer, it was beyond the scope of this research since it examined the interior of a lesion.

Dimension

The 'D' in the ABCD chart stands for dimension and was the fourth characteristic that was examined. Dimension as it applies to the characteristics of moles is defined where a mole's diameter is greater than 6mm or approximately larger than a pencil's eraser (UMMC, 2004). Dimensional measurements such as area (A) of the image in pixels will be used to meet and objectively compare the images (National Instruments, 2005).

Evolution

Recently, 'E' has been added to the traditional ABCD chart, which stands for evolution or evolving and is the fifth and final characteristic that will be discussed. Evolution is the change of a mole or lesion that is an indication that the lesion is becoming malignant. Everyone should see a physician at least once a year, especially people with a family history of skin cancer or dysplastic nevus syndrome (multiple atypical moles) (Rigel, Friedman, Kopf, and Polsky, 2005). An increase in dimensional measurements such as area (*A*) and perimeter (*P*) mentioned above would be evaluated over time. While this is an important attribute in the identification of skin cancer, it was beyond the scope of this research since it measures variance over a long period of time.

Statistical Sample Size

This research is a feasibility study, and not a clinical study, so sample size for this research was not justified by statistical inference. Fifteen volunteers were chosen to provide a reasonable amount of diversity as well as provide a reasonable number of candidates likely to volunteer. The skin tone diversity sought in this research was not sought by collecting data on ethnicity; instead it was categorized by skin tone reflectivity. This protected a volunteer's privacy by not creating a link between the image and the volunteer. The research goal was not to ensure one sample of skin cancer in the sample size; the goal was to have a representative sample of different skin tones or complexions since we were characterizing images to the color baseline as well as to each other.

Non-Visible Light Spectral Filter Coverage

The B+W 403/Schott UG1 filter was selected for its UV and IR characteristics. This filter passes UV A radiation (300 to 400 nanometers) and IR (700 to 900 nanometers), but blocks visible light and looks pitch-black to our eyes. This filter is used in applications such as forensics or materials research. (Schneider Optik, 2006). This filter should not be confused with UV-blocking filters that photographers normally refer to as “UV Filters” such as the Heliopan Digital 8125 filter (refer to Figure 34).

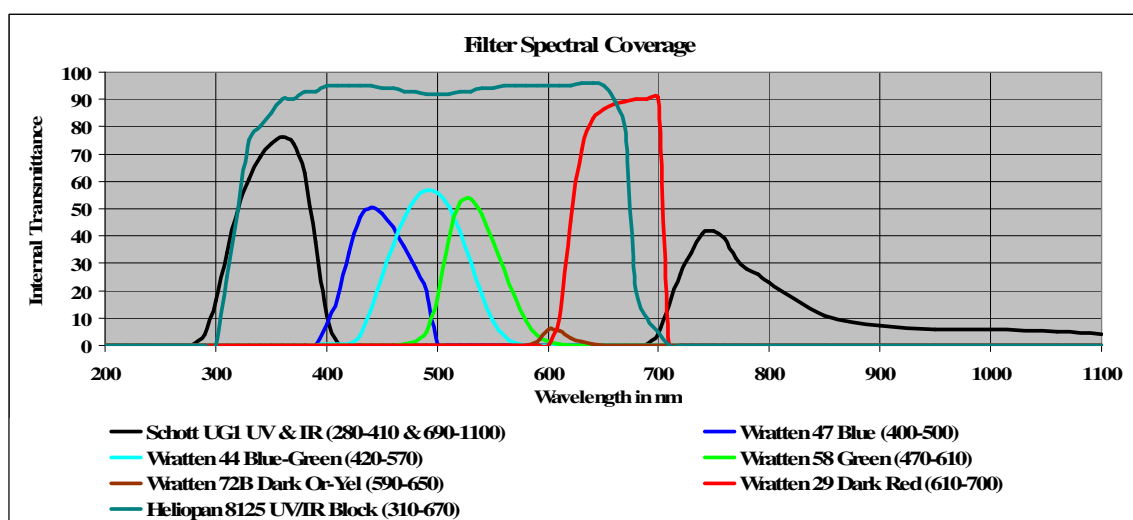


Figure 34. Filter Spectral Coverage (Weast, 1985)

Visible Light Spectral Filter Coverage

The Heliopan Digital 8125 filter was selected for its UV and IR blocking characteristics. This filter passes UV A radiation (280 to 410 nanometers) and IR (690 to 1100 nanometers), but blocks non-visible light. As can be noted in Figure 34, while the Heliopan 8125 does block light above 700 nanometers in the IR band, it does not completely block light below 400 nanometers. The internal IR blocking filter was removed from the camera in order to widen the frequency response on Sigma SD-10.

This allowed the spectral coverage to be controlled externally by adding or removing filters (refer to Appendix I). The Wratten 29 (Dark Red), Wratten 44 (Blue – Green), Wratten 47 (Blue), Wratten 58 (Green), and the Wratten 72B (Dark Orange – Yellow) were selected for spectral coverage (refer to Figure 34 and Table 4). Refer to Appendix J for the frequency response and graphs for each filter selected.

Table 4. Filter Selection (Weast, 1985)

	Filter	Frequency Band in nanometers (nm)	Description
1	Heliopan Digital UV – blocking filter (8125)	400 – 700	UV & IR Blocking (Passes Visible Light)
2	Wratten 29	610 – 700	Dark Red
3	Wratten 72B	590 – 650	Dark Orange – Yellow
4	Wratten 58	470 – 610	Green
5	Wratten 44	420 – 570	Blue – Green
6	Wratten 47	400 – 500	Blue
7	B+W 403 Schott UG1	280 – 410	Ultraviolet (UV) (Blue Channel S/W Extracted)
8	B+W 403 Schott UG1	690 – 1100	Infrared (IR) (Red Channel S/W Extracted)

Specific Procedures

Approach

The overall approach involved finding qualified volunteers, briefing them on the research, if qualified then getting their consent, acquiring the images, preprocessing the images, processing the images, and analyzing the data (refer to Figure 35).

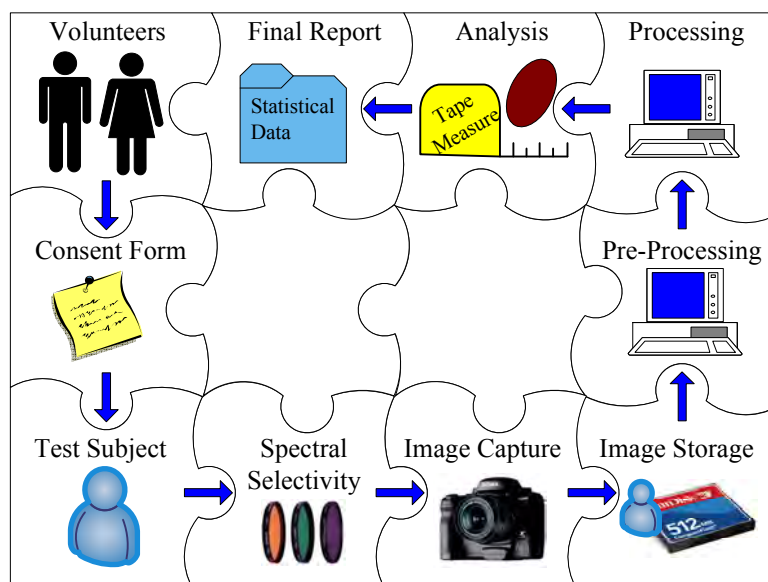


Figure 35. Overall Approach Flow Chart

The first step was finding qualified individuals that were willing to participate in this research. Once a volunteer was identified, he/she was briefed on the research and what would be done to protect their privacy.

Research Involving Human Subjects

Since this research involved human subjects, it would have to comply with the NSU's Institutional Review Board (IRB). The IRB's mission is to protect human subjects involved in research and ensure appropriate practices are being conducted. The protection of the rights and privacy of human subjects involved in research activities is mandated by federal law, which includes: The National Research Act Public Law 99-158, The Health Research Extension Act of 1985, and the National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. These regulations provide guidelines for research with human subjects to ensure their

protection. In keeping with the federal requirements, the NSU IRB process is designed to protect the rights of human subjects involved in any and all research conducted by Nova Southeastern University students (Cannady, 2006). A consent form for this research was developed per the IRB process. Each prospective volunteer was briefed on the research and asked to initial each page and sign the last page. This consent form was designed and is in compliance with the consent form checklist. The following paperwork was submitted to the IRB and IRB approval was received on 15 January 2007 (refer to Appendix H).

- Adult/General Informed Consent (Appendix B)
- Informed Consent Form Checklists (Appendix C)
- Research Protocol (Appendix D)
- Outline of Research Protocol (Appendix E)
- Certificate of Human Subjects (Appendix F)
- Data Collection Instruments (Appendix G)

Once the volunteer had read and signed the “Adult/General Informed Consent” form, then the images necessary for the data acquisition step of the process were captured.

Data Acquisition

This research project included close-up image captures of skin lesions located on the human body in easily accessible as well as non-personal areas. The duration for a volunteer’s participation was less than 30 minutes. The volunteer was asked to position himself/herself and hold still while approximately eight images were captured at a distance of approximately 8 inches. Skin lesions photographed were located in easily accessible non-personal areas (e.g., arms, back, and legs). This process was similar to having a digital picture taken at a close range (refer to Figure 36).



Figure 36. Hand Held Data Acquisition Instrument

This research captured images of skin lesions located on the human body and did not involve cancer diagnosis. This research was intended to measure whether edge detection algorithms are significantly affected if the inputs to the algorithm are filtered images as compared to standard images inside and outside the visible light spectrum. The images were assigned an alphanumeric identifier by the camera (e.g., IMG12345.X3F). This filename had the filter number appended to the name upon transfer to the processing computer (refer to Table 5 for shutter speed settings for each image).

Table 5. Setting for Data Acquisition

Source Image	Visible Light Heliopan 8125	Dark Red Wratten 29	Dark Or-Yel Wratten 72B	Green Wratten 58	Blue-Green Wratten 44	Blue Wratten 47	IR/UV B + W 403 Schott UG1	Shutter Speed	f - Stop	Flash Power	Wavelength
1st	✓							1/125	f 16	1/2	400–700
2nd	✓	✓						1/125	f 16	1/2	415–485
3rd	✓		✓					1/125	f 16	1/2	450–550
4th	✓			✓				1/125	f 16	Full	500–565
5th	✓				✓			1/125	f 16	Full	590–650
6th	✓					✓		1/125	f 16	Full	620–710
7th	✓						✓	1/125	f 11	Full	280–400
8th		✓					✓	1/125	f 11	1/4	700–1100

There were eight exposures per subject. The Heliopan 8125 filter was used with images one through six since the Wratten gel filters also pass a large amount of IR and this was contaminating the results. The Heliopan 8125 blocked the IR. The seventh and eighth images were added when preliminary research identified that there was not a single exposure setting that would work for both UV and IR with just the B+W 403 filter. The B+W 403 filter passes more IR than UV so any setting that works well for UV will overexpose the IR and vice/versa. All of the images required a preprocessing step once the data was acquired.

Preprocessing

Each raw image, approximately 5 megabytes in size, was written to a standard Compact Flash memory card. The Sigma SD10 supports writing the Foveon .X3F file format – which is a compressed linear 3-channel “raw” format, e.g., each channel is the output from the camera’s internal 12-bit A/D converter. The files were processed by a modified version of “dcraw.c” raw format decoding software. The dcraw software was modified to add four new options for this research:

1. “-D” outputs the Foveon raw color channels without converting to RGB
2. “-R r g b d” combines the color channels using four values: ‘r’ multiplier, ‘g’ multiplier, ‘b’ multiplier, and the ‘d’ divisor which will produce a monochrome output. When used with “-D” switch this option can either return a weighted sum of channels or a single channel depending on the values. This option was used to isolate the IR and Ultraviolet Channels.
3. “-g” writes a histogram in CSV format to ‘stdout’
4. “-N” will not perform the Foveon noise reduction

The original source code can be down loaded from Dave Coffin's Web Page at

<http://cybercom.net/~dcoffin/dcraw>. The steps to re-create dcraw version used in this document are as follows:

1. Go to the dcraw home page at <http://cybercom.net/~dcoffin/dcraw> and download the “dcraw.c,v -- complete unabridged RCS file.”
2. The GNU's Not Unix (GNU) Revision Control System (RCS) manages multiple revisions of files by automating the storage, retrieval, and merging of revisions (refer to <http://www.gnu.org/software/rsc/> for information and download instructions for RCS). The version used for this research was based on revision 1.355 of dcraw.c. Using the RCS “co” checkout program, get revision 1.355 from the dcraw.c,v file using the following command:

```
co -r 1.355 dcraw.c
```

3. The GNU ‘diff’ program outputs differences between files line by line. This set of differences is often called a ‘patch’ (refer to <http://www.gnu.org/software/diffutils/diffutils.html> for information and download instructions for diffutils). Refer to Appendix K for a listing of the patch source code (x3vuvir.patch) that was modified for this research.
4. The GNU ‘patch’ takes a patch file containing a difference listing produced by diff and applies those differences to one or more original files, producing patched versions (refer to <http://www.gnu.org/software/patch/> for information and download instructions for patch). Using the GNU patch program, apply the x3fuvir patches to this version of dcraw.c using the following command:

```
patch -p0 <dcraw-x3vuvir.patch dcraw.c
```

5. The ‘cygwin’ program is a Linux-like environment for Microsoft Windows (refer to <http://www.cygwin.com/> for information and download instructions for cygwin). Compile the resulting program as follows using the Cygwin gcc compiler:

```
gcc -o dcraw -O4 dcraw.c -lm -DNO_JPEG -DNO_LCMS
```

The dcraw was set to not perform the usual color processing and instead just uncompress and output the raw A/D values for each channel. No conventional photographic processing of the image data (e.g., sharpening, automatic white balance) was performed. The red and blue channels required some extra processing steps to extract the UV and IR channels into separate images. This processing required some modifications to David Coffin’s open-source dcraw program (2005). The result was one image from the blue channel which was the light passed via the UV band and the other was the light passed via the IR which was the light passed via the red channel. The green channel has no useful information in it with the B+W 403/Schott UG1 filter installed and was discarded. Dcraw, using the settings, preprocessed the eight source images (refer to Table 6). Refer to Appendix M for a thumbnail sample of the X3F to TIF images.

Table 6. DCRaw GUI Interface Settings

Source Image	GUI Option	Filters	DCRaw Settings
1st	2	Heliopan 8125	-T -D
2nd	2	Heliopan 8125 Wratten 29 (Dark Red)	-T -D
3rd	2	Heliopan 8125 Wratten 72B (Dark Or-Yel)	-T -D
4th	2	Heliopan 8125 Wratten 58 (Green)	-T -D
5th	2	Heliopan 8125 Wratten 44 (Blue-Green)	-T -D
6th	2	Heliopan 8125 Wratten 47 (Blue)	-T -D
7th	3	Heliopan 8125 B + W 403 Schott UG1 (UV)	UV: -T -D -R 0.0 0.0 1.0 1.0
8th	4	Wratten 29 (Dark Red) B + W 403 Schott UG1 (IR)	IR: -T -D -R 1.0 0.0 0.0 1.0

The preprocessing tab of the LabVIEWTM software designed for this research automatically sets up the ddraw software switches depending on which option is selected (refer to Figure 37).

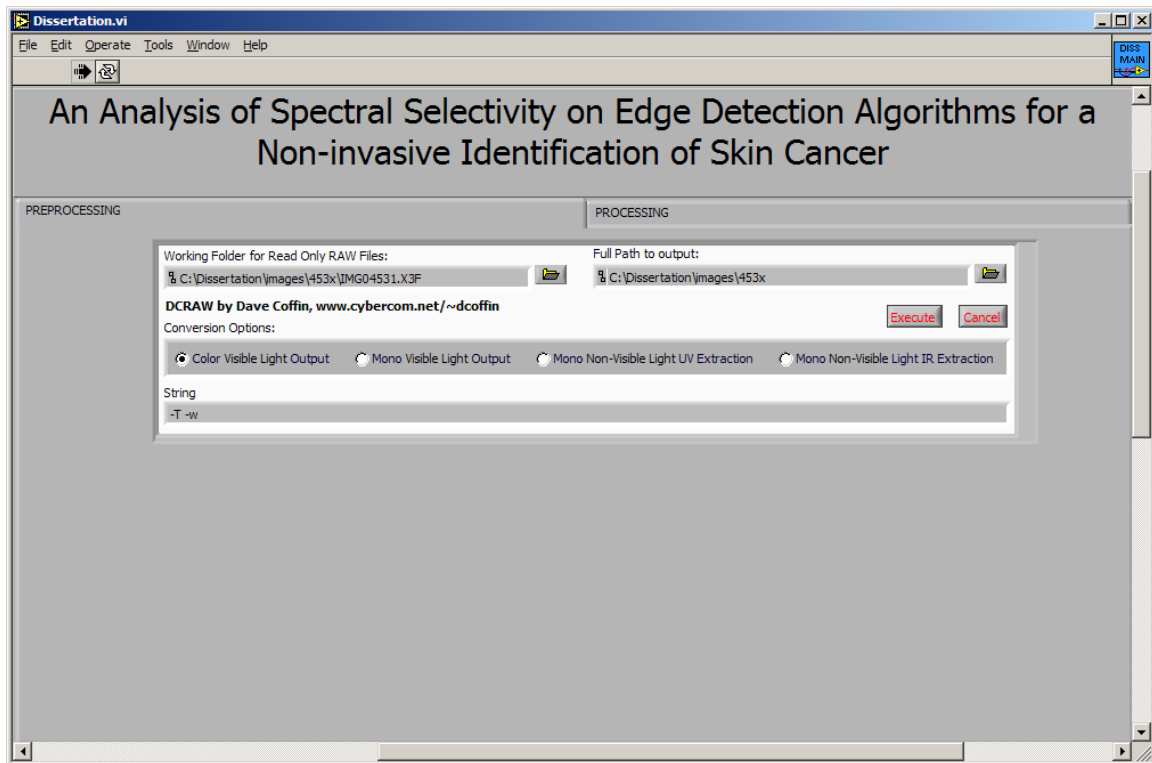


Figure 37. Dissertation LabVIEW™ Application for Preprocessing

Calibration

Once the images are converted to TIFF files in the preprocessing step, the next step was to process each image with the National Instruments Vision software; however, this software required an image calibration step first. The area each image covers is 42.2 mm x 28.1 mm (approximately one inch high by one and a half inches). The ddraw image size output in pixels is 2304 x 1531. This means the resolution of each image is 18.3 μm per pixel (42.2 mm / 2304 pixels), or 1386.8 pixels per inch (refer to Figure 38).

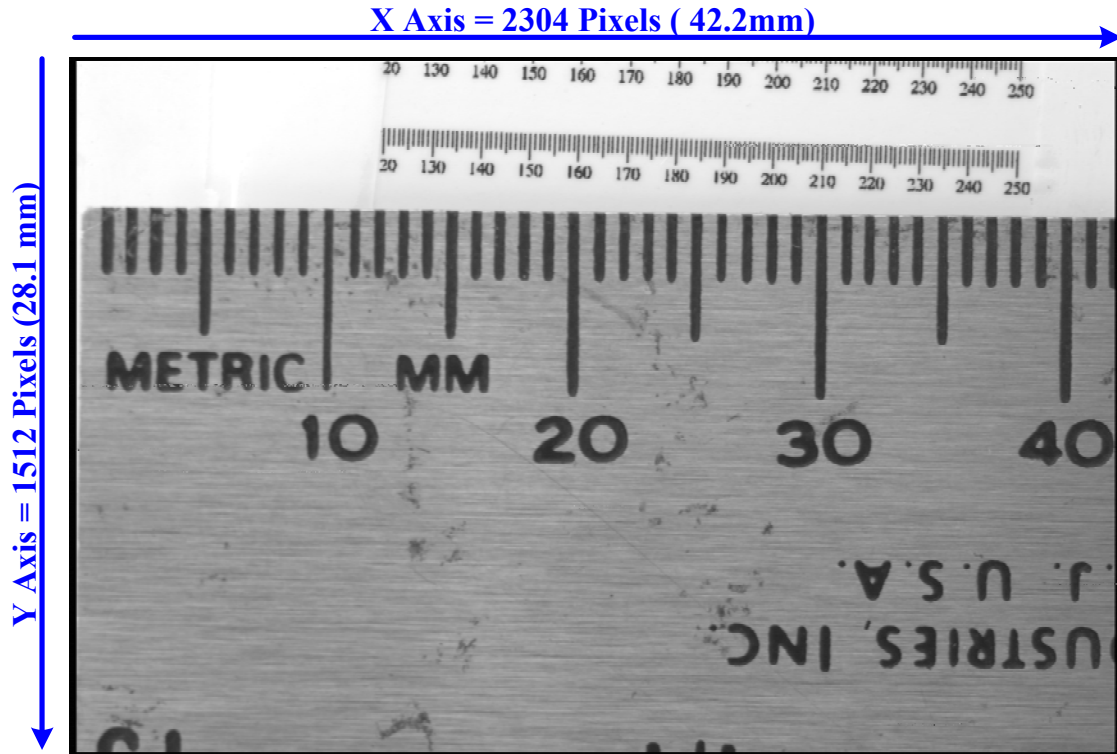


Figure 38. National Instruments Vision Image Calibration

The National Instruments Vision software calibration transforms a pixel coordinate to a real-world coordinate through scaling in the x (horizontal) and y (vertical) directions. This is accomplished by defining the distance between two points on a calibrated image (refer to Figure 39). The calibration process is only required if real-world units are required. This research used raw measurements to avoid introducing any calibration error, for example, raw measurements will be in pixels. Refer to Appendix O for the calibration process steps if required.

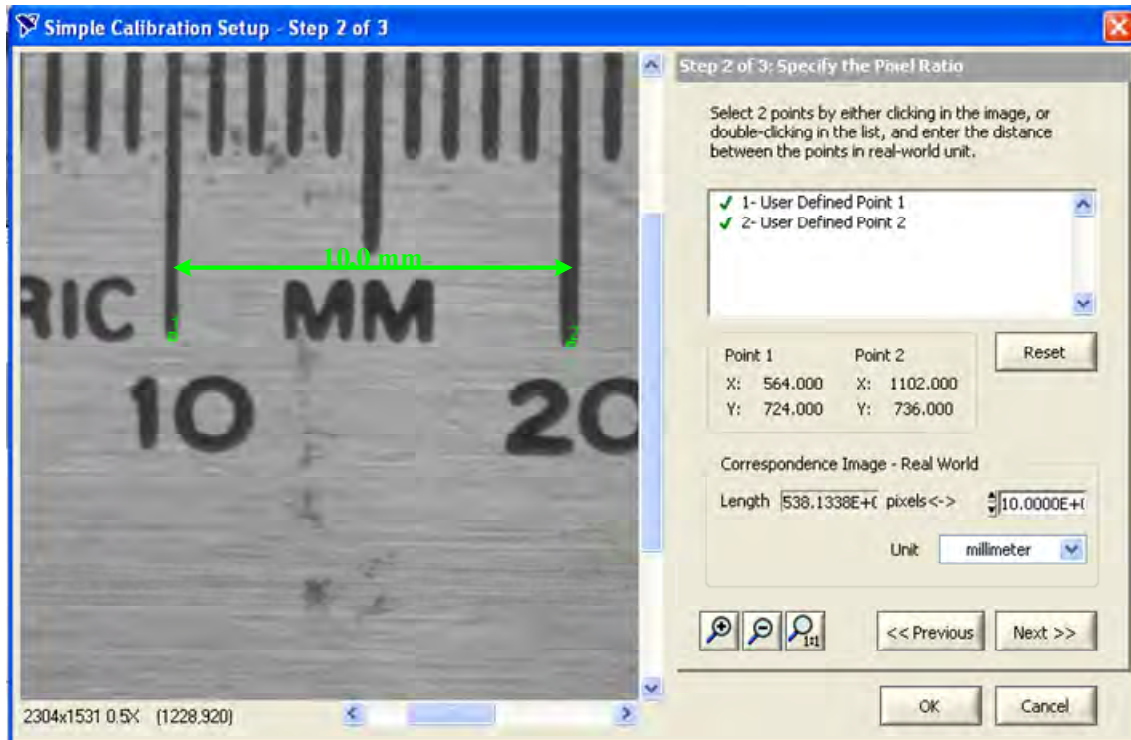


Figure 39. National Instruments Calibration Process

Processing

The next step requires the images to be processed. First, an auto threshold for the moments was performed which applies a threshold to an image by using a statistical tool which recalculates a theoretical binary image based on the histogram (refer to Figure 40).

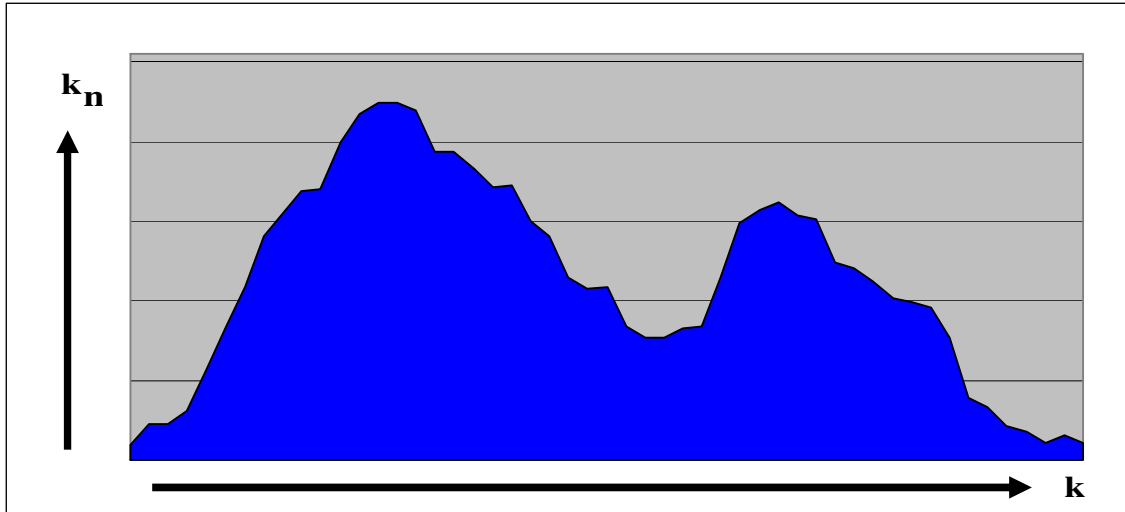


Figure 40. Image Grayscale Histogram

Next the border of the image was removed as well as any small objects. Then different edge detection algorithms were applied against the image. Particle Analysis calculated measurements for every particle in the image. Refer to Appendix N for the particle analysis report. The contour of the image was overlaid on the initial image and displayed. The image as well as the measurements of the image was saved for later analysis. A script for this process was tested and validated with National Instrument's Vision Assistant prior to converting to a NI LabVIEW™ Virtual Instrument (VI) (refer to Figure 41). Refer to Appendix L for the NI LabVIEW™ Code and panels.

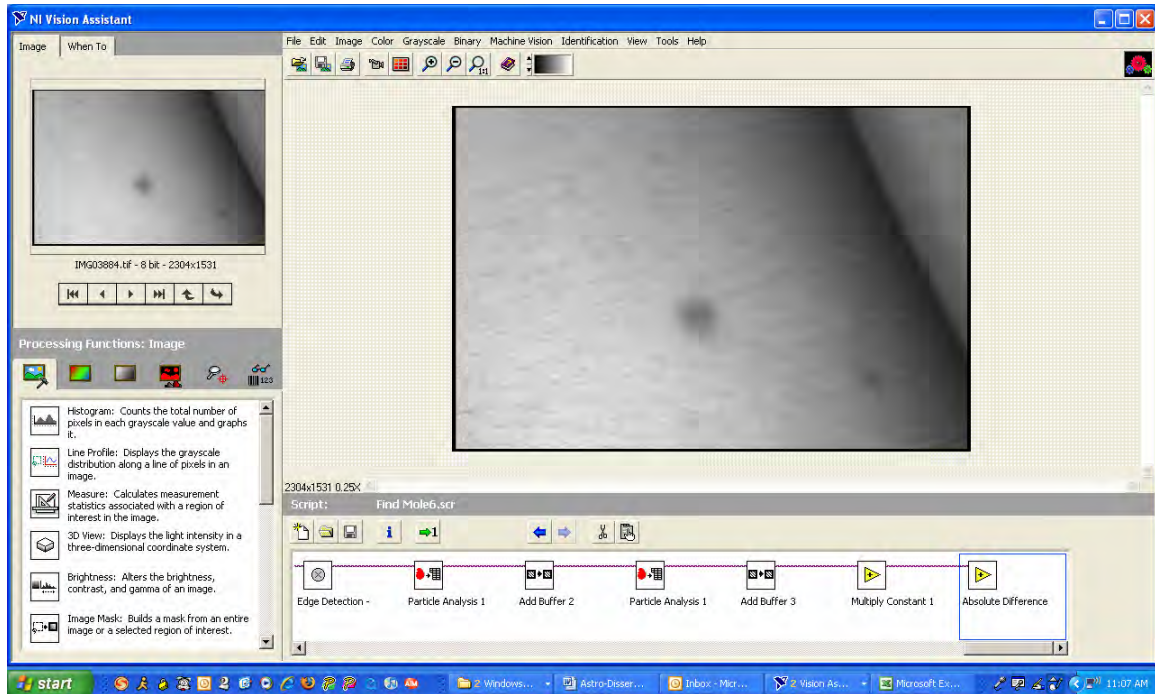


Figure 41. National Instruments Vision

The processing tab of the LabVIEW™ software designed for this research automatically analyzes all the TIF images in the directory selected. The erosion factor is selectable; however, the default is set to four. If the “Find Particle” button is clicked, then only the edge detection algorithm selected will be analyzed. If the “Find All Particles” button is clicked, then all seven edge detection algorithms will be processed and analyzed. The user has the option of scrolling through all of the processed images (refer to Figure 42).

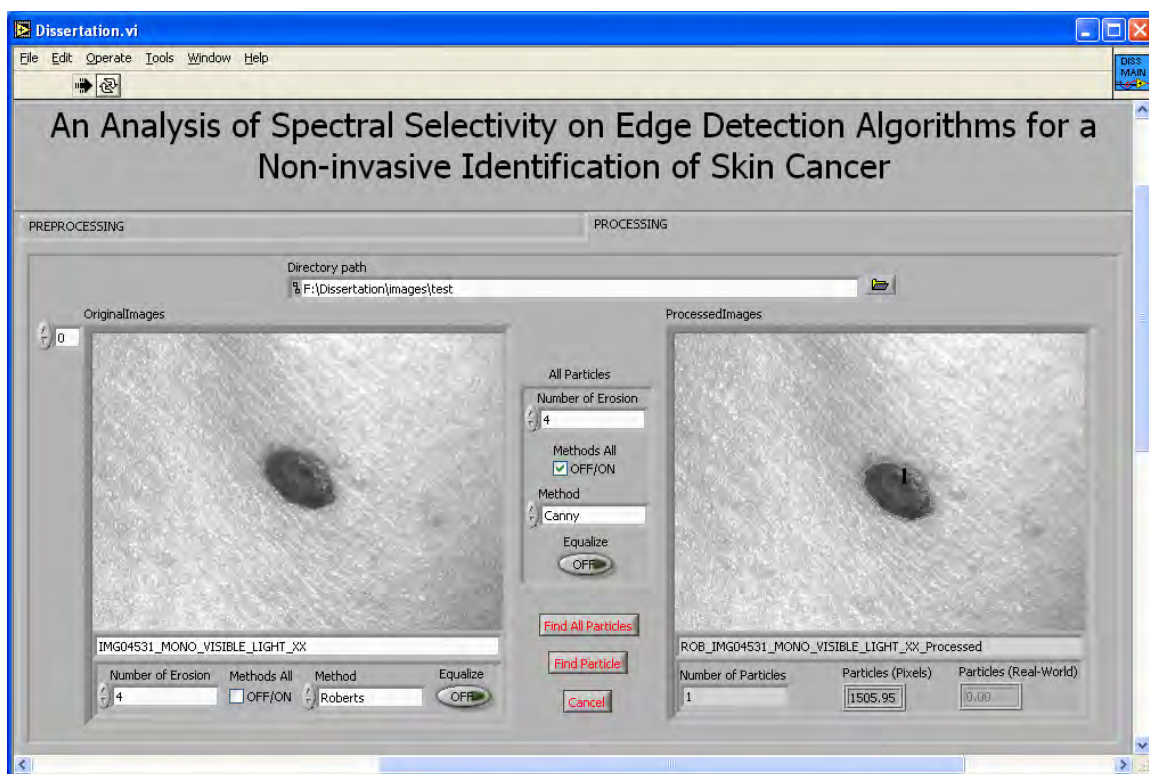


Figure 42. Dissertation LabVIEW™ Application for Processing

Data Analysis

Once the images were processed, the system generated a report of analytical measurements for all of the images (refer to Appendix N). Each image was analyzed and compared against a non-filtered, visual spectrum baseline image (i.e., visible color light with 8125 filter) as well as being analyzed against the other filtered wavelengths for that same image. The results for each filter wavelength per image was recorded in a table for asymmetry, border and dimension (refer to Table 7).

Table 7. Data Analysis Table

Parameter	Asymmetry	Border	Dimension	Baseline 8/25	UV/IR Blocking	Schott UG1	IR	Schott UG1	UV	Dark Red	Wratten 29	Blue-green	Wratten 44	Blue	Wratten 47	Green	Wratten 58	Dark Or-Yel	Wratten 72B	Dk Amber	Wratten 90
Elongation Factor (<i>E</i>)	✓																				
Compactness Factor (<i>C</i>)	✓																				
Perimeter (<i>P</i>)		✓																			
Heywood Circularity (<i>H</i>)		✓																			
Area (<i>A</i>)			✓																		

As can be noted in Appendix N, there was a large amount of data to analyze. Every lesion photographed had a report like this not only for each lesion, but also for each edge detection algorithm the lesion image was run against. For example, an image from volunteer one lesion one was run against the Canny edge detection algorithm and the area was analyzed and graphed. In addition, a polynomial trend line was added to show the overall impact of spectral selectivity. This process was repeated for all the spectral selectivity images in a set against all the edge detection algorithms. The graphs combined with the analysis reports determined the hypotheses were correct (refer to Figure 43).

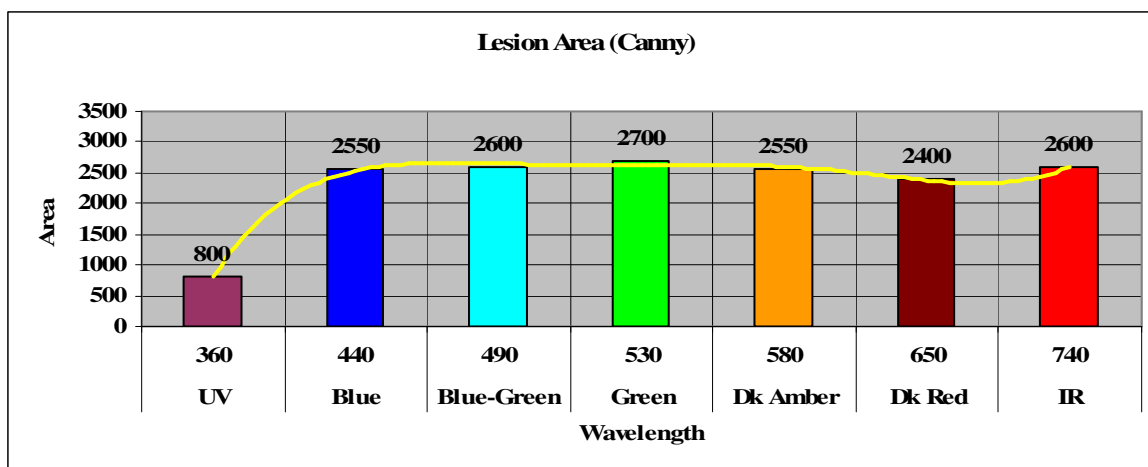


Figure 43. Canny Edge Detection Area per Wavelength

Resource Requirements

The preliminary resource list needed for this project is listed in Table 8. The cost of the known items for this research is \$14,530.00. Some of the resources were borrowed in order to offset the cost.

Table 8. Resource List

Description	Resources Borrowed	Resources Purchased
P4 Computer with Windows XP OS		\$1,500.00
NI LabVIEW™ Professional v8.2	\$4,095.00	
NI Vision Development Module	\$2,895.00	
- Large library of common vision algorithms - Integrates with LabVIEW™ control software		
NI Vision Builder for Automated Inspection	\$1,495.00	
Sigma SD10 DSLR Camera		\$1,000.00
Camera Lens	\$900.00	
8-48mm focal length, C-mount	\$300.00	
Nikon El-Nikkor 80mm f/5.6 lens, and bellows		\$250.00
Sunpak DX8R Ring Flash		\$100.00
Heliopan Digital UV-blocking filter (8125)		\$75.00
Schott UG1 UV & IR (B+W 403)		\$75.00
Assorted Wratten Filters 29, 44, 47, 58, and 90		\$100.00
	\$11, 430.00	\$3100.00

Summary

In summary, the background, the research methodology, and the specific procedures employed were discussed in detail. The background information laid a solid foundation starting with how the eye sees color, digital images, digital photography, Bayer image sensors, Foveon X3 image sensor, camera basics, the camera selected for this research, camera lenses, camera lighting, image storage, and image compression. The research methodology discussed the overall approach by providing a solid foundation on edge detection fundamentals, edge detection search methodologies, image filtering, spectral selectivity, image analysis, as well as fundamental malignant melanoma terms used in identification: asymmetry, border, color, dimension, and evolution.

Spectral selectivity provided at least two opportunities to see things in a different light:

1. We may be able to eliminate extraneous information
2. We may be able to provide information that is not visible to the human eye.

The specific procedures used for this dissertation were covered in sufficient detail as to permit replication, reliability and validity.

Chapter 4

Results

Data Sets

While the goal was to include all the data collected, the fact is that 10 of the 18 lesions had to be excluded from the final analysis. For example, the Sigma SD10 internal filter was used for some data captures to see if it offered any significant advantage over the Heliopan 8125. The internal camera filter did not offer any advantages, and the risk of damage to the internal filter by repeated insertion was instrumental in discarding these images. The images discarded for this reason included 453X, 473X, 474X, and 477X. In addition, some data sets were excluded from the analysis since the data capture of the lesions missed the intended target such as 456X. One contributing factor was the B + W 403 Schott UG1 blocks visible light, which eliminates the use of the camera viewfinder thus making it difficult to center the target lesion. Other data sets were excluded for failing to identify the target lesions for one reason or another. Lesions that were included that fell into this category included 457X, 458X, 480X, 481X, and 482X.

Findings

Overall, the wavelengths that consistently showed the overall best results were at 400-500 nanometers (Wratten 47 Blue) and 420-570 nanometers (Wratten 44 Blue

Green). The probable reason for this is the good color separation at those wavelengths for the majority of the lesions. The number of particles found peaked at 310-700 nanometers (Visible Light) and 420-570 nanometers (Wratten 44 Blue Green); however, for this measurement the peak is not necessarily a good thing. One could argue that a large number indicates that this wavelength is more sensitive but, ideally, only one particle is desired, which is the target lesion. This measurement is also dependent on consistent lighting as well as the color separation between the skin background and the lesion (refer to Table 9).

Table 9. Lesion Peak Wavelength Analysis Summary

Lesion Set	Included in Study	Parts Found	Elongation Factor	Compactness Factor	Perimeter (Pixels)	Heywood Cir.	Area (Pixels sq)
453X	X	400-500	400-500	400-500	420-570	420-570	420-570
454X	✓	420-570	280-410	690-1100	400-500	610-700	400-500
455X	✓	310-700	400-500	400-500	310-700	310-700	310-700
456X	X	310-700	420-570	470-610	420-570	420-570	420-570
457X	X	310-700	400-500	280-410	310-700	310-700	310-700
458X	X	0	0	0	0	0	0
459X	✓	400-500	590-650	280-410	310-700	310-700	310-700
460X	✓	310-700	420-570	690-1100	400-500	400-500	400-500
472X	✓	400-500	310-700	590-650	400-500	590-650	400-500
473X	X	400-500	400-500	690-1100	420-570	420-570	420-570
474X	X	420-570	690-1100	690-1100	310-700	310-700	590-650
475X	✓	400-500	690-1100	610-700	400-500	400-500	400-500
476X	✓	310-700	690-1100	280-410	310-700	310-700	310-700
477X	X	310-700	310-700	690-1100	400-500	400-500	400-500
479X	✓	400-500	400-500	420-570	420-570	420-570	400-500
480X	X	690-1100	690-1100	420-570	690-1100	690-1100	690-1100
481X	X	400-500	690-1100	610-700	470-610	420-570	470-610
482X	X	590-650	610-700	400-500	420-570	420-570	420-570

An analysis of each individual lesion can be found in the following text. If a lesion was not included in the analysis, then that reason is stated. If the target lesion was not identified at a certain wavelength, then the analysis will state this up front. The reason a target lesion sometimes fails to be identified is the lack of color separation at these wavelengths, in other words, the target lesion is too close in color to the background color. For the following lesion analysis, refer to Appendix P for the preprocessed raw source images, Appendix Q for the processed images, Appendix R for the lesion measurement reports, and Appendix S for the lesion analysis graphs.

Lesion 453X

This data set was excluded from the analysis since the internal camera filter was used at 310-700 nanometers (Visible Light) instead of the Heliopan 8125.

Lesion 454X

The results from the edge detection algorithms were quite similar for this lesion with the exception of the Sigma edge detection algorithm, which showed anomalous readings at several wavelengths. None of the edge detection filters identified the target lesion at 590-650 nanometers (Wratten 72B Dark Orange Yellow) and 690-1100 nanometers (B+W 403 UG1 Infrared). Even when the target lesion was identified, on three occasions, the Sigma edge detection algorithms did not find any particles. In addition, the Sigma detection algorithm broke the target lesion into three segments at 280-410 nanometers (B+W 403 UG1 Ultraviolet) while this was not the case for the other

algorithms. The number of particles found peaked at 420-570 nanometers (Wratten 44 Blue-Green) before starting to decrease again. The elongation factor was slightly higher for 280-410 nanometers (B+W 403 UG1 Ultraviolet) than the control, but all the wavelengths in the visible light spectrum were approximately the same as the control. The compactness factor increased slightly in the visible spectrum over the control; however, there was a noticeable increase in the non-visible light spectrum at 280-410 nanometers (B+W 403 UG1 Ultraviolet). The perimeter peaked way above the control at 420-570 nanometers (Wratten 44 Blue Green). The analysis of the Heywood Circularity factor showed no significant difference between the control and the other wavelengths. The area also peaked way above the control at 420-570 nanometers (Wratten 44 Blue Green). For this lesion, 420-570 nanometers (Wratten 44 Blue Green) provided the greatest color separation.

Lesion 455X

The results from the edge detection algorithms were quite similar for this lesion with the exception of the Gradient and Sigma edge detection algorithm, which showed anomalous readings at several wavelengths. None of the edge detection filters identified the target lesion at 280-410 nanometers (B+W 403 UG1 Ultraviolet), 590-650 nanometers (Wratten 72B Dark Orange Yellow), and 690-1100 nanometers (B+W 403 UG1 Infrared). Even when the target lesion was identified, on two occasions, the Sigma edge detection algorithm did not find any particles. The number of particles found was either one or two for all the visible light wavelengths; however, the particles increased from four to seven depending on what edge detection algorithm was used for the control.

Again, this can be explained by the color separation at specific wavelengths where the control is a composite of all the visible light wavelengths. The elongation factor was slightly higher for 400-500 nanometers (Wratten 47 Blue) than the control as well as the other wavelengths. An unexplainable anomaly was the Gradient edge detection algorithm showed a 2.0 increase over all the other algorithms for the control. In addition, the Sigma edge detection algorithm showed a 1.0 increase over all the other algorithms at 400-500 nanometers (Wratten 58 Green). The compactness factor peaked at 400-500 nanometers (Wratten 47 Blue) with all the spectrums being slightly higher than the control. The perimeter peaked at 420-570 nanometers (Wratten 44 Blue Green) with Gradient and Sigma far exceeding the other edge detection algorithms at this wavelength band. The Heywood Circularity factor performed the same as the perimeter for the control and as well as the other wavelengths. The area peaked at 420-570 nanometers (Wratten 44 Blue Green) but was still less than the control, which was a composite of the visible light wavelengths.

Lesion 456X

This data set was excluded from the analysis since 280-410 nanometers (B+W 403 UG1 Ultraviolet) image missed centering the target lesion within the field of view.

Lesion 457X

This data set was excluded from the analysis since two lesions approximately the same size in target area could skew data findings if included; especially if the software alternated between which one returned the largest area.

Lesion 458X

This data set was excluded from the analysis since all of the edge detection filters failed to identify the target lesion during processing. The suspected reason for the failure to identify the target lesion is the gradual transition of the lesion or corrupted source image. This could be compensated for by adjusting the threshold values in the software but the result would be an inconsistent baseline.

Lesion 459X

The results from the edge detection algorithms were quite similar for this lesion. None of the edge detection filters identified the target lesion at 280-410 nanometers (B+W 403 UG1 Ultraviolet), 590-650 nanometers (Wratten 72B Dark Orange Yellow), 610-700 nanometers (Wratten 29 Dark Red), and 690-1100 nanometers (B+W 403 UG1 Infrared). The number of particles found ranged from 20 to 33 when the lesion was identified and performed the same for all the edge detection algorithms. The elongation factor was slightly higher for 400-500 nanometers (Wratten 47 Blue) than the control as well as the other wavelengths. The compactness factor was the same as the control when the lesion was identified. The perimeter peaked at 420-570 nanometers (Wratten 44 Blue Green) but this peak was well below the control. The Heywood Circularity factor performed the same as the control for visible light with the exception of 400-500 nanometers (Wratten 47 Blue) which was considerably lower. The area peaked at 420-570 nanometers (Wratten 44 Blue Green) but was still less than the control, which was a composite of the visible light wavelengths.

Lesion 460X

The results from the edge detection algorithms were quite similar for this lesion with the exception of the Gradient edge detection algorithm, which showed anomalous readings at several wavelengths. All of the edge detection filters identified the target at all of the wavelengths. The number of particles found peaked at 420-570 nanometers (Wratten 44 Blue Green) before starting to decrease again but none of the wavelengths were as high as the control. In addition, the Gradient edge detection algorithm broke the target lesion into smaller segments thus resulting in a much higher particle count than the other edge detection algorithms. All of the edge detection algorithms performed exceptionally well for this lesion by identifying only the target lesion in the non-visible light wavelengths at 280-410 nanometers (B+W 403 UG1 Ultraviolet) and 690-1100 nanometers (B+W 403 UG1 Infrared). The elongation factor peaked at 420-570 nanometers (Wratten 44 Blue Green) while the compactness factor peaked at 690-1100 nanometers (B+W 403 UG1 Infrared). In addition, the Sigma edge detection algorithm was 0.3 higher than all the other algorithms at 280-410 nanometers (B+W 403 UG1 Ultraviolet). The perimeter, Heywood Circularity factor, and area peaked at 400-500 nanometers (Wratten 47 Blue). The Gradient edge detection algorithm was higher than the other edge detection algorithms for the perimeter and Heywood Circularity factor.

Lesion 472X

The results from the edge detection algorithms were quite similar for this lesion with the exception of the Sigma edge detection algorithm, which showed anomalous readings at several wavelengths. None of the edge detection filters identified the target

lesion at 280-410 nanometers (B+W 403 UG1 Ultraviolet) and 690-1100 nanometers (B+W 403 UG1 Infrared). The number of particles found peaked at 400-500 nanometers (Wratten 47 Blue) and was considerably higher than the control. The elongation factor was consistent across all wavelengths with the exception of the Sigma edge detection algorithm that peaked above the rest at 590-650 nanometers (Wratten 72B Dark Orange Yellow), and 610-700 nanometers (Wratten 29 Dark Red). The compactness factor peaked at 590-650 nanometers (Wratten 72B Dark Orange Yellow). The perimeter and Heywood Circularity factor was consistent across all wavelengths with the exception of the Gradient edge detection algorithm which peaked above the rest at 590-650 nanometers (Wratten 72B Dark Orange Yellow) and at the control, 310-700 nanometers (Heliopan 8125). The area peaked at 400-500 nanometers (Wratten 47 Blue). The Sigma edge detection algorithm was considerably lower than the rest of the edge detection algorithms at 610-700 nanometers (Wratten 29 Dark Red) for the perimeter, Heywood Circularity factor, and area.

Lesion 473X

This data set was excluded from the analysis since the internal camera filter was used at 310-700 nanometers (Visible Light) instead of the Heliopan 8125. In addition, this data set missed centering the target lesion within the field of view at 280-410 nanometers (B+W 403 UG1 Ultraviolet).

Lesion 474X

This data set was excluded from the analysis since the internal camera filter was used at 310-700 nanometers (Visible Light) instead of the Heliopan 8125.

Lesion 475X

The results from the edge detection algorithms were quite similar for this lesion. None of the edge detection filters identified the target lesion at 280-410 nanometers (B+W 403 UG1 Ultraviolet), and 610-700 nanometers (Wratten 29 Dark Red), and 690-1100 nanometers (B+W 403 UG1 Infrared). The number of particles found ranged from seven to 54 when the lesion was identified and performed relatively the same for all the edge detection algorithms. Numerous artifacts were identified for this lesion and the target lesion was segmented for some wavelengths. The elongation factor and compactness factor peaked at 590-650 nanometers (Wratten 72B Dark Orange Yellow), which was higher than the control. The perimeter, Heywood Circularity factor, and area peaked at 400-500 nanometers (Wratten 47 Blue).

Lesion 476X

The results from the edge detection algorithms were quite similar for this lesion with the exception of the Gradient edge detection algorithm, which showed anomalous readings at several wavelengths for all of the recorded parameters. None of the edge detection filters identified the target lesion at 280-410 nanometers (B+W 403 UG1 Ultraviolet and 690-1100 nanometers (B+W 403 UG1 Infrared). The number of particles found ranged from 1 to 13 when the lesion was identified; however, the Gradient edge

detection algorithm peaked at 34 particles found. For some reason this algorithm broke the lesion into small segments especially along the edge of the target lesion. The elongation factor and compactness factor was consistent across all the wavelengths and peaked at 610-700 nanometers (Wratten 29 Dark Red). The perimeter, Heywood Circularity factor, and area peaked at 400-500 nanometers (Wratten 47 Blue), which was slightly lower than the control.

Lesion 477X

This data set was excluded from the analysis since the internal camera filter was used at 310-700 nanometers (Visible Light) instead of the Heliopan 8125. In addition, this data set missed centering the target lesion at several wavelengths.

Lesion 479X

The results from the edge detection algorithms were quite similar for this lesion. This lesion was unique in that the target lesion was only identified at 400-500 nanometers (Wratten 47 Blue) and 420-570 nanometers (Wratten 44 Blue Green). The reason for this is unclear since the target lesion is centered and appears to show good color separation; however, the brightness of the images are slightly on the light side. In addition, this data set was almost excluded from the analysis since the control also failed to identify the target lesion; however, when the target lesion was identified at other wavelengths it showed outstanding color separation. The number of particles found ranged from 20 to 32 when the lesion was identified. The elongation factor was slightly higher at 400-500 nanometers (Wratten 47 Blue) while the compactness factor was slightly higher at 420-

570 nanometers (Wratten 44 Blue Green). The perimeter and Heywood Circularity factor peaked at 420-570 nanometers (Wratten 44 Blue Green). The area was slightly larger at 400-500 nanometers (Wratten 47 Blue). While the target lesion was only identified at two wavelengths, when the target was identified the algorithms did an outstanding job of outlining the perimeter of the lesion.

Lesion 480X

This data set was excluded from the analysis since all of the edge detection filters failed to identify the target lesion during processing. The suspected reason for the failure to identify the target lesion is the gradual transition of the lesion or corrupted source image. This could be compensated for by adjusting the threshold values in the software but the result would be an inconsistent baseline.

Lesion 481X

This data set was excluded from the analysis since all of the edge detection filters failed to identify the target lesion due to the interference of the surrounding hair.

Lesion 482X

This data set was excluded from the analysis since all of the edge detection filters failed to identify the target lesion during processing. The suspected reason for the failure to identify the target lesion is the gradual transition of the lesion or corrupted source image. This could be compensated for by adjusting the threshold values in the software but the result would be an inconsistent baseline.

Summary

In summary, this chapter analyzed all the lesions; however, some data sets were not used for the final analysis. For example, all of the data sets that used the Sigma SD10 internal filter were excluded from the analysis since they were not part of the final procedures. While this was an experiment to see if it offered any significant advantage over the Heliopan 8125, the risk of damage to the internal filter was instrumental in discarding these images as a valid option. In addition, some data sets were excluded from the analysis since the data capture of the lesions missed the intended target. The major contributing factor is that the B + W 403 Schott UG1 blocks visible light, which eliminates the use of the camera viewfinder. Other reason data sets were discarded included hair interference and the failure of the software to identify the target lesion.

Overall, The results from the edge detection algorithms were quite similar for all of the lesions that were included in the analysis. While the Canny edge detection algorithm is a more sophisticated edge detection approach, it performed only moderately better than its predecessors: Differentiation, Gradient, Prewitt, Roberts, Sigma, and Sobel. The Prewitt and Robert edge detection algorithms had the next best consistency and performed relatively the same despite the fact that they are not suited for the same applications. The Prewitt edge detection algorithm is a nonlinear high-pass filter that extracts the contours in gray-level values using a 3×3 filter kernel and is best suited for curved contours. The Roberts edge detection algorithm is a nonlinear high-pass filter that outlines the contours in grayscale that highlight pixels where an intensity variation occurs along the diagonal axis. While the Prewitt edge detection algorithm should have been

more suited to this application, the Roberts and Prewitt performed about the same. The Differentiation edge detection algorithm is a nonlinear high-pass filter that produces continuous contours by highlighting each pixel where an intensity variation occurs between itself and its three upper-left neighbors. The Sobel edge detection algorithm is a nonlinear high-pass filter that extracts the contours in gray-level values using a 3×3 filter kernel. The Sobel filter is better suited for squared contours yet for some reason worked well for this application. The Differentiation, Prewitt, Roberts, and Sobel edge detection algorithms, despite the different mathematical approaches, all had similar results. The Gradient and Sigma edge detection algorithms showed anomalous readings at several wavelengths. The Gradient edge detection algorithm is a nonlinear high-pass filter that highlights the variations of light intensity along a specific direction, which has the effect of outlining edges and revealing texture. Since this algorithm is designed to reveal texture, then it makes sense that it is susceptible to subtle changes in light and could explain why the results were sometimes anomalous. The Sigma edge detection algorithm is a nonlinear high-pass filter that outlines edges. A Sigma filter outlines contours and details by setting pixels to the mean value found in their neighborhood if the deviation from this value is not significant.

The elongation factor, compactness factor, and Heywood Circularity factor varied from 280-410 nanometers (B+W 403 UG1 Ultraviolet) to 690-1100 nanometers (B+W 403 UG1 Infrared) and all the wavelengths in between. This brought into question whether these measurements add any value. While there is probably useful data that can be extrapolated from these measurements, they did not provide any value for this research

other than to verify that they are affected by spectral selectivity. The perimeter and area trended around the lower wavelengths at 310-700 nanometers (Visible Light), 400-500 nanometers (Wratten 47 Blue), and 420-570 nanometers (Wratten 44 Blue Green). The perimeter and area turned out to be the most practical for this research and these measurements alone would have validated the hypothesis and greatly simplified the research and software. That is not to say that the elongation factor, compactness factor, and Heywood Circularity factor do not add value, especially for future research. Despite this oversight, the data still confirmed that all of the recorded parameters were definitely affected by spectral selectivity for visible as well as non-visible light.

Chapter 5

Conclusions, Recommendations, Implications, and Summary

Conclusions

This research examined the preliminary benefits provided by visual and non-visual spectral selectivity on edge detection. This was accomplished by answering the following questions on whether different optical filters or the combination of optical filters can aid in edge detection of skin lesions:

1. Does spectral selectivity of visible light (color filtration) affect the results of an edge detection algorithm?
2. Does spectral selectivity of non-visible light (ultraviolet (UV), and infrared (IR)) affect the results of an edge detection algorithm?
3. Does spectral selectivity affect lesion parameter measurements (e.g., asymmetry, border, and dimension)?

The first goal for this research was to determine whether spectral selectivity of visible light (color filtration) affected the results of an edge detection algorithm. The data supported that spectral selectivity of visible light does affect edge detection algorithms. The lesion area varied when different filters were used with different edge detection algorithms. Refer to Figure 44 for a comparison of the lesion area for the different edge detection algorithms: Canny (solid blue), Differentiation (red diagonal brick pattern), Gradient (green

horizontal lines), Prewitt (purple vertical lines), Roberts (red diamond pattern), Sigma (blue diagonal lines), and Sobel (orange checkerboard).

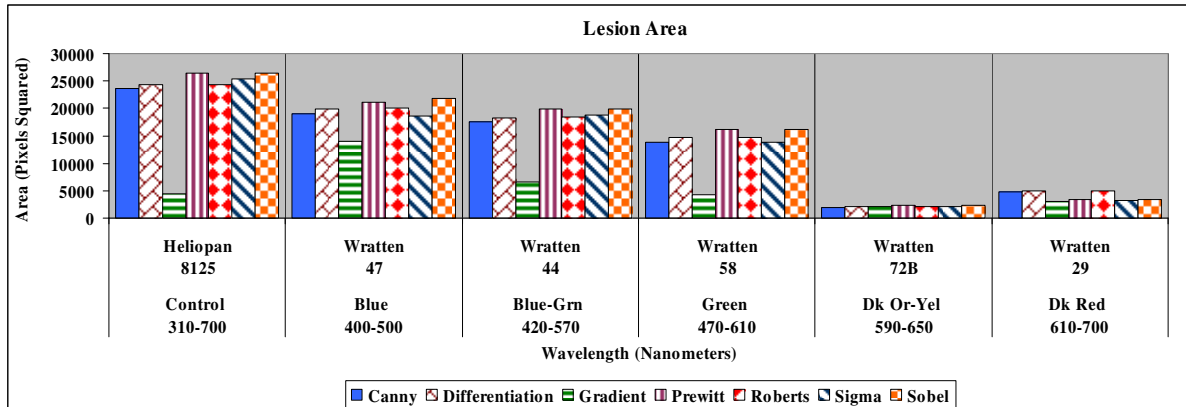


Figure 44. Lesion Area for Visible Light versus Control (Lesion 476X)

Since it has been shown that these edge detection algorithms are affected by spectral selectivity, the Canny Edge Detection filter will be used to focus in on the area since it is the newest and most sophisticated edge detection methodology and is known for locating edges accurately, even under low signal-to-noise conditions in an image. The area peaked at 400-500 nanometers (Wratten 47 Blue); however, no wavelengths had an area as high as the control at 310-700 nanometers (Heliopan 8125). This can be explained by the color separation at specific wavelengths where the control is a composite of all the visible light wavelengths. A fifth order polynomial trend line peaks near the center of the visible light spectrum for the area (refer to Figure 45).

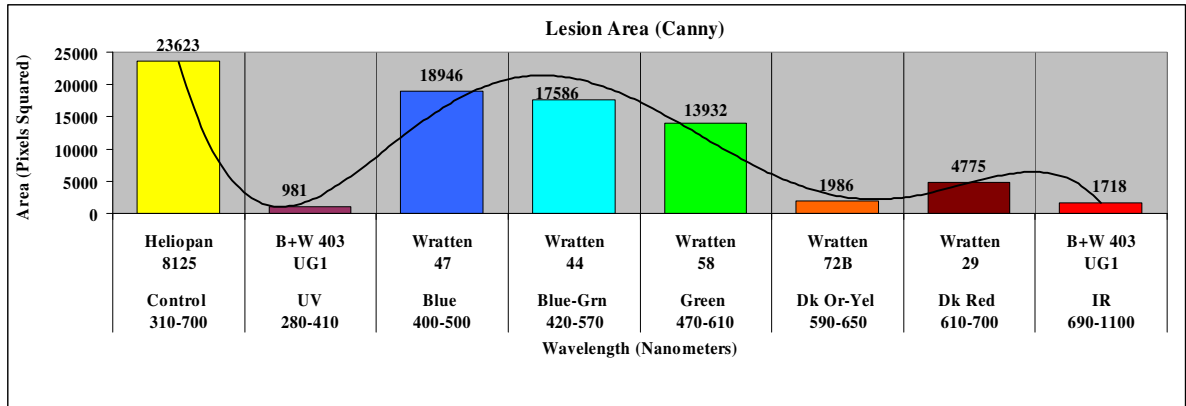


Figure 45. Canny Edge Detection Lesion Area (Lesion 476X)

The second goal for this research was to determine whether spectral selectivity of non-visible light (ultraviolet (UV), and infrared (IR)) affected the results of an edge detection algorithm. The data supported that spectral selectivity of non-visible light does affect edge detection algorithms. The lesion area varied when different filters were used with different edge detection algorithms. Refer to Figure 46 for a comparison of the lesion area for non-visible light for the different edge detection algorithms: Canny (solid blue), Differentiation (red diagonal brick pattern), Gradient (green horizontal lines), Prewitt (purple vertical lines), Roberts (red diamond pattern), Sigma (blue diagonal lines), and Sobel (orange checkerboard).

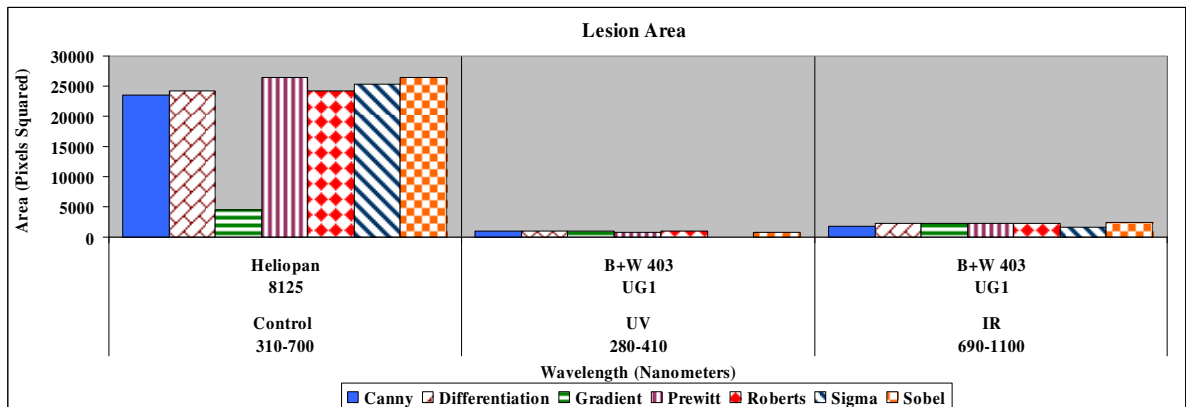


Figure 46. Lesion Area for Non-visible Light versus Control (Lesion 476X)

As can be noted from the graph, the area is lower than the control in the non-visible light wavelengths at 280-410 nanometers (B+W 403 UG1 Ultraviolet) and 690-1100 nanometers (B+W 403 UG1 Infrared).

The final goal for this research was to determine whether spectral selectivity affects lesion parameter measurements (e.g., asymmetry, border, and dimension)? The data supported that spectral selectivity does affect lesion parameter measurements. Again, since all the algorithms were affected equally, this analysis will focus on the Canny edge detection algorithm since not only is it the newest, it is also the most sophisticated of the edge detection algorithms utilized. The number of particles found ranged 1 to 13 and peaked at 400-500 nanometers (Wratten 47 Blue) which was only one was less particle than the control. A fifth order polynomial trend line peaks near the center of the visible light spectrum for the particles found (refer to Figure 47).

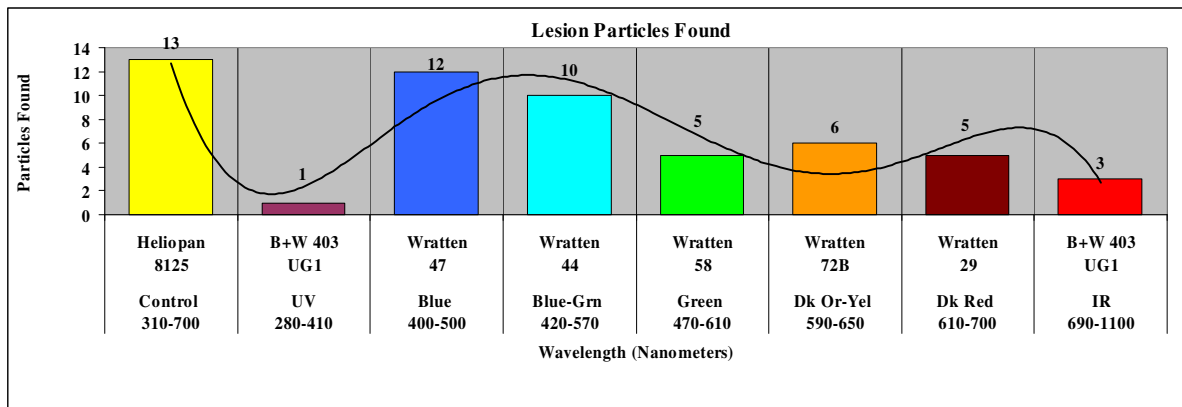


Figure 47. Canny Edge Detection Lesion Particles Found (Lesion 476X)

The elongation factor measures how elongated the shape of a particle is. The higher the value the more elongated the lesion is while a value of zero indicates a perfect circle. The elongation factor peaked at 610-700 nanometers (Wratten 29 Dark Red) and 690-1100

nanometers (B+W 403 UG1 Infrared). For this lesion, the elongated factor increased as frequency increased as shown by a fifth order polynomial trend line (refer to Figure 48).

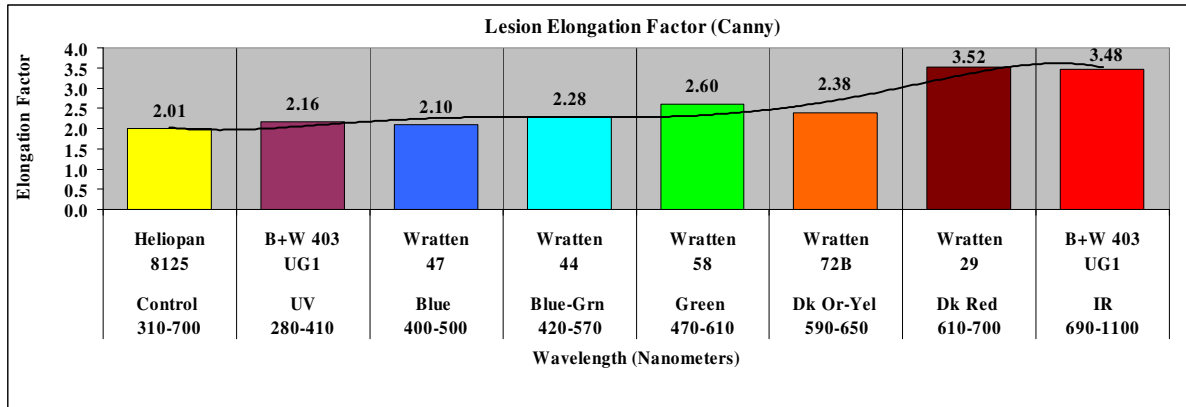


Figure 48. Canny Edge Detection Lesion Elongation Factor (Lesion 476X)

The compactness factor measures the area of the lesion divided by the area of a square encompassing that lesion. Basically, the compactness factor is a factor between zero and one which shows protrusions or indentations of a circle within a square. A compactness factor of .785 would indicate a perfect circle. The compactness factor peaked at 280-410 nanometers (B+W 403 UG1 Ultraviolet). For this lesion, the compactness factor was the highest in the non-visible light wavelengths at 280-410 nanometers (B+W 403 UG1 Ultraviolet) and 690-1100 nanometers (B+W 403 UG1 Infrared). A fifth order polynomial trend line dips near the center of the visible light spectrum for the lesion compactness (refer to Figure 49).

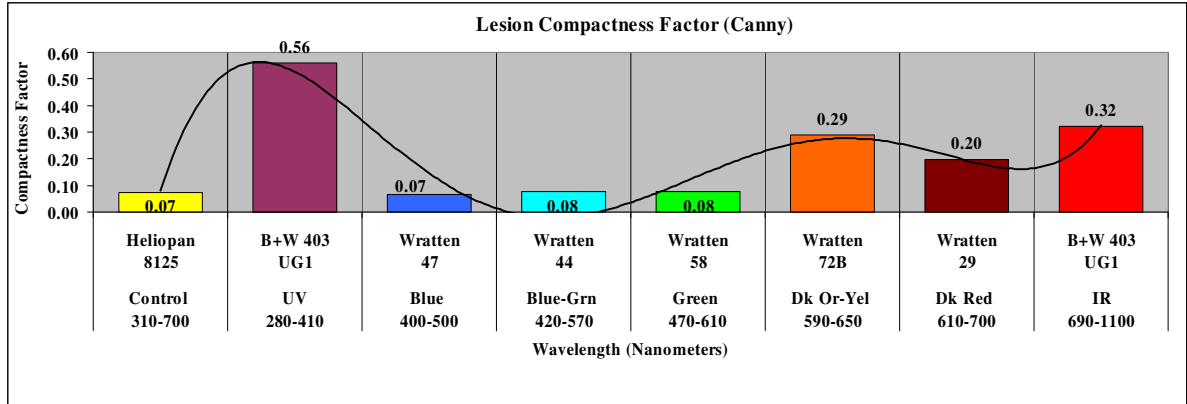


Figure 49. Canny Edge Detection Lesion Compactness Factor (Lesion 476X)

The perimeter measures the number of pixels around the circumference of the lesion. The perimeter peaked at 400-500 nanometers (Wratten 47 Blue) which was less than the control. A fifth order polynomial trend line peaks near the center of the visible light spectrum for the perimeter (refer to Figure 50).

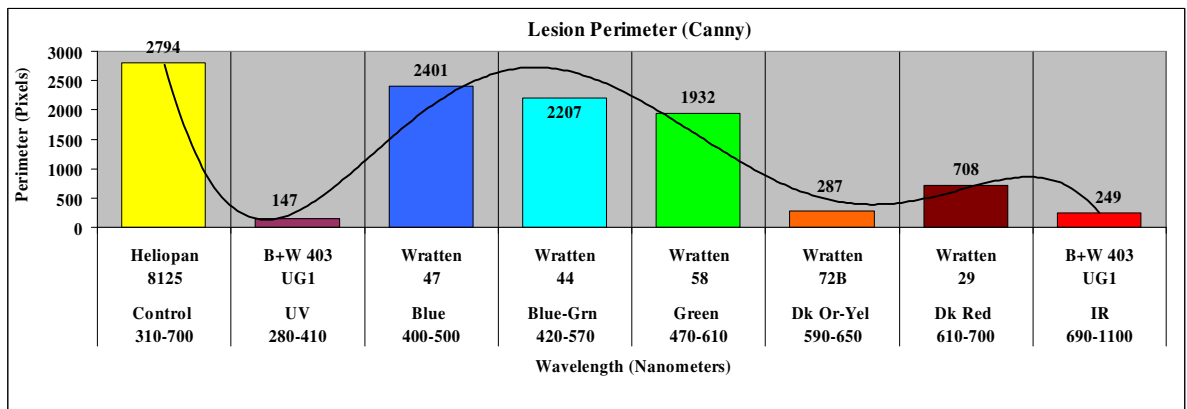


Figure 50. Canny Edge Detection Lesion Perimeter (Lesion 476X)

The Heywood Circularity factor measures the circularity of a lesion where one is a perfect circle. The Heywood Circularity factor peaked at 400-500 nanometers (Wratten 47 Blue). A fifth order polynomial trend line peaks near the center of the visible light spectrum for the perimeter (refer to Figure 51).

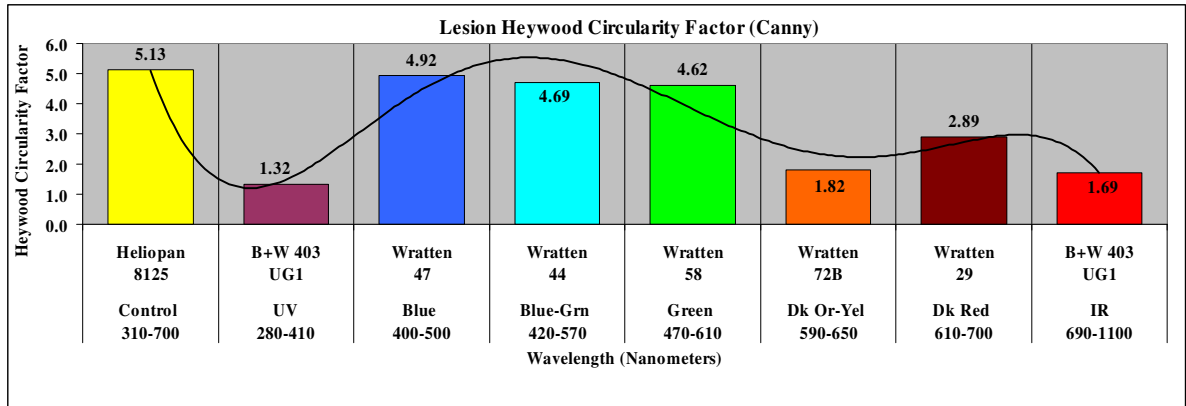


Figure 51. Canny Edge Detection Lesion Heywood Circularity Factor (Lesion 476X)

The strengths of this research were that the analysis of the lesion measurements supported all three hypotheses. While there were weaknesses of this research, none of these weaknesses affected the validation of the hypothesis. However, that is not to say that changes are not necessary for future research. An example of a weakness was the variation of light on a curved surface such as an arm. The last issue to address was whether there were any known limitations for this research. An example of such a limitation was the ability to deal with hair in the lesion. The weaknesses and limitations of this research and the recommendations on how they should be addressed in future research will be discussed next.

Recommendations

Change in Research Methods

Despite all the preparation, several new issues arose once the actual research had begun. For one, some edge detection algorithms are more sensitive than others.

Unfortunately, some of these algorithms found artifacts other than the lesion. There were

approaches considered to overcome this obstacle. The first approach was to modify the LabVIEW™ Vision software to examine a region of interest (ROI) specified. The second approach was to examine and record the particle with the largest area. While the ROI approach did not affect the calibration or measurements, the second approach was chosen simply to reduce or filter the data down to a manageable size for presentation. While this approach was more practical for this research, the software could be modified for future research to define an ROI.

During the course of this research, it was discovered that there is a focus shift between the visible and non-visible light spectrums. In other words, ultraviolet (UV) and infrared (IR) do not focus at exactly the same spot as visible light. The process for this research was to set the focus for visible light at a fixed distance. That same focus setting was used for UV and IR since the B+W 403 UG1 blocks visible light thus rendering the viewfinder as well as manual focusing useless. The reason this methodology was used was to keep the test environment as consistent as possible but the result was the lack of color separation for UV and IR. This could be addressed in future research by setting the focus separately for the different light spectrums.

Further Research

An opportunity for further research would be an analysis of spectral selectivity on edge detection algorithms between the two different digital color sampling technologies: the Bayer RGB color filter array sensor and Foveon X3 solid state full color direct image sensor. While both sensor technologies correlate well with actual images, color aliasing artifacts in the Bayer mosaic depend on whether an anti-aliasing optical low-pass filter is

used and are severe without such a filter. The Foveon X3 direct image sensor generates few or no color aliasing artifacts associated with sampling. Ideally, while a great foundation was laid, this research needs to be extended to comparing the performance of the traditional Bayer CFA image sensor technology and the Foveon X3 image sensor technology. A Bayer CFA image sensor without a blur filter shows significant color artifacts resulting from the improper sampling. The combination of a blur filter and increased color interpolation complexity can be used to partially compensate for the deficiencies in the Bayer sensor. Real-world image captures clearly show that there are advantages of the Foveon technology with respect to color artifacts and sharpness (Guttosch, 2005). Comparing these differing technologies will be difficult since the sensors are used in different camera shells.

Even if the competing sensor technologies could be interchanged in a controlled environment, there is still another obstacle to overcome. The Bayer sensor is not linear across the entire spectrum, in other words, the Bayer sensor is more sensitive in the middle of the light spectrum (green) than for blue or red. This nonlinearity is simply explained since there are twice as many green photons as there are blue or red. This would make comparing the sensor technologies more difficult. This research would be expensive to complete but if completed and the Foveon technology proves superior, then a completely new host of medical instrumentation could be upgraded to this technology for superior accuracy.

Future research also needs to deal with real-world issues such as hair extending from the lesions and intersecting the lesion boundaries. Either a new algorithm will have to be developed or an existing one will need to be implemented and tested. This algorithm will

have to calculate where the actual edge of the lesion is located and where the hair intersects the lesion boundary. In other words, future research will need to identify an algorithm that is capable of identification and removal of hair in order to appropriately analyzing the underlying lesion.

Finally, future research needs to implement an algorithm that will automatically threshold the image based on overall skin background color. This research used a histogram to identify the threshold, which is really the overall average of the image. Unfortunately, this sometimes led to a poor color separation for some wavelengths.

Change in Professional Practice

While the above changes will someday be instrumental in a system capable of identifying and analyzing lesions, a more serious approach needs to be taken now. First, people need to take skin cancer, especially when it comes to melanoma, more seriously and take precautions to limit exposure to the sun and to use sunscreen. In addition, doctors need to be proactive in looking for suspicious lesions during regular office visits or annual physicals. The responsibility does not lie with doctors only, people also need to do regular skin exams and track each lesion using the ABCDE recognition features (Rigel, Friedman, Kopf, and Polsky, 2005). This highlights the implications of this research.

Implications

The early detection of skin cancer, especially malignant melanoma considerably reduces morbidity and mortality. The impact of this work is not only public awareness but also the research foundation for a non-intrusive detection of skin cancer. This research's

contribution verified that spectral selectivity of visible light, as well as non-visible light, does affect edge detection algorithms. In addition, this research verified that spectral selectivity does affect lesion parameter measurements such as the: elongation factor, compactness factor, perimeter, Heywood Circularity factor, and area.

Summary

The number one form of cancer in humans today is skin cancer and a small percentage may ultimately be fatal. Unfortunately, it is very difficult for a doctor to detect a benign lesion from a cancerous lesion. If a doctor had access to a certified visual inspection system, then it could potentially help make an accurate diagnosis and prevent serious life-threatening conditions from going undiagnosed.

The examination of the existing research in the field of computer imagery as it applied to the ultimate goal of an automated melanoma recognition system found a void. The existing research focused on computer aided image analysis, research data description, segmentation, feature calculation, and classification. The void in research was edge detection, which typically falls under segmentation, and how spectral selectivity affects these algorithms. Several edge detection algorithms were implemented and analyzed for this research: Differentiation, Gradient, Prewitt, Roberts, Sigma, and Sobel. In addition, the Canny edge detection algorithm was implemented and analyzed since it brought a more sophisticated approach as compared to its predecessors. This research specifically addressed how spectral selectivity affects edge detection algorithms and needed to be filled if the ultimate goal of a non-invasive identification of skin cancer is ever to be achieved.

In order for this research to be successful and since it crossed over into more than one domain, a solid foundation had to be laid down. This study started by researching on how the eye sees color, digital images, digital photography, Bayer image sensors, Foveon X3 image sensor, camera basics, the camera selected for this research, camera lenses, camera lighting, image storage, and image compression. Next, the research addressed edge detection fundamentals, edge detection search methodologies, image filtering, spectral selectivity, and image analysis. Finally, this study gave a fundamental understanding of skin cancer and the terms used in identification such as: asymmetry, border, color, dimension, and evolution.

This research examined the preliminary benefits provided by visual and non-visual spectral selectivity on edge detection. Simply put, can different optical filters or the combination of optical filters aid in edge detection of skin lesions? This was accomplished by answering the following questions on whether different optical filters or the combination of optical filters can aid in edge detection of skin lesions:

1. Does spectral selectivity of visible light (color filtration) affect the results of an edge detection algorithm?
2. Does spectral selectivity of non-visible light (ultraviolet (UV), and infrared (IR)) affect the results of an edge detection algorithm?
3. Does spectral selectivity affect lesion parameter measurements (e.g., asymmetry, border, and dimension)?

Several obstacles had to be resolved in order for this research to be as successful.

The first was researching hardware that was capable of supporting this research. Several cameras as well as video capture cards were considered before the Sigma SD10 was selected. The Sigma SD10 Digital Single-Lens Reflex (DSLR) camera was selected since it

allowed the internal filter to be removed and replaced with swappable external filters thus allowing spectral selectivity to be tested more easily. The Sigma SD10 camera also supported the Foveon X3[®] Direct Image Sensor. Most of the cameras available utilized the Bayer Color Filter Array (CFA). Unfortunately, the drawback of the Bayer Color Filter Array (CFA) is not every point is sampled for red, green, and blue (R, G, and B). While this accounts for the sensor's low cost, it also requires the use of an optical blur filter, also known as an Anti-Aliasing filter, or an optical low-pass filter (OLPF) to interpolate the missing color data in order to create a complete color image. While the cost was low, the disadvantage stemmed from the data interpolation thus affecting the sharpness of the image. The technical deficiencies of the Bayer CFA were finally resolved with the introduction of the Foveon X3[®] Direct Image Sensor. This sensor uses the ability of silicon to absorb different wavelengths of light at different depths. The advantage is that this sensor captures red, green, and blue light at every point of the image without the use of any optical blur filter. The Sigma SD10 camera along with the Foveon X3[®] Direct Image Sensor technology met the research goals since the uncertainty of digital data interpolation was avoided.

The next challenge was the preprocessing of the images. The DCRaw software selected would require modifications for this research, for example, the red and blue channels required some extra processing steps to extract the UV and IR channels into separate images. The result was one image from the blue channel for the UV band and another image from the red channel for the IR band. Finally, the software converted the camera raw image (X3F) file format to the tagged image file (TIF) format for further processing.

The next hurdle was the processing of the images that required the development of a LabVIEWTM vision software application from scratch. While this development application had vision tools built into its library, designing an application capable of analyzing and measuring these lesions turned out to be an enormous undertaking. Once the images were processed, the system generated a report of analytical measurements for all of the images for all seven edge detection algorithms. Each image was analyzed and compared against a baseline image as well as being analyzed against the other filtered wavelengths for that same image.

Once the software was completed, volunteers were sought that had easily accessible skin lesions. This study complied with NSU's Institutional Review Board (IRB) whose mission is to protect human subjects involved in research and ensure appropriate practices are being conducted. A consent form for this research was developed per the IRB process and every volunteer was required to read and sign it.

Once the images were collected from the volunteers, the next step involved the processing and analysis of the lesions. All seven edge detection algorithms performed relatively equal for all the lesions that were included in the analysis. The newer and more sophisticated Canny edge detection did perform slightly better than its predecessors: Differentiation, Gradient, Prewitt, Roberts, Sigma, and Sobel. The Differentiation, Prewitt, Roberts, and Sobel edge detection algorithms, despite the different mathematical approaches, all had similar results. The Gradient and Sigma edge detection algorithms showed anomalous readings at several wavelengths.

The wavelengths that consistently showed the overall best results were at 400-500 nanometers (Wratten 47 Blue) and 420-570 nanometers (Wratten 44 Blue Green). The probable reason for this is the good color separation at those wavelengths. While elongation factor, compactness factor, and Heywood Circularity factor varied based on what wavelength was elected, the perimeter and area turned out to be the most practical for this research and these measurements alone validated the hypothesis. However, the elongation factor, compactness factor, and Heywood Circularity factor could add more value for future research.

The goal of this research was to analyze images of skin lesions with filtered light to determine if there were visible or non-visible characteristics of potentially cancerous lesions that the human eye could not see. This research verified that spectral selectivity of visible light, as well as non-visible light, does affect edge detection algorithms. Finally, this research verified that spectral selectivity does affect lesion parameter measurements.

Appendix A

The Skin Quiz: What are chances of skin cancer? (AAD, 2005)

1. Your hair color is:

- a. blonde or red (4)
- b. brown (3)
- c. black (1)

2. Your eye color is:

- a. blue or green (4)
- b. hazel (3)
- c. brown (2)

3. When exposed to one hour of summer sun, you

- a. burn and sometimes blister (4)
- b. burn, then tan (3)
- c. tan (1)

4. You have

- a. many freckles (5)
- b. some freckles (3)
- c. none at all (0)

5. Your job is

- a. outdoors (4)
- b. mixed (3)
- c. indoors (0)

6. Where in the United States did you live most before age 18?

- a. The South (4)
- b. The Midwest (3)
- c. The North (2)

7. Has anyone in your family had skin cancer?

- a. Yes (5)
- b. No (1)

Add up your points.

If your score is 15 or below, your risk is below average; 16 to 22, average; 23 to 25 high; 26 to 30 is very high risk. If you scored average or above, talk to your physician about having your skin monitored for signs of cancer.

Appendix B

Adult/General Informed Consent

Adult/General Informed Consent

General Informed Consent form for Participation in An Analysis of Spectral Selectivity on
Edge Detection Algorithms for a Non-invasive Identification of Skin Cancer Study

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Fort Lauderdale, FL 33314
(954) 262-5369
IRB@nsu.nova.edu

Graduate School of Computer and Information
Sciences

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Description of the Study:

Skin cancer is the number one form of cancer in humans today. Most skin lesions are non-cancerous or benign; however, a small percentage may actually be cancerous and can ultimately be fatal. A doctor has to draw from his or her own experience and manually inspect lesions for characteristics of skin cancer during a patient's medical exam. A problem exists in that it is very difficult to detect a benign lesion from a cancerous lesion. Being able to make this distinction would prevent serious life-threatening conditions from going undiagnosed. Maybe this problem could be avoided in the future if there was a certified visual inspection system. This system would aid patients as well as doctors and help avoid situations where a judgment call is necessary.

Since current research depends so much on accurate edge detection, new research should focus on what can be done to enhance the image for edge detection analysis. The capture of an image is dependent on the reflectivity of the target. Different people's skin depending on their skin tone will reflect different amounts of light. Therefore, this research would not be possible without the support of volunteer participation in the study.

This research will examine the preliminary benefits provided by visual and non-visual spectral selectivity on edge detection. Simply put, do different optical filters or the combination of optical filters affect an edge detection algorithm of skin lesions? The goal of this research is to analyze images of skin lesions with filtered light to determine if there are visible or non-visible characteristics of potentially cancerous lesions that the human eye cannot see? Please note that the objective of this dissertation is not to determine a way to correctly identify a malignant or benign lesion.

The procedure involves taking close-up pictures of a participant's skin lesions located in easily accessible as well as non-personal areas. The expected duration of the subject's participation should not exceed 30 minutes and no further participation is necessary. This procedure involves taking up to eight close-up digital photographs of each lesion in a controlled environment and is not likely to cause stress, pain, or any other unpleasant reaction.

Image Captures:

This research project will include close-up image captures of skin lesions located on the human body in easily accessible as well as non-personal areas. These image captures will be available to be seen by the researcher, the IRB, the dissertation chair and committee, as well as other researchers. The image captures will be numerically numbered and disassociated with the participants upon transfer to the storage computer. Since an image could be potentially identifiable by anyone who sees the photograph, a participant's confidentiality cannot be guaranteed. However, this researcher minimizes the risk by removing any association with the source after the image is captured. The images along with their analytical data will become part of the dissertation documentation and stored within indefinitely. All links between the image and the volunteer will be severed to protect the volunteer's privacy. Any images not published in the final report will be destroyed upon completion of the research.

Risks /Benefits to the Participant:

The risks of physical pain or discomfort, psychological or emotional harm, invasion of privacy, loss of time or pay for participation in this study have been determined to be minimal. The duration for a volunteer's participation should be less than 30 minutes. This includes the volunteer's reading, questions, and signing of the "Adult/General Informed Consent" form. After that, the volunteer will be asked to position himself/herself and hold still while approximately 8 images are captured at a distance of approximately 8 inches. Skin lesions photographed will be located in easily accessible non-personal areas (e.g., arms, back, and legs). This process is similar to having a digital picture taken at a close range. This study will ensure subject confidentiality by ensuring there is no link between the captured image and the volunteer as well as not collecting any personal data. The duration for this study should be no more than six months after IRB approval.

This research captures images of skin lesions located on the human body and does not involve cancer diagnosis. This research is intended to measure whether edge detection algorithms are significantly affected if the inputs to the algorithm are filtered images as compared to standard images inside and outside the visible light spectrum. The images are assigned an alphanumeric identifier by the camera (e.g., IMG12345.X3F). This filename will have the filter number appended to the name upon transfer to the processing computer. The original images stored in the camera will be deleted. No other personal information is required nor collected from the volunteer. While many of these images **will be** published in the final report, it would be very difficult for anyone to distinguish one skin lesion from another due the small focal length, approximately 8 inches. In addition, the captured image is approximately one inch high by one and a half inches wide and while possible, it would be difficult to positively identify a subject's lesion without an expert's analysis. Although there is no personal information in the images, the consent forms themselves will provide a list of volunteers. Each subject must be given a complete copy of the consent form. A copy

of the consent form will be kept on file by the researcher for a period of 3 years following the completion of the research, after which time all of the consent forms will be destroyed.

There are no direct potential benefits to subjects that participate in this research. The risks of and the benefits from participating in this study are considered minimal. The benefits of this research could lay the foundation for not only the early identification of skin cancer while it is still treatable, but also a non-invasive identification of skin cancer. However, without a biopsy, no one can currently positively identify whether a lesion is cancerous or not. If a volunteer discovers later that a lesion is cancerous then he/she may have trouble acquiring health insurance, employment, etc. To protect against a subject's loss of confidentiality, the process described above will ensure that a subject's anonymity is protected. Individual concerns about the risks or benefits of participating in this study can be directed to Gerald Williams or the IRB office at the numbers indicated above.

Costs and Payments to the Participant:

There are no costs or payments made for participating in this study.

Confidentiality and Privacy:

Confidentiality and privacy will be maintained by disassociating images from participants immediately following data capture. The image captures will be an alphanumeric number and stored with the filter used for the capture embedded in the file name. All information obtained in this study is strictly confidential unless disclosure is required by law. The IRB as well as any regulatory agencies has the right to review any research records.

Use of Protected Health Information (PHI):

This study does not require the disclosure of any Protected Health Information.

Participant's Right to Withdraw from the Study:

You have the right to refuse to participate or to withdraw at any time, without penalty. If you choose to withdraw, you may request that any of your data, which has been collected, be destroyed. The destruction of an individual's images is only feasible immediately after the photographs are captured. After this time, and in the interest of an individual's privacy, the image captures are disassociated with the research participants making it more difficult to identify and destroy them.

Other Considerations:

If significant new information relating to the study becomes available which may relate to your willingness to continue to participate, this information will be provided to you by the investigator.

Voluntary Consent by Participant:

I have read the preceding consent form, or it has been read to me, and I fully understand the contents of this document and voluntarily consent to participate. All of my questions concerning the research have been answered. I hereby agree to participate in this research study. If I have any questions in the future about this study they will be answered by Gerald Williams. A copy of this form has been given to me. This consent ends at the conclusion of this study.

Participant's Signature: _____ Date: _____

Witness's Signature: _____ Date: _____

Appendix C

IRB – Informed Consent Form Checklist

Nova Southeastern University
IRB - Informed Consent Form Checklist

This form must be completed by the researcher and submitted with the research protocol and informed consent form. Failure to do so will cause review of your protocol to be deferred.

Informed consent is one of the primary ethical requirements for research with human subjects; it reflects the basic principle of respect for persons. No principal investigator may involve a human being as a subject in research, as defined in the Nova Southeastern University Institutional Review Board Policy and Procedure Manual for Research with Human Subjects, unless the investigator has obtained the subject's informed consent. The process of informed consent is constituted on two essential elements: (1) the subject has the information he or she requires to make an effective decision, and (2) the subject's participation is not coerced, i.e., his or her consent is voluntary.

The checklist below is provided to ensure that each of the following components is included in your Informed Consent form. Please check N/A next to those items that are not applicable to the protocol being submitted.

This checklist is intended for the following consent form:

General Informed Consent form for Participation in An Analysis of Spectral Selectivity on Edge Detection Algorithms for a Non-invasive Identification of Skin Cancer Study

Table 11. Informed Consent Form Checklist

Included	N/A	Component
☒	☐	The Informed Consent form is written in a language understandable to the subject or his/her legal representative.
☒	☐	The Informed Consent form is written in a consistent voice, preferably second with the exception of the Voluntary Consent section, which is written in the first person.
☒	☐	Each page of the Informed Consent form is on original Nova Southeastern University letterhead, except in cases of collaborative projects when the letterhead from a hospital, university, etc. is acceptable
☐	☒	If the research is externally funded, the funding agency is listed under funding source.
☒	☐	The title of the study and the name, address, and telephone number of the investigator(s) is listed.
☒	☐	If the principal investigator is a student, the address and phone number of his/her advisor(s), clinical Supervisor(s) are listed. Site information (address) of where research will be collected or research activities will occur with subjects if this information is different than the address of investigator/co-investigator or there are multiple sites.
☒	☐	The phone number 954-262-5369 and email: IRB@nsu.nova.edu for the IRB Office is listed.
☒	☐	A statement that the study involves research and an explanation of the purpose of the research is included.
☒	☐	A concrete description of the study procedures, including the amount of time subjects are being asked to contribute and the nature of the questions or data to be collected, is

		included. Any procedures which are experimental are identified and any alternative procedures disclosed. Information about financial agreements with the investigators must be discussed. Audio and Video tape information.
☒	☐	A description of any risks and possible discomforts to the subjects, if any, is included.
☒	☐	A description of any benefits to the subjects is included. If no benefits are expected, this is stated.
☐	☒	If subjects will be compensated for their participation, a statement has been included addressing this.
☒	☐	A statement describing the extent to which confidentiality will be maintained is included in addition to a clause that states that all information obtained is strictly confidential unless disclosure is required by law.
☒	☐	As a part of the confidentiality section, a statement that the NSU-IRB and other regulatory agencies may review research records.
☒	☐	A statement regarding the use, or non-use, of Protected Health Information (PHI) if the study involves PHI.
☐	☒	A statement regarding the use, or non-use, of information from student records if the study involves student records.
☒	☐	A statement that participation is voluntary, that refusal to join the study or to leave the study involves no penalty, and that the subject may discontinue participation at any time. This statement must be followed by an explanation of how data collected will be managed if a participant decides to leave (e.g., destroyed at any time, except in situations that violate state and/or federal laws and regulations, kept until the conclusion of the study, etc.).
☒	☐	A statement indicating who the subject can contact for any questions about the study.
☒	☐	The Informed Consent contains no language through which the subject is made to waive any of his/her legal rights or which releases the investigator, the sponsor, or the institution from liability for negligence.
☒	☐	The entire paragraph under Section VI-Voluntary Consent on the Informed Consent form appears in boldface and reads "I have read the preceding consent form, or it has been read to me, and I fully understand the contents of this document and voluntarily consent to participate. All of my questions concerning the research have been answered. I hereby agree to participate in this research study. If I have any questions in the future about this study they will be answered by (fill in name). (If applicable: I also voluntarily agree to the release of my PHI as described in this document.) A copy of this form has been given to me. This consent ends at the conclusion of this study."
☒	☐	A space for the subject's signature, the date, the signature of a witness is provided, the date. Space is also provided for the signature of an authorized representative, date, and the basis for that representation if applicable.
☐	☒	An assent form is included for subjects 7-17 years of age. This may be either a child assent, an adolescent assent, or both (depending on the age range of subjects).
☒	☐	Flyers, brochures, advertisements, or other recruitment materials are attached. Recruitment material must have Nova Southeastern University and the NSU sun logo on them.
☐	☒	If the language of the Informed Consent Form is other than English, a certified copy of the Informed Consent Form in that language is included or the investigator may wait until notified by the IRB to have the consent form translated.
☒	☐	All consent pages are numbered. All non-final pages contain a blank space for initials and date.

Appendix D

IRB – New Protocol Submission Form

**Nova Southeastern University
Institutional Review Board for Research with Human Subjects (IRB)
New Protocol Submission Form**

To be completed by Center/College Representative	
Date Received: 5 Sept 2006	NSU Center/College: SCIS
Center/College Representative: James Cannady, Ph.D.	
Protocol Qualifies for:	
Full Review ☐	Expedited Review ☐ College/Center Level Review ☒
To be completed by IRB	
Protocol Number: cannady01150701	

Instructions: In order to comply with federal regulations as well as to conform with guidelines of the University's Institutional Review Board (IRB), the principal investigator is required to complete all of the following items contained in the Submission Form and the IRB Protocol. Upon completion of all information, the principal investigator must submit the original Submission Form and one copy of the IRB Protocol, including all consent forms and research instruments (questionnaires, interviews, etc.) to the appropriate IRB College/Center Representative for review and action. Once reviewed, if the protocol requires full review, the College/Center Representative will direct the principal investigator to submit 23 copies (**AND 1 original**) of the New Protocol Submission Form and all supporting materials (research protocol, consent/assent forms, checklists, letters of authorization, etc.) to the College/Center Representative who will forward to the Office of Grants and Contracts. The pages of the packet must be numbered sequentially. Please note, **ONLY ONE** copy of all research instruments (tests instruments, interview protocols, etc.) must be submitted. The completed package must be received by the Office of Grants and Contracts by the last business day of the month prior to the next scheduled IRB meeting. The IRB's Web site should be consulted for IRB meeting dates. Incomplete forms may delay review by the IRB. For further information, refer to the *Procedures Manual for Research with Human Subjects*.

I. General Information

Project Title

An Analysis of Spectral Selectivity on Edge Detection

Algorithms for a Non-invasive Identification of Skin Cancer

Proposed Start Date 15 Sept 2006

Proposed Duration of Research 6 months

Performance Site(s)

Ft. Lauderdale, FL, Melbourne, FL, Buffalo, NY, Hartford, CT

Principal Investigator Information

Name Gerald R. Williams		Relationship to NSU: Faculty ☐ Staff ☐ Student ☒
Home Mailing Address (for students) 887 Greenwood Manor Circle City/State/Zip: West Melbourne, FL 32904		
Office Phone: N/A	Home Phone (for students): (321) 223-9616	
Email Address: gerawill@nova.edu		Fax: N/A

Co-Investigators Information (including faculty advisers):

	Co-Investigator 1	Co-Investigator 2	Co-Investigator 3
Name	Sumitra Mukherjee, Ph.D.	N/A	N/A
Address	Nova Southeastern University 3301 College Avenue DeSantis Building Room 4070 Ft. Lauderdale, FL 33314		
Contact Phone Number	(954) 262-2079 (800) 986-2247, ext. 2079		
Email Address	sumitra@nsu.nova.edu		

Have the Primary Investigator and Co-Investigators completed the NSU-designated human subjects research training (CITI Program)? Yes ☒ No ☐

If you answered yes, please include a copy of your training certificate. If you answered no to this question, please note that no IRB action may take place until proof of completion of training is provided.

II. Funding Information

Will this research be funded? Yes ☐ No ☒

If yes was indicated, please provide the following information:

A. Source of Funding _____

B. Project Title (if different from above) _____

C. Principal Investigator (if different from above) _____

D. Type of Application: Grant _____ Subcontract _____ Contract _____ Fellowship _____

E. Date of Submission _____

F. Grant Amount _____

Does the primary investigator or any co-investigators have a significant financial interest (i.e., salary/payments, equity interests, intellectual property rights) in relation to this study?

Yes ☐ No ☒

If you answered yes, please be sure to include within the description section of all applicable consent forms the following statement: "The principal investigator and/or co-investigator(s) of this research study have a significant financial interest as it relates to this study."

III. Cooperative Research

Cooperative research projects are those that involve more than one institution and can be designed to be both multi-site and multi-protocol in nature. Each participating institution is responsible for safeguarding the rights and welfare of human subjects and for complying with all regulations. If this proposal has been submitted to another Institutional Review Board (or authorizing individual/entity) please provide the following:

Name of Institution _____

Date of Review _____ Contact Person _____

IRB Recommendation _____

IV. Subject/patient Information

A. Types of Subjects/Patients (check all that apply and provide number of subjects):								
Subject Group	Fetus in Utero/ non-viable fetuses/ abort uses	Newborns or Infants	Children aged 2-7	Children aged 8-12	Adolescents aged 13-17	Adults aged 18+	Pregnant Women	Adults with Guardians
Check if in Study	☐	☐	☐	☐	☐	☒	☐	☐
# of Subjects						15		

Do any of the checked subjects belong to a special population (e.g., prisoners, mentally disabled)? Yes ☐ No ☒ If you indicated Yes, please specify: ☐ Prisoners ☐ Mentally disabled ☐ Mentally ill ☐ Other (specify): _____ If you answered yes, please specify in detail the nature of the special population(s)? _____ Will the study require translation of consent forms? Yes ☐ No ☒ If you answered yes, please specify the language(s) that the consent forms will be translated in to: _____
--

B. Other (Check all that apply):
Use of investigational drugs or devices ☐
Information to be collected may require special sensitivity (e.g., substance abuse, sexual behavior) ☐ Please specify:

C. Total Number of Subjects/Patients	15
D. Approximate time commitment for each subject/patient	15 minutes
E. Compensation to subjects/patients: Yes ☐ No ☒	
F. If you answered yes to letter E, please indicate the form of Compensation (e.g., cash, taxi fare, meals, gifts) _____	
Amount (value)_____ (per person)	

G. Does this study involve the use of protected health information (PHI) from client charts or other records? Yes ☐ No ☒
If Yes, will consent be obtained from the client for all PHI collected? Yes ☐ No ☐
If consent is not obtained, which of the following applies?
☐ The data will be collected in a fully de-identified data set.
☐ The data will be collected as part of a limited dataset agreement.
☐ The data will be collected under a waiver from a duly constituted privacy board. (Please attach a copy of the waiver to this form).

V. Submission Checklist (to be completed by primary investigator)

- ☒ Research Protocol
- ☒ Informed Consent Form Checklists (one checklist per consent form)
- ☒ Consent Form(s)
- ☐ Data Collection Instruments
- ☒ Cooperative Research IRB/Administration Approval Letter(s)
- ☐ If this is an Health Professions Division (HPD) study, the appropriate approvals are attached and review by the HPD Research Committee has occurred.
- ☒ Certificate of Human Subjects Research Training

VI. Principal Investigator Assurance and Obligations

I certify that all information provided in this submission (including information provided in the research protocol and supporting documents) is a complete and accurate description of the proposed study.

I agree to the following:

- This study will be conducted in the manner described in this submission. No changes to this to this study will be implemented until a revision form has been submitted and approved by the IRB.
- This study will be conducted during the one year IRB approval (or less as stipulated by the IRB). If the study will exceed the approval period I will submit in a timely manner a Continuation/Renewal/Revision form. I understand that the study may not continue past an approval period.
- When applicable, I will provide a copy of the signed informed consent form to the subject or patient.
- I will retain all signed informed consent documents for a minimum of three (3) years (or longer as stipulated by funding agencies) from the date the study is concluded.
- I will report in writing any serious adverse events to the IRB within 24 hours.
- I will provide participants with any significant new information obtained during the course of the study.
- If my study has been approved at the Expedited or Full Review levels I will report to the IRB when this study has closed.

Principal Investigator's Signature: _____ Date: _____

If this study is for the completion of a degree requirement, the thesis adviser or dissertation chair must sign the attestation below:

All departmental approvals by the student's committee (if applicable) and chair or thesis adviser have been completed.

Chair/Adviser Signature: _____ Date: _____

Appendix E

IRB – Outline of Research Protocol

Outline of Research Protocol

Description of Study

Protocol Title

An Analysis of Spectral Selectivity on Edge Detection Algorithms for a Non-invasive Identification of Skin Cancer

Principal Investigator:

Name	Gerald R. Williams
Address	887 Greenwood Manor Circle West Melbourne, FL 32904
Contact Phone Number	(321) 223-9616
Email Address	gerawill@nova.edu

Co-Investigators Information:

	Co-Investigator 1	Co-Investigator 2	Co-Investigator 3
Name	Sumitra Mukherjee, Ph.D.	N/A	N/A
Address	Nova Southeastern University 3301 College Avenue DeSantis Building Room 4070 Ft. Lauderdale, FL 33314		
Contact Phone Number	(954) 262-2079 (800) 986-2247, ext. 2079		
Email Address	sumitra@nsu.nova.edu		

Funding/Sponsor of the Study

None.

Purpose and Potential Benefits

Skin cancer is the number one form of cancer in humans today. Most skin lesions are non-cancerous or benign; however, a small percentage may actually be cancerous and can ultimately be fatal. A doctor has to draw from his or her own experience and manually inspect lesions for characteristics of skin cancer during a patient's medical exam. A problem exists in that it is very difficult to detect a benign lesion from a cancerous lesion. Being able to make this distinction would prevent serious life-threatening conditions from going undiagnosed. Maybe this problem could be avoided in the future if there was a certified visual inspection system. This system would aid patients as well as doctors and help avoid situations where a judgment call is necessary.

Since current research depends so much on accurate edge detection, new research should focus on what can be done to enhance the image for edge detection analysis. The capture of an image is dependent on the reflectivity of the target. Different people's skin depending on their skin tone will reflect different amounts of light. Therefore, this research would not be possible without the support of volunteer participation in the study.

This research will examine the preliminary benefits provided by visual and non-visual spectral selectivity on edge detection. Simply put, do different optical filters or the combination of optical filters affect an edge detection algorithm of skin lesions? The goal of this research is analyze images of skin lesions with filtered light to determine if there are visible or non-visible characteristics of potentially cancerous lesions that the human eye cannot see? Please note that the objective of this dissertation is not to determine a way to correctly identify a malignant or benign lesion.

Location of Study

Volunteers for this research will be solicited from the following cities:

- Ft. Lauderdale, FL
- Melbourne, FL
- Buffalo, NY
- Hartford, CT

These cities are just where the primary researcher is located and has access to volunteers who wish to participate in this study. The location of study will be any semi-private place where the subject is comfortable.

Dates of Study

Start Date: Upon IRB approval

End Date: 1 year after IRB approval

Subjects

This study will solicit adult volunteers with skin lesions.

Sample Size and Composition

This study will solicit approximately 15 adult volunteers with easily accessible skin lesions. It is not the intent to recruit volunteers from the protected population (such as pregnancy, mental health disorder, illness, prisoner, decisionally impaired, etc.). If a person has a unique skin tone and he/she is the only one like that in the study, then that person's images will be discarded so as to protect the privacy of that person. If a volunteer has more than one accessible image, and the volunteer is willing, then each accessible lesion will be photographed for analysis.

Subject Selection, Recruitment, and Eligibility Requirements

Volunteers will be recruited from locations where the primary researcher is located that week during the data acquisition period. The primary researcher for this project travels between cities for work and volunteers will be recruited from each site. Volunteers will typically be acquaintances, friends or workmates of the primary researcher. Unless there are not enough volunteers, it is not the intent to use any media, including flyers, brochures, or other advertisements to recruit human subject participation in a research study. If this becomes the case then any media will be submitted to the IRB for review and re-approval.

Once a recruit is selected, he/she will be asked to read the informed consent form. Any questions he/she has will be explained and upon satisfactory explanation, they will be asked to sign the informed consent form. If there is a language barrier, (e.g., the recruit does not read or understand English), then the recruit is not appropriate for this research and will not be considered further.

Methods and Procedures

The procedure involves taking close-up pictures of a participant's skin lesions located in easily accessible as well as non-personal areas. The expected duration of the subject's participation should not exceed 30 minutes and no further participation is necessary. This procedure involves taking up to eight close-up digital photographs of each lesion in a controlled environment and is not likely to cause stress, pain, or any other unpleasant reaction. There is no compensation for subjects participating in this study.

Measures and Administration

This research involves the post analysis of images taken of the subject's lesions. This analysis involves a sophisticated software package, which analyzes the lesions and produces a statistical / mathematical report of key measurements for comparison. The research paper

does have a questionnaire on skin cancer but it is for background information only and it will not be part of the data given to or collected by participants.

Risks to Subjects

The risks of physical pain or discomfort, psychological or emotional harm, invasion of privacy, loss of time or pay for participation in this study have been determined to be minimal. The duration for a volunteer's participation should be less than 30 minutes. This includes the volunteer's reading, questions, and signing of the "Adult/General Informed Consent" form. After that, the volunteer will be asked to position himself/herself and hold still while approximately 8 images are captured at a distance of approximately 8 inches. Skin lesions photographed will be located in easily accessible non-personal areas (e.g., arms, back, and legs). This process is similar to having a digital picture taken at a close range. This study will ensure subject confidentiality by ensuring there is no link between the captured image and the volunteer as well as not collecting any personal data. The duration for this study should be no more than six months after IRB approval.

This research captures images of skin lesions located on the human body and does not involve cancer diagnosis. This research is intended to measure whether edge detection algorithms are significantly affected if the inputs to the algorithm are filtered images as compared to standard images inside and outside the visible light spectrum. The images are assigned an alpha numeric identifier by the camera (e.g., IMG12345.X3F). This filename will have the filter number appended to the name upon transfer to the processing computer. The original images stored in the camera will be deleted. No other personal information is required nor collected from the volunteer. While many of these images **will be** published in the final report, it would be very difficult for anyone to distinguish one skin lesion from another due the small focal length, approximately 8 inches. In addition, the captured image is approximately one inch high by one and a half inches wide and while possible, it would be difficult to positively identify a subject's lesion without an expert's analysis. Although there is no personal information in the images, the consent forms themselves will provide a list of volunteers. Each subject must be given a complete copy of the consent form. A copy of the consent form will be kept on file by the researcher for a period of 3 years following the completion of the research, after which time all of the consent forms will be destroyed.

There are no direct potential benefits to subjects that participate in this research. The risks of and the benefits from participating in this study are considered minimal. The benefits of this research could lay the foundation for not only the early identification of skin cancer while it is still treatable, but also a non-invasive identification of skin cancer. However, without a biopsy, no one can currently positively identify whether a lesion is cancerous or not. If a volunteer discovers later that a lesion is cancerous then he/she may have trouble acquiring health insurance, employment, etc. To protect against a subject's loss of confidentiality, the process described above will ensure that a subject's anonymity is protected. Individual concerns about the risks or benefits of participating in this study can be directed to Gerald Williams or the IRB office at the numbers indicated above.

The risks of physical pain or discomfort, psychological or emotional harm, invasion of privacy, loss of time or pay for participation in this study have been determined to be minimal. The duration for a volunteer's participation should be less than 30 minutes. This includes the volunteer's reading, questions, and signing of the "Adult/General Informed Consent" form. After that, the volunteer will be asked to position themselves and hold still while approximately 8 images are captured at a distance of approximately 8 inches. Skin lesions photographed will be located in easily accessible non-personal areas (e.g., arms, back, and legs). This process is similar to having a digital picture taken at a close range. This study will ensure subject confidentiality by ensuring there is no link between the captured image and the volunteer as well as not collecting any personal data. The duration for this study should be no more than six months after IRB approval.

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To protect against a subject's loss of confidentiality, the process described above will ensure that a subject's anonymity is protected. If a volunteer discovers later that a lesion is cancerous then he/she may have trouble acquiring health insurance, employment, etc. Without a biopsy, no one can currently positively identify whether an image of a lesion is cancerous or not. To protect against a subject's loss of confidentiality, the process described above will ensure that a subject's anonymity is protected.

Benefits to Subjects

There are no direct potential benefits to subjects that participate in this research.

Risk/Benefit Ratio

The risks of and the benefits from participating in this study are considered minimal. The benefits of this research could lay the foundation for not only the early identification of skin cancer while it is still treatable, but also a non-invasive identification of skin cancer.

However, without a biopsy, no one can currently positively identify whether a lesion is cancerous or not. If a volunteer discovers later that a lesion is cancerous then he/she may have trouble acquiring health insurance, employment, etc. To protect against a subject's loss of confidentiality, the process described above will ensure that a subject's anonymity is protected. Individual concerns about the risks or benefits of participating in this study can be directed to Gerald Williams or the IRB office at the numbers indicated above.

Consent Forms

The consent form "General Informed Consent form for Participation in An Analysis of Spectral Selectivity on Edge Detection Algorithms for a Non-invasive Identification of Skin Cancer Study" will be presented to each volunteer by the primary researcher. This study does not require a translated informed consent form.

PHI Use

This study does not require the disclosure of any Protected Health Information.

Credentials/Qualifications of Researcher(s)

Biographical Sketch			
Name: Gerald R. Williams		Position Title: Student	
Education/Training			
Institution and Location	Degree	Year(s)	Field of Study
University of Memphis	BS	1989	Computer Systems Engineering
Webster University	MA	1998	Business
University of Central Florida	MS	2001	Software Engineering
NOVA Southeastern University	PhD Candidate	2007	Computer Information Systems

Research and Professional Experience:

Infantry and Radar Technician, USMC

1976 – 1987

Troubleshoot and repaired F4/F18 airborne Pulse and Pulse Doppler search and track radar and weapon systems, which included the Visual Target Acquisition System, AIM-7 Constant Missile guidance system, and the AIM-9 Sidewinder system. Taught Navy and Marine students DC/AC circuit analysis, transistor theory, AM/FM radio transmitters and receivers, analog and digital circuits, electronic countermeasures, navigation equipment, computers and radars.

Reserve Officer Training Corps (ROTC), USAF

1987 – 1990

ROTC Student at Memphis State University – Graduated first and awarded distinguished graduate (DG)

Chief, Satellite Engineering and Simulation Software, USAF 1990 – 1994

Operations Commander for a 15-member crew during satellite launch and early orbit. Responsible for all real-time operations for the GPS constellation, Defense Satellite Program and the Defense Meteorological Satellite Program satellite systems. Developed training and simulation requirements for space surveillance, meteorological and communications missions. Taught satellite Electrical Power Systems to contractors and future satellite operators.

Operations Officer, USAF, United Nations (UN) 1994

Planned and led long-range ground and air patrols monitoring the cease-fire between Moroccan and Algerian-backed guerrilla forces. Established and maintained liaison with senior military officials involved in the conflict.

Flight Commander, Range Operations Commander, Engineer USAF 1995 – 1999

Supervised a team of 50 Air Force and contractor personnel during launch operations in charge of worldwide radar, optics, telemetry, and computers supporting Athena, Atlas, Delta, Pegasus, Titan, Trident and the Space Shuttle programs.

Associate Professor, Columbia College 1999 – 2004

Instructor for the following courses: Visual Basic, Assembly Language, Intro to Programming (C), Advanced Programming (C++), Data Structures, Intro to Programming Languages, Operating Systems, Information Resource Management, Artificial Intelligence, Java, and Software Engineering.

Site/Program Manager / Systems and S/W Engr, ENSCO Inc. 2000 – Date

Management Consultant on the F-35 Joint Strike Fighter Electro-Hydrostatic Actuation System. Duties include daily resolution of technical and program issues including managing and coordinating schedule, staff, and prioritization of activities of 10 engineers. Led the development of a simulator that integrated custom software with COTS hardware for telemetry, radar, and optics systems for launch safety systems. Developed code for the development of a real-time weather forecasting and toxic modeling system.

Papers

Williams, G., (2001). *Automated Spacelift Training for Range Ops*, University of Central Florida thesis.

Ostroff, R., Dianic, A., and Williams, G. (2003). *Development and Operational Applications of a Real-time Range Data Simulator*. 41st Space Congress, Cape Canaveral, FL.

Williams, G., Keen, J., Ostroff, R., and Richard, D. (2004). *Use of Neural Networks as a Range Safety Decision Support System*. 41st Space Congress.

Appendix F

Certificate of Human Subjects Research Training

**Gerald Williams, Nova Southeastern
University**

Wednesday, August 30, 2006

CITI Course in The Protection of Human Research Subjects

[Main Menu](#) | [Grade Book](#) | [General Information](#) | [FAQ](#) | [Logoff](#)

Grade Book

Congratulations Gerald Williams you have now successfully completed all of the requirements for 6. SCIS as defined by Nova Southeastern University. You may now print a completion certificate indicating your accomplishment. In addition, all modules and quizzes are now accessible if you wish to do more than your institution's minimum requirement.

[View completion report](#)

Active status in the current group is set for 3 years and this status will expire on 08/04/09. Until that time, you can continue to take both required and optional modules. Additional optional modules may be taken and will be listed on the Completion Report, but quiz scores for these optional modules will not contribute to the "passing score" set by your institution. After 08/04/09, this completion report will expire, the grade book will be reset and the completion report archived.

[Click here](#) for information on CME/CEU credits.

If you wish to close out the current grade book and start a new one before the expiration date, [CLICK HERE TO RESET GRADE BOOK](#). The current grade book completion report will be archived according to Learner Group and completion date. You will be able to retrieve the completion report at any time in the future as evidence of course completion.

The modules that you have completed are indicated with a score and a completion date. Required modules, yet to be completed, are indicated under the "Required Modules" heading as "incomplete". Complete the required modules in order. The optional modules will become available when all required modules are completed. If you want to improve a quiz score, you may review the module as often as needed and retake any or all quizzes. Your highest quiz score will be saved by the software.

To be able to print a course completion report you must:

Complete all the required modules.

Correctly answer 90% of the quiz questions for required modules (Scores for the optional module quizzes will not "count" toward the 90% score requirement.)

<i>A.1.1.1.1 Required Modules</i>	<i>A.1.1.1.2 Date</i>	<i>A.1.1.1.3 Your Score</i>	<i>A.1.1.1.4 Possible Points</i>	<i>Total</i>
Introduction	08/03/06	no quiz *		
History and Ethical Principles - SBR	08/03/06	5 *	5	
Defining Research with Human Subjects - SBR	08/03/06	4 *	5	
The Regulations and The Social and Behavioral Sciences - SBR	08/03/06	10 *	10	
Assessing Risk in Social and Behavioral Sciences - SBR	08/03/06	5 *	5	
Informed Consent - SBR	08/03/06	5 *	5	
Privacy and Confidentiality - SBR	08/03/06	5 *	5	
Internet Research - SBR	08/04/06	3 *	4	
Nova Southeastern University	08/04/06	no quiz *		
<i>A.1.1.1.5 Optional Modules</i>	<i>A.1.1.1.6 Date</i>	<i>A.1.1.1.7 Your Score</i>	<i>A.1.1.1.8 Possible Points</i>	<i>Total</i>
Students in Research - SBR	Incomplete			
Percent correct for required modules:		95%		

[Current completion report](#)

[Apply for 6 CME Credits](#). A minimum of 12 modules must be completed to obtain 6 CME /CEU credits.

CME credits are only available for completion of the Human Subjects Course.

[CITI Learner Satisfaction Survey](#)

* Module included on completion report.

[CME/CEU](#) | [Copyright and Disclaimer](#) | [About CITI](#) | [Acknowledgements](#) | [Contact CITI](#)

Bottom of Form

Appendix G

Data Collection Instruments

The data collection instruments used for this research was the Sigma SD10 Digital Single-Lens Reflex (DSLR) Camera with the Foveon X3® Direct Image Sensor and the internal UV/IR filter removed (refer to Figure 52 and Figure 53).



Figure 52. Sigma SD10 DSLR with FOVEON X3® Direct Image Sensor (Side View)



Figure 53. Sigma SD10 DSLR with FOVEON X3[®] Direct Image Sensor (Front View)

Appendix H

IRB Approval



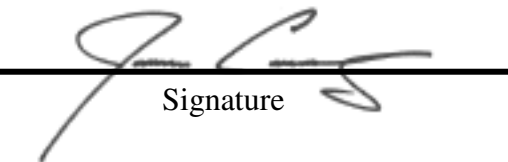
**NOVA SOUTHEASTERN
UNIVERSITY**
Office of Grants and Contracts
Institutional Review Board

MEMORANDUM

To: Gerald Williams

From: James Cannady, Ph.D.
Institutional Review Board

Date: January 15, 2007


Signature

Re: *An Analysis of Spectral Selectivity on Edge Detection Algorithms for a Non-invasive Identification of Skin Cancer*

IRB Approval Number: cannady01150701

I have reviewed the above-referenced research protocol at the center level. Based on the information provided, I have determined that this study is exempt from further IRB review. You may proceed with your study as described to the IRB. As principal investigator, you must adhere to the following requirements:

- 1) **CONSENT:** If recruitment procedures include consent forms these must be obtained in such a manner that they are clearly understood by the subjects and the process affords subjects the opportunity to ask questions, obtain detailed answers from those directly involved in the research, and have sufficient time to consider their participation after they have been provided this information. The subjects must be given a copy of the signed consent document, and a copy must be placed in a secure file separate from de-identified participant information. Record of informed consent must be retained for a minimum of three years from the conclusion of the study.
- 2) **ADVERSE REACTIONS:** The principal investigator is required to notify the IRB chair and me (954-262-5369 and 954-262-2085 respectively) of any adverse reactions or unanticipated events that may develop as a result of this study. Reactions or events may include, but are not limited to, injury, depression as a result of participation in the study, life-threatening situation, death, or loss of confidentiality/anonymity of subject. Approval may be withdrawn if the problem is serious.
- 3) **AMENDMENTS:** Any changes in the study (e.g., procedures, number or types of subjects, consent forms, investigators, etc.) must be approved by the IRB prior to implementation. Please be advised that changes in a study may require further review depending on the nature of the change. Please contact me with any questions regarding amendments or changes to your study.

The NSU IRB is in compliance with the requirements for the protection of human subjects prescribed in Part 46 of Title 45 of the Code of Federal Regulations (45 CFR 46) revised June 18, 1991.

Cc: Protocol File
Office of Grants and Contracts (if study is funded)

Appendix I

Sigma SG10 Camera Modification

Procedures:

1. Turn the “D” – Dial to the “OFF” position and remove the lens.
2. Use a Phillips head screwdriver to loosen and remove the screw for the IR/UV Blocking dust protector. Note: Be careful not to drop anything into the mirror box.
3. Remove the IR Blocking/ Dust protector by pulling on the lug in the direction of the arrow. Note: Be careful not to touch the glass.

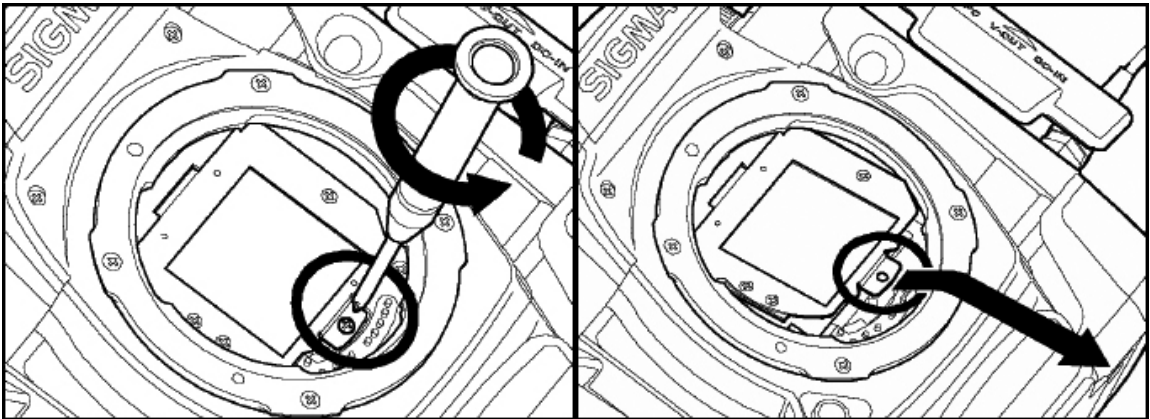


Figure 54. Sigma SG10 IR/UV Dust Protector Removal (courtesy of Sigma Users Manual)

Appendix J

Filter Specifications

Heliopan 8125 UV/IR Blocking Filter Specifications

Table 12. Heliopan 8125 UV/IR Blocking Filter Specifications

Wavelength in nm	Heliopan 8125 UV/IR Block	Wavelength in nm	Heliopan 8125 UV/IR Block	Wavelength h in nm	Heliopan 8125 UV/IR Block	Wavelength h in nm	Heliopan 8125 UV/IR Block
200	0	370	90	540	94	710	0
210	0	380	93	550	94	720	0
220	0	390	93	560	95	730	0
230	0	400	95	570	95	740	0
240	0	410	95	580	95	750	0
250	0	420	95	590	95	760	0
260	0	430	95	600	95	770	0
270	0	440	95	610	95	780	0
280	0	450	94	620	95	790	0
290	0	460	94	630	96	800	0
300	0	470	93	640	96	850	0
310	25	480	93	650	95	900	0
320	50	490	92	660	90	950	0
330	75	500	92	670	80	1000	0
340	80	510	92	680	20	1060	0
350	85	520	93	690	10	1100	0
360	90	530	93	700	5		

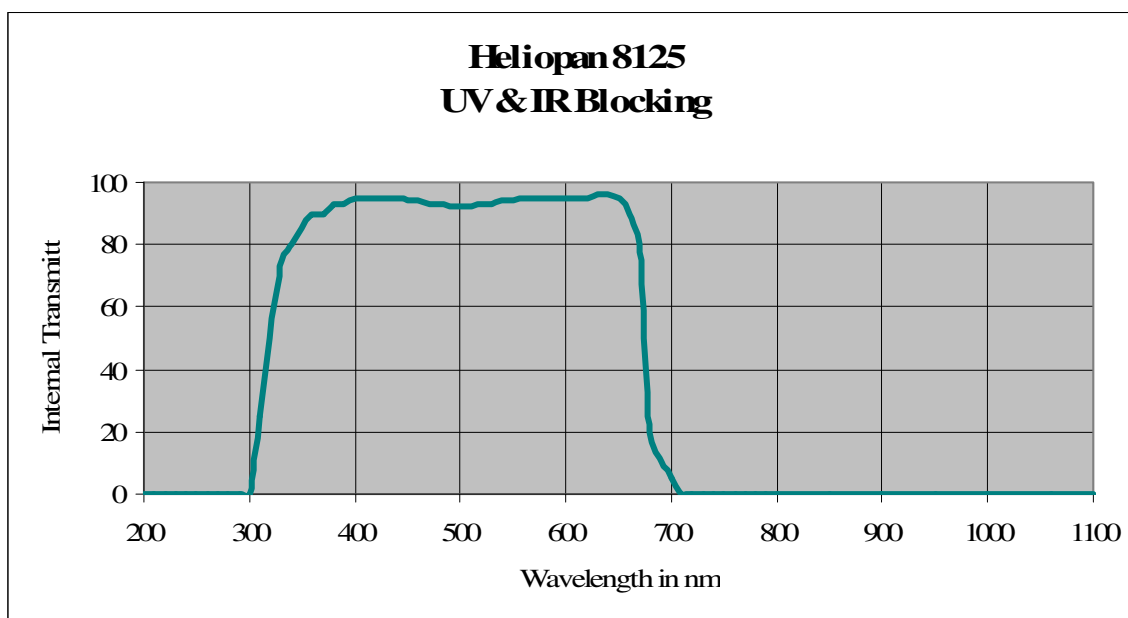


Figure 55. Heliopan 8125 UV/IR Blocking Filter Graph

Wratten 47 Blue Filter Specifications

Table 13. Wratten 47 Blue Filter Specifications

Wavelength in nm	Wratten 47 Blue	Wavelength in nm	Wratten 47 Blue	Wavelength in nm	Wratten 47 Blue	Wavelength in nm	Wratten 47 Blue
200	0	370	0	540	0	710	0
210	0	380	0	550	0	720	0
220	0	390	0	560	0	730	0
230	0	400	7.8	570	0	740	0
240	0	410	17.4	580	0	750	0
250	0	420	34	590	0	760	0
260	0	430	47	600	0	770	0
270	0	440	50.3	610	0	780	0
280	0	450	48.3	620	0	790	0
290	0	460	43.4	630	0	800	0
300	0	470	36.2	640	0	850	0
310	0	480	28.5	650	0	900	0
320	0	490	19.6	660	0	950	0
330	0	500	0.36	670	0	1000	0
340	0	510	0	680	0	1060	0
350	0	520	0	690	0	1100	0
360	0	530	0	700	0		

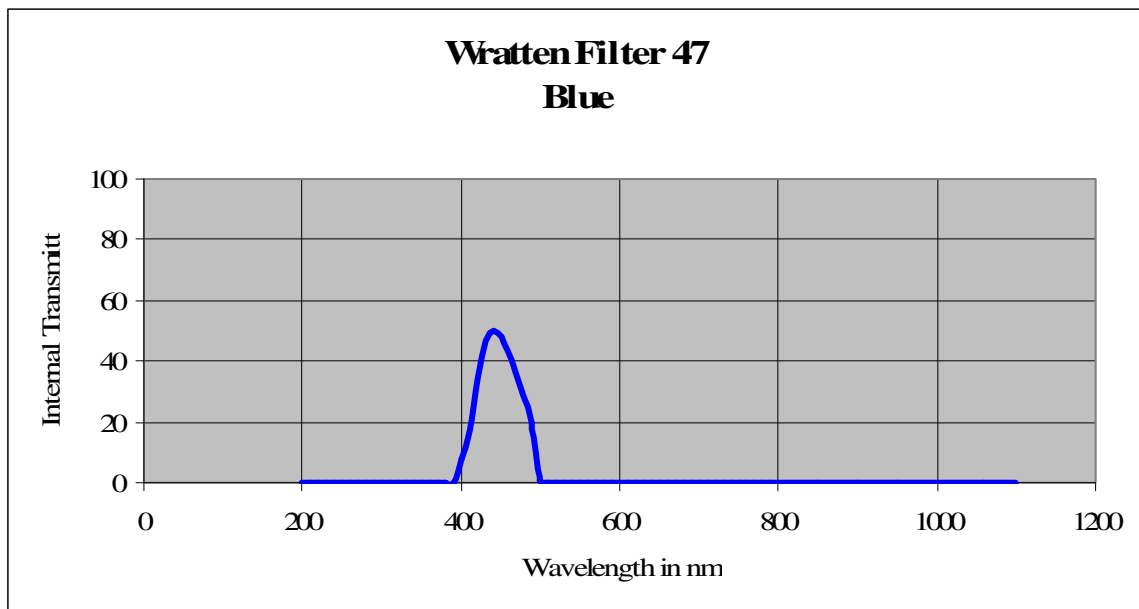


Figure 56. Wratten 47 Blue Filter Graph

Wratten 29 Dark Red Filter Specifications

Wratten 44 Blue-Green Filter Specifications

Table 14. Wratten 44 Blue-Green Filter Specifications

Wavelength in nm	Wratten 44 Blue-Grn	Wavelength in nm	Wratten 44 Blue-Grn	Wavelength in nm	Wratten 44 Blue-Grn	Wavelength in nm	Wratten 44 Blue-Grn
200	0	370	0	540	18.6	710	0
210	0	380	0	550	8.99	720	0
220	0	390	0	560	3.59	730	0
230	0	400	0.44	570	0.8	740	0
240	0	410	0.36	580	0	750	0
250	0	420	0.63	590	0	760	0
260	0	430	3.63	600	0	770	0
270	0	440	13.1	610	0	780	0
280	0	450	25.4	620	0	790	0
290	0	460	36.5	630	0	800	0
300	0	470	46.5	640	0	850	0
310	0	480	53.6	650	0	900	0
320	0	490	56.8	660	0	950	0
330	0	500	55.8	670	0	1000	0
340	0	510	50.9	680	0	1060	0
350	0	520	42.1	690	0	1100	0
360	0	530	30.5	700	0		

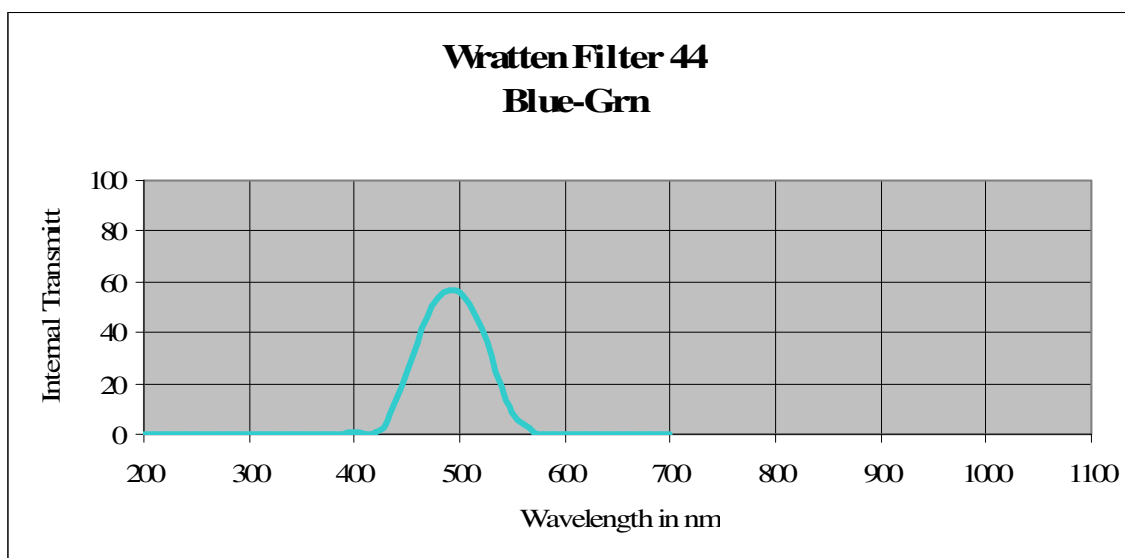


Figure 57. Wratten 44 Blue-Green Filter Graph

Wratten 58 Green Filter Specifications

Table 15. Wratten 58 Green Filter Specifications

Wavelength in nm	Wratten 58 Green	Wavelength in nm	Wratten 58 Green	Wavelength in nm	Wratten 58 Green	Wavelength in nm	Wratten 58 Green
200	0	370	0	540	47.6	710	0
210	0	380	0	550	38.4	720	0
220	0	390	0	560	27.8	730	0
230	0	400	0	570	17.4	740	0
240	0	410	0	580	9	750	0
250	0	420	0	590	3.5	760	0
260	0	430	0	600	1.5	770	0
270	0	440	0	610	0.41	780	0
280	0	450	0	620	0	790	0
290	0	460	0	630	0	800	0
300	0	470	0.23	640	0	850	0
310	0	480	1.38	650	0	900	0
320	0	490	4.9	660	0	950	0
330	0	500	17.7	670	0	1000	0
340	0	510	38.8	680	0	1060	0
350	0	520	52.2	690	0	1100	0
360	0	530	53.6	700	0		

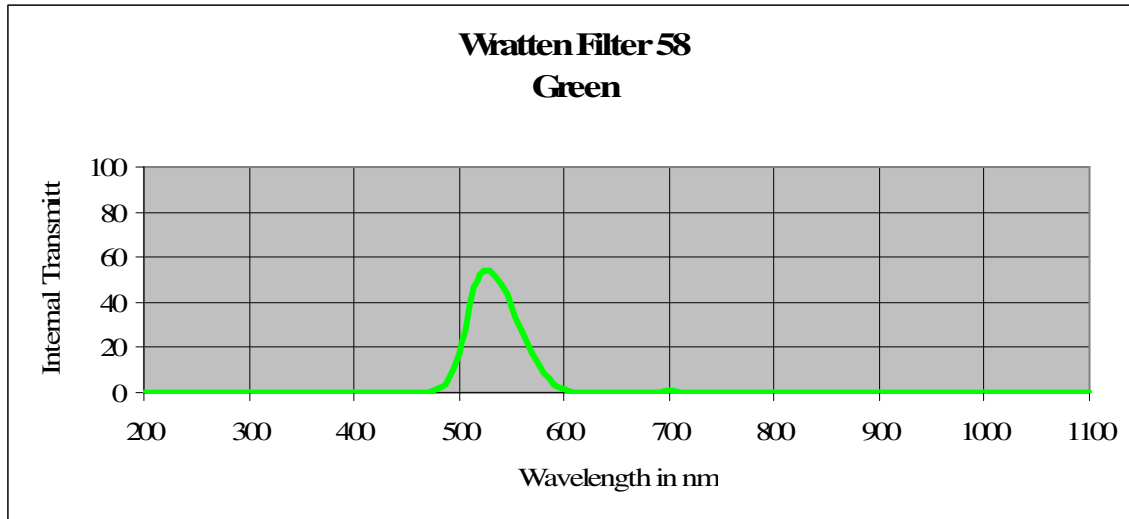


Figure 58. Wratten 58 Green Filter Graph

Wratten 72B Dark Orange-Yellow Filter Specifications

Table 16. Wratten 72B Dark Orange-Yellow Filter Specifications

Wavelength in nm	Wratten 72B Dark Or-Yel	Wavelength in nm	Wratten 72B Dark Or-Yel	Wavelength in nm	Wratten 72B Dark Or-Yel	Wavelength in nm	Wratten 72B Dark Or-Yel
200	0	370	0	540	0	710	0
210	0	380	0	550	0	720	0
220	0	390	0	560	0	730	0
230	0	400	0	570	0	740	0
240	0	410	0	580	0	750	0
250	0	420	0	590	1.26	760	0
260	0	430	0	600	5.89	770	0
270	0	440	0	610	5.25	780	0
280	0	450	0	620	2.88	790	0
290	0	460	0	630	1.26	800	0
300	0	470	0	640	0.48	850	0
310	0	480	0	650	0.14	900	0
320	0	490	0	660	0	950	0
330	0	500	0	670	0	1000	0
340	0	510	0	680	0	1060	0
350	0	520	0	690	0	1100	0
360	0	530	0	700	0		

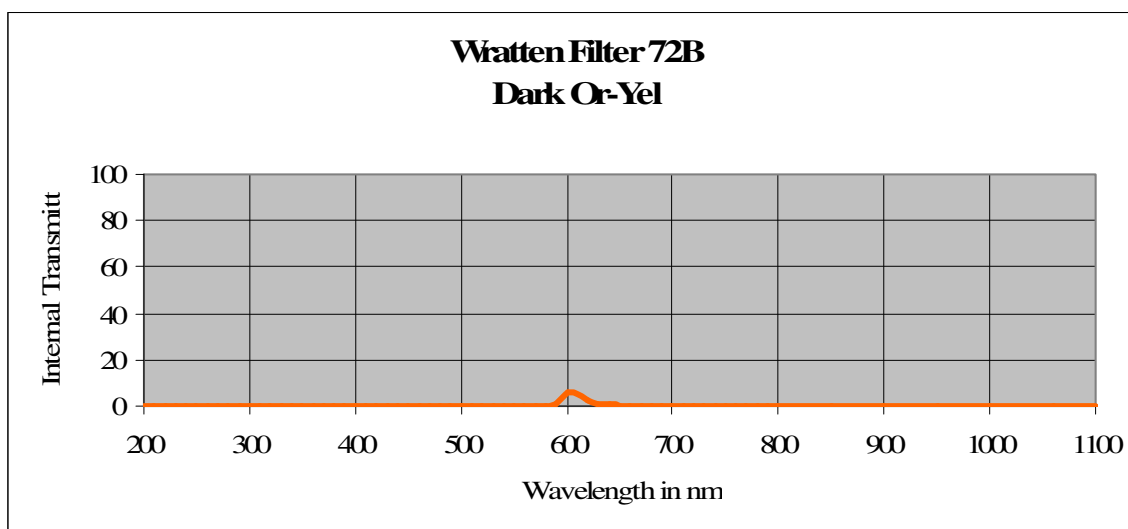


Figure 59. Wratten 72B Dark Orange-Yellow Filter Graph

Wratten 29 Dark Red Filter Specifications

Table 17. Wratten 29 Dark Red Filter Specifications

Wavelength in nm	Wratten 29 Dark Red	Wavelength in nm	Wratten 29 Dark Red	Wavelength in nm	Wratten 29 Dark Red	Wavelength in nm	Wratten 29 Dark Red
200	0	370	0	540	0	710	0
210	0	380	0	550	0	720	0
220	0	390	0	560	0	730	0
230	0	400	0	570	0	740	0
240	0	410	0	580	0	750	0
250	0	420	0	590	0	760	0
260	0	430	0	600	0	770	0
270	0	440	0	610	10	780	0
280	0	450	0	620	45.3	790	0
290	0	460	0	630	71.4	800	0
300	0	470	0	640	82.7	850	0
310	0	480	0	650	86.6	900	0
320	0	490	0	660	88.4	950	0
330	0	500	0	670	89.4	1000	0
340	0	510	0	680	90	1060	0
350	0	520	0	690	90.3	1100	0
360	0	530	0	700	90.4		

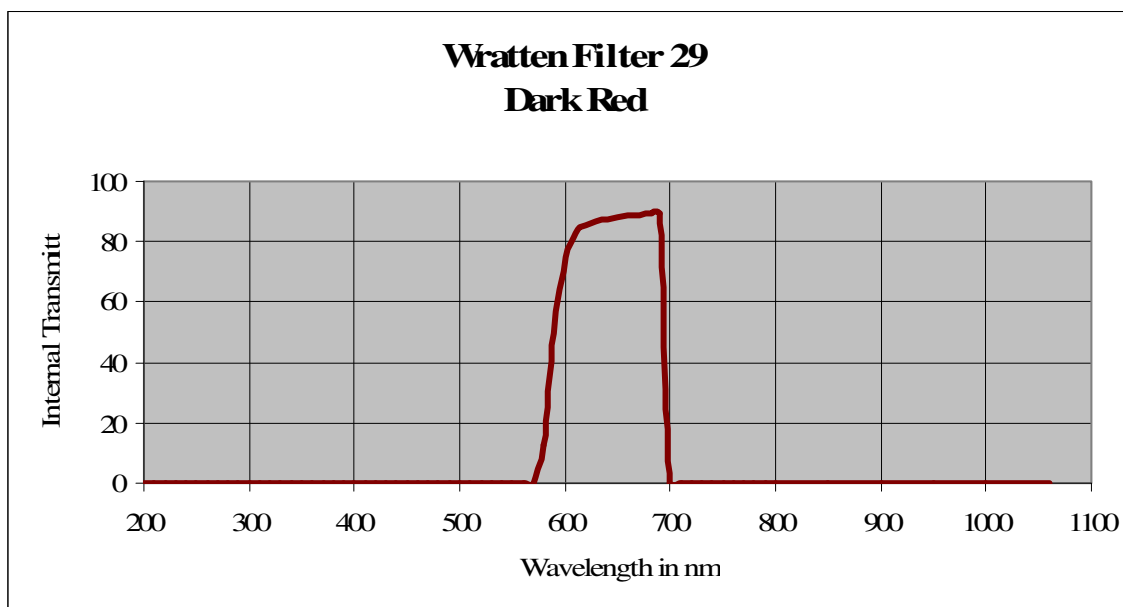


Figure 60. Wratten 29 Dark Red Filter Graph

B+W 403 Schott UG1 UV/IR Filter Specifications

Table 18. B+W 403 Schott UG1 UV/IR Filter Specifications

Wavelength in nm	B+W 403 Schott UG1 UV/IR	Wavelength in nm	B+W 403 Schott UG1 UV/IR	Wavelength in nm	B+W 403 Schott UG1 UV/IR	Wavelength in nm	B+W 403 Schott UG1 UV/IR
200	0	370	74	540	0	710	15
210	0	380	63	550	0	720	26
220	0	390	38	560	0	730	34
230	0	400	11	570	0	740	41
240	0	410	1	580	0	750	42
250	0	420	0	590	0	760	39
260	0	430	0	600	0	770	32
270	0	440	0	610	0	780	28
280	0.4	450	0	620	0	790	26
290	4	460	0	630	0	800	23
300	16	470	0	640	0	850	11
310	34	480	0	650	0	900	7
320	50	490	0	660	0	950	6
330	61	500	0	670	0	1000	6
340	69	510	0	680	0	1060	5
350	74	520	0	690	0.4	1100	4
360	76	530	0	700	4		

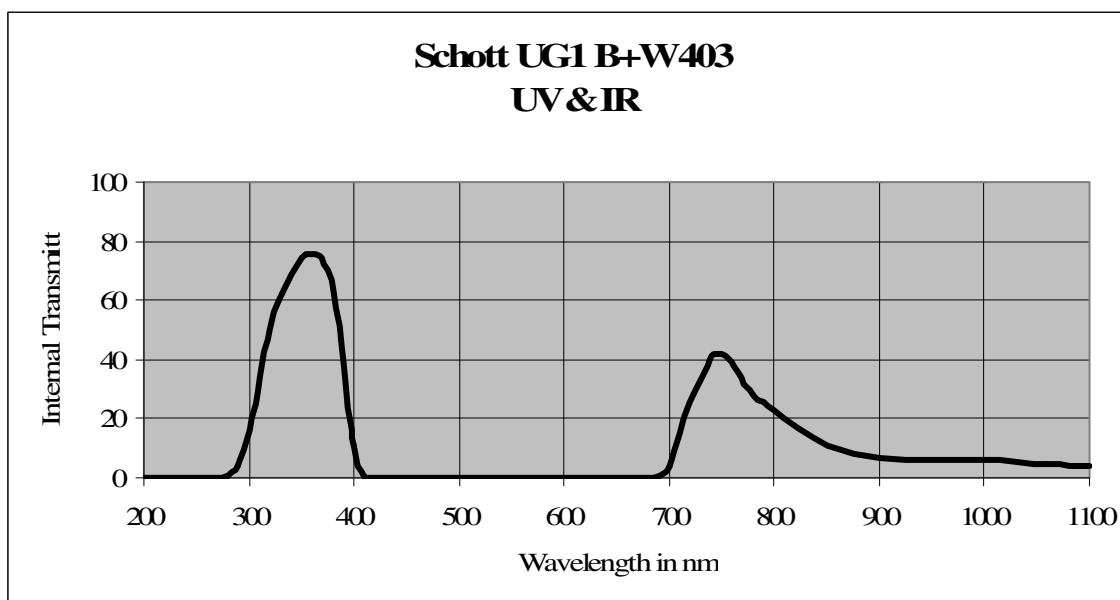


Figure 61. B+W 403 Schott UG1 UV/IR Filter Graph

Appendix K

Dcrow Preprocessing Patch Source Code

```

*** dcraw.c Sat Nov  4 15:55:41 2006
--- dcraw-x3uvir.c      Wed May  9 22:18:00 2007
*****
*** 21,28 ****

    $Revision: 1.355 $
    $Date: 2006/11/04 15:55:41 $
!   */

#define VERSION "8.42"

#define _GNU_SOURCE
--- 21,40 ----

    $Revision: 1.355 $
    $Date: 2006/11/04 15:55:41 $
!   */
!
!   /*
!   Modified 2006/11/18 by Erik Magnuson and Gerald Williams.
!   Added extra code to do monochrome channel sums
!   Optionally suppress noise reduction
!   And print a histogram
!   Modified code sections marked by
!   #ifdef X3FUVIR
!   #endif
!   */

+ #define X3FUVIR 1
+
+ #define VERSION "8.42"

#define _GNU_SOURCE
*****
*** 84,90 ****
    All global variables are defined here, and all functions that
    access them are prefixed with "CLASS".  Note that a thread-safe
    C++ class cannot have non-const static local variables.
!   */
    FILE *ifp;
    short order;
    char *ifname, make[64], model[72], model2[64], *meta_data, cdesc[5];
--- 96,108 ----
    All global variables are defined here, and all functions that
    access them are prefixed with "CLASS".  Note that a thread-safe
    C++ class cannot have non-const static local variables.
!   */
!   #ifdef X3FUVIR
!   /* Variables for new options */
!   int nr=1;
!   float channel_mul[4] = {1.0, 1.0, 1.0, 3.0};
!   int histout = 0;
!   #endif
    FILE *ifp;
    short order;

```

```

    char *ifname, make[64], model[72], model2[64], *meta_data, cdesc[5];
    *****
    *** 2422,2427 ****
    --- 2440,2469 ----
        meta_data[i] ^= (((key << 8) - val) >> 1) + val) >> 17;
    }
}

+
+ #ifdef X3FUVIR
+ /* Code to create monochrome output by combining the
+    3 data channels according to the values in the channel_mul array.
+    Can be used to extract a single channel or to linearly combine
multiple channels
+    The sum of all channels in an X3F file has the least noise.
+ */
+ void CLASS foveon_monochrome()
+ {
+     int row, col;
+
+     if (verbose)
+         fprintf (stderr, "Foveon monochrome: %f %f %f %f\n",
channel_mul[0], channel_mul[1], channel_mul[2], channel_mul[3]);
+
+     use_gamma=0;
+     colors=1;
+     for (row=0; row < height; row++) {
+         for (col=0; col < width; col++)
+             image[row*width+col][0] = (short) ((float)
image[row*width+col][0] * channel_mul[0] +
+             (float)image[row*width+col][1] * channel_mul[1] +
+             (float)image[row*width+col][2] * channel_mul[2]) / (float)
channel_mul[3];
+     }
+ }
+ #endif

    void CLASS foveon_load_raw()
    {
    *****
    *** 2777,2783 ****
        }
        free (badpix);
    }

!
    /* Array for 5x5 Gaussian averaging of red values */
    smrow[6] = (int (*)[3]) calloc (width*5, sizeof **smrow);
    merror (smrow[6], "foveon_interpolate()");
    --- 2819,2827 ----
        }
        free (badpix);
    }

! #ifdef X3FUVIR
! if (nr) {
! #endif
    /* Array for 5x5 Gaussian averaging of red values */

```

```

        smrow[6] = (int (*)[3]) calloc (width*5, sizeof **smrow);
        merror (smrow[6], "foveon_interpolate()");
*****
*** 2962,2969 ****
        free (shrink);
        free (smrow[6]);
        for (i=0; i < 8; i++)
!         free (curve[i]);
!
        /* Trim off the black border */
        active[1] -= keep[1];
        active[3] -= 2;
--- 3006,3016 ----
        free (shrink);
        free (smrow[6]);
        for (i=0; i < 8; i++)
!         free (curve[i]);
! #ifdef X3UVIR
!     }
! #endif
!
        /* Trim off the black border */
        active[1] -= keep[1];
        active[3] -= 2;
*****
*** 6637,6650 ****
        }
        FORC3 img[c] = CLIP((int) out[c]);
        }
!         else if (document_mode)
            img[0] = img[FC(row,col)];
            else if (mix_green)
                img[1] = (img[1] + img[3]) >> 1;
                FORCC histogram[c][img[c] >> 3]++;
        }
        if (colors == 4 && (output_color || mix_green)) colors = 3;
!         if (document_mode && filters) colors = 1;
    }

    void CLASS fuji_rotate()
--- 6684,6705 ----
        }
        FORC3 img[c] = CLIP((int) out[c]);
        }
!         else if (document_mode < 2)
            img[0] = img[FC(row,col)];
            else if (mix_green)
                img[1] = (img[1] + img[3]) >> 1;
                FORCC histogram[c][img[c] >> 3]++;
        }
        if (colors == 4 && (output_color || mix_green)) colors = 3;
!         if (document_mode && filters) colors = 1;
! #ifdef X3UVIR
!         if (histout) {
!             for (i=0; i < 0x2000; i++) {

```

```

!         FORCC { printf ("%d,", histogram[c][i]); }
!         printf ("\n");
!     }
! }
! #endif
! }

void CLASS fuji_rotate()
*****
*** 6831,6838 ***
    for (row=0; row < height; row++, soff += rstep) {
        for (col=0; col < width; col++, soff += cstep)
            FORCC for (i=0; i < xmag; i++)
!         if (output_bps == 8)
!             ppm [(col*xmag+i)*colors+c] = lut[image[soff][c]];
        else ppm2[(col*xmag+i)*colors+c] = image[soff][c];
        if (output_bps == 16 && !output_tiff && th.order == 0x4949)
            swab (ppm2, ppm2, xmag*width*colors*2);
--- 6886,6893 ----
        for (row=0; row < height; row++, soff += rstep) {
            for (col=0; col < width; col++, soff += cstep)
                FORCC for (i=0; i < xmag; i++)
!             if (output_bps == 8)
!                 ppm [(col*xmag+i)*colors+c] = lut[image[soff][c]];
            else ppm2[(col*xmag+i)*colors+c] = image[soff][c];
            if (output_bps == 16 && !output_tiff && th.order == 0x4949)
                swab (ppm2, ppm2, xmag*width*colors*2);
*****
*** 6891,6897 ***
        "\n-j          Show Fuji Super CCD images tilted 45 degrees"
        "\n-s [0-99] Select a different raw image from the same file"
        "\n-4          Write 16-bit linear instead of 8-bit with gamma"
!     "\n-T          Write TIFF instead of PPM"
        "\n\n", argv[0]);
        return 1;
    }
--- 6946,6957 ----
        "\n-j          Show Fuji Super CCD images tilted 45 degrees"
        "\n-s [0-99] Select a different raw image from the same file"
        "\n-4          Write 16-bit linear instead of 8-bit with gamma"
!     "\n-T          Write TIFF instead of PPM"
! #ifdef X3FUVIR
!     "\n-g          Write write histogram csv values to stdout"
!     "\n-N          No Foveon noise reduction."
!     "\n-R r g b d Combine Foveon color channels using r g b multipliers
divided by d"
! #endif
        "\n\n", argv[0]);
        return 1;
    }
*****
*** 6940,6946 ***
        case 'j': use_fuji_rotate = 0; break;
        case 'm': output_color = 0; break;
        case 'T': output_tiff = 1; break;

```

```

!         case '4':  output_bps      = 16;  break;
!         default:
!             fprintf (stderr, "Unknown option \"-%c\".\n", opt);
!             return 1;
--- 7000,7011 ---
!         case 'j':  use_fuji_rotate  = 0;  break;
!         case 'm':  output_color     = 0;  break;
!         case 'T':  output_tiff      = 1;  break;
!         case '4':  output_bps      = 16;  break;
! #ifdef X3UVIR
!         case 'R':  FORC4 channel_mul[c] = atof(argv[arg++]); break;
!         case 'N':  nr                = 0;  break;
!         case 'g':  histout           = 1;  break;
! #endif
!         default:
!             fprintf (stderr, "Unknown option \"-%c\".\n", opt);
!             return 1;
*****
*** 7094,7100 ***
!         #ifdef COLORCHECK
!             colorcheck();
!         #endif
!         if (is_foveon && !document_mode) foveon_interpolate();
!         if (!is_foveon && document_mode < 2) scale_colors();
!         if (shrink) filters = 0;
!         cam_to_cielab (NULL,NULL);
--- 7159,7168 ---
!         #ifdef COLORCHECK
!             colorcheck();
!         #endif
!         if (is_foveon && !document_mode) foveon_interpolate();
! #ifdef X3FUVIR
!         if (is_foveon && document_mode == 2) foveon_monochrome();
! #endif
!         if (!is_foveon && document_mode < 2) scale_colors();
!         if (shrink) filters = 0;
!         cam_to_cielab (NULL,NULL);
*****
*** 7110,7116 ***
!         if (use_fuji_rotate) fuji_rotate();
!         #ifndef NO_LCMS
!             if (cam_profile) apply_profile (cam_profile, out_profile);
!         #endif
!         convert_to_rgb();
!         thumbnail:
!             if (write_fun == &CLASS jpeg_thumb)
--- 7178,7184 ---
!             if (use_fuji_rotate) fuji_rotate();
!             #ifndef NO_LCMS
!                 if (cam_profile) apply_profile (cam_profile, out_profile);
!             #endif
!             convert_to_rgb();
!             thumbnail:
!                 if (write_fun == &CLASS jpeg_thumb)

```

Appendix L

NI LabVIEW™ Source Code

Dissertation LabVIEW™ Virtual Instrument (VI) Source Code

Description



This is the top level VI which controls the preprocessing and processing selection.

Front Panel

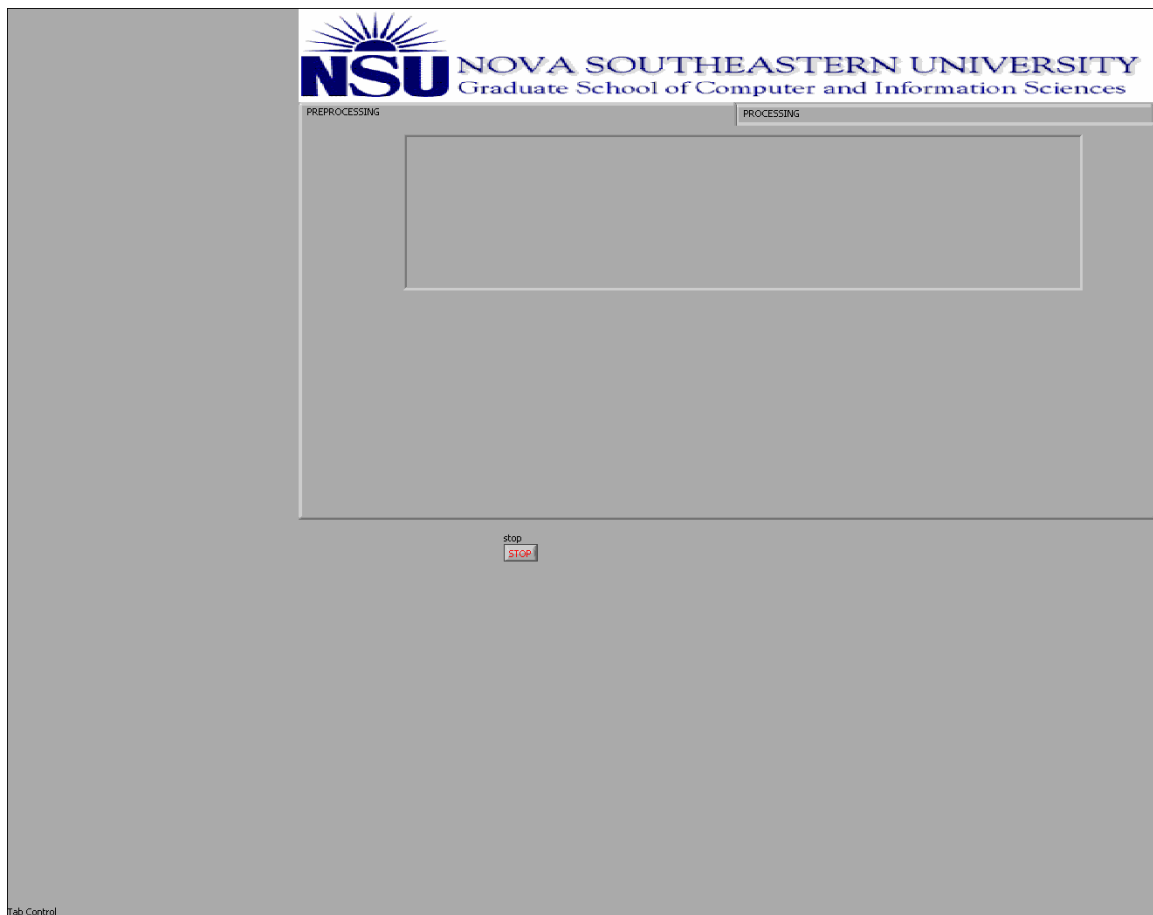


Figure 62. Dissertation.vi Front Panel

Block Diagrams

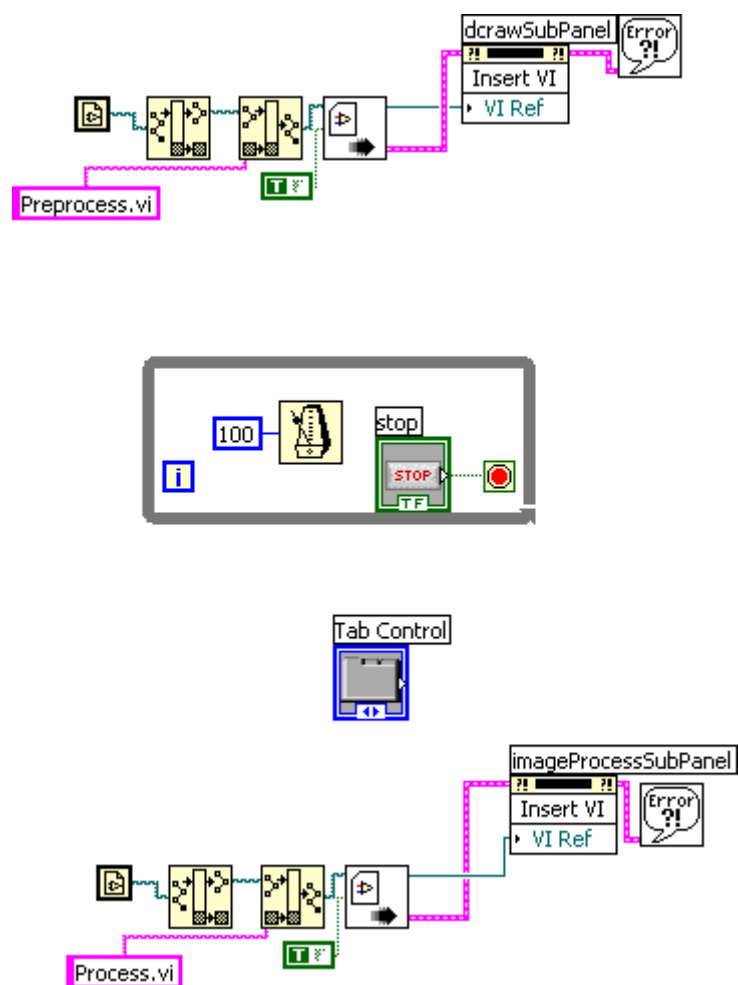


Figure 63. Dissertation.vi Block Diagram

Position in Hierarchy

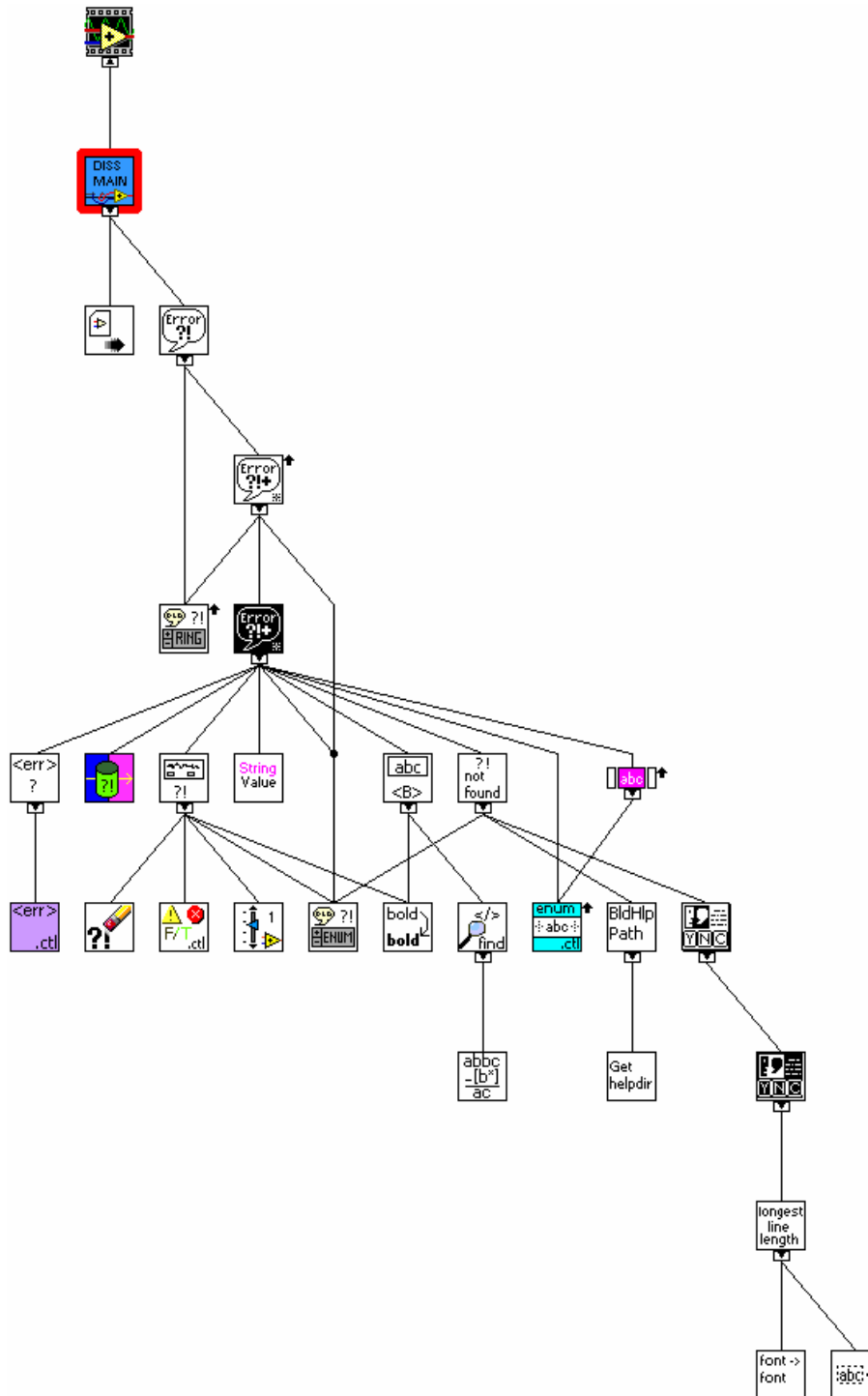


Figure 64. Dissertation.vi Position in VI Hierarchy

Preprocessing LabVIEW™ Virtual Instrument (VI) Source Code

Description



This VI performs preprocessing on dissertation research images for an "An Analysis of Spectral Selectivity on Edge Detection Algorithms for a Non-invasive Identification of Skin Cancer."

Images

1.	IMGXXXX1.X3F	Opt 1	Color Visible Light Heliopan 8125
2.	IMGXXXX1.X3F	Opt 2	Grayscale Visible Light Heliopan 8125
3.	IMGXXXX2.X3F	Opt 2	Grayscale Visible Light Heliopan 8125 and Wratten 29 (Dark Red)
4.	IMGXXXX3.X3F	Opt 2	Grayscale Visible Light Heliopan 8125 and Wratten 72B (Dark Or-Yel)
5.	IMGXXXX4.X3F	Opt 2	Grayscale Visible Light Heliopan 8125 and Wratten 58 (Green)
6.	IMGXXXX5.X3F	Opt 2	Grayscale Visible Light Heliopan 8125 and Wratten 44 (Blue-Green)
7.	IMGXXXX6.X3F	Opt 2	Grayscale Visible Light Heliopan 8125 and Wratten 47 (Blue)
8.	IMGXXXX7.X3F	Opt 3	Grayscale Non-Visible Ultraviolet Light Heliopan 8125 and B + W 403 UG1 (UV)
9.	IMGXXXX8.X3F	Opt 4	Grayscale Non-Visible Infrared Light Wratten 29 (Dk Red) and B + W 403 UG1 (IR)

Valid options:

```
-v          Print verbose messages
-c          Write image data to standard output
-e          Extract embedded thumbnail image
-i          Identify files without decoding them
-z          Change file dates to camera timestamp
-a          Use automatic white balance
-w          Use camera white balance, if possible
-r <nums>  Set raw white balance (four values required)
-b <num>   Adjust brightness (default = 1.0)
-k <num>   Set black point
-H [0-9]   Highlight mode (0=clip, 1=no clip, 2+=recover)
-t [0-7]   Flip image (0=none, 3=180, 5=90CCW, 6=90CW)
-o [0-5]   Output colorspace (raw,sRGB,Adobe,Wide,ProPhoto,XYZ)
-o <file>  Apply output ICC profile from file
-p <file>  Apply camera ICC profile from file or "embed"
-d          Document Mode (no color, no interpolation)
-D          Document Mode without scaling (totally raw)
-q [0-3]   Set the interpolation quality
-h          Half-size color image (twice as fast as "-q 0")
-f          Interpolate RGGB as four colors
-B <domain> <range> Apply bilateral filter to reduce noise
-j          Show Fuji Super CCD images tilted 45 degrees
```

-s [0-99] Select a different raw image from the same file
-4 Write 16-bit linear instead of 8-bit with gamma

Dissertation Modification options:

-T Write TIFF instead of PPM
-g Write write histogram csv values to stdout
-N No Foveon noise reduction.
-R r g b d Combine Foveon color channels using r g b multipliers
divided by d

Front Panel

Working Folder for Read Only RAW Files: Full Path to output:

DCRAW by Dave Coffin, www.cybercom.net/~dcoffin Execute Cancel

Conversion Options:

☒ Color Visible Light Output ☐ Mono Visible Light Output ☐ Mono Non-Visible Light UV Extraction ☐ Mono Non-Visible Light IR Extraction

String
-T -w

Images

1. IMGXXXX1.X3F Opt 1 Color Visible Light Heliopan 8125
2. IMGXXXX1.X3F Opt 2 Grayscale Visible Light Heliopan 8125
3. IMGXXXX2.X3F Opt 2 Grayscale Visible Light Heliopan 8125 and Wratten 29 (Dk Red)
4. IMGXXXX3.X3F Opt 2 Grayscale Visible Light Heliopan 8125 and Wratten 72B (Dk Or-Yel)
5. IMGXXXX4.X3F Opt 2 Grayscale Visible Light Heliopan 8125 and Wratten 58 (Green)
6. IMGXXXX5.X3F Opt 2 Grayscale Visible Light Heliopan 8125 and Wratten 44 (Blue-Green)
7. IMGXXXX6.X3F Opt 2 Grayscale Visible Light Heliopan 8125 and Wratten 47 (Blue)
8. IMGXXXX7.X3F Opt 3 Grayscale Non-Visible Ultraviolet Light Heliopan 8125 & B+W403 (UV)
9. IMGXXXX8.X3F Opt 4 Grayscale Non-Visible Infrared Light Wratten 29 (Dk Red) & B+W403

UG1 (IR)

Valid options:

- v Print verbose messages
- e Extract embedded thumbnail image
- z Change file dates to camera timestamp
- w Use camera white balance, if possible
- b <num> Adjust brightness (default = 1.0)
- H [0-9] Highlight mode (0=clip, 1=no clip, 2+=recover)
- o [0-5] Output colorspace (raw,sRGB,Adobe,Wide,ProPhoto,XYZ)
- D Document Mode without scaling (totally raw)
- h Half-size color image (twice as fast as "-q 0")
- B <domain> <range> Apply bilateral filter to reduce noise
- s Use secondary pixels (Fuji Super CCD SR only)
- T Write TIFF instead of PPM
- c Write image data to standard output
- i Identify files without decoding them
- a Use automatic white balance
- r <nums> Set raw white balance (four values required)
- k <num> Set black point
- t [0-7] Flip image (0=none, 3=180, 5=90CCW, 6=90CW)
- d Document Mode (no color, no interpolation)
- q [0-3] Set the interpolation quality
- f Interpolate RGB as four colors
- j Show Fuji Super CCD images tilted 45 degrees
- 4 Write 16-bit linear instead of 8-bit with gamma

Dissertation Modification options:

- g Write write histogram csv values to stdout
- N No Foveon noise reduction
- R <nums> r g b d Combine Foveon color channels using r g b multipliers divided by d

appended path

appended path 2

Path 3

Array

0	-T -w	_COLOR_VISIBLE_LIGHT_NO
0	-T -D	_MONO_VISIBLE_LIGHT_XX
	-T -D -R 0.0 0.0 1.0 1.0	_MONO_NONVISIBLE_LIGHT_UV
	-T -D -R 1.0 0.0 0.0 1.0	_MONO_NONVISIBLE_LIGHT_IR

Modified 2006/11/18 by Erik Magnuson and Gerald Williams.
Added extra code to do monochrome channel sums
Optionally suppress noise reduction
And print a histogram
Modified code sections marked by
#ifdef X3FUVIR
#endif

error out status code

☒ ☐ d0

source

standard error

Figure 65. Preprocess.vi Front Panel

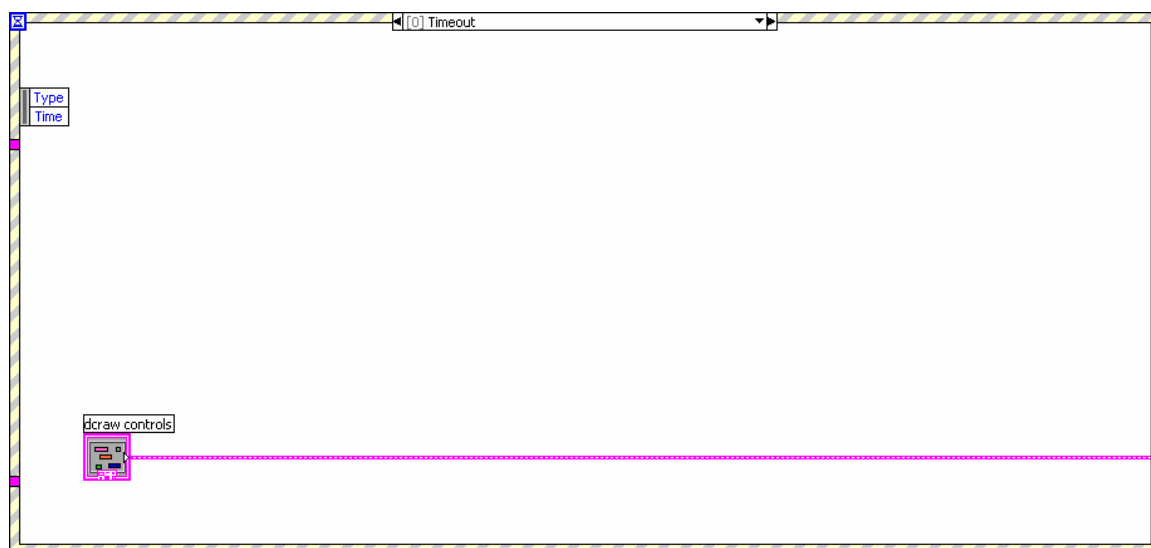


Figure 67. Preprocess.vi Block Diagram with Event Structure for “Timeout”

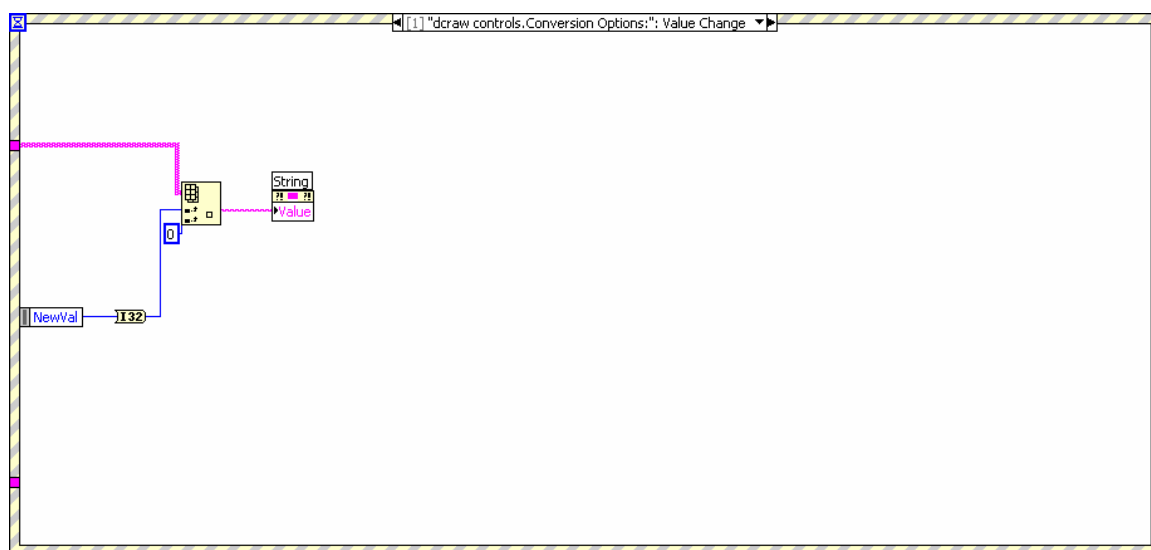


Figure 68. Preprocess.vi Block Diagram with Event Structure for “Options”

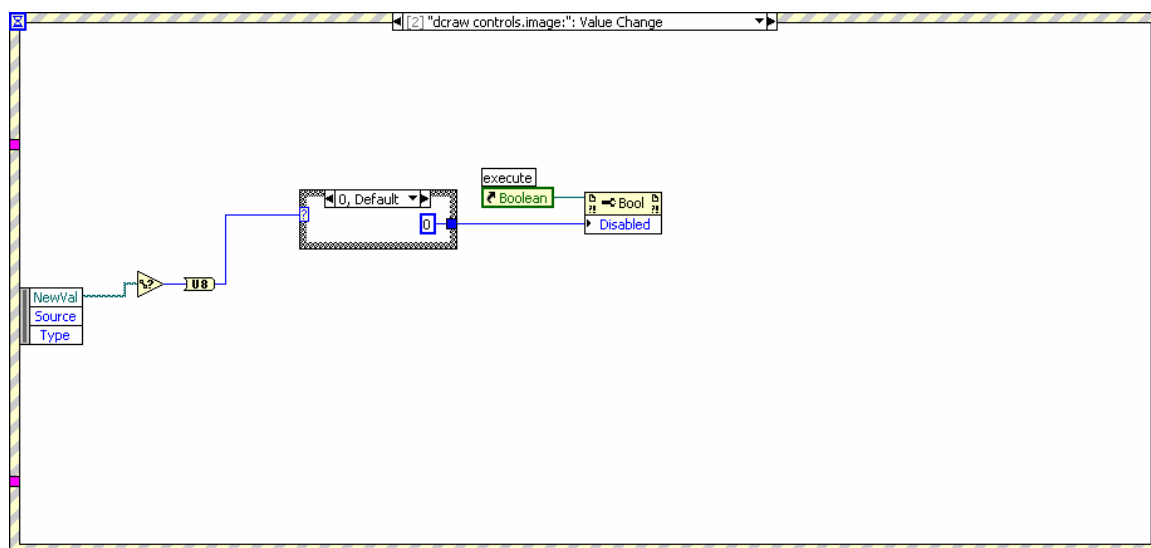


Figure 69. Preprocess.vi Block Diagram with Event Structure for “Image”

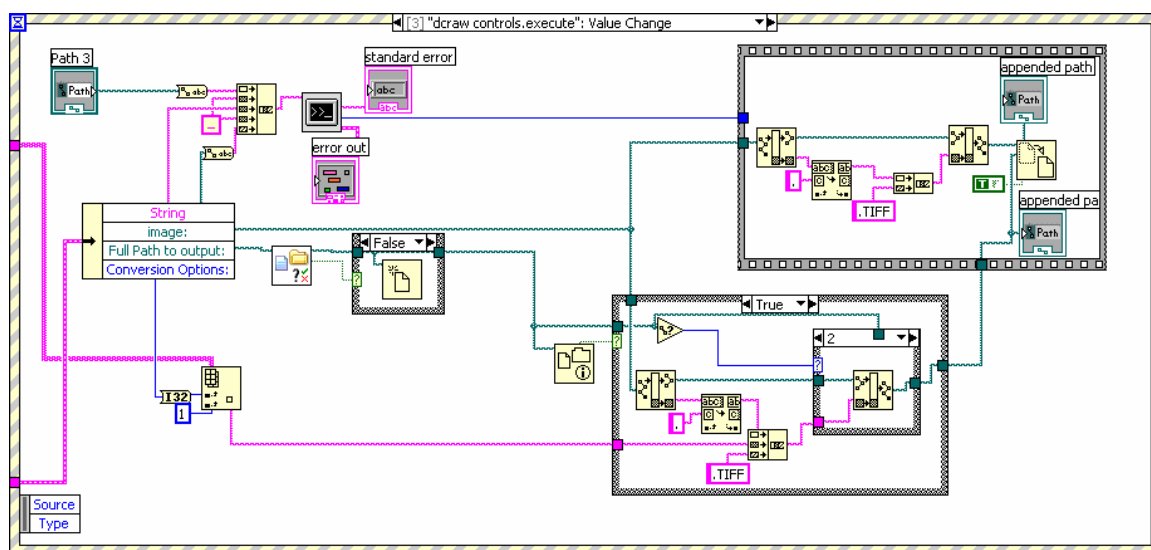


Figure 70. Preprocess.vi Block Diagram with Event Structure for “Execute”

Position in Hierarchy

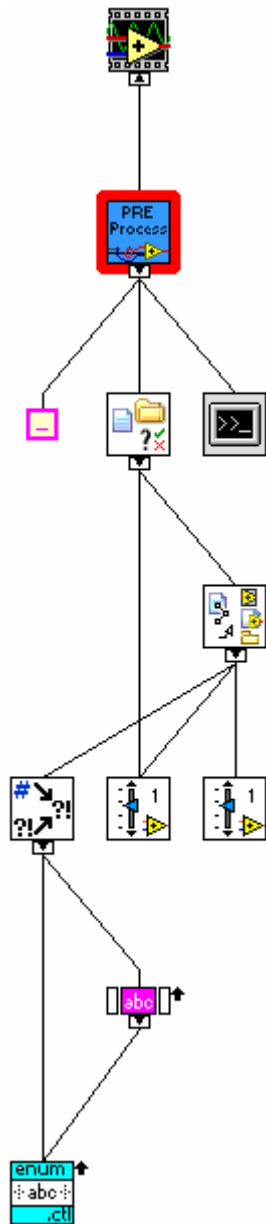
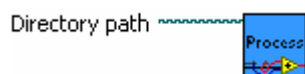


Figure 71. Preprocessing.vi Position in VI Hierarchy

Processing LabVIEW™ Virtual Instrument (VI) Source Code

Description



This VI performs the processing steps on the TIF source image and calls ParticleFind, ParticleNumber, and DataParse.

Front Panel

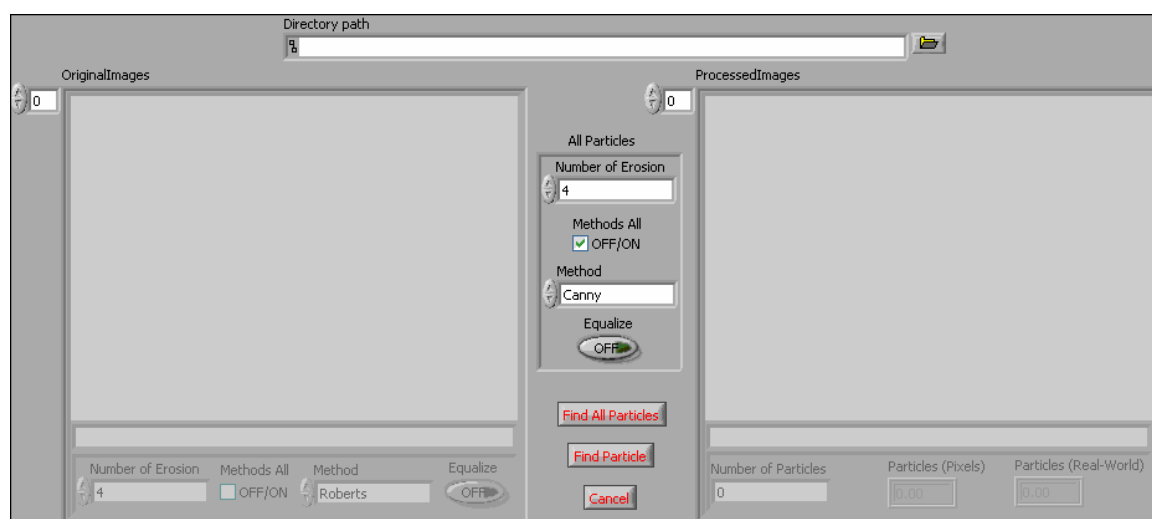


Figure 72. Process.vi Front Panel

Block Diagrams

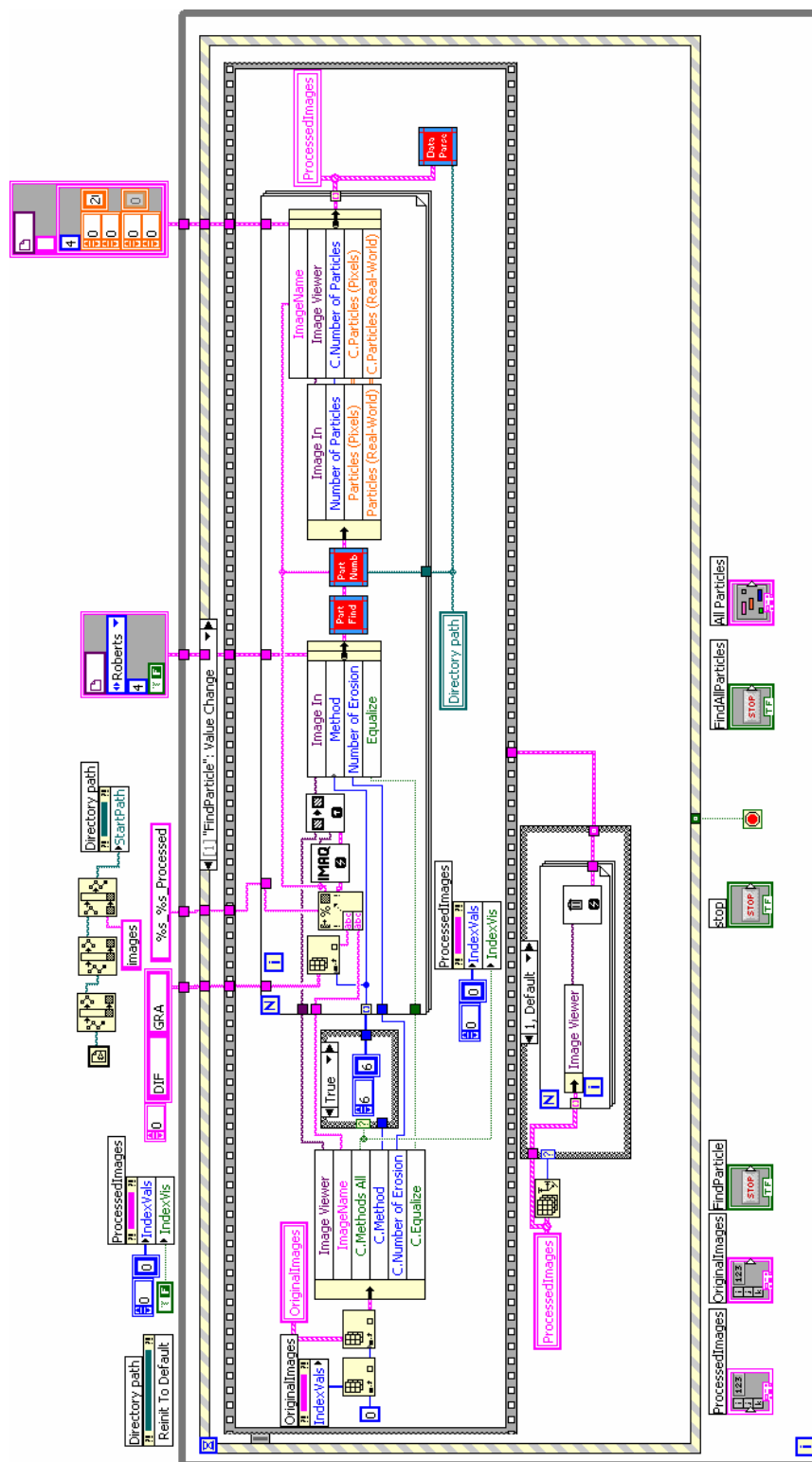


Figure 73. Process.vi Overall Block Diagram with Event Structure “FindParticle” Selected

The LabVIEW block diagram illustrates the particle counting system. It features a main loop structure. The input 'OriginalImages' is connected to an 'Image Viewer' (labeled 'True'). The 'Image In' block is connected to the 'Image In Method' block (labeled 'Number of Erosion Equalize'). The output of the 'Image In Method' block is connected to the 'Image Viewer' (labeled 'Default'). The 'ProcessedImages' output is connected to the 'Image Viewer' (labeled 'Default'). A 'Data Path' block is also shown, connected to the 'Image Viewer' (labeled 'Default').

Figure 76. Process.vi Block Diagram with Event Structure for “FindAllParticles”

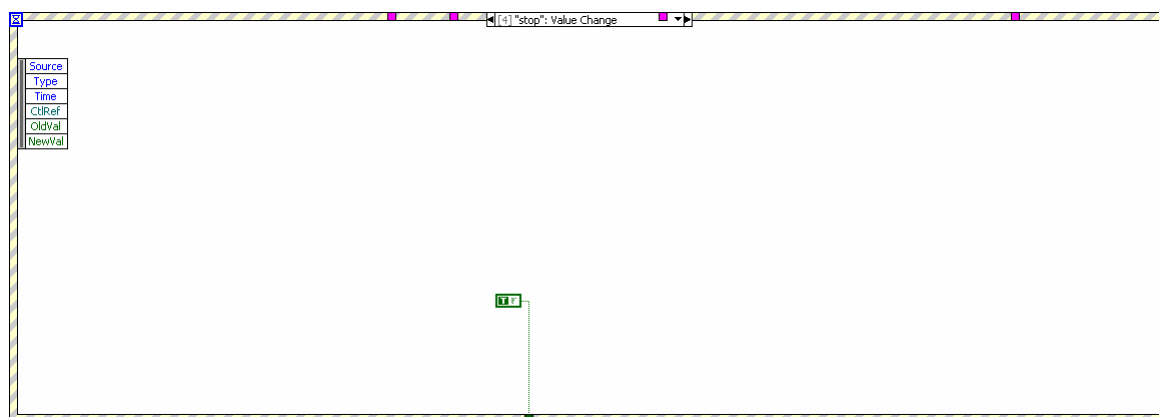
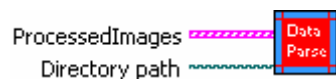


Figure 77. Process.vi Block Diagram with Event Structure for “Stop”

Data Parse LabVIEW™ Virtual Instrument (VI) Source Code

Description



This VI parses through the 81 measurements for each particle found and extracts the measurements required for this research: the number of particles found, the elongation factor, the compactness factor, the perimeter, the Heywood Circularity factor, and the area. The process is repeated for all seven edge detection algorithms: Canny, Differentiation, Gradient, Prewitt, Roberts, Sigma, and Sobel.

Front Panel

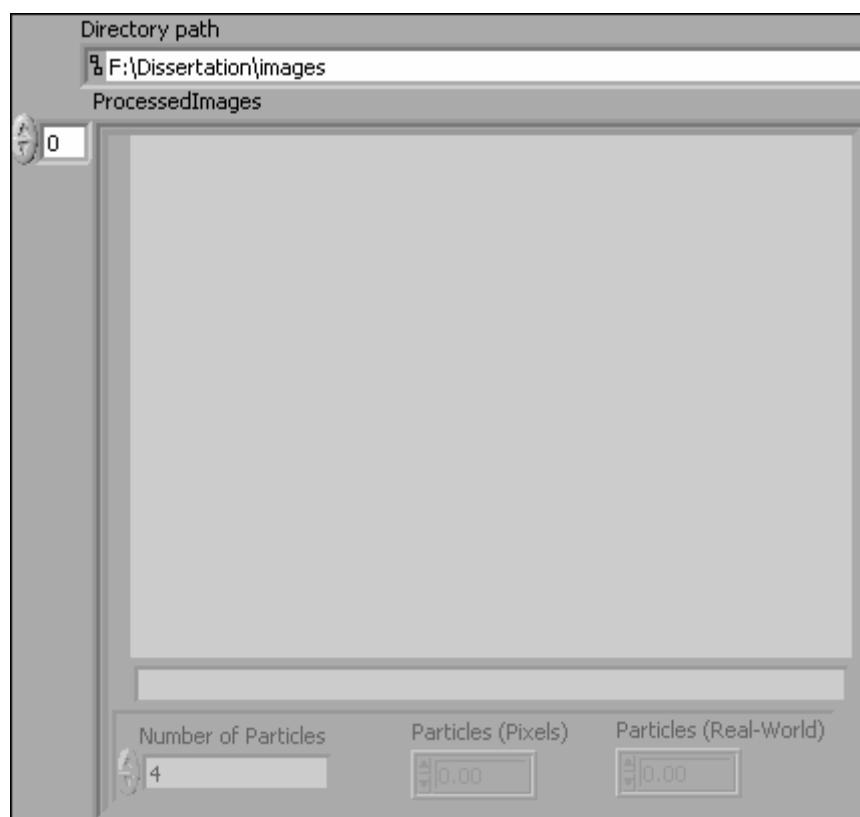


Figure 79. DataParse.vi Front Panel

Block Diagrams

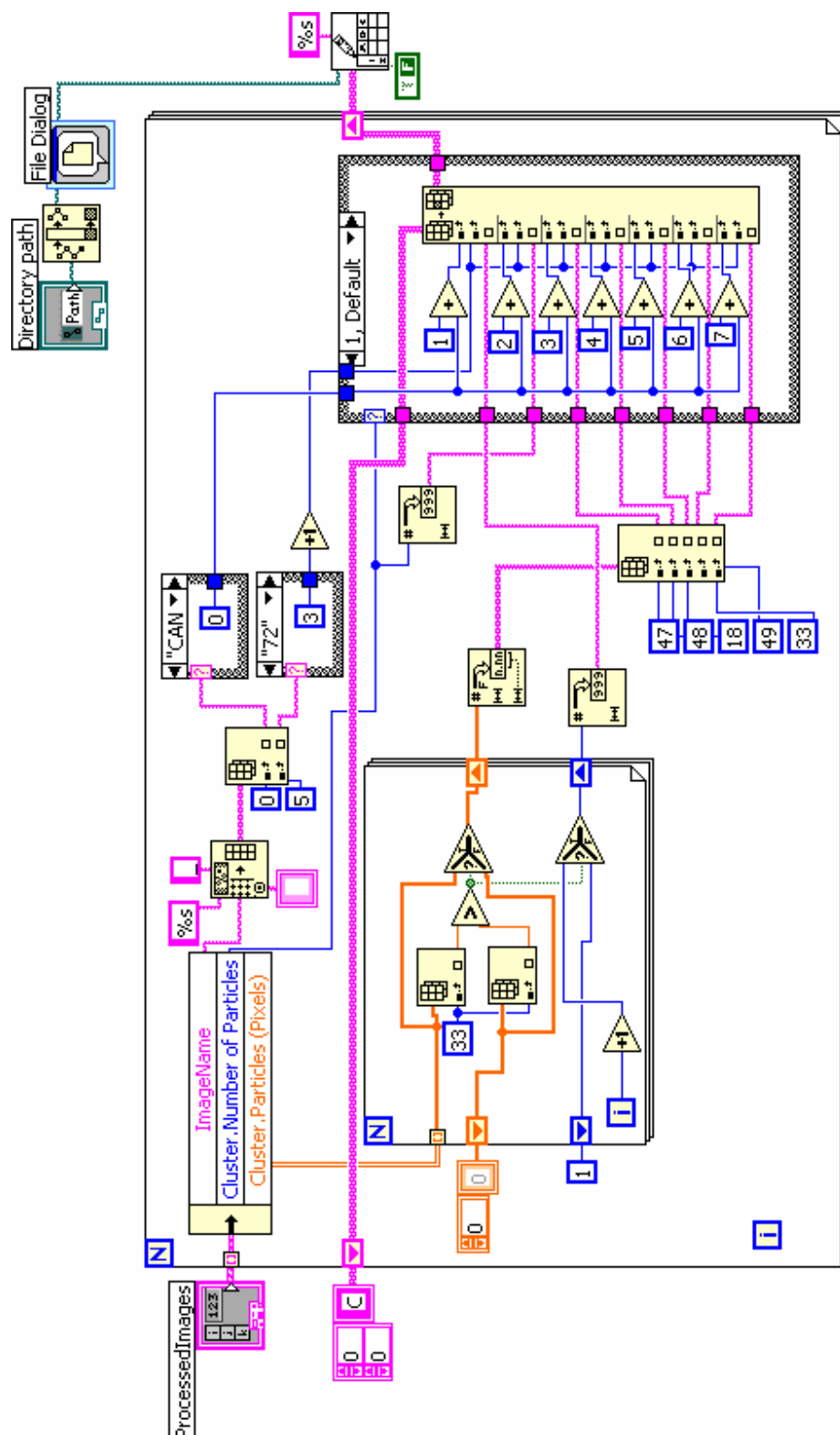


Figure 80. DataParse.vi Overall Block Diagram

Position in Hierarchy

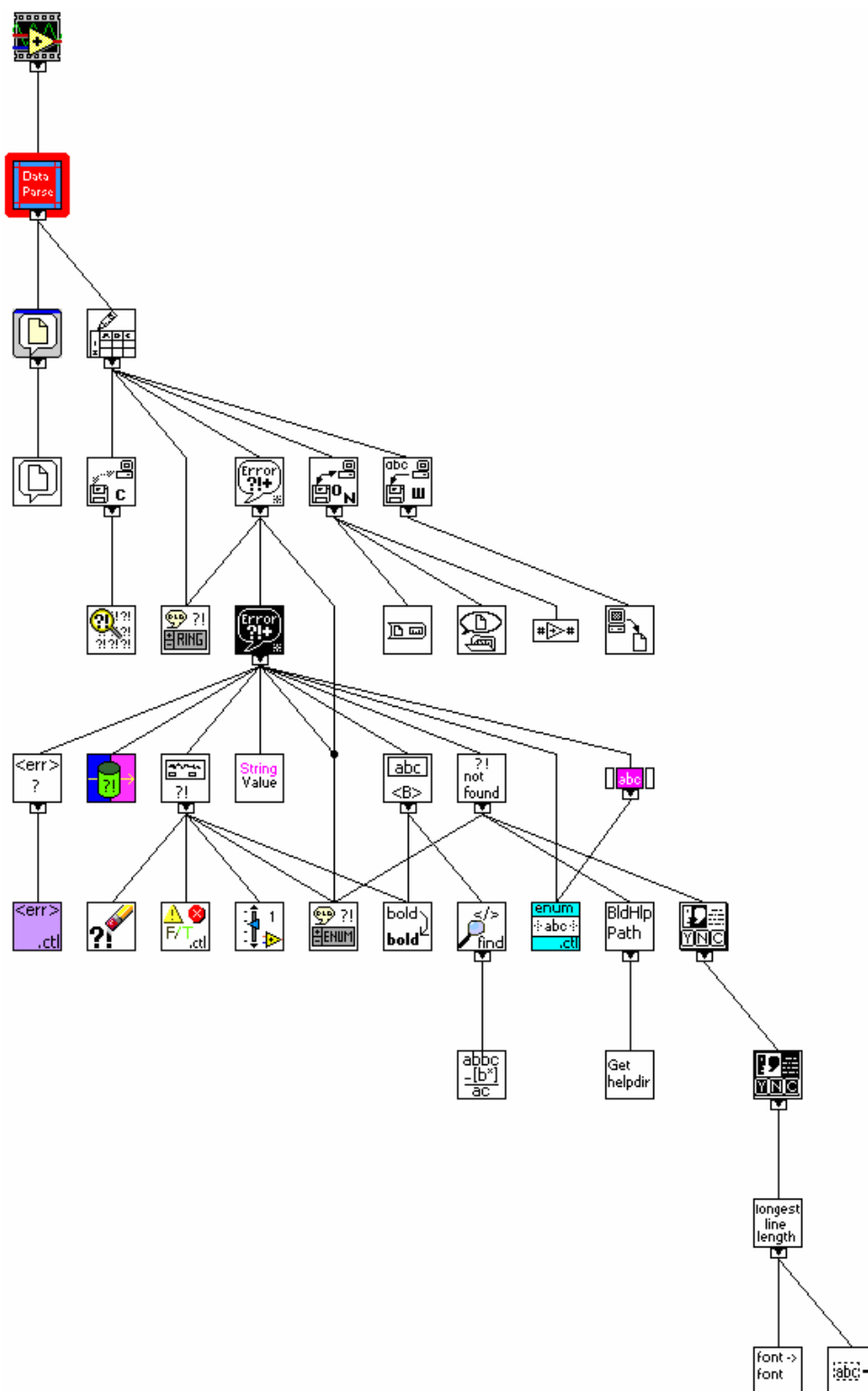


Figure 81. DataParse.vi Position in VI Hierarchy

Figure 82.

Particle Find LabVIEW™ Virtual Instrument (VI) Source Code

Description



This VI uses all the seven edge detection algorithms to locate the edges of the particles located in the image: Canny, Differentiation, Gradient, Prewitt, Roberts, Sigma, and Sobel.

Front Panel

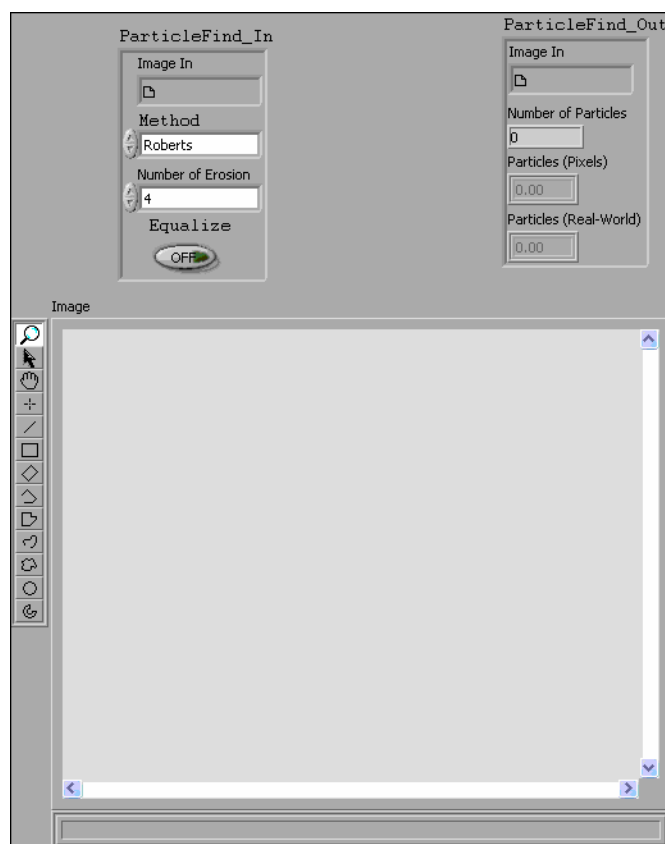
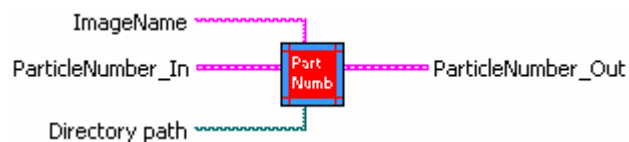


Figure 83. ParticleFind.vi Front Panel

Particle Number LabVIEW™ Virtual Instrument (VI) Source Code

Description



This VI overlays the numerical number on the JPG image of the particle that corresponds to the excel data file. This allows the user to visualize what statistical data matches what particle in the image.

Front Panel



Figure 86. ParticleNumber.vi Front Panel

Block Diagrams

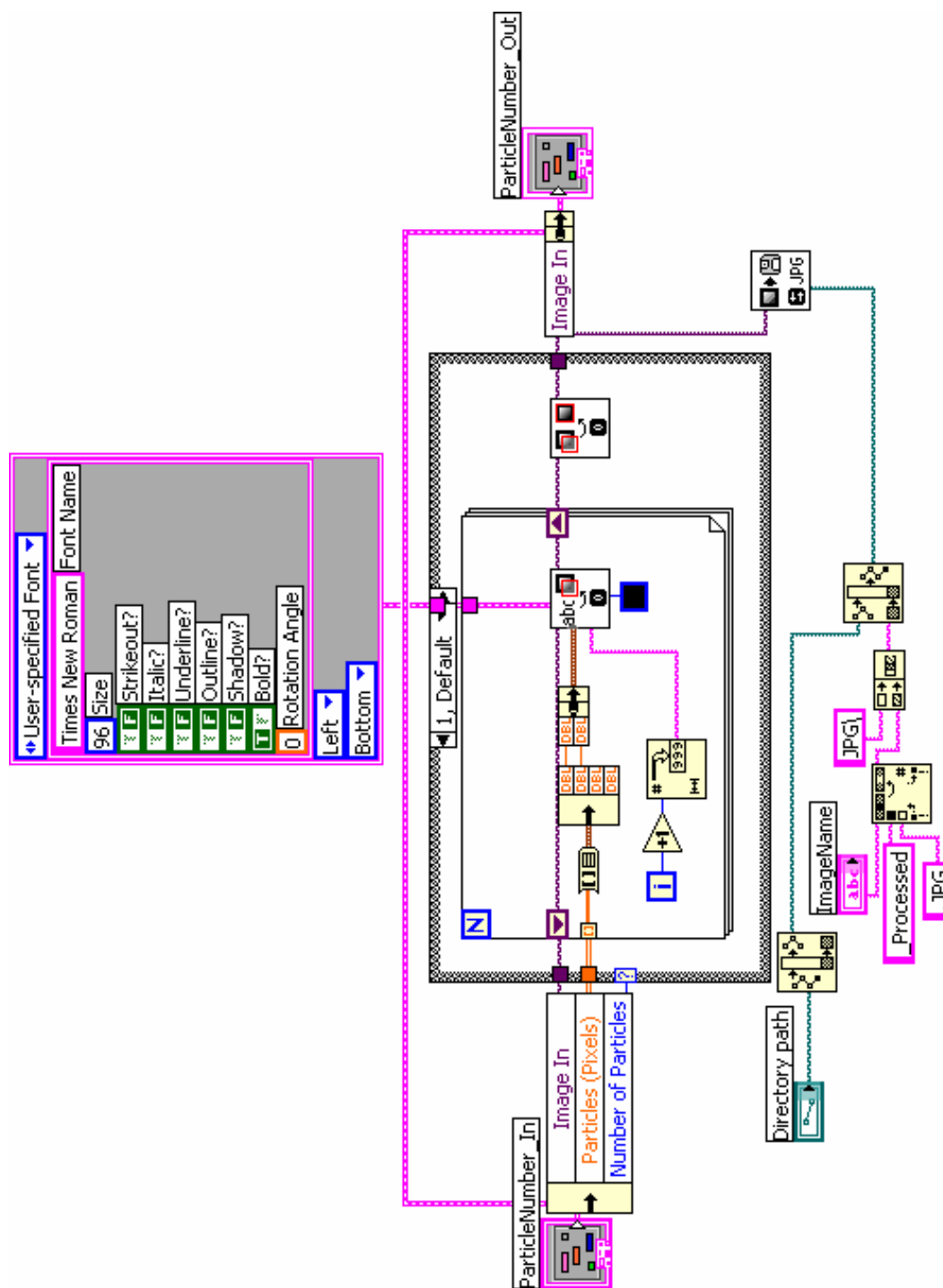


Figure 87. ParticleNumber.vi Overall Block Diagram

Position in Hierarchy

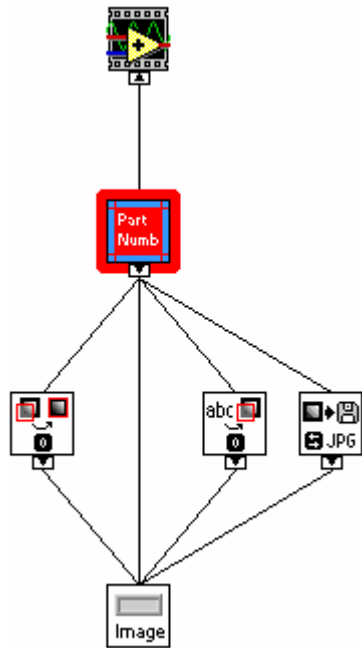


Figure 88. ParticleNumber.vi Position in VI Hierarchy

Appendix M

Sample Lesion Raw Images

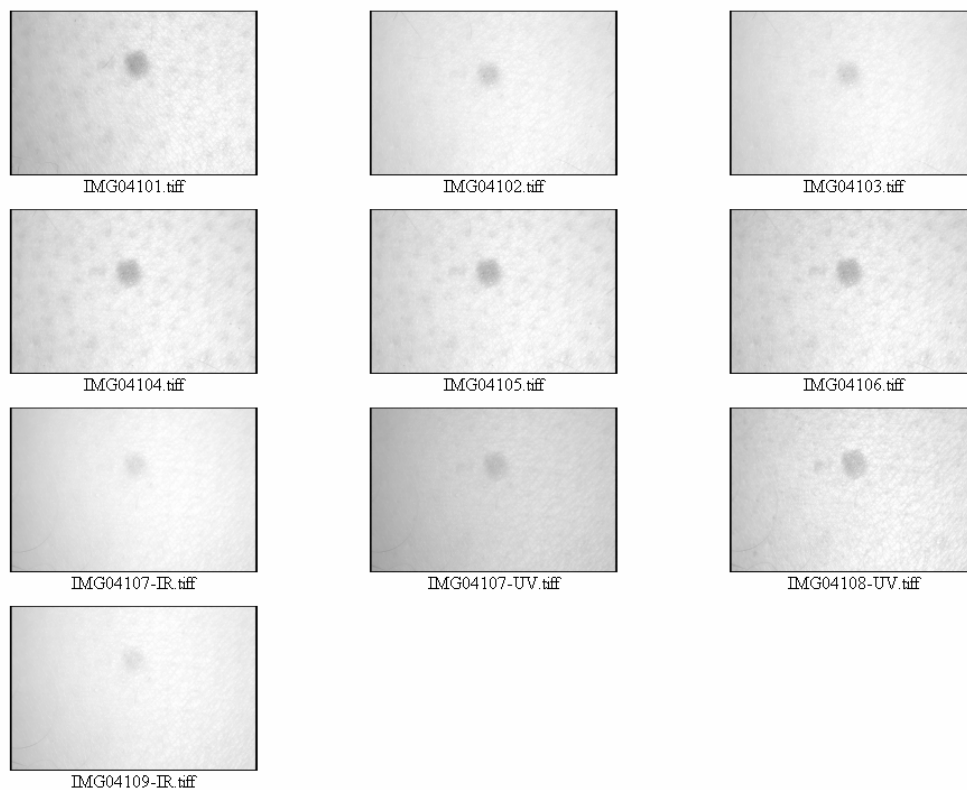


Figure 89. Sample Images for Lesion 1

Appendix N

Sample Lesion Measurement Report

Table 19. NI LabVIEW™ Roberts Parameter Output #1

Parameter	Particle #1	Particle #2
Center of Mass X	17.216802	20.371862
Center of Mass Y	-24.158194	-11.115267
First Pixel X	17.077537	20.273768
First Pixel Y	-24.473467	-12.301773
Bounding Rect Left	16.863836	19.000851
Bounding Rect Top	-24.482759	-12.311065
Bounding Rect Right	17.588562	21.751096
Bounding Rect Bottom	-23.850945	-9.765229
Max Feret Diameter Start X	16.901001	19.000851
Max Feret Diameter Start Y	-24.389845	-11.437676
Max Feret Diameter End X	17.56998	21.751096
Max Feret Diameter End Y	-23.906694	-11.047438
Max Horiz. Segment Length Left	924	1124
Max Horiz. Segment Length Right	933	1139
Max Horiz. Segment Length Row	243	873
Bounding Rect Width	0.724727	2.750245
Bounding Rect Height	0.631813	2.545835
Bounding Rect Diagonal	0.961466	3.747683
Perimeter	2.219497	9.754292
Convex Hull Perimeter	2.000478	7.840377
Holes' Perimeter	2.029275	9.479884
Max Feret Diameter	0.825208	2.777793
Equivalent Ellipse Major Axis	0.9961	4.390077
Equivalent Ellipse Minor Axis	0.077685	0.088734
Equivalent Ellipse Minor Axis (Feret)	0.514421	2.282575
Equivalent Rect Long Side	1.051975	4.813586
Equivalent Rect Short Side	0.057773	0.06356
Equivalent Rect Diagonal	1.05356	4.814005
Equivalent Rect Short Side (Feret)	0.404025	1.79273
Average Horiz. Segment Length	0.000894	0.000862

Table 20. NI LabVIEW™ Roberts Parameter Output #2

Parameter	Particle #1	Particle #2
Average Vert. Segment Length	0.00075	0.000754
Hydraulic Radius	0.027383	0.031366
Waddel Disk Diameter	0.278177	0.624139
Area	0.060776	0.305952
Holes' Area	0.240687	4.035388
Particle & Holes' Area	0.301463	4.34134
Convex Hull Area	0.333405	4.979834
Image Area	1218.083658	1218.083658
Number of Holes	2	13
Number of Horiz. Segments	68	355
Number of Vert. Segments	81	406
Orientation	148.591516	150.358099
Max Feret Diameter Orientation	144.162347	171.924104
% Area/Image Area	0.004989	0.025117
% Area/(Particle & Holes' Area)	20.160367	7.047407
Ratio of Equivalent Ellipse Axes	12.822226	49.47446
Ratio of Equivalent Rect Sides	18.208693	75.732846
Elongation Factor	2.042465	1.549476
Compactness Factor	0.13273	0.043697
Heywood Circularity Factor	2.539706	4.974669
Type Factor	0.106284	0.035719
Sum X	1.046368	6.23281
Sum Y	-1.468238	-3.400737
Sum XX	18.018406	127.191205
Sum XY	-25.277432	-69.264991
Sum YY	35.472314	38.000291
Sum XXX	310.332592	2599.963388
Sum XXY	-435.25982	-1413.196253
Sum XYY	610.674541	773.846008
Sum YYY	-857.059467	-426.824291

Table 21. NI LabVIEW™ Roberts Parameter Output #3

Parameter	Particle #1	Particle #2
Moment of Inertia XX	0.003289	0.217252
Moment of Inertia XY	0.000938	0.014362
Moment of Inertia YY	0.002326	0.200186
Moment of Inertia XXX	0.000015	-0.009985
Moment of Inertia XXY	0.000036	-0.01715
Moment of Inertia XYY	0.000039	0.028582
Moment of Inertia YYY	-0.000046	0.009347
Norm. Moment of Inertia XX	0.890388	2.320904
Norm. Moment of Inertia XY	0.253905	0.153426
Norm. Moment of Inertia YY	0.629599	2.13859
Norm. Moment of Inertia XXX	0.01689	-0.192851
Norm. Moment of Inertia XXY	0.039581	-0.331227
Norm. Moment of Inertia XYY	0.042592	0.552021
Norm. Moment of Inertia YYY	-0.050705	0.180522
Hu Moment 1	1.519987	4.459494
Hu Moment 2	0.325882	0.127397
Hu Moment 3	0.041009	4.79723
Hu Moment 4	0.003662	0.151715
Hu Moment 5	-0.000041	0.024044
Hu Moment 6	0.000218	-0.013841
Hu Moment 7	0.000019	-0.127178

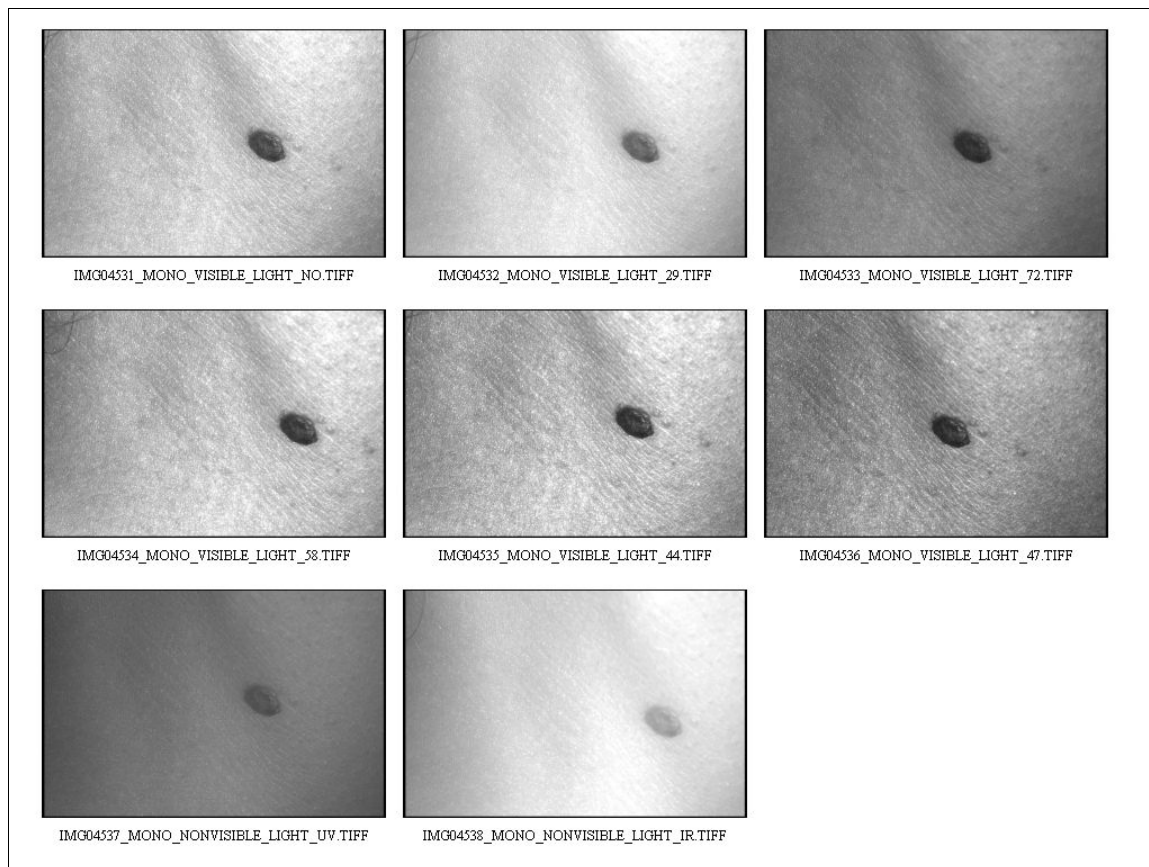
Appendix O

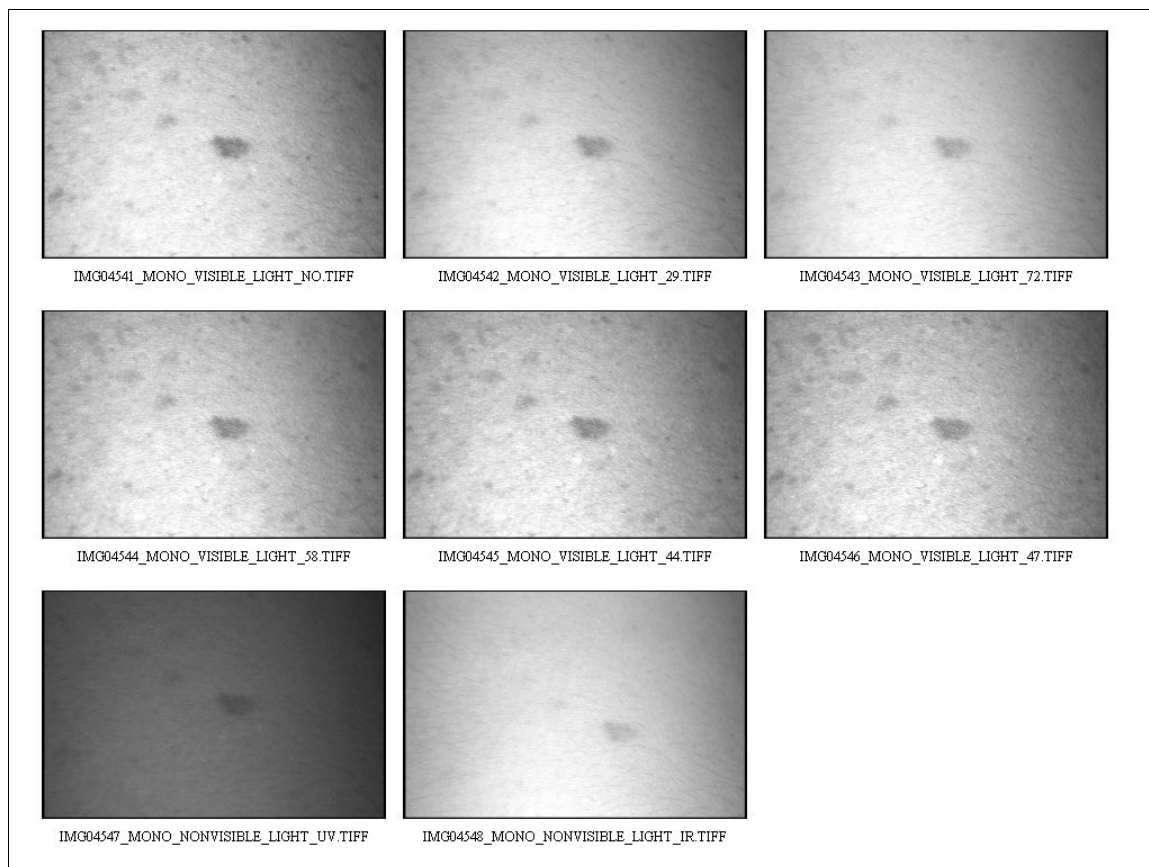
Vision Calibration

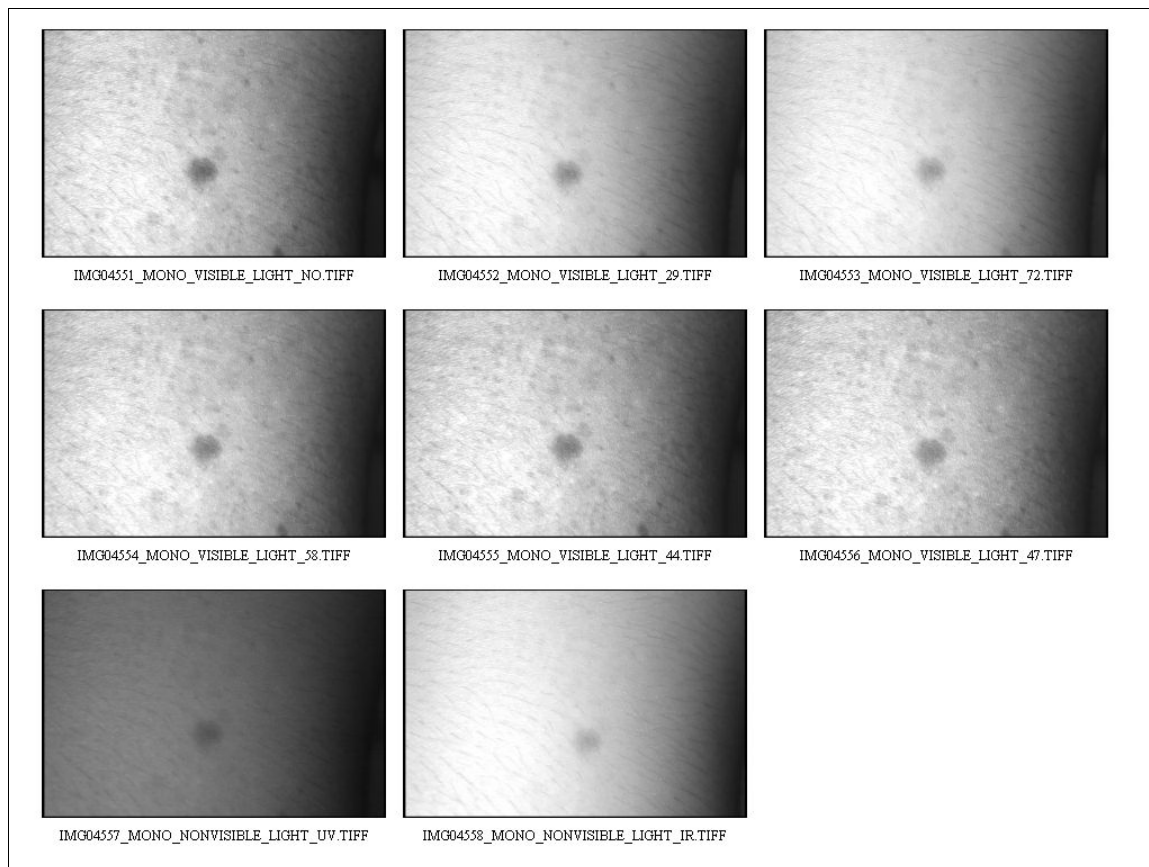
1. Click **Image → Image Calibration**
2. Select “Simple Calibration” and click OK.
3. Select “Square” for the pixel type of the camera.
4. Click Next.
5. Select two new points in the image that are a known distance apart.
6. Enter the distance between the two selected points in real-world units
7. Specify millimeters for the units.
8. Click Next.
9. Select an Axis Reference, point 0,0 is the top left corner of the image
10. Click OK to apply the calibration.
11. Save the calibration information in, enter a File name, and click OK.
12. Click OK to save the step in the script and close the Parameter window (National Instruments, 2006).

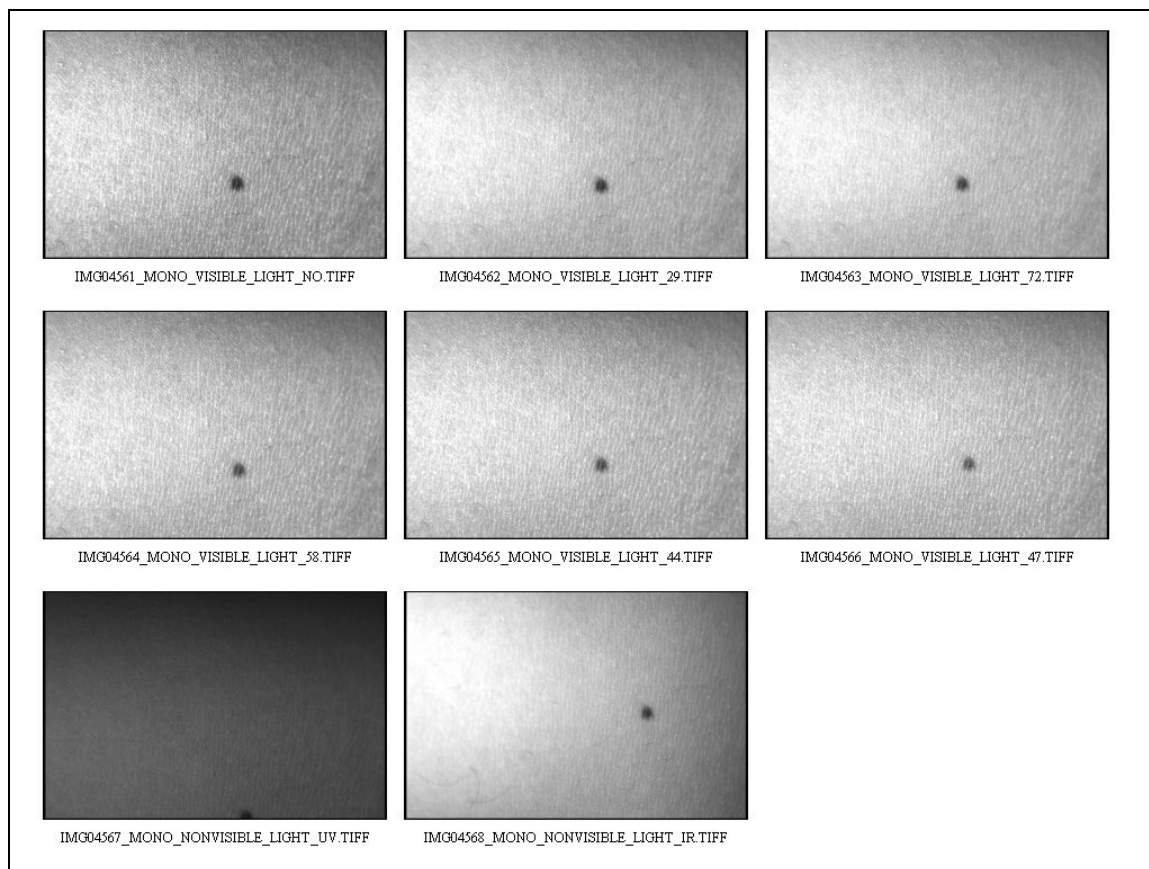
Appendix P

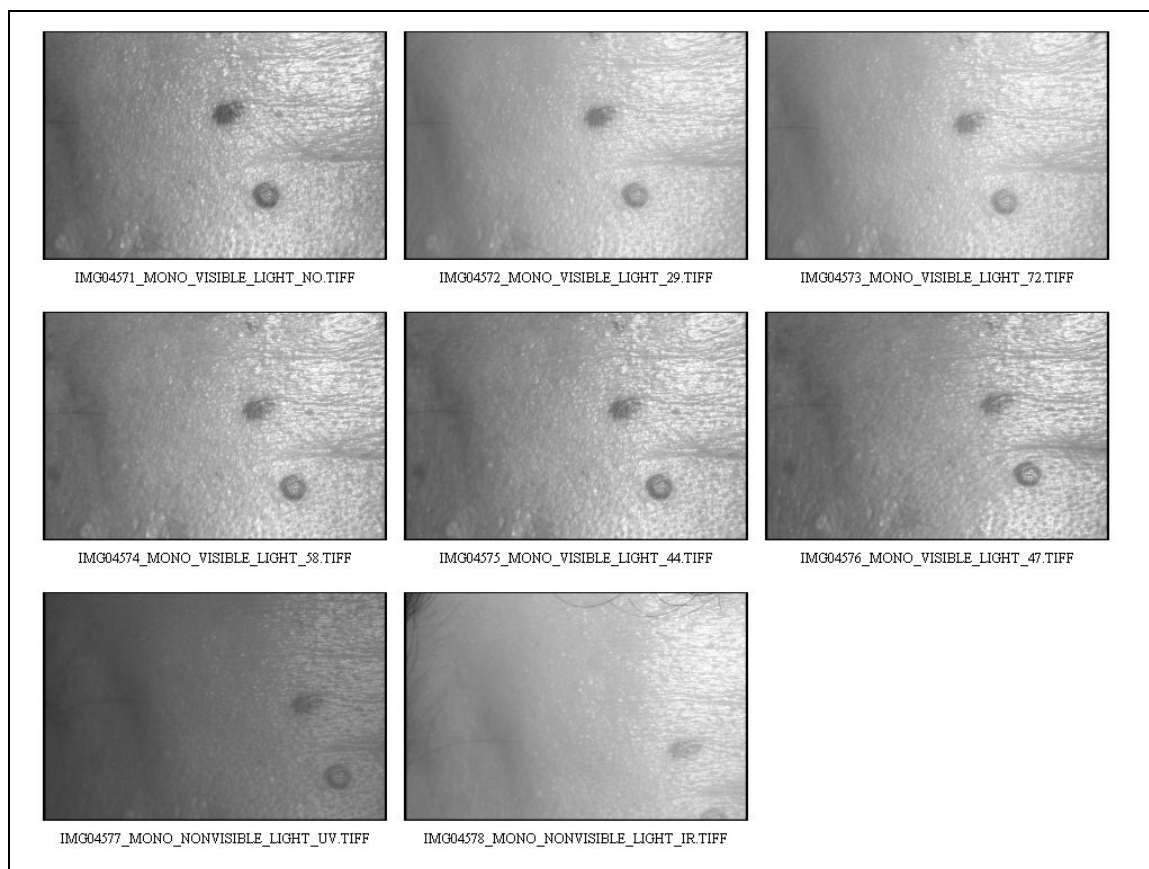
Lesion Raw Images

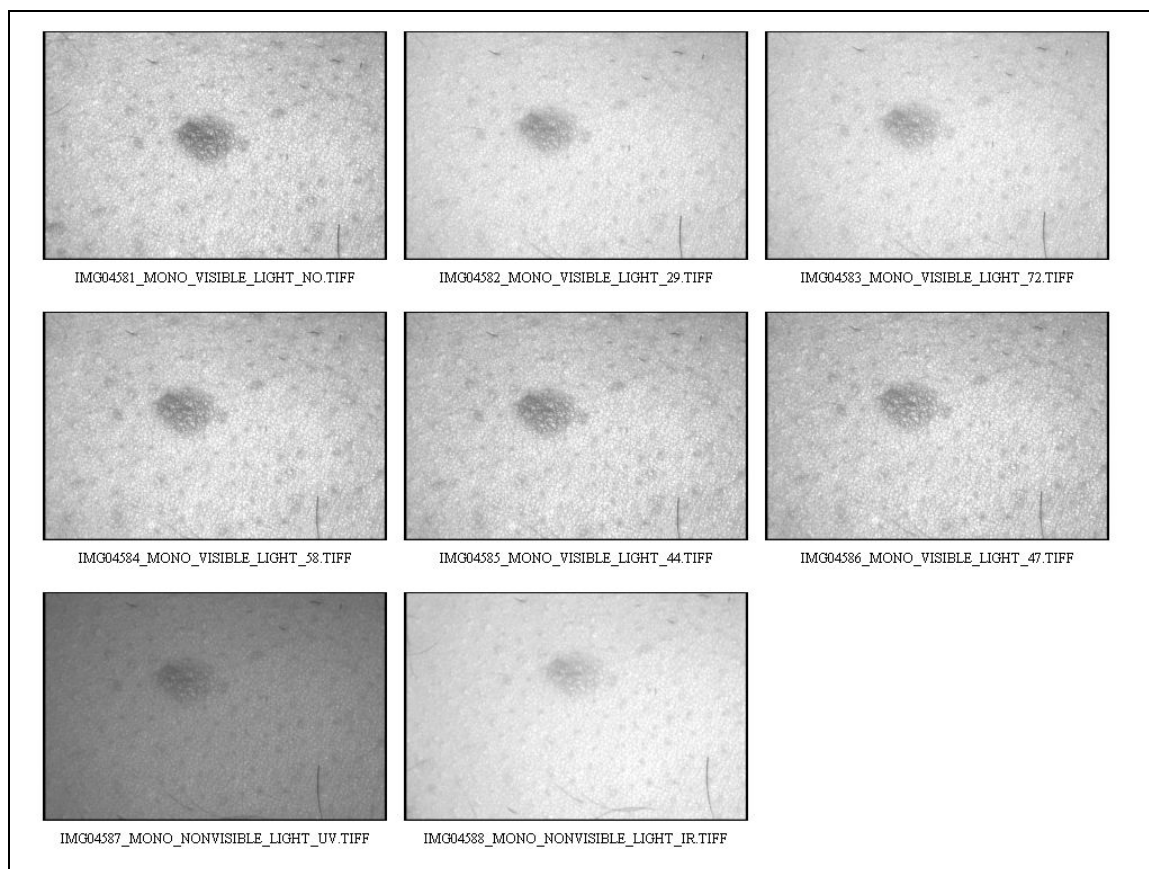
Lesion 453X**Figure 90. Lesion 453X Preprocessed TIF Images**

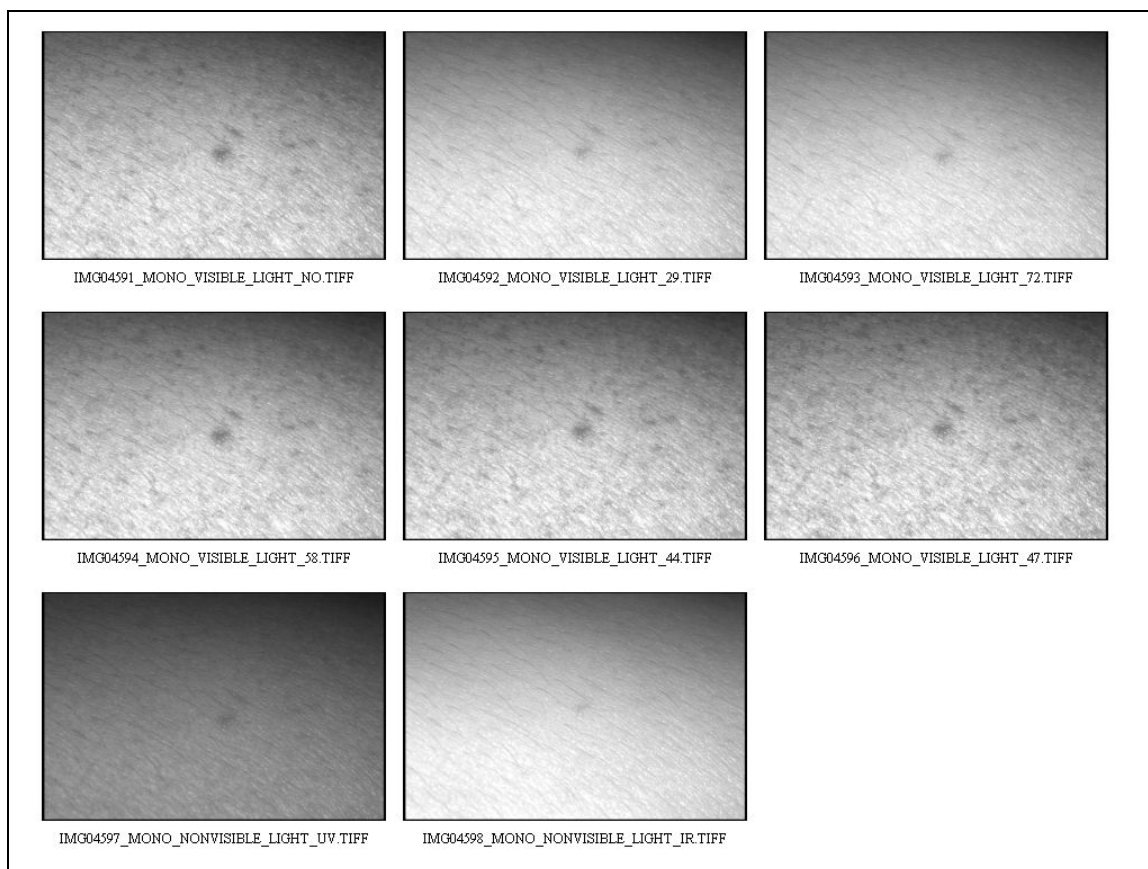
Lesion 454X**Figure 91. Lesion 454X Preprocessed TIF Images**

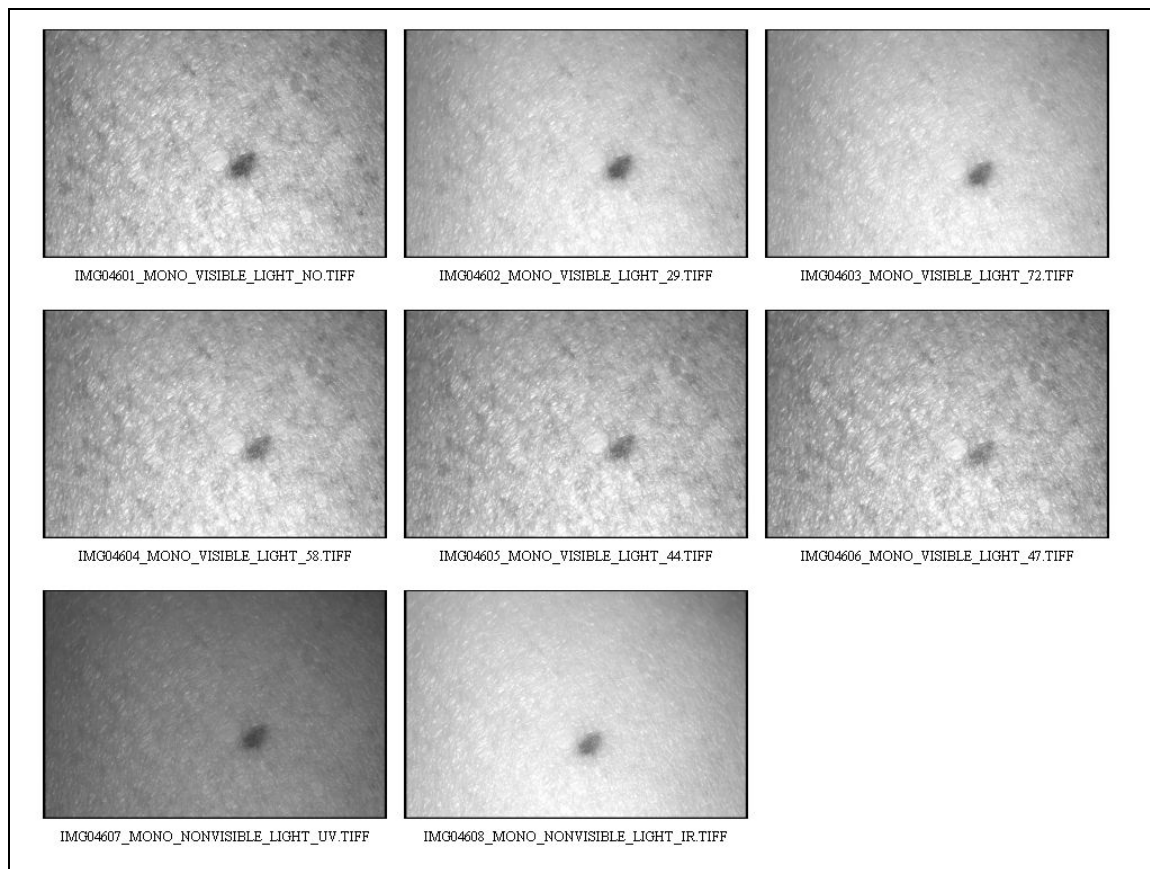
Lesion 455X**Figure 92. Lesion 455X Preprocessed TIF Images**

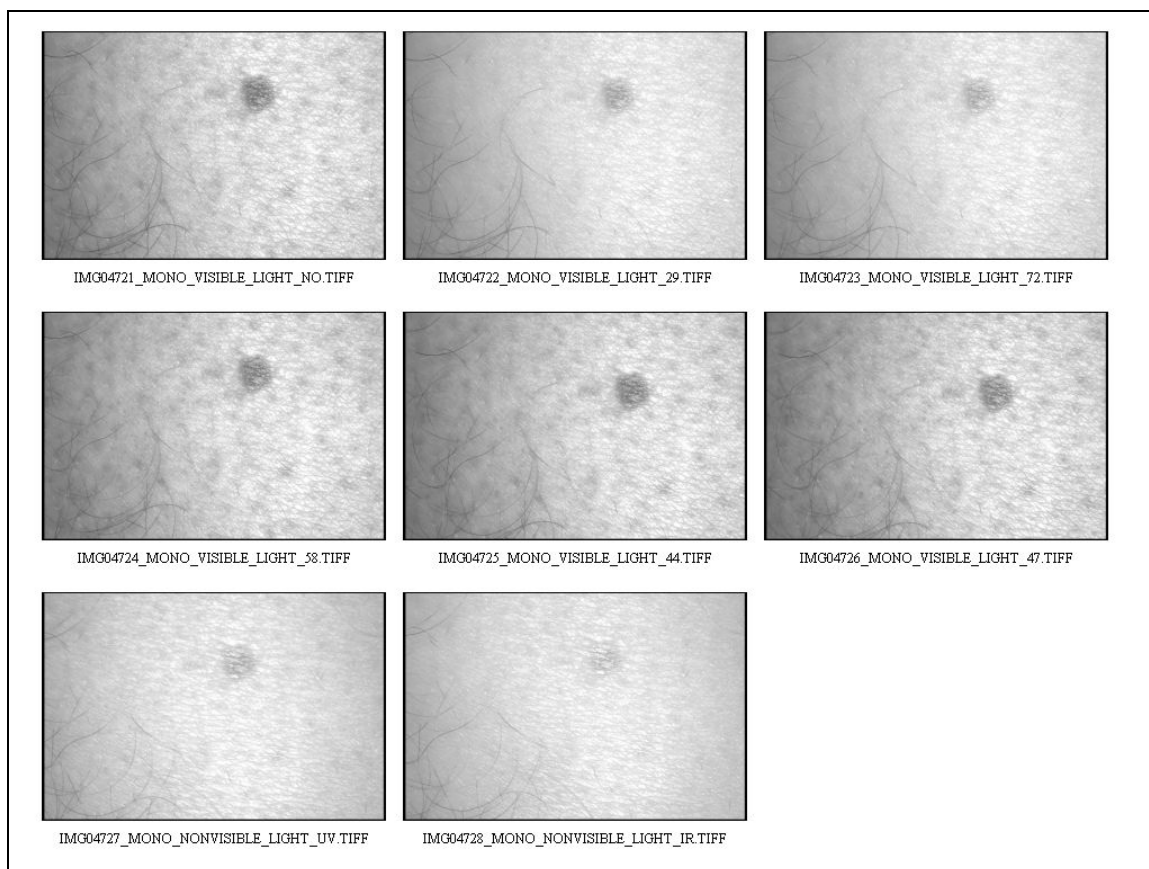
Lesion 456X**Figure 93. Lesion 456X Preprocessed TIF Images**

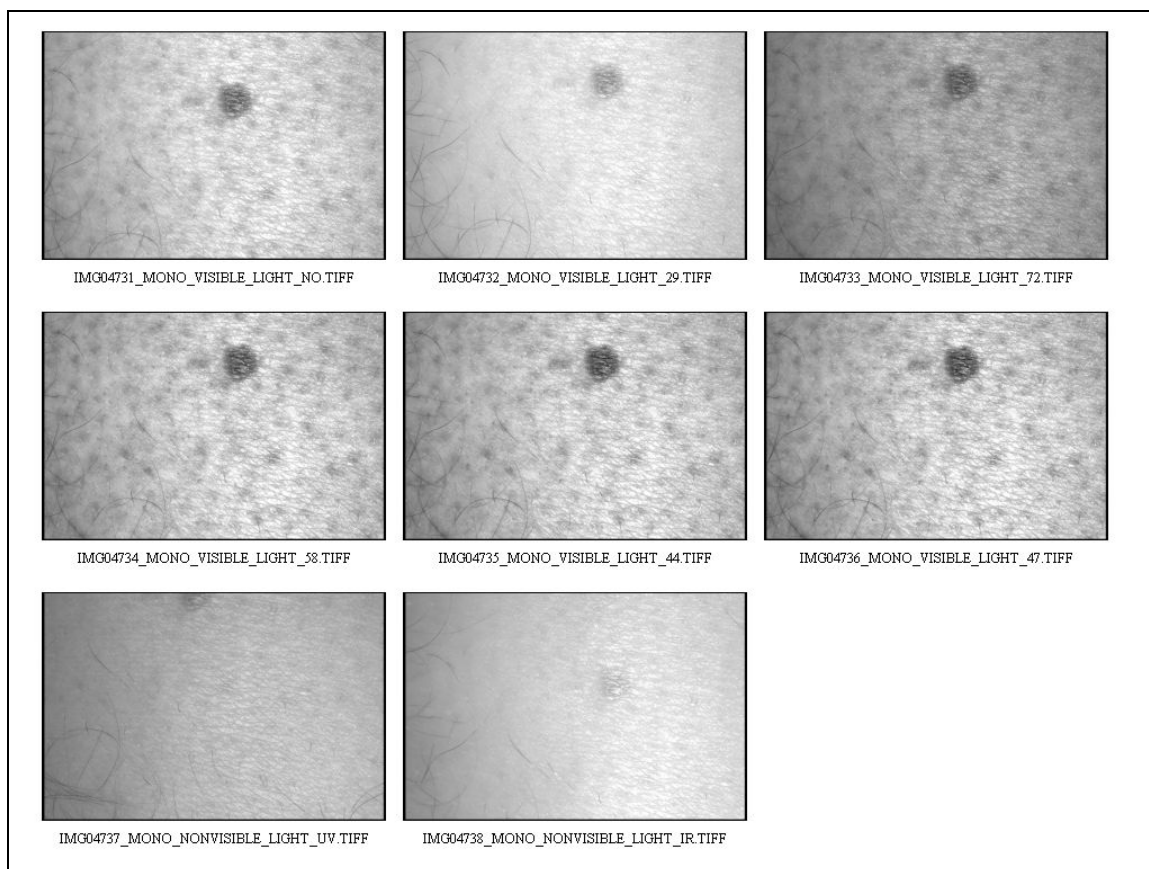
Lesion 457X**Figure 94. Lesion 457X Preprocessed TIF Images**

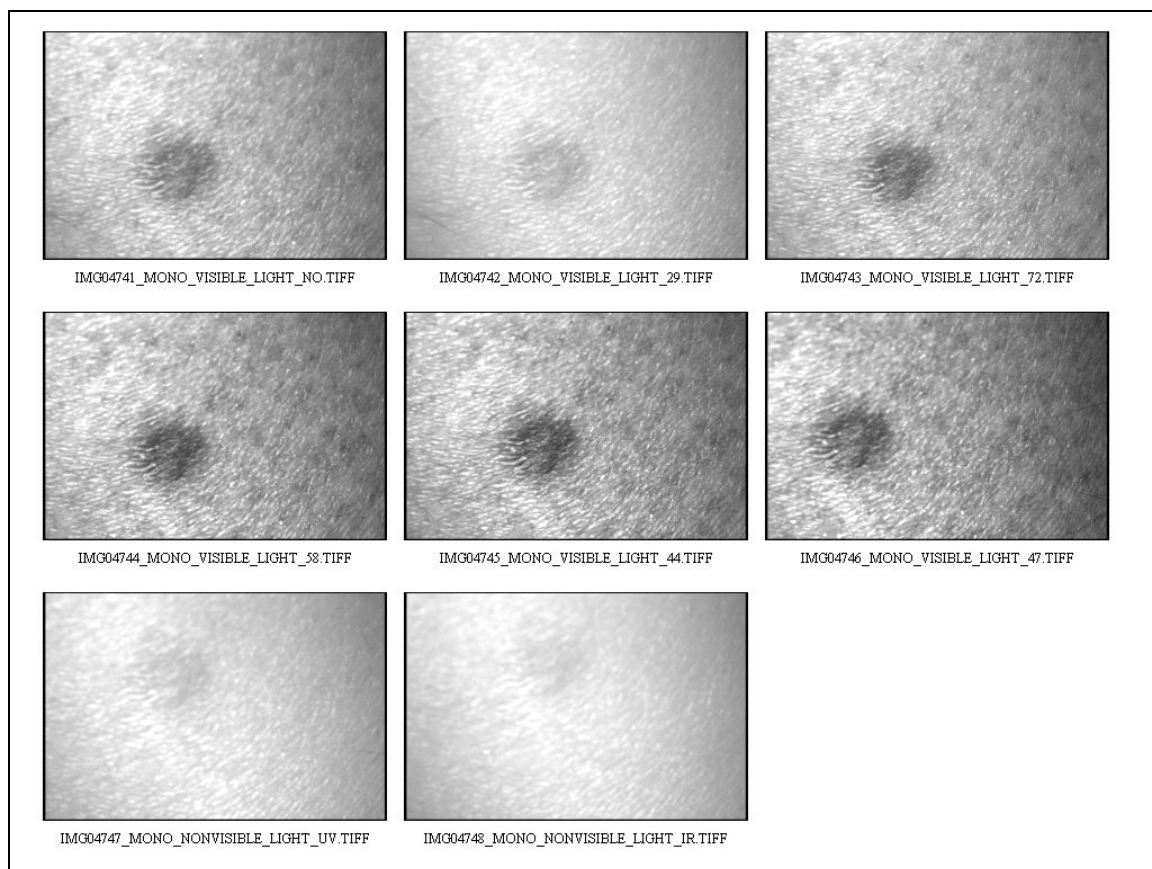
Lesion 458X**Figure 95. Lesion 458X Preprocessed TIF Images**

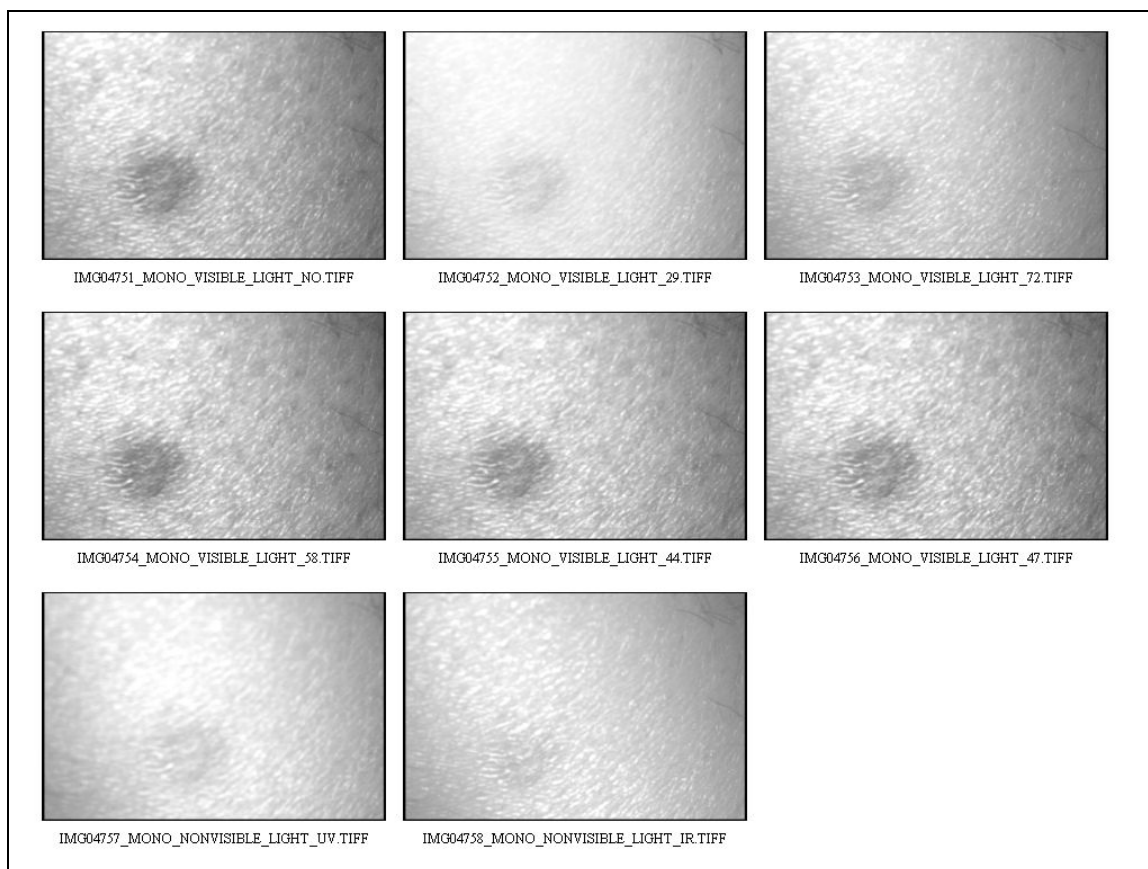
Lesion 459X**Figure 96. Lesion 459X Preprocessed TIF Images**

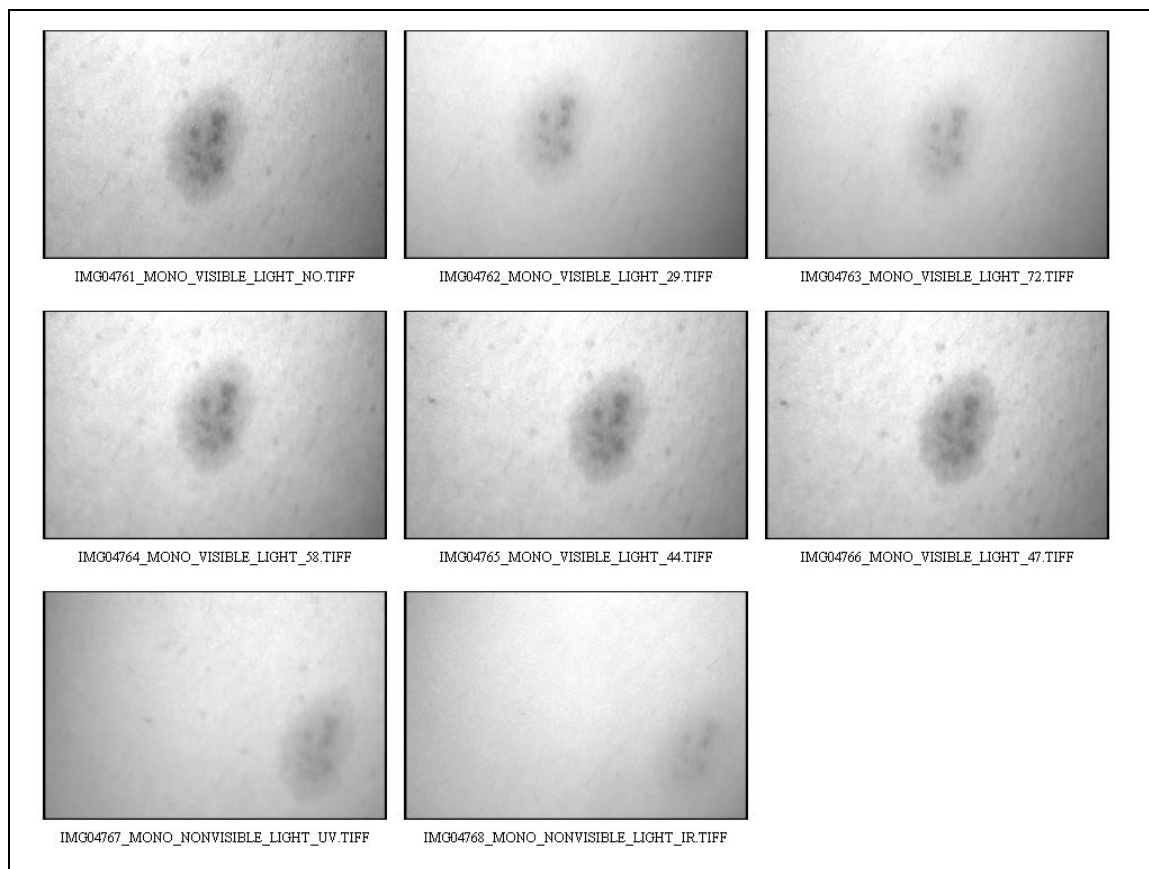
Lesion 460X**Figure 97. Lesion 460X Preprocessed TIF Images**

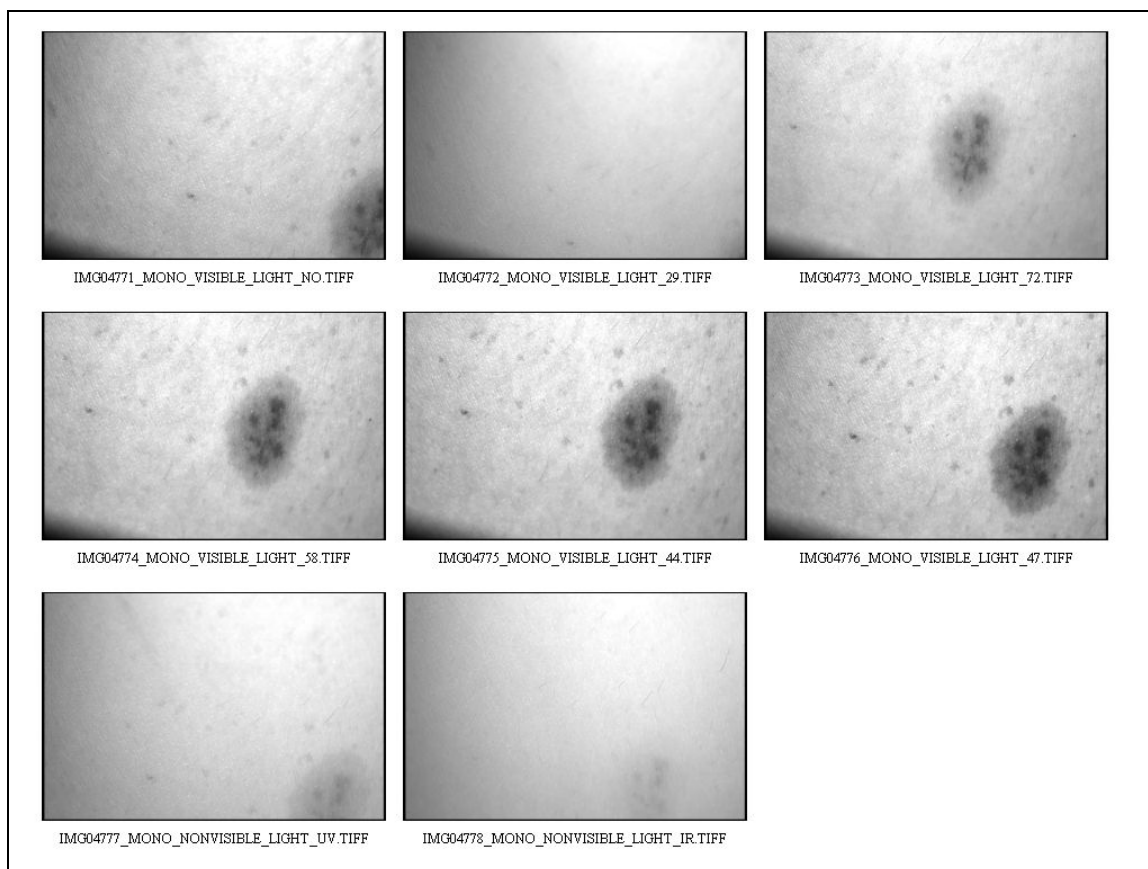
Lesion 472X**Figure 98. Lesion 472X Preprocessed TIF Images**

Lesion 473X**Figure 99. Lesion 473X Preprocessed TIF Images**

Lesion 474X**Figure 100. Lesion 474X Preprocessed TIF Images**

Lesion 475X**Figure 101. Lesion 475X Preprocessed TIF Images**

Lesion 476X**Figure 102. Lesion 476X Preprocessed TIF Images**

Lesion 477X**Figure 103. Lesion 477X Preprocessed TIF Images**

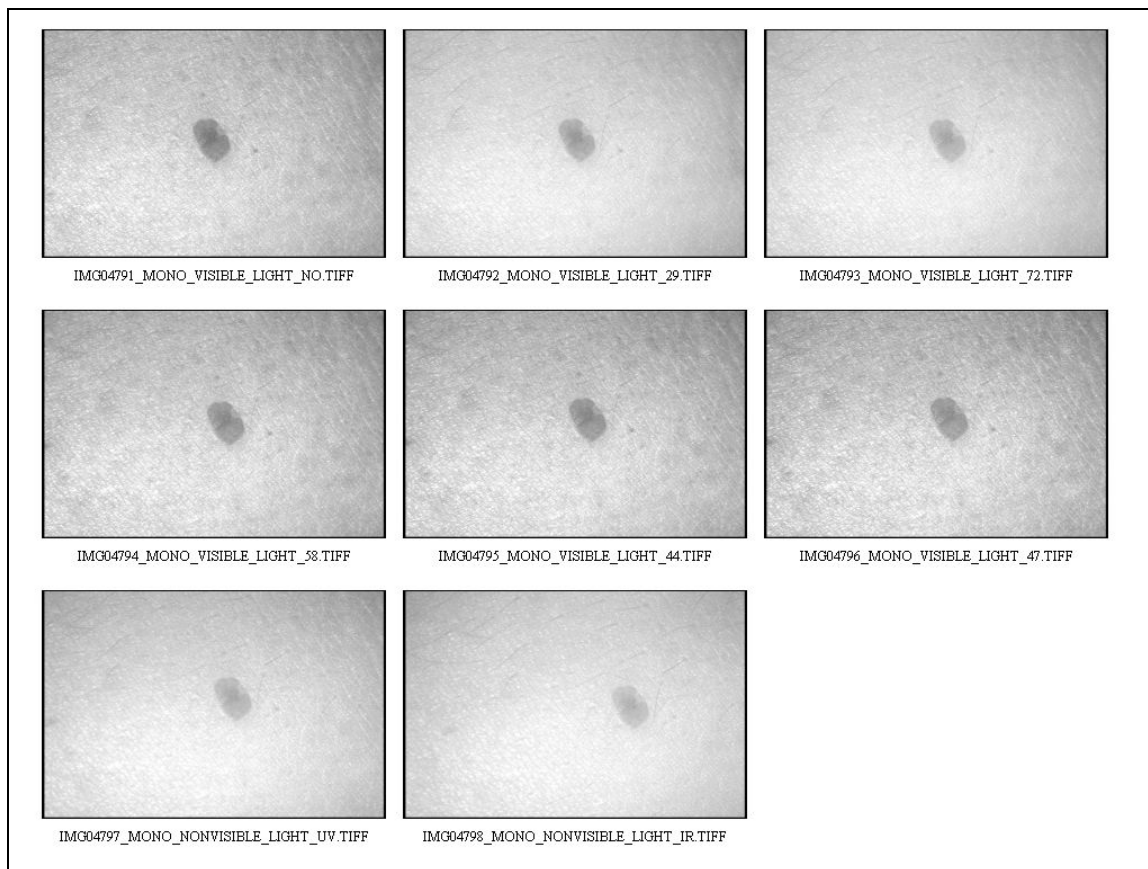
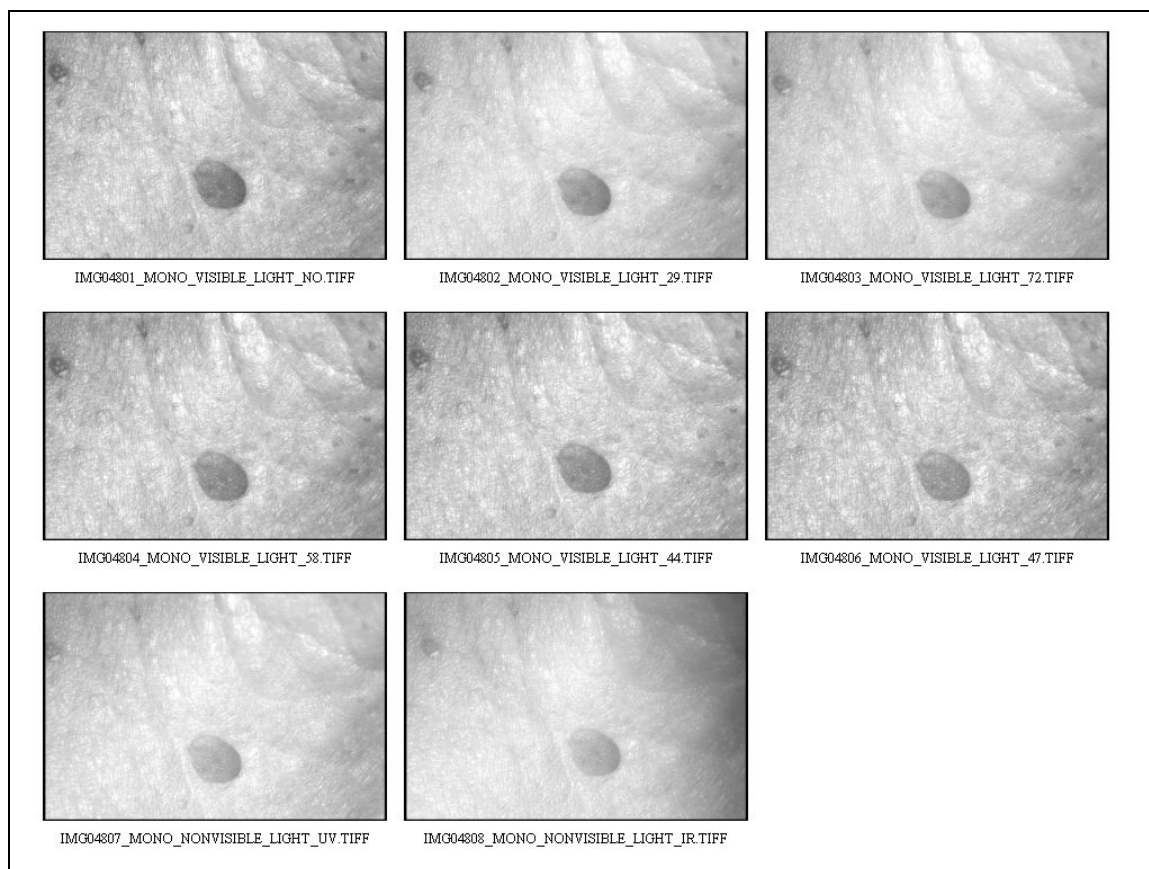
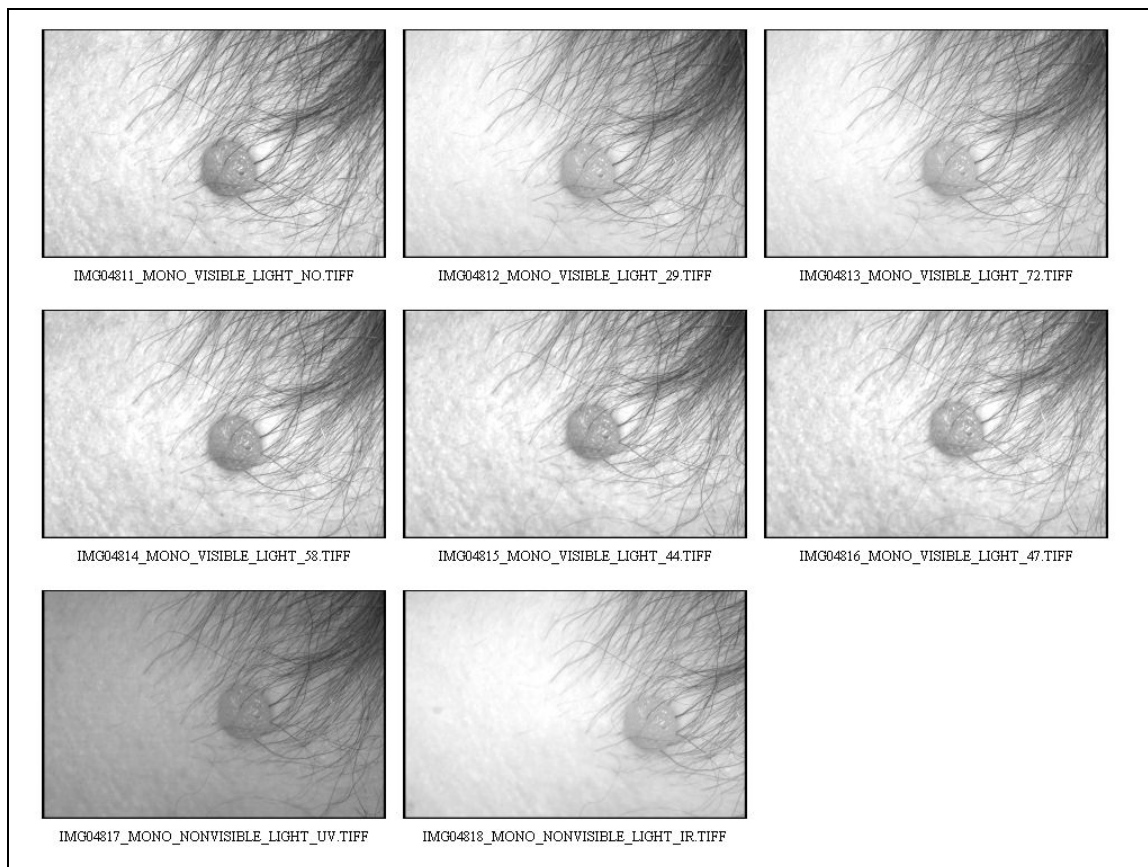
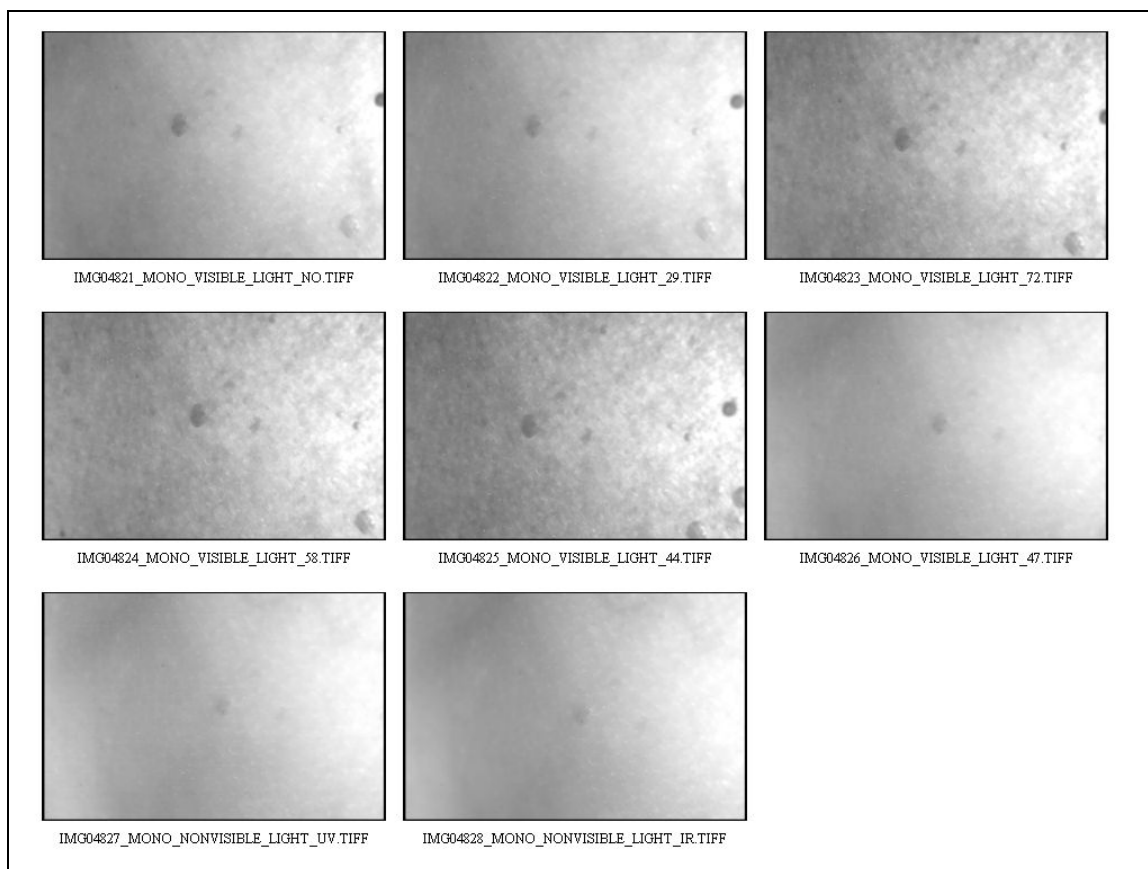
Lesion 479X

Figure 104. Lesion 479X Preprocessed TIF Images

Lesion 480X**Figure 105. Lesion 480X Preprocessed TIF Images**

Lesion 481X**Figure 106. Lesion 481X Preprocessed TIF Images**

Lesion 482X**Figure 107. Lesion 482X Preprocessed TIF Images**

Appendix Q

Lesion Processed Images

Lesion 453X

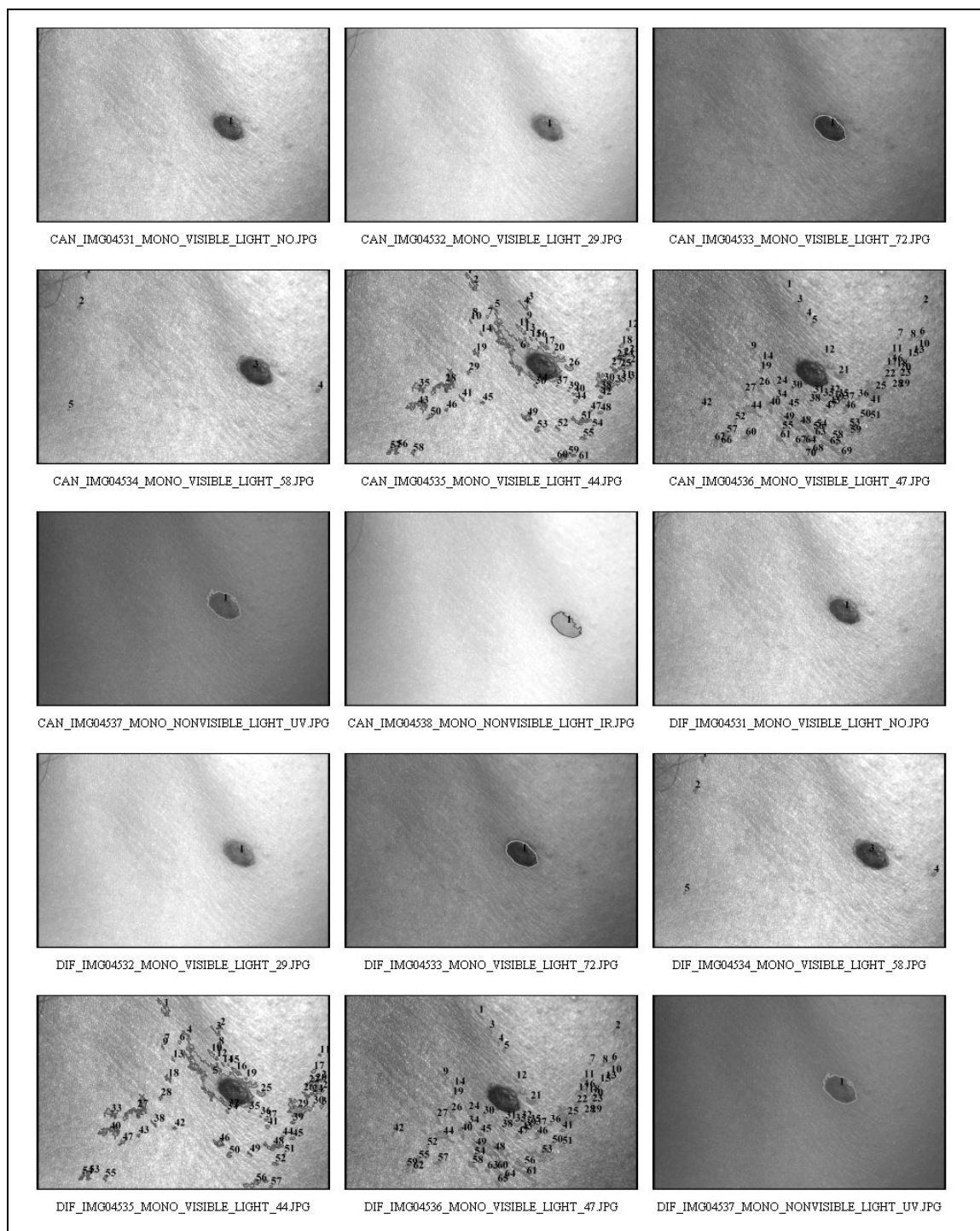


Figure 108. Lesion 453X Processed Sheet 1

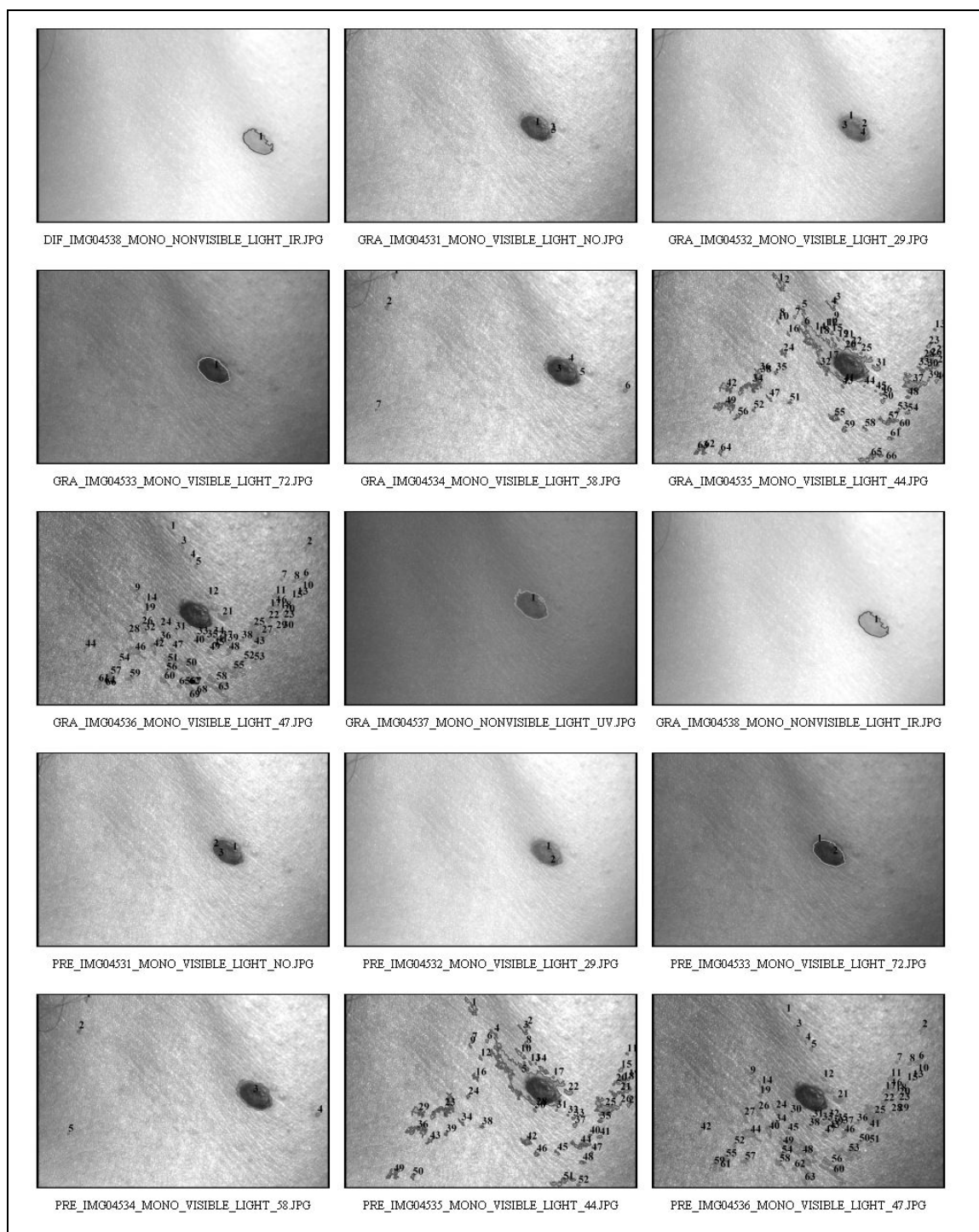


Figure 109. Lesion 453X Processed Sheet 2

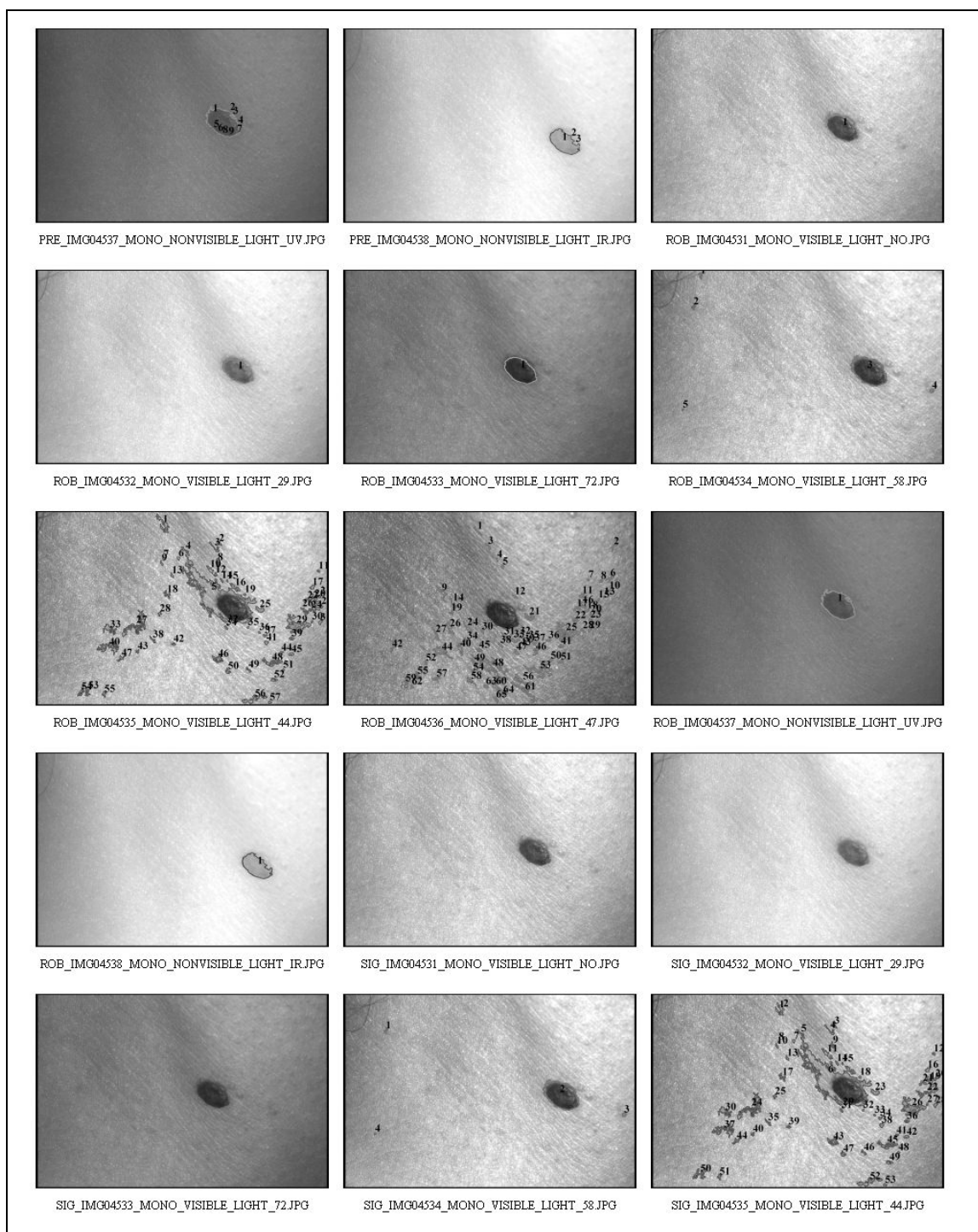


Figure 110. Lesion 453X Processed Sheet 3

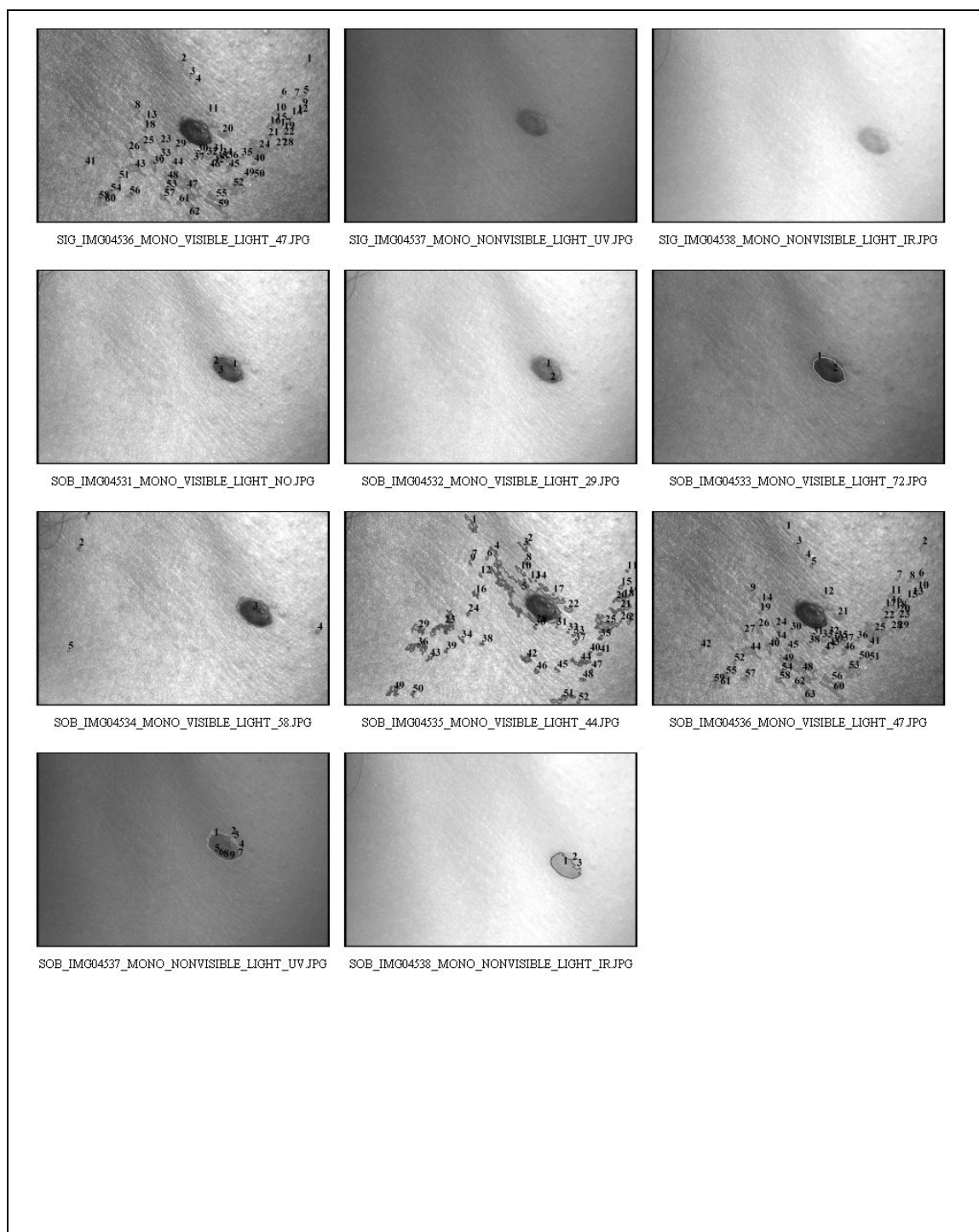


Figure 111. Lesion 453X Processed Sheet 4

Lesion 454X

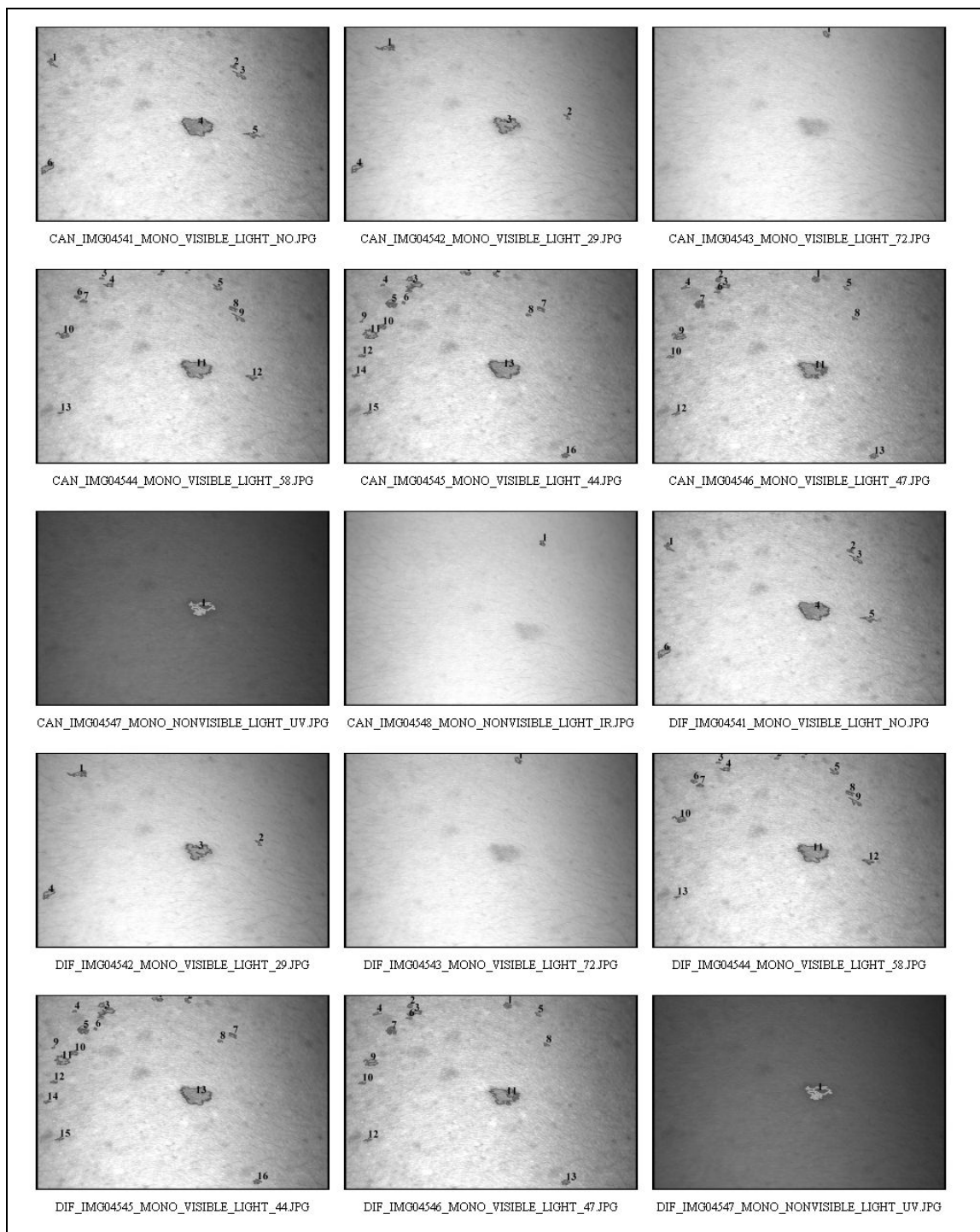


Figure 112. Lesion 454X Processed Sheet 1

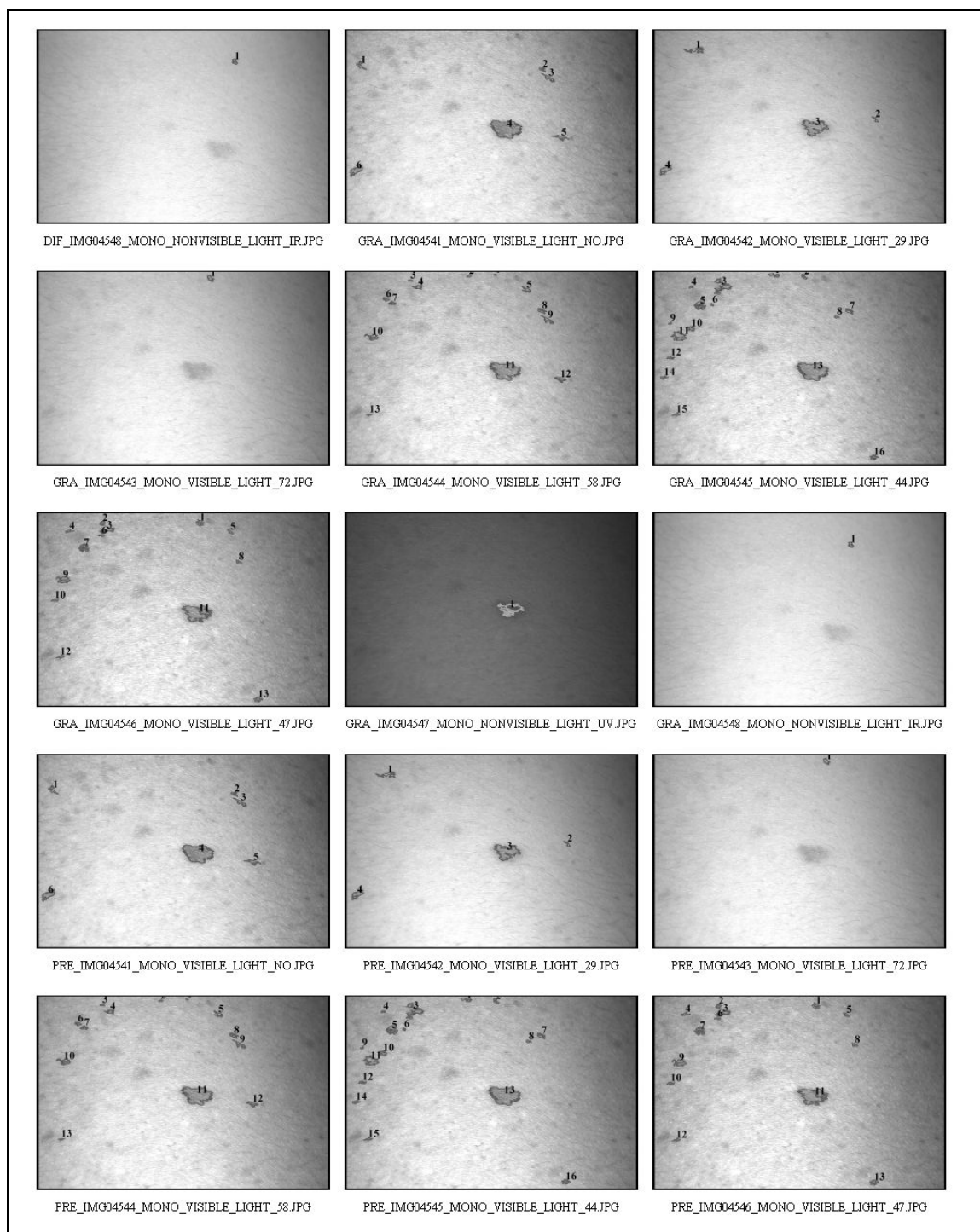


Figure 113. Lesion 454X Processed Sheet 2

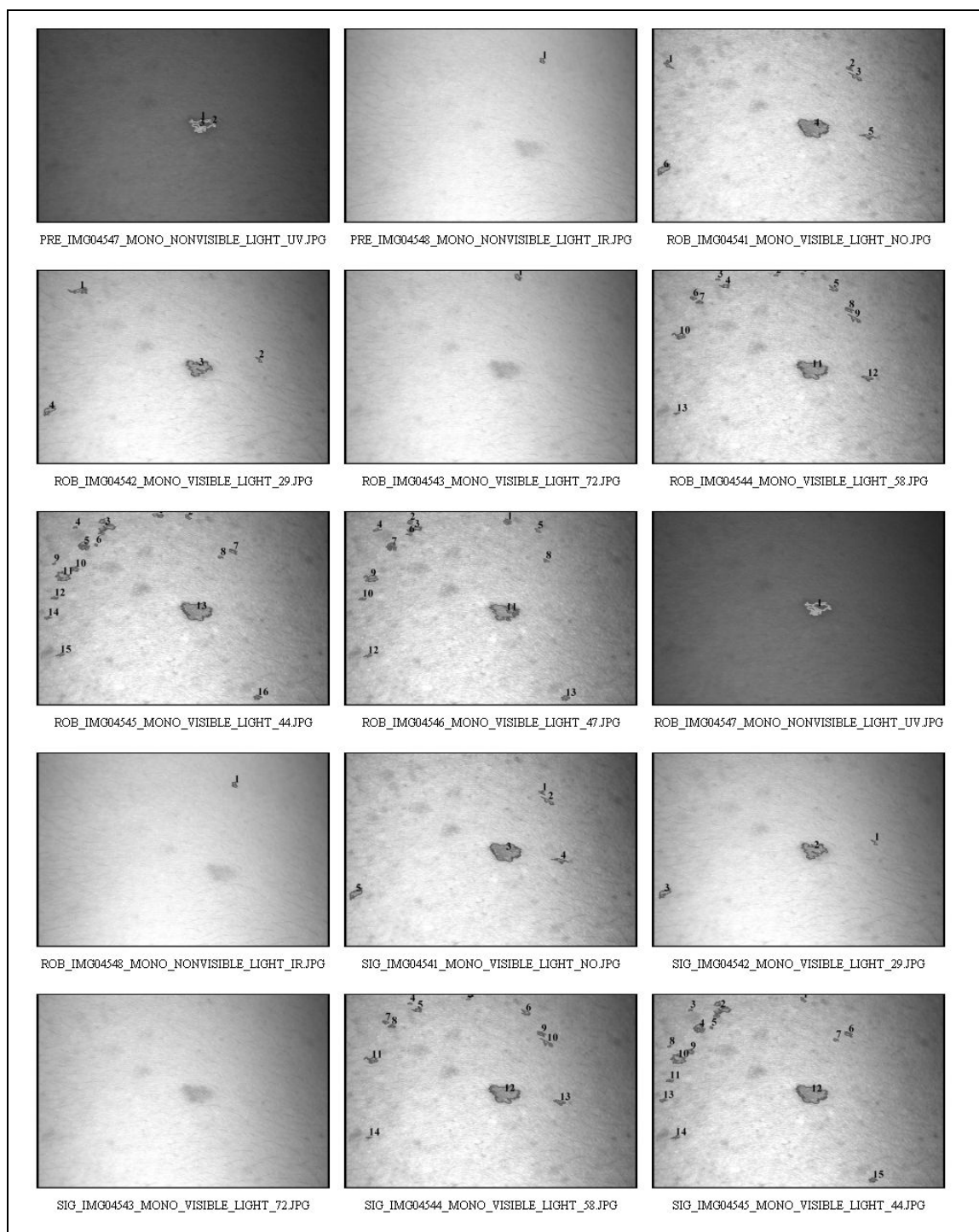


Figure 114. Lesion 454X Processed Sheet 3

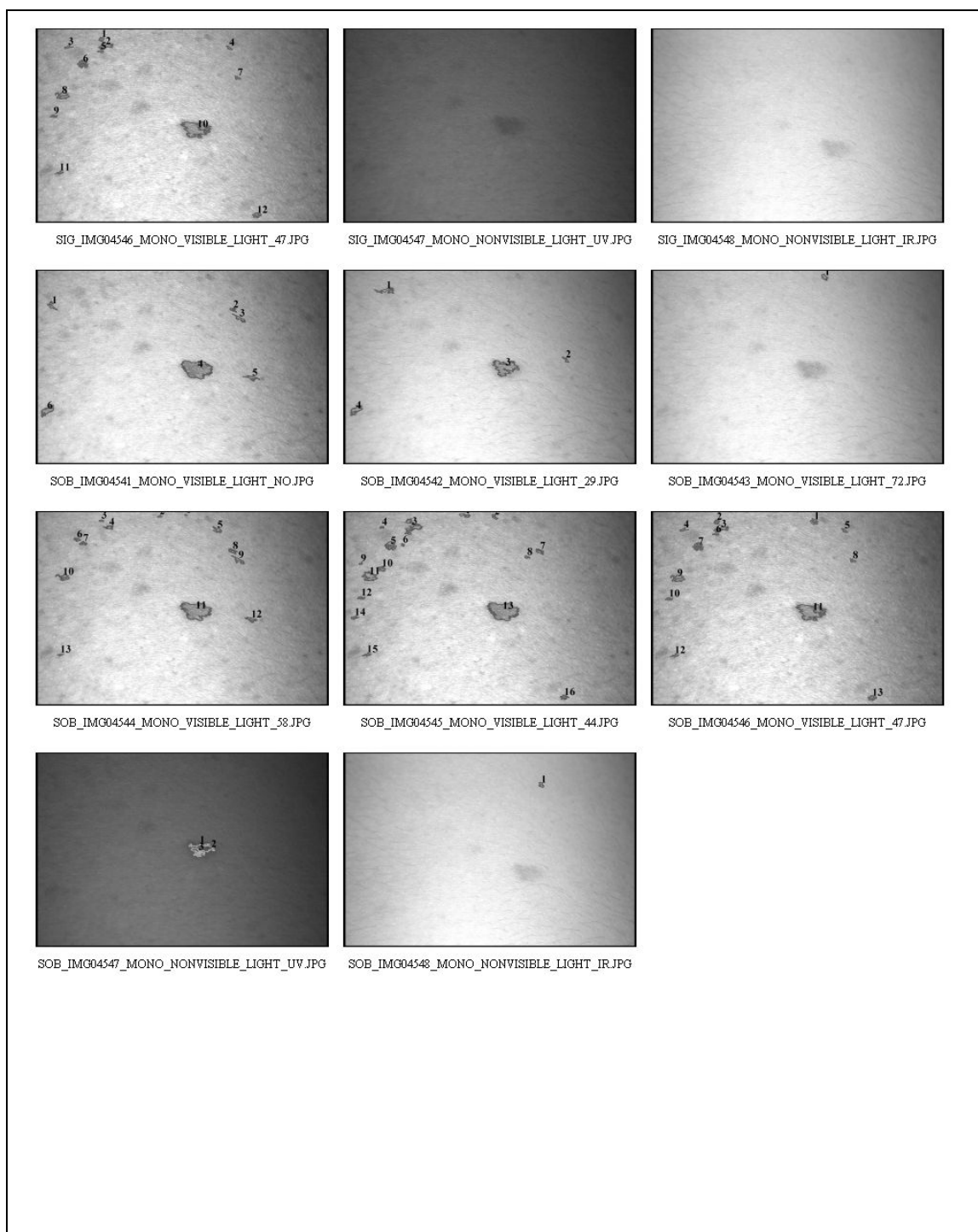


Figure 115. Lesion 454X Processed Sheet 4

Lesion 455X

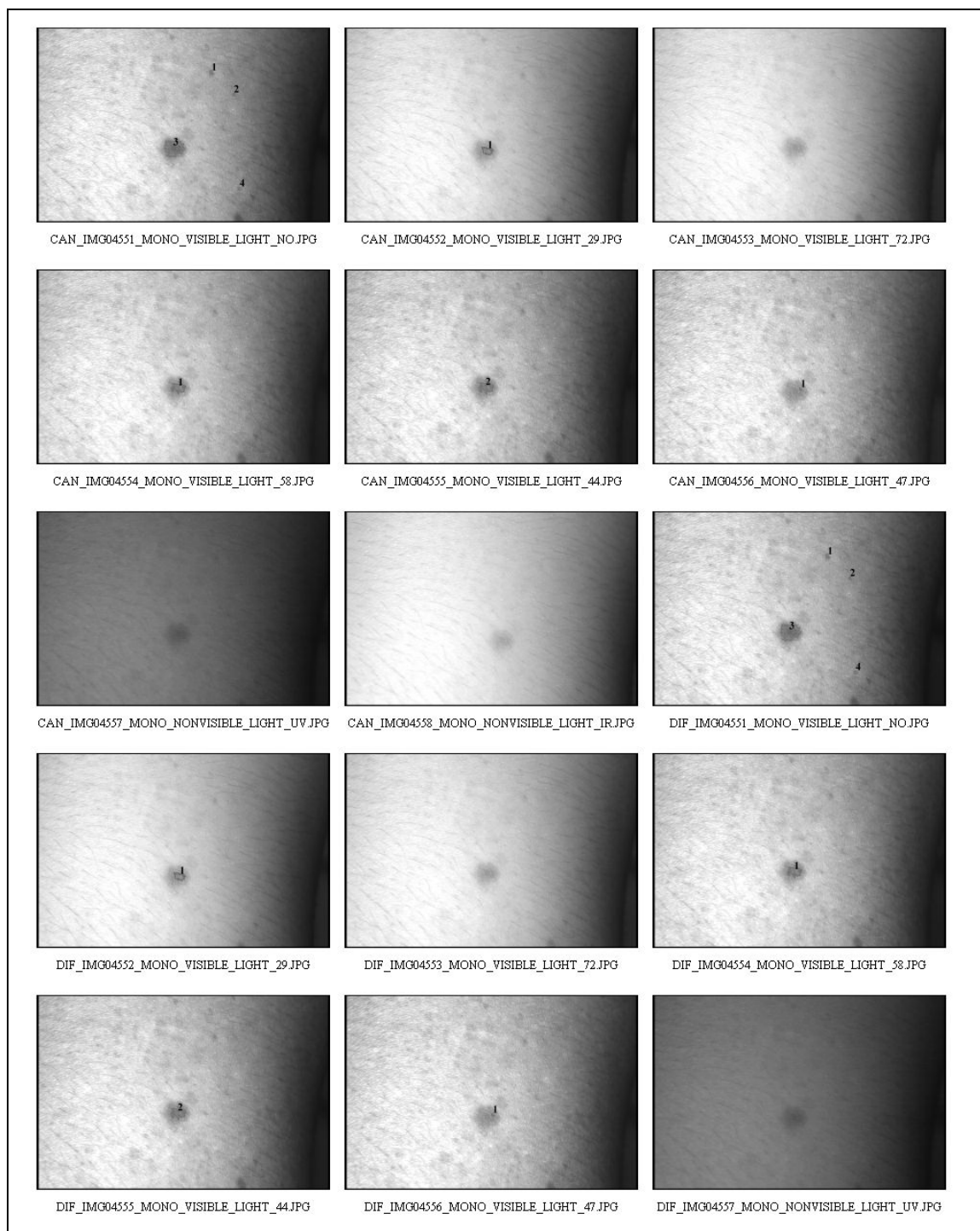


Figure 116. Lesion 455X Processed Sheet 1

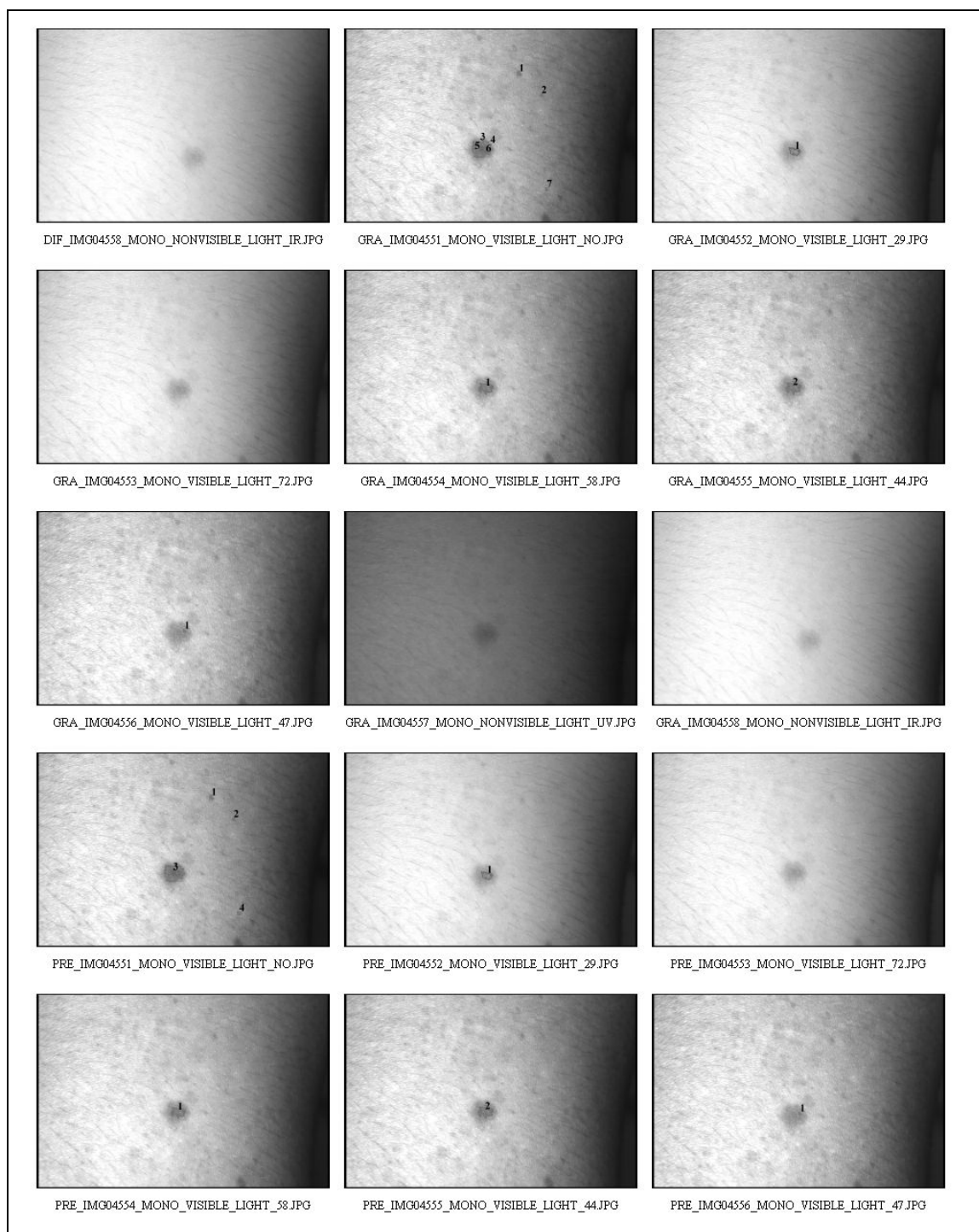


Figure 117. Lesion 455X Processed Sheet 2

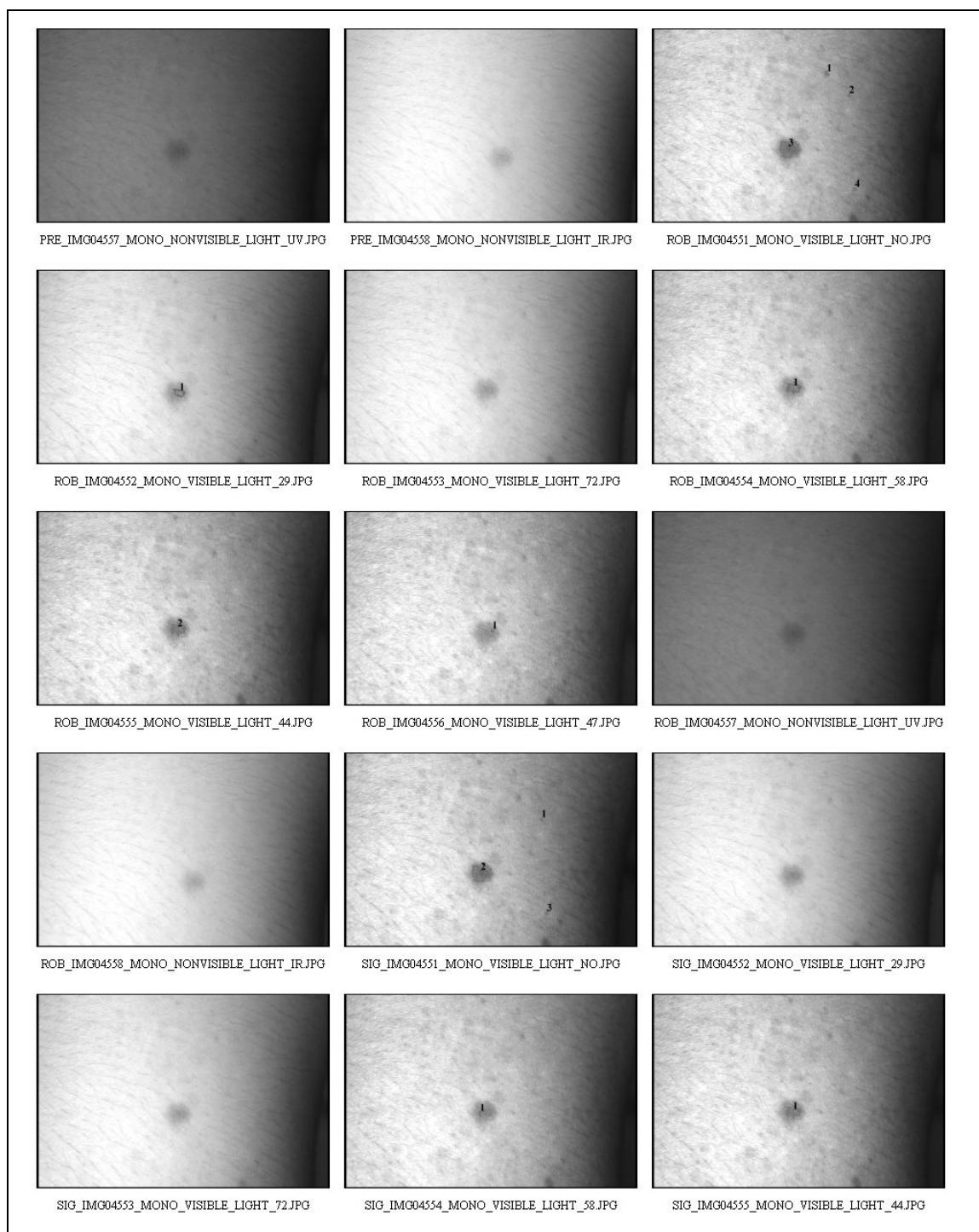


Figure 118. Lesion 455X Processed Sheet 3

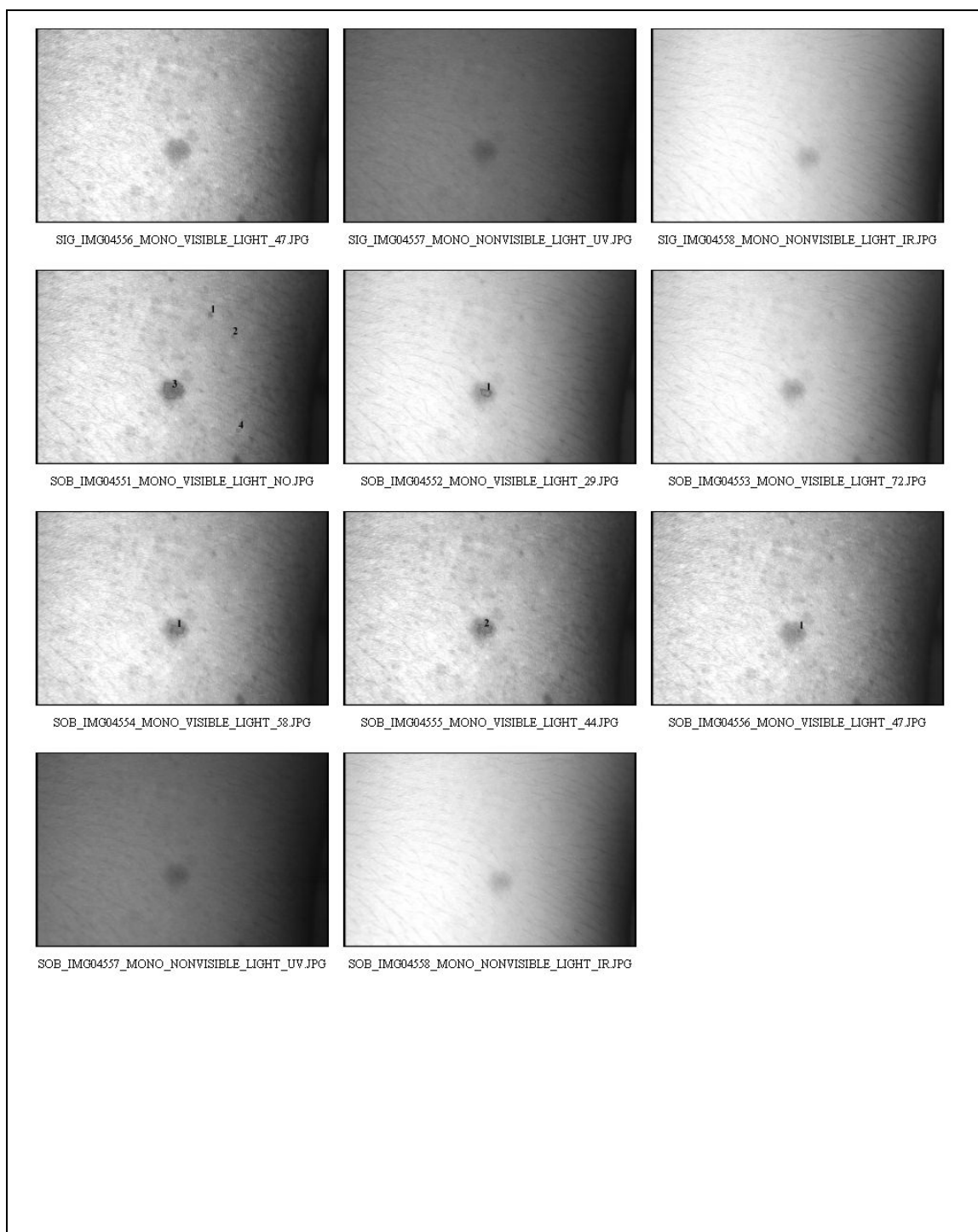


Figure 119. Lesion 455X Processed Sheet 4

Lesion 456X

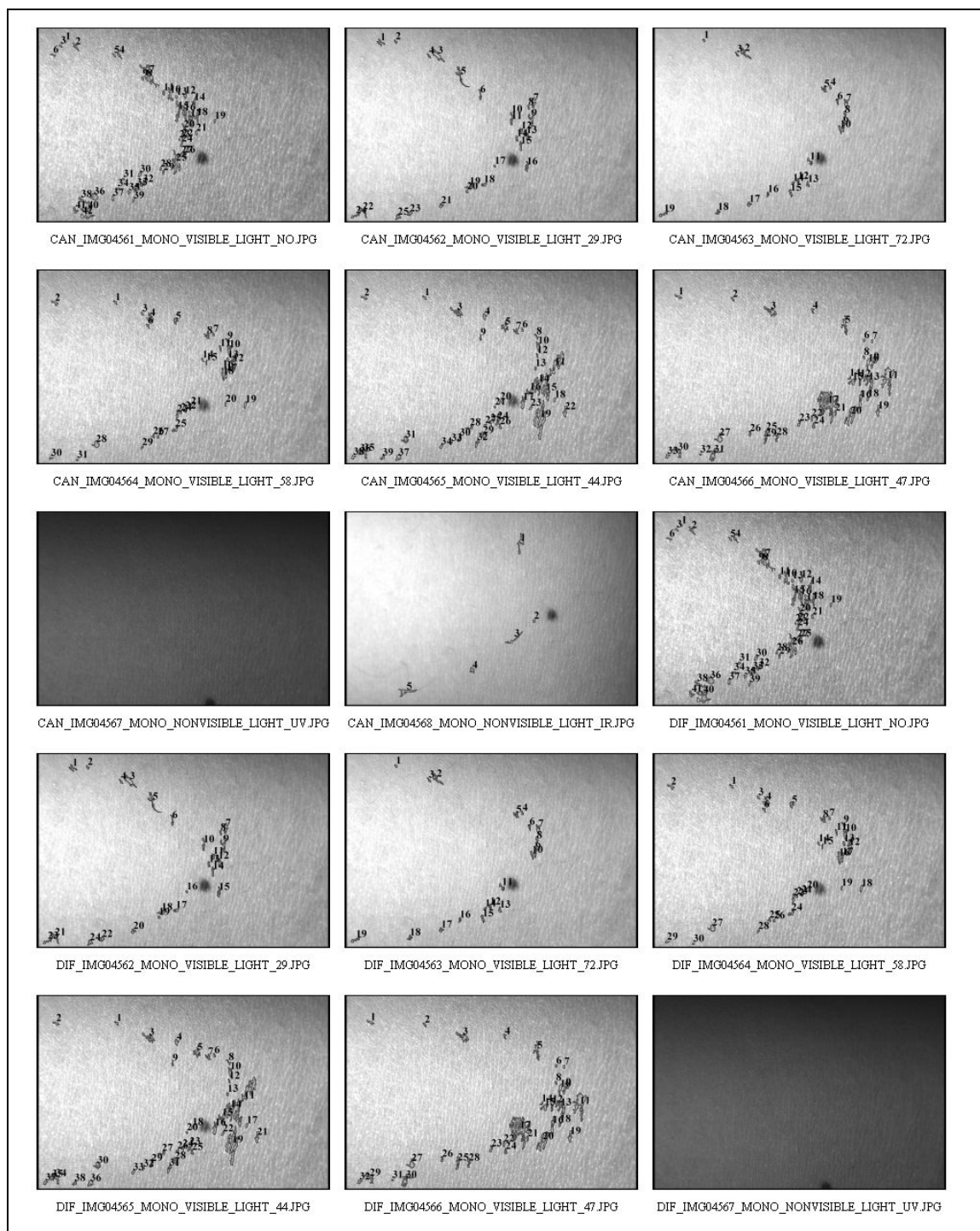


Figure 120. Lesion 456X Processed Sheet 1

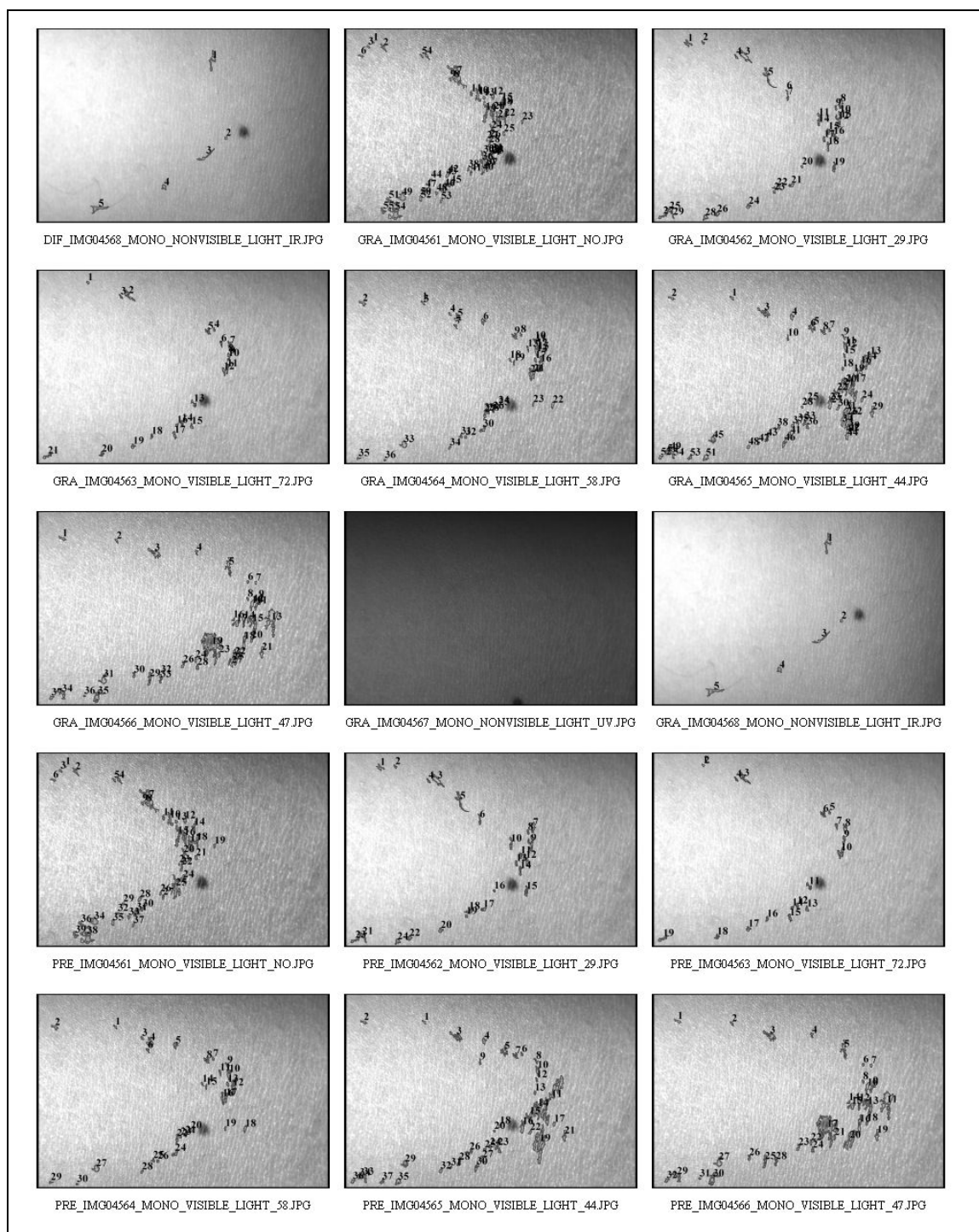


Figure 121. Lesion 456X Processed Sheet 2

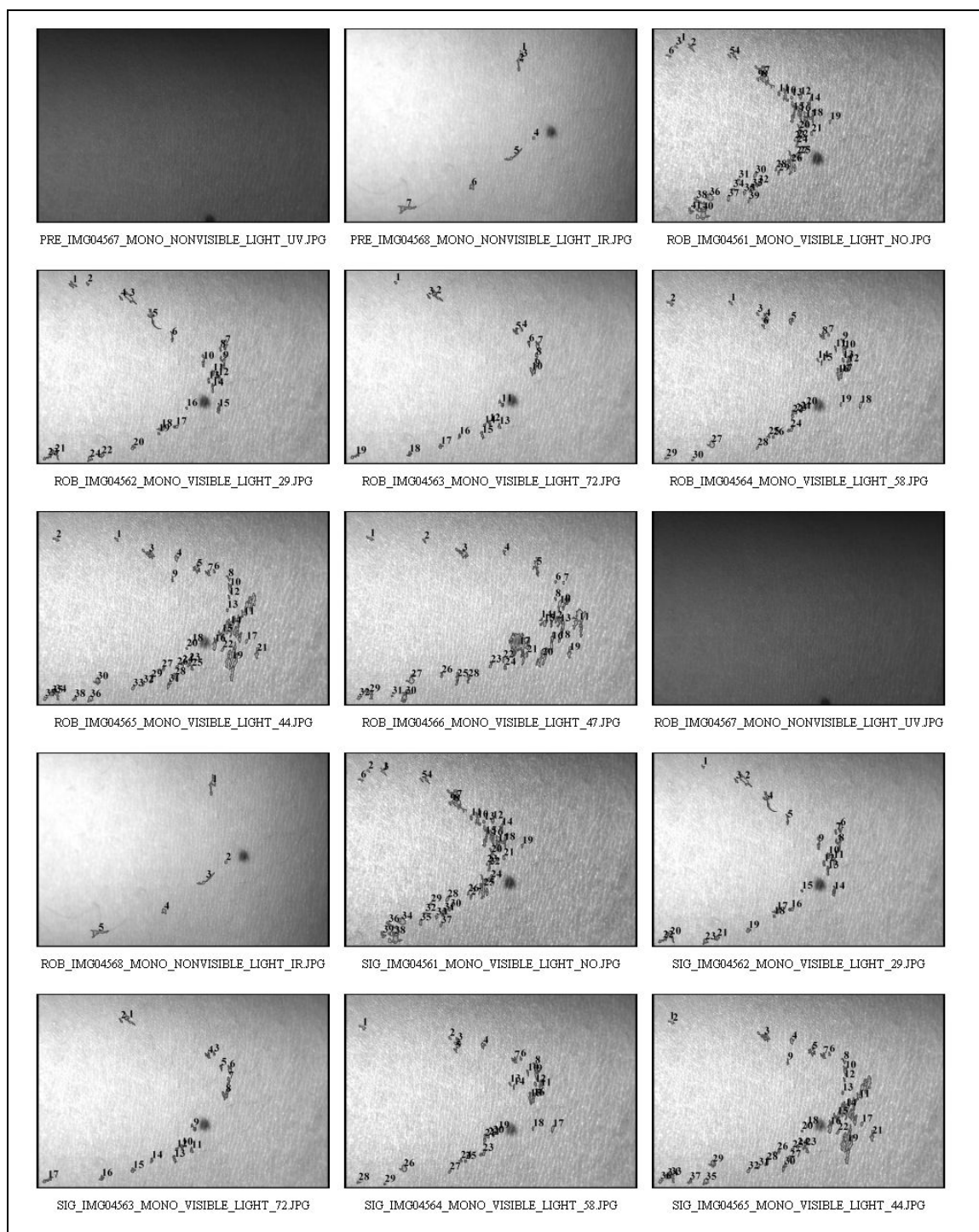


Figure 122. Lesion 456X Processed Sheet 3

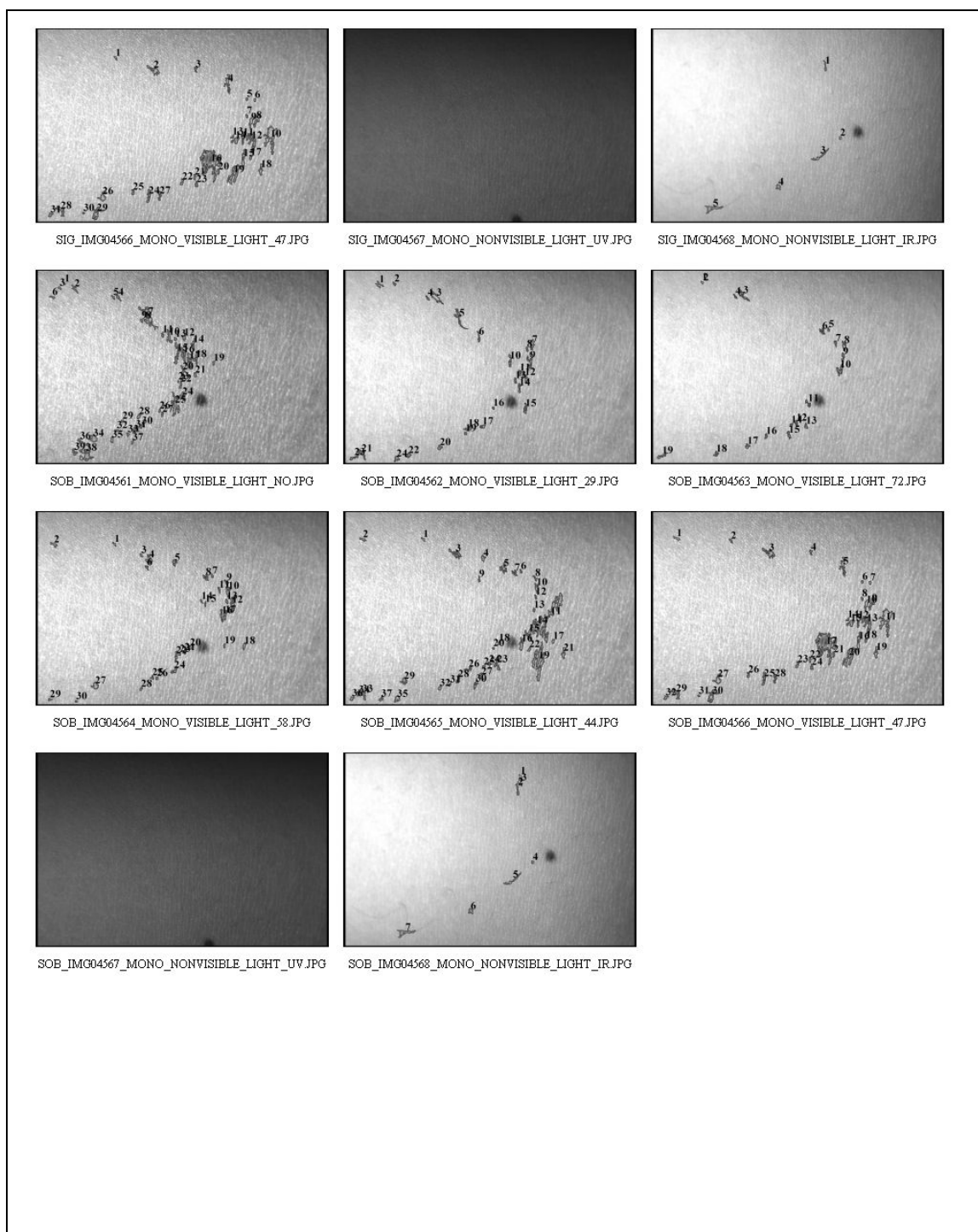


Figure 123. Lesion 456X Processed Sheet 4

Lesion 457X

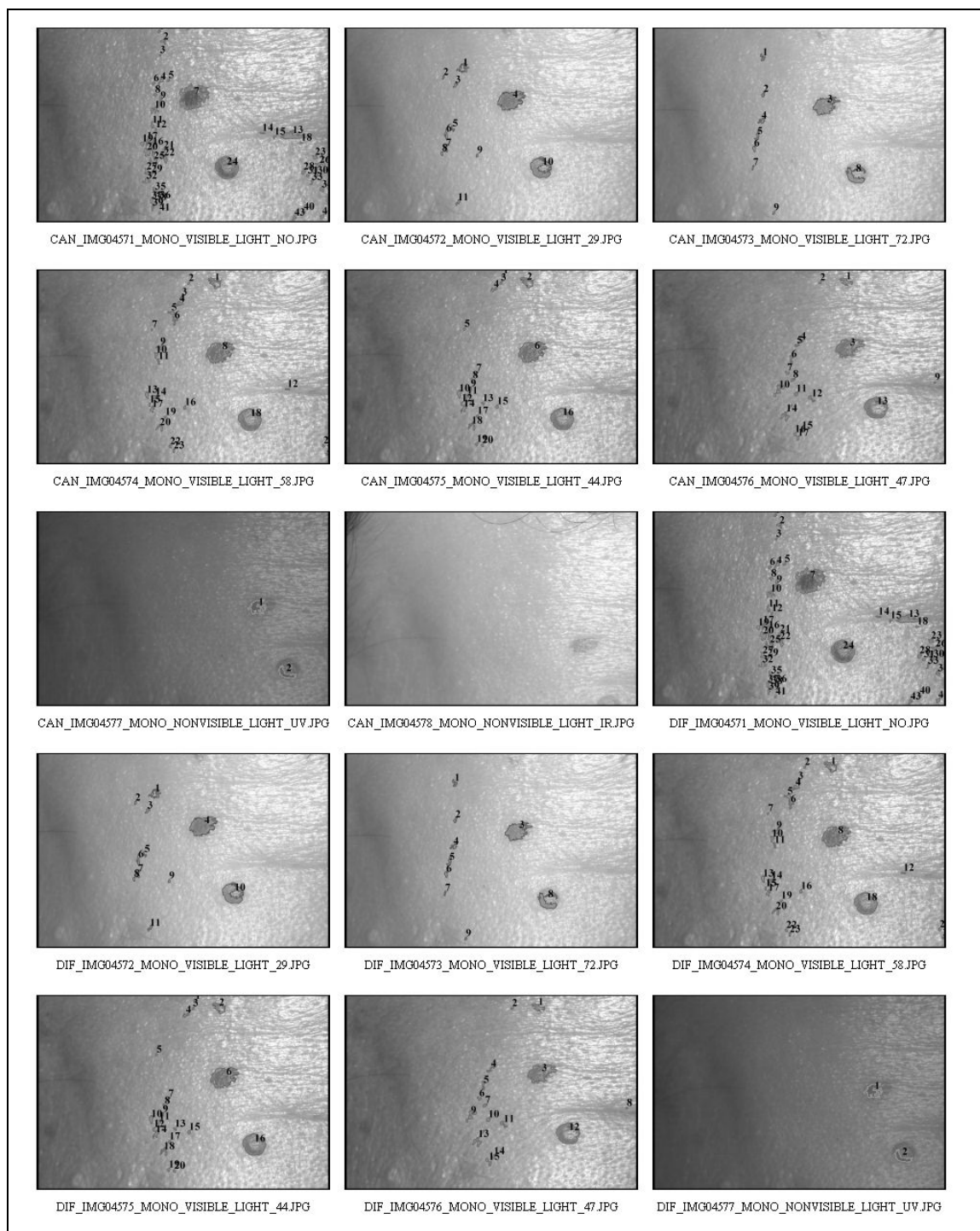


Figure 124. Lesion 457X Processed Sheet 1

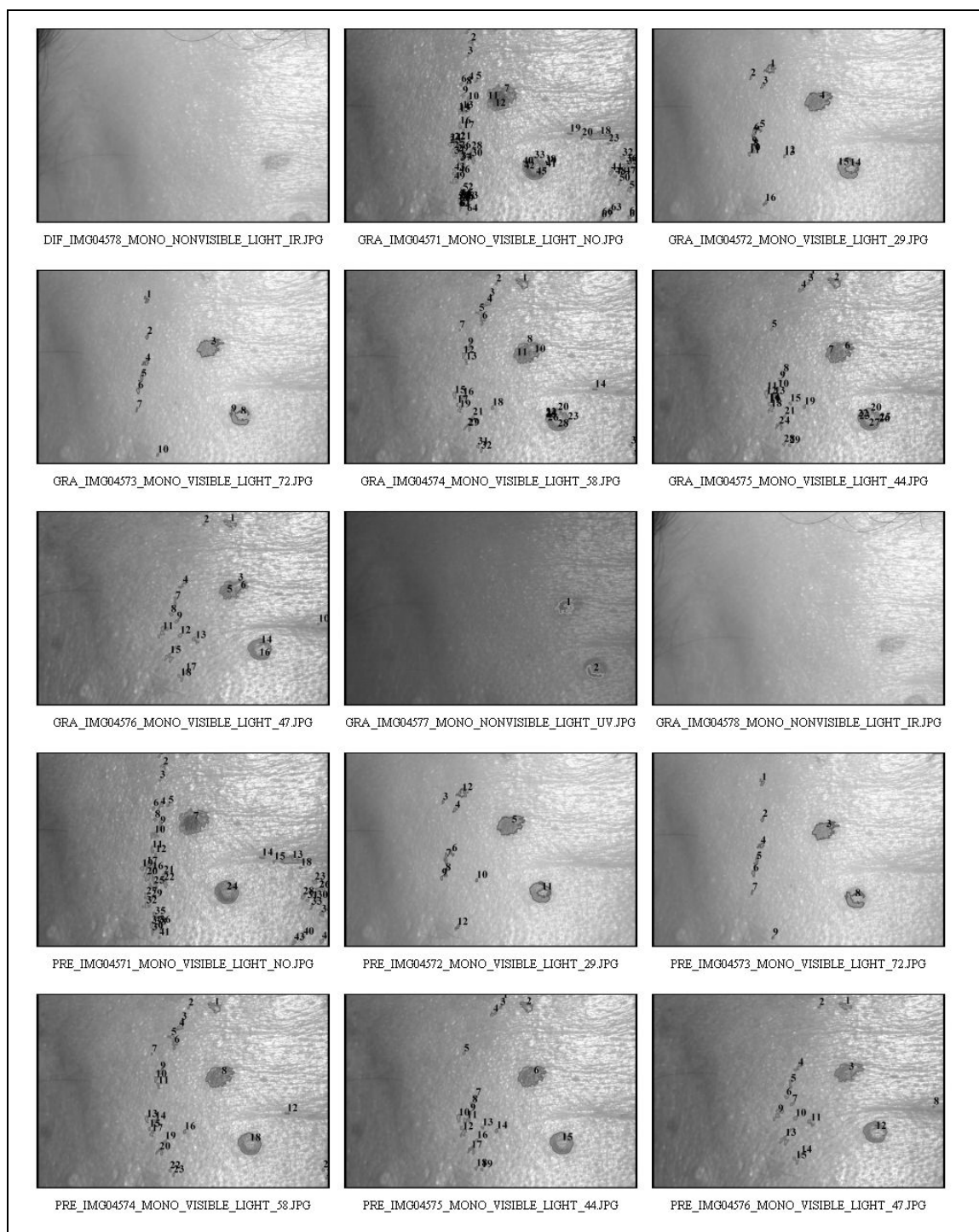


Figure 125. Lesion 457X Processed Sheet 2

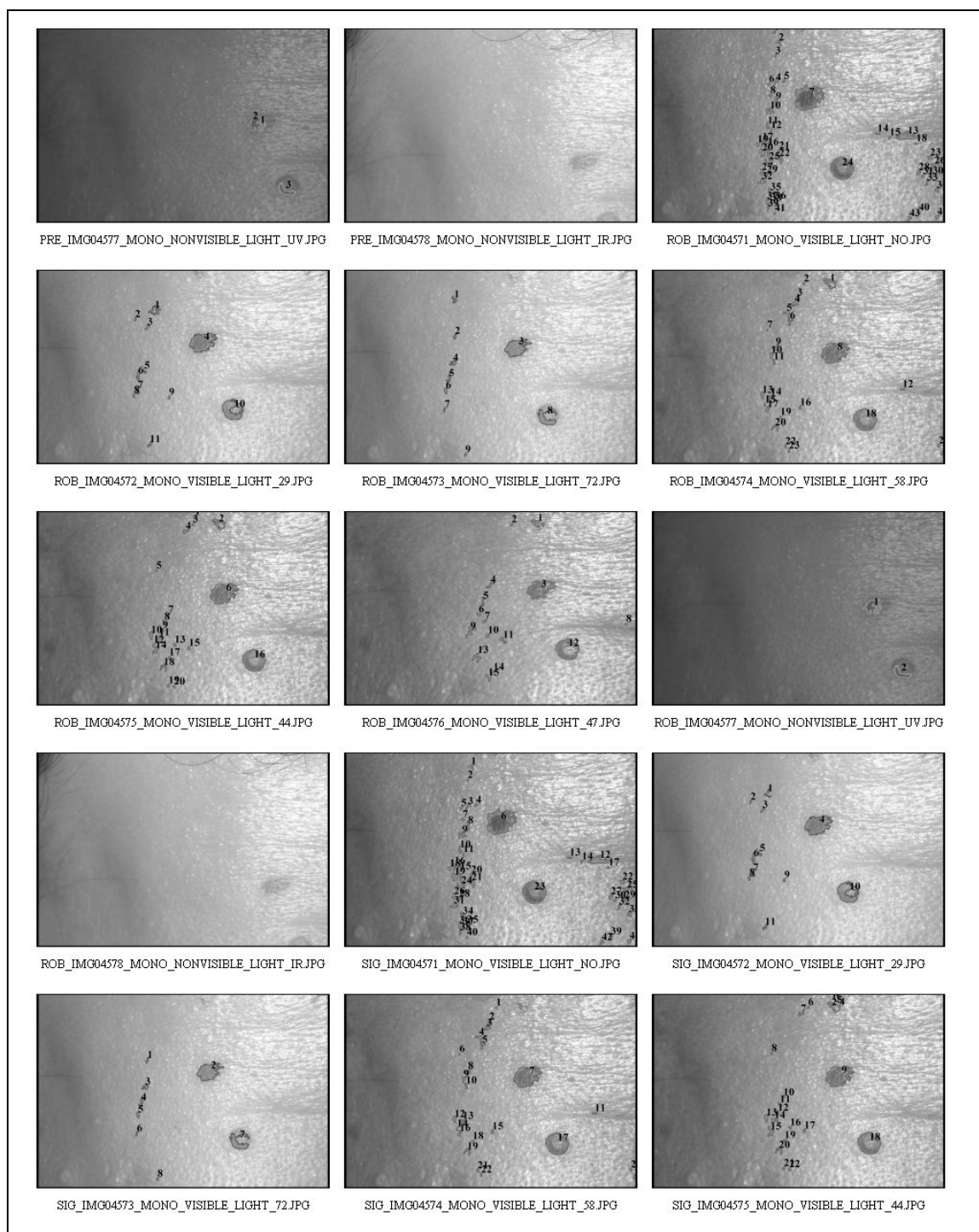


Figure 126. Lesion 457X Processed Sheet 3

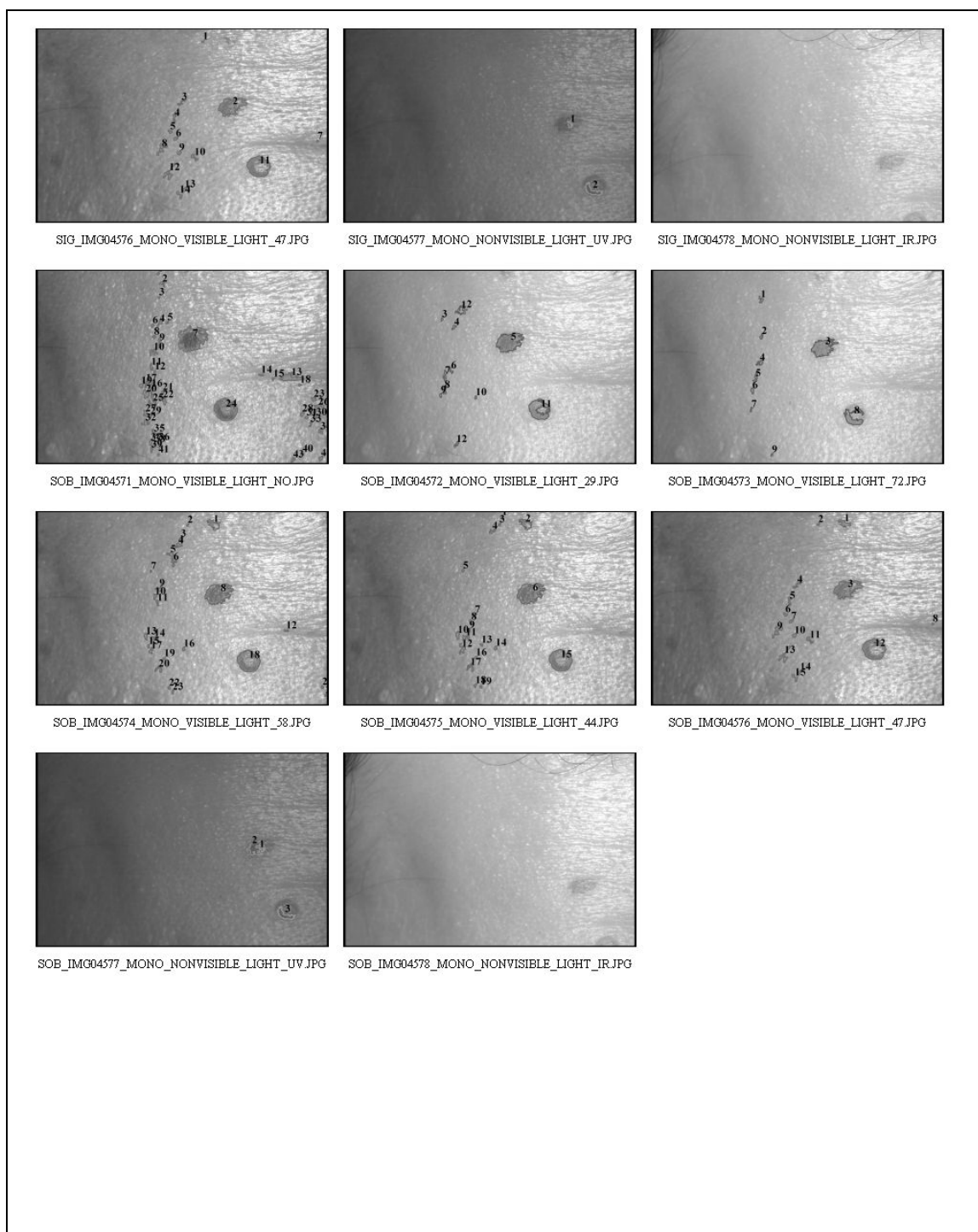
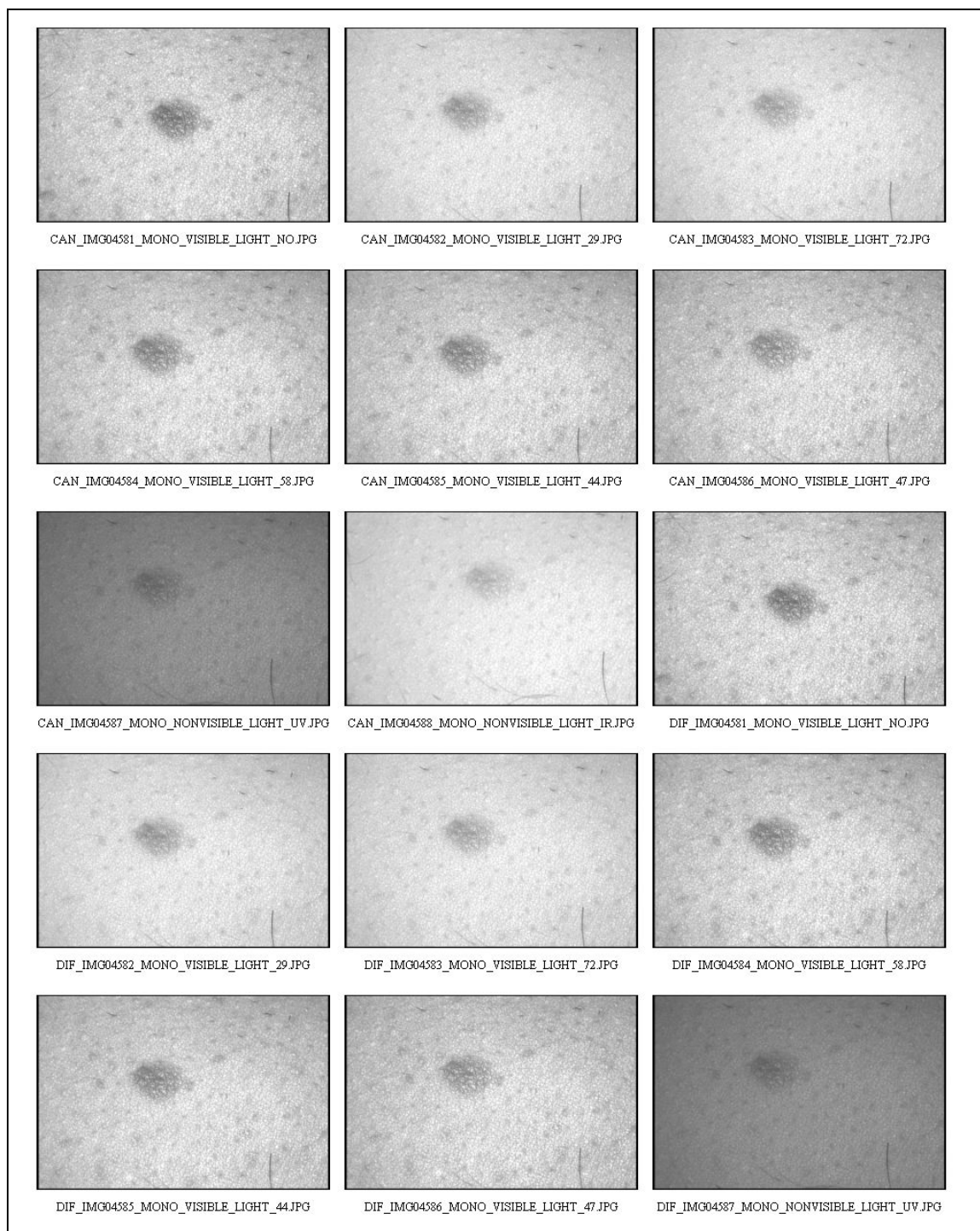


Figure 127. Lesion 457X Processed Sheet 4

Lesion 458X**Figure 128. Lesion 458X Processed Sheet 1**

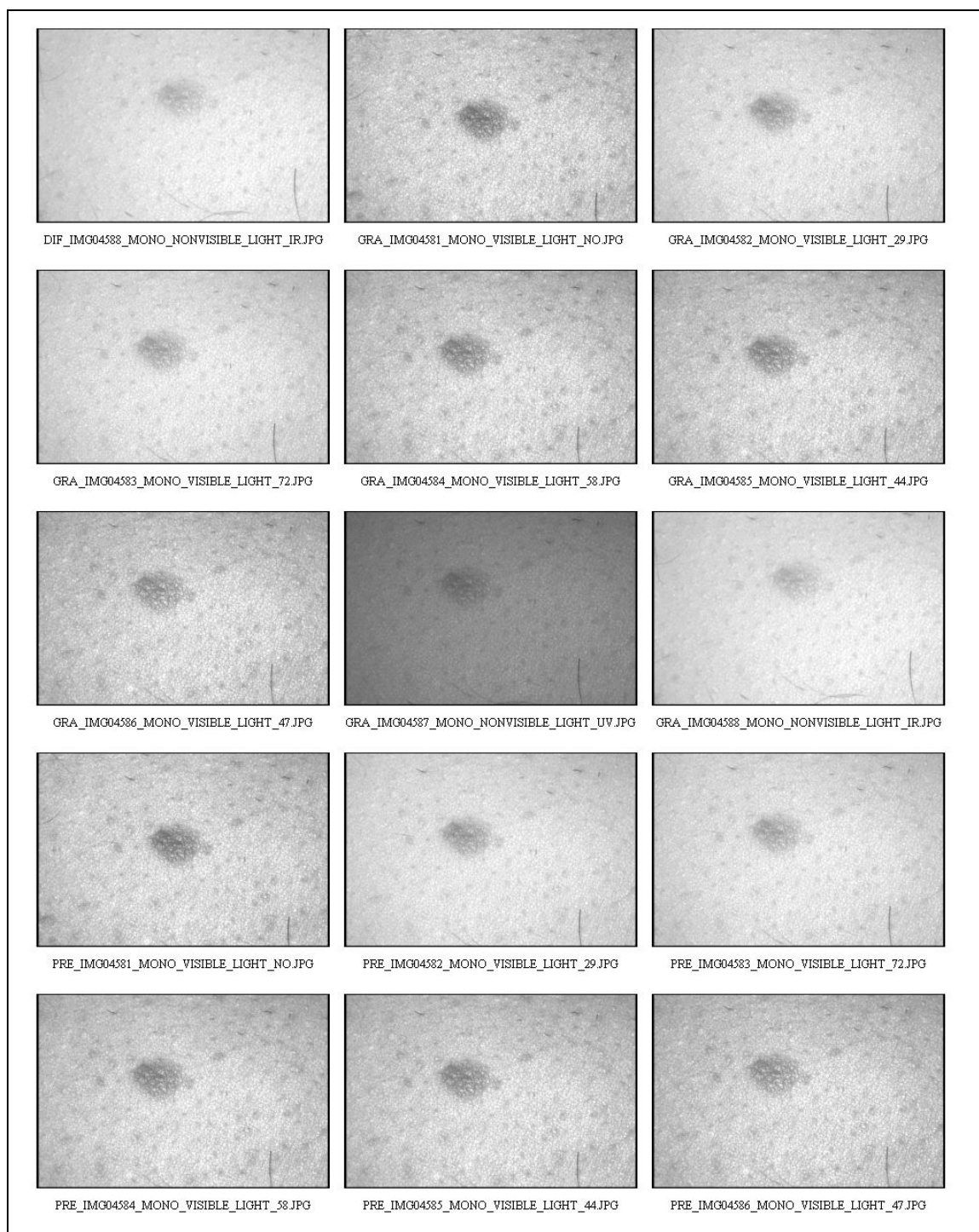


Figure 129. Lesion 458X Processed Sheet 2

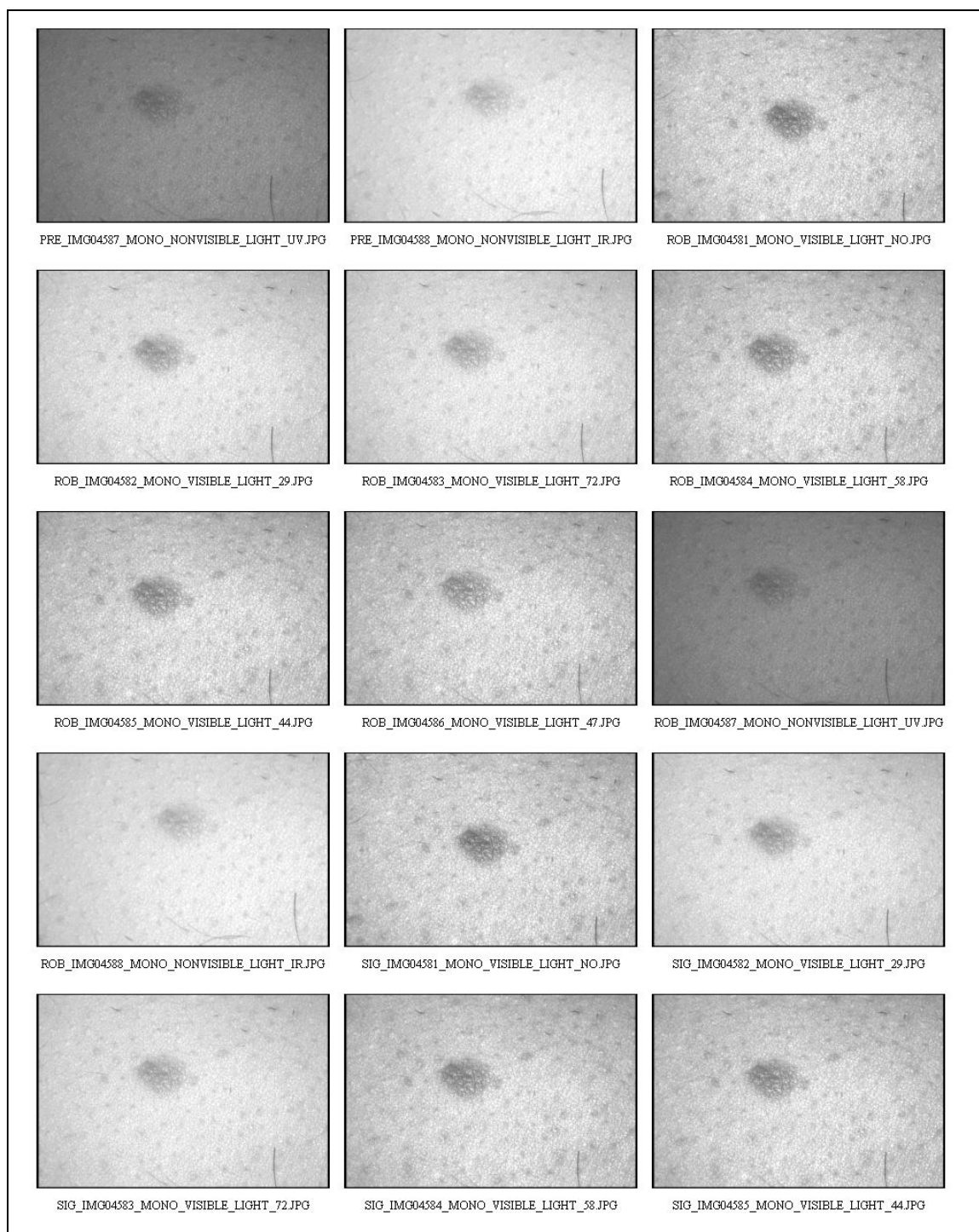


Figure 130. Lesion 458X Processed Sheet 3

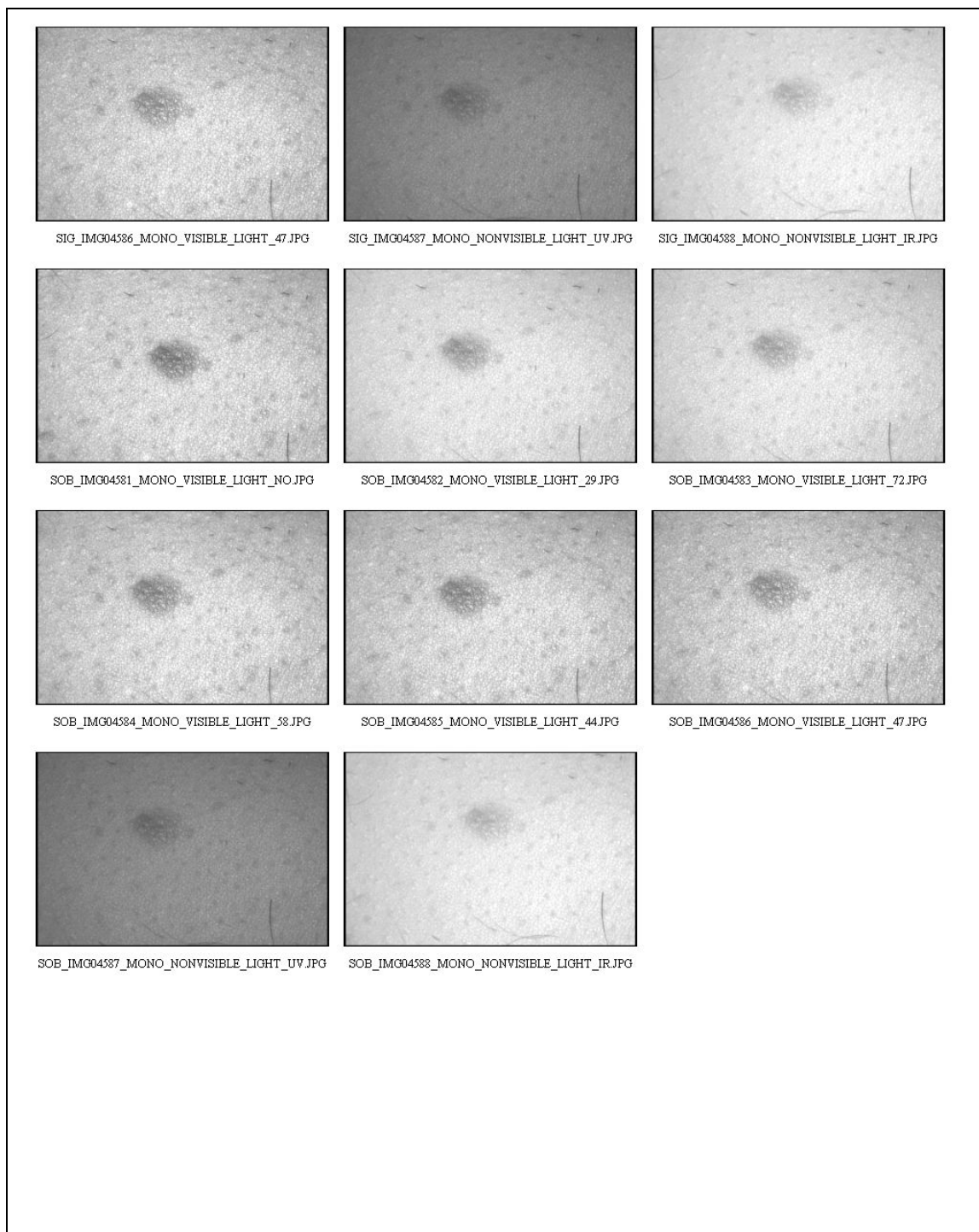


Figure 131. Lesion 458X Processed Sheet 4

Lesion 459X

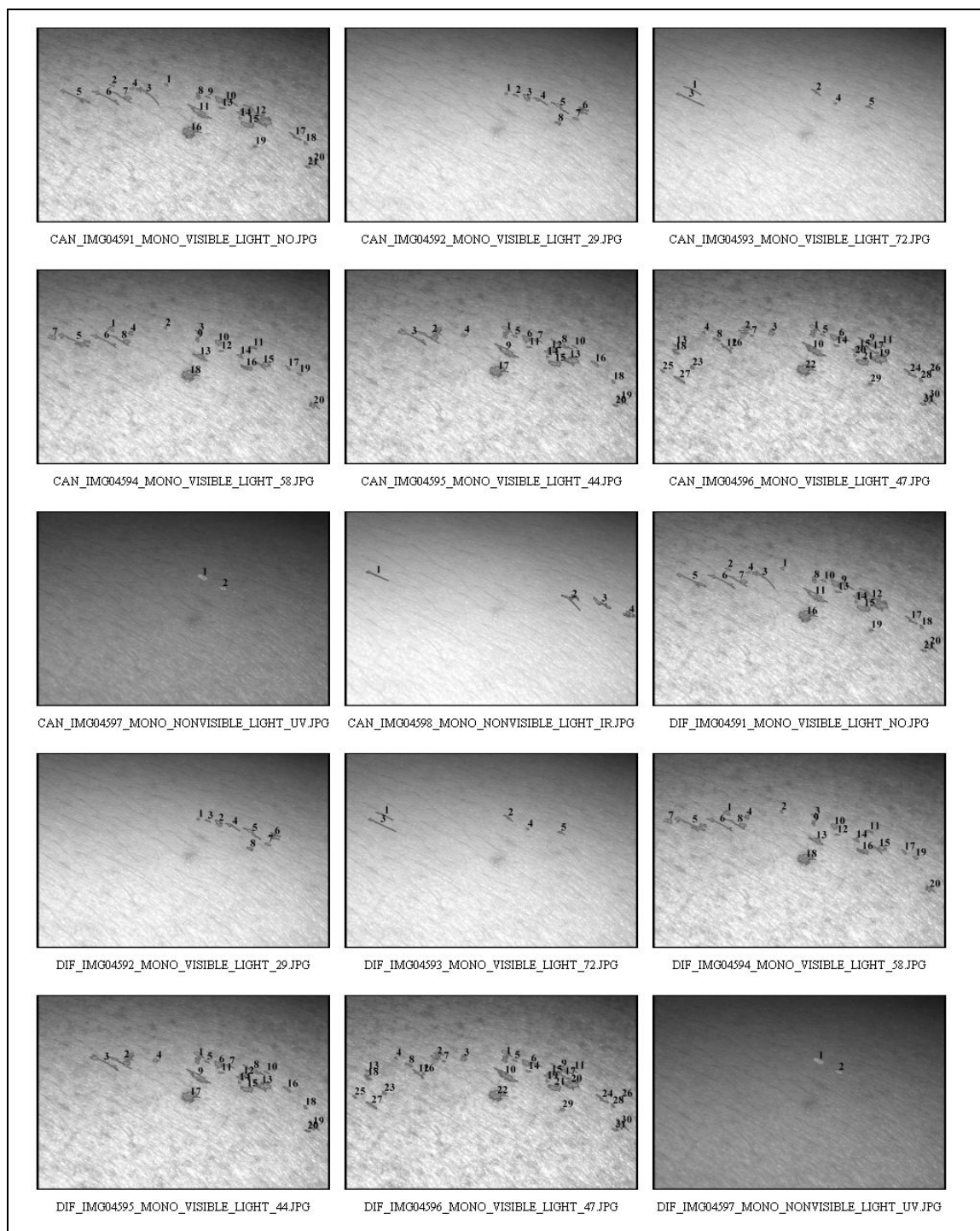


Figure 132. Lesion 459X Processed Sheet 1

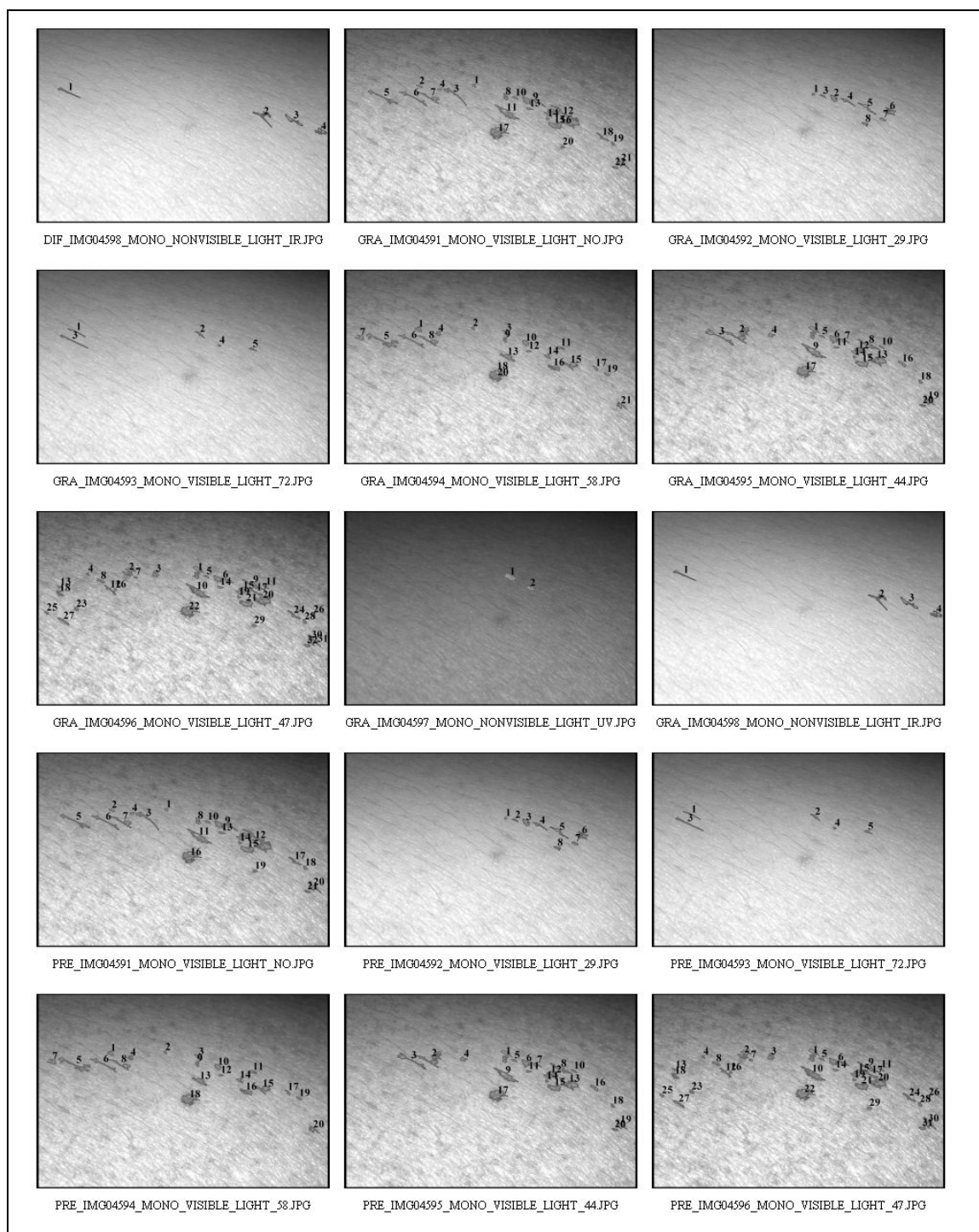


Figure 133. Lesion 459X Processed Sheet 2

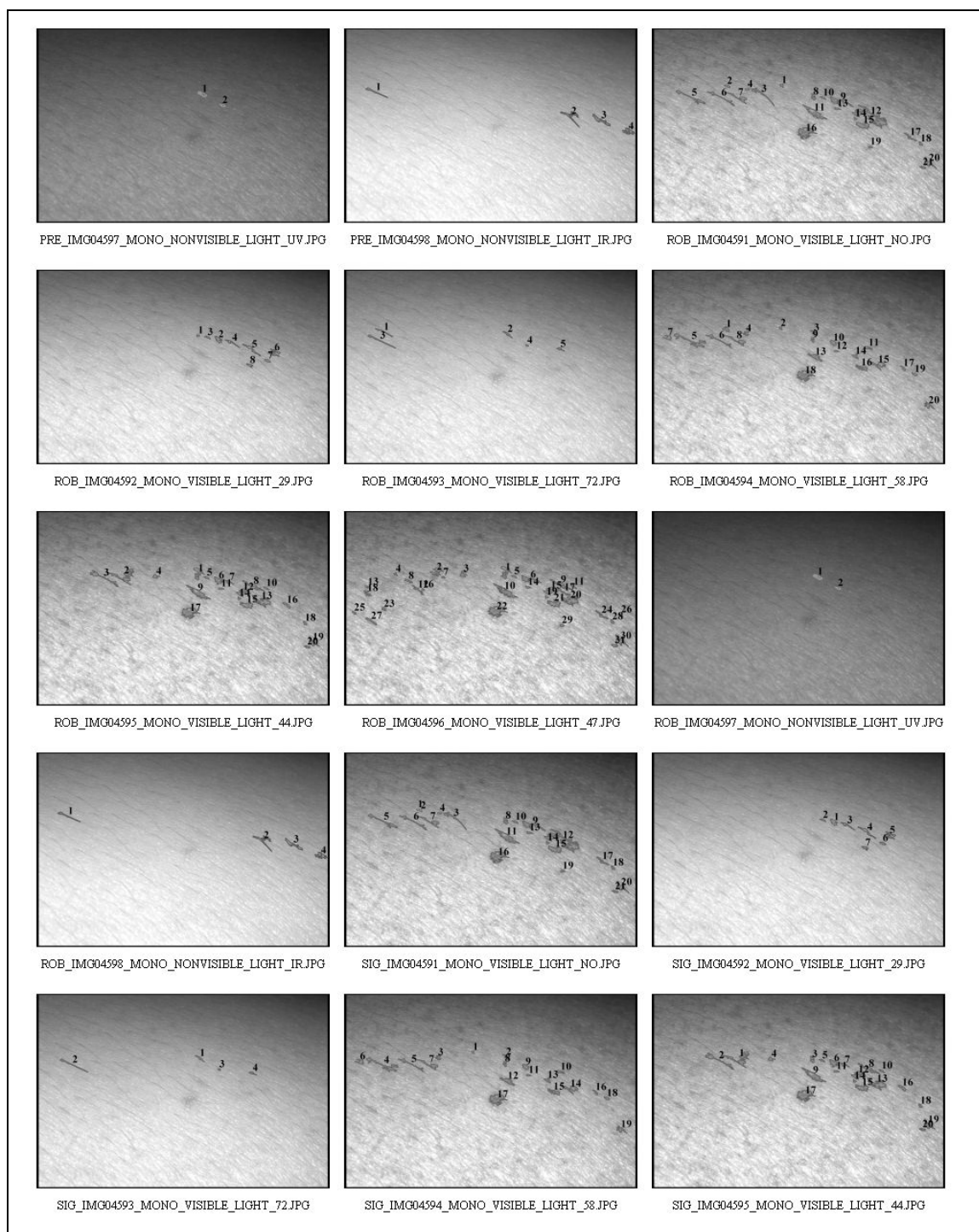


Figure 134. Lesion 459X Processed Sheet 3

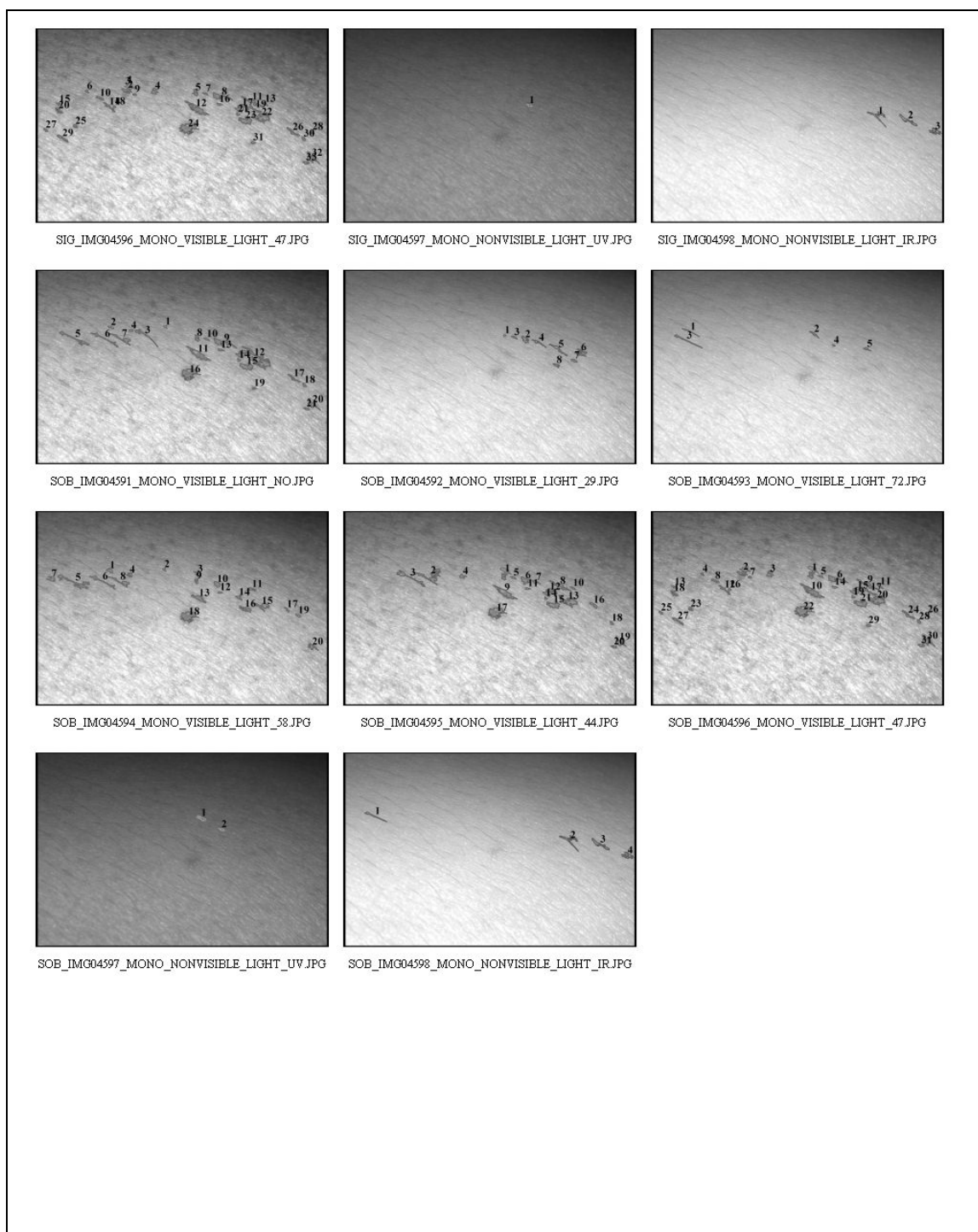


Figure 135. Lesion 459X Processed Sheet 4

Lesion 460X

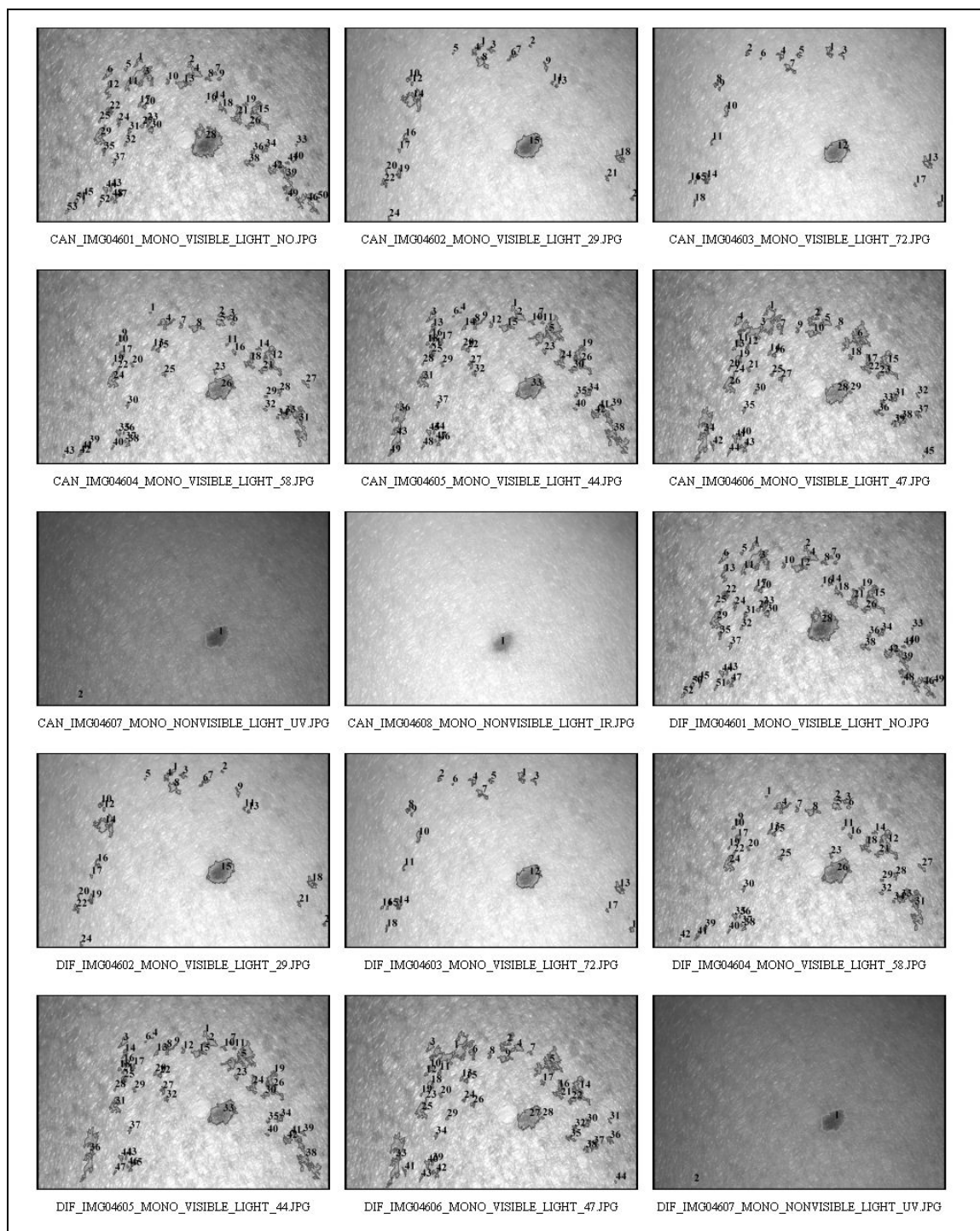


Figure 136. Lesion 460X Processed Sheet 1

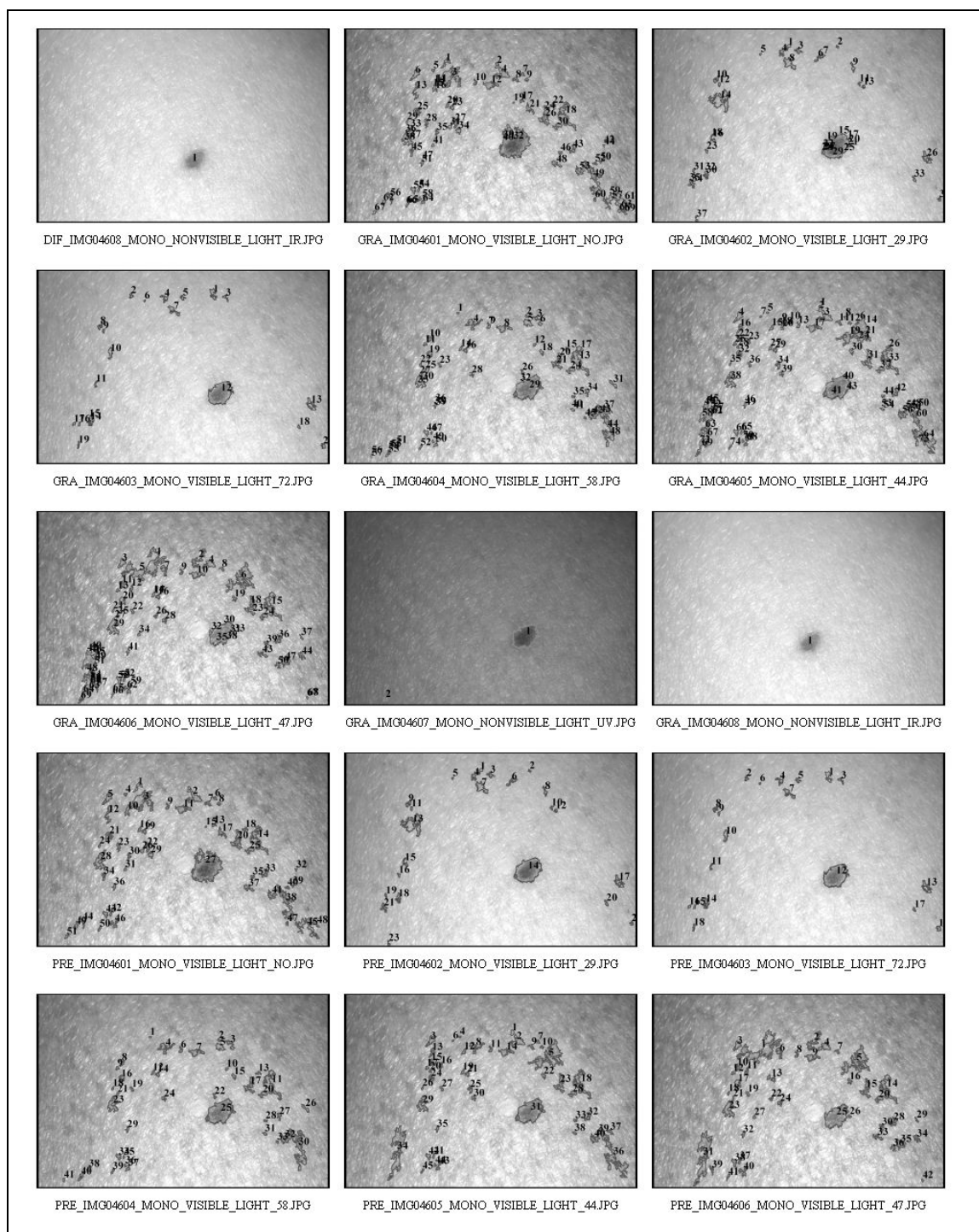


Figure 137. Lesion 460X Processed Sheet 2

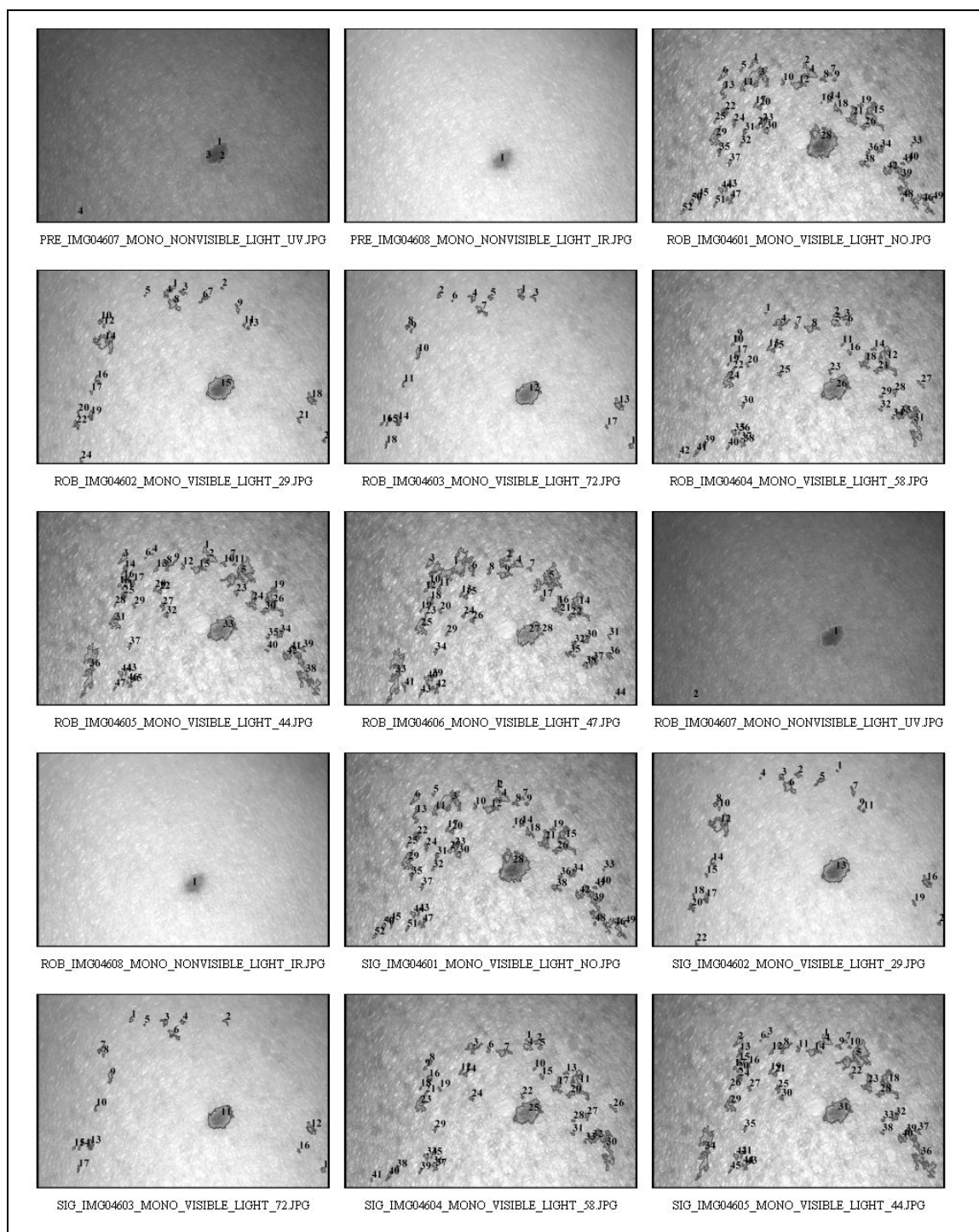


Figure 138. Lesion 460X Processed Sheet 3

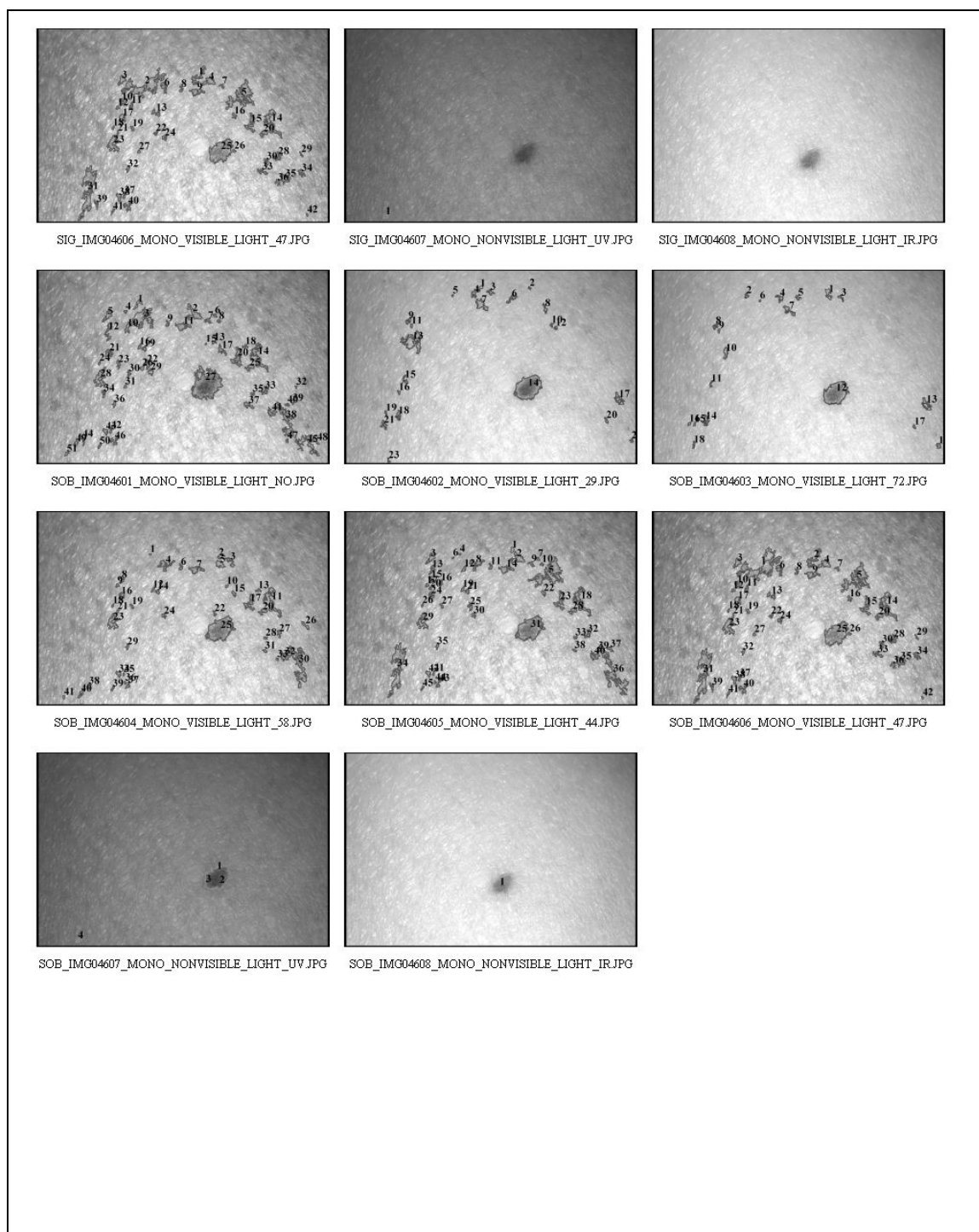


Figure 139. Lesion 460X Processed Sheet 4

Lesion 472X

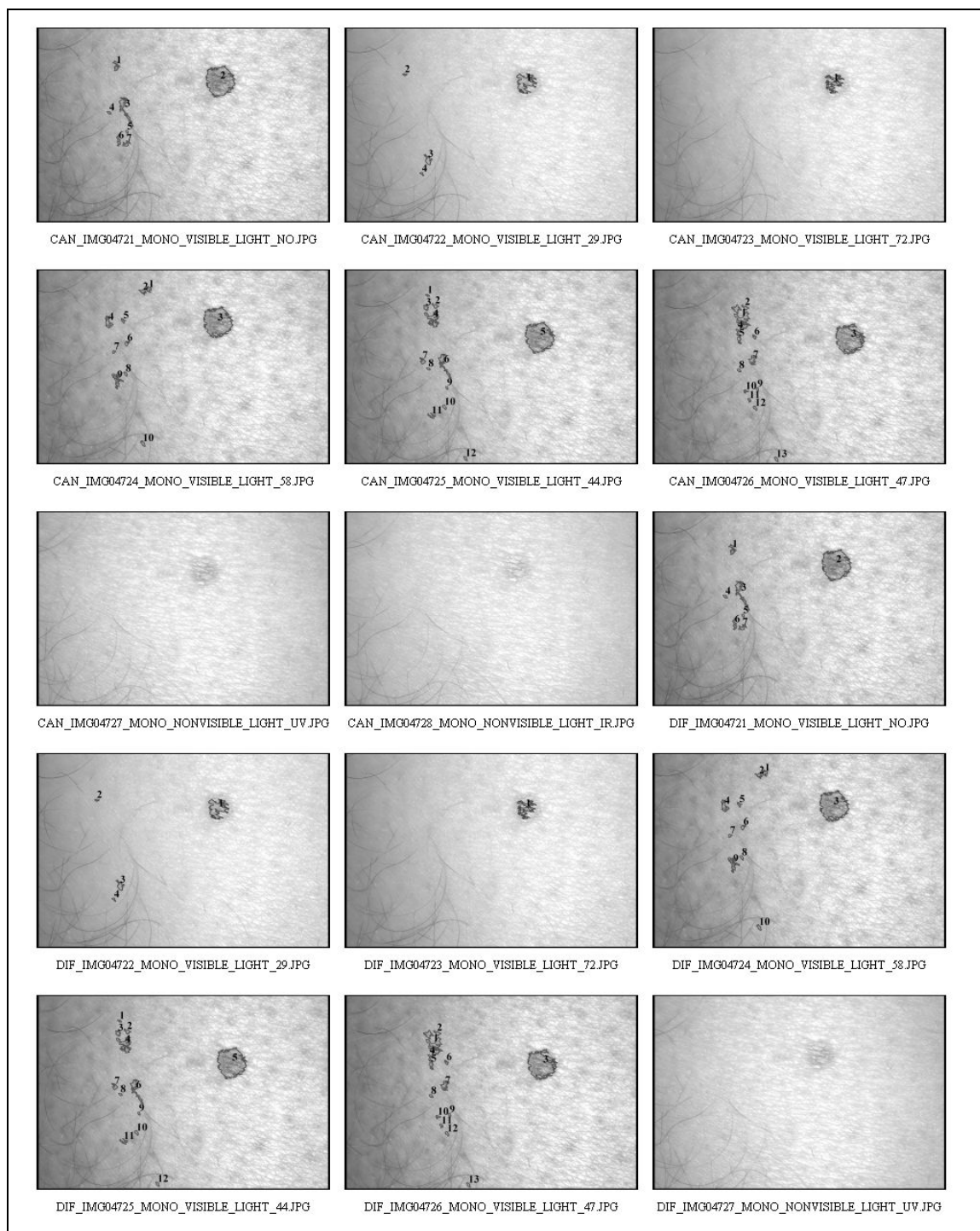


Figure 140. Lesion 472X Processed Sheet 1

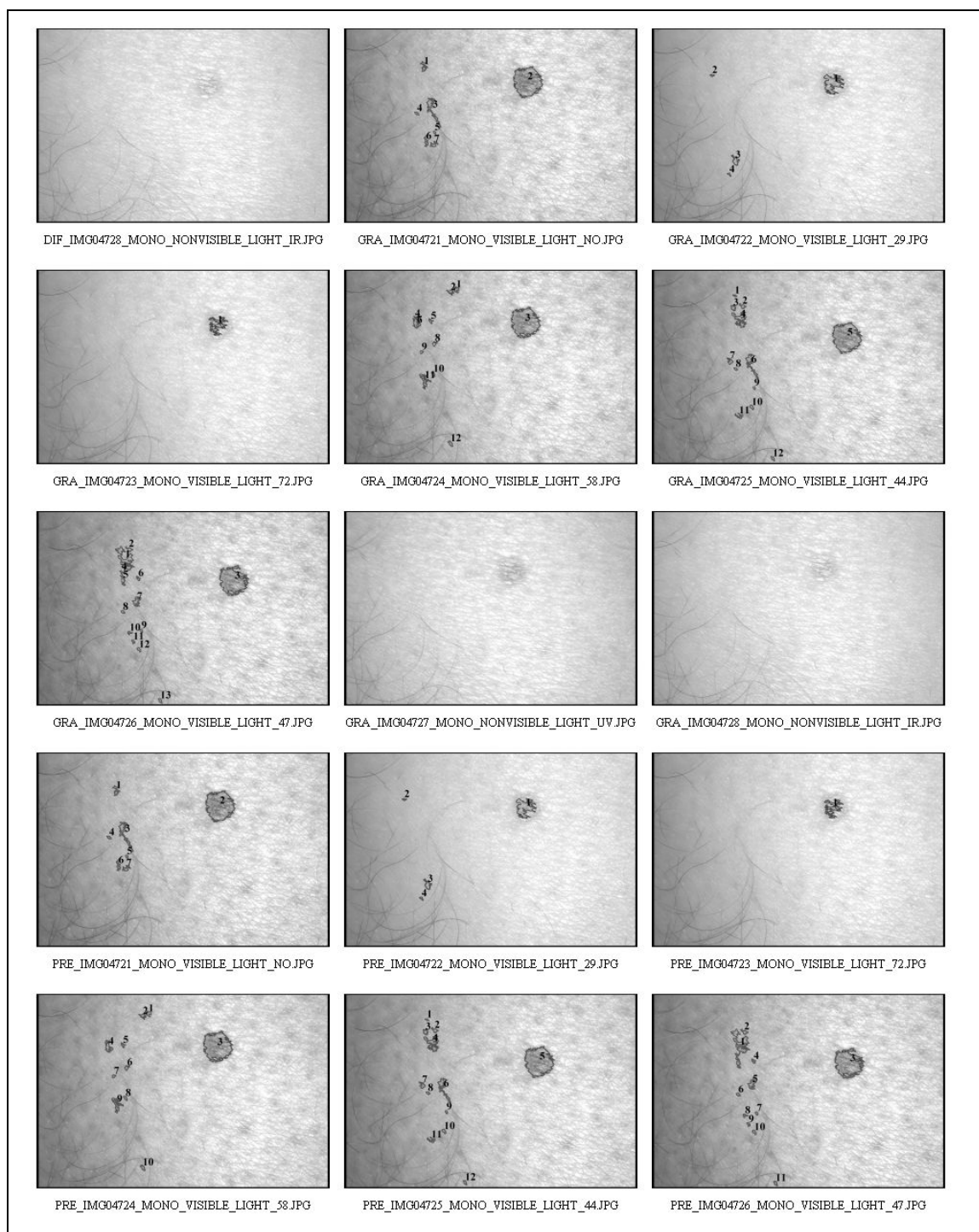


Figure 141. Lesion 472X Processed Sheet 2

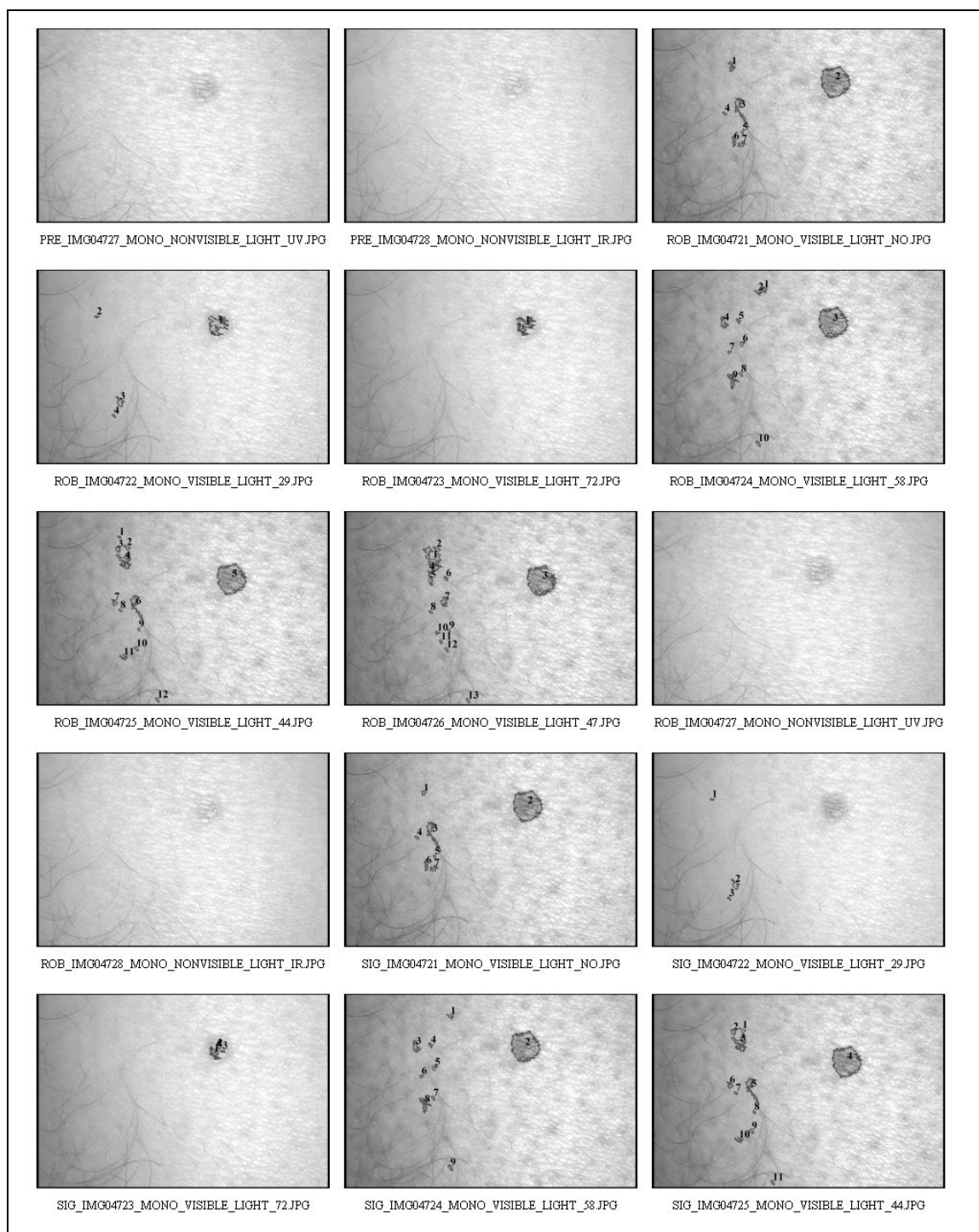


Figure 142. Lesion 472X Processed Sheet 3

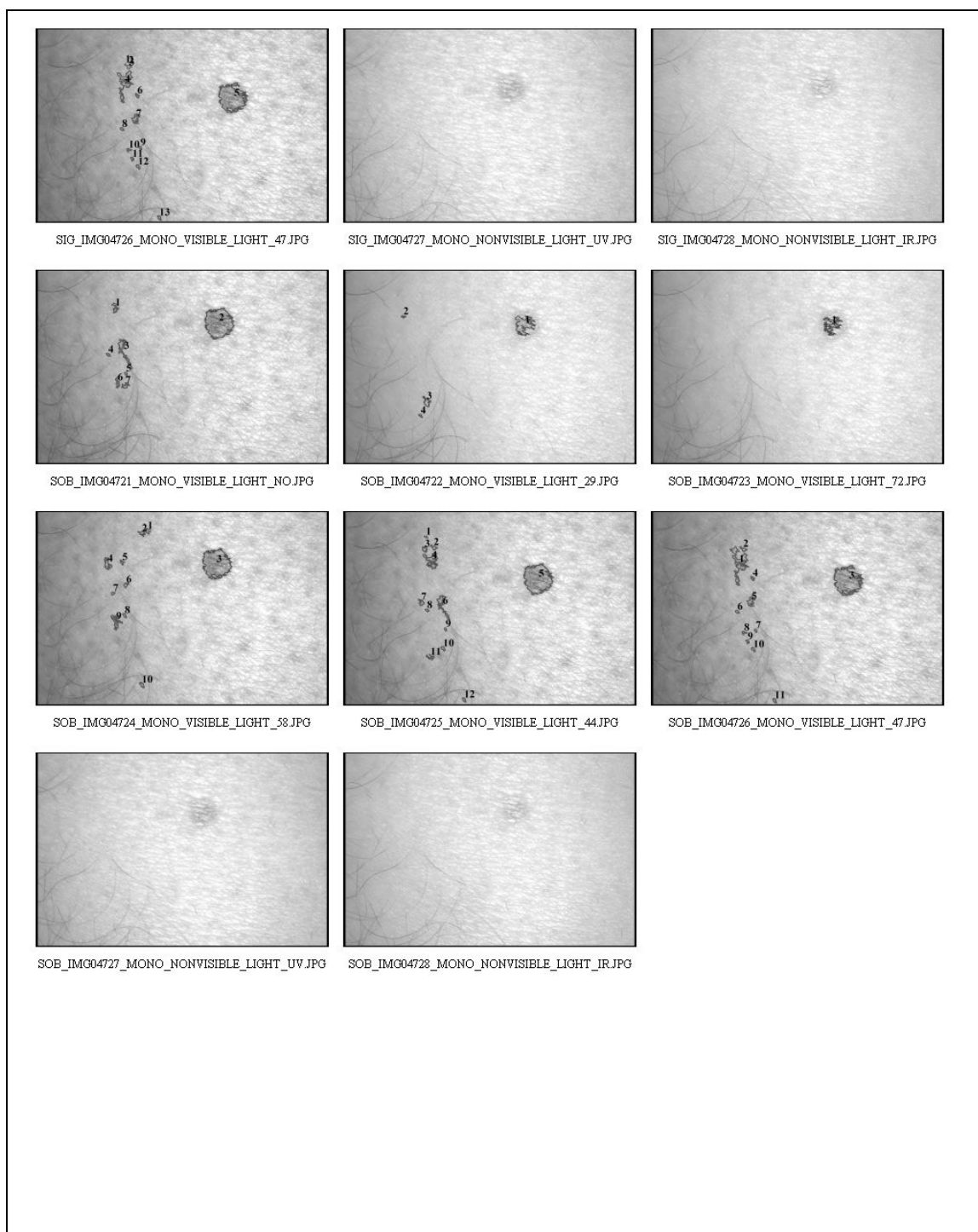


Figure 143. Lesion 472X Processed Sheet 4

Lesion 473X

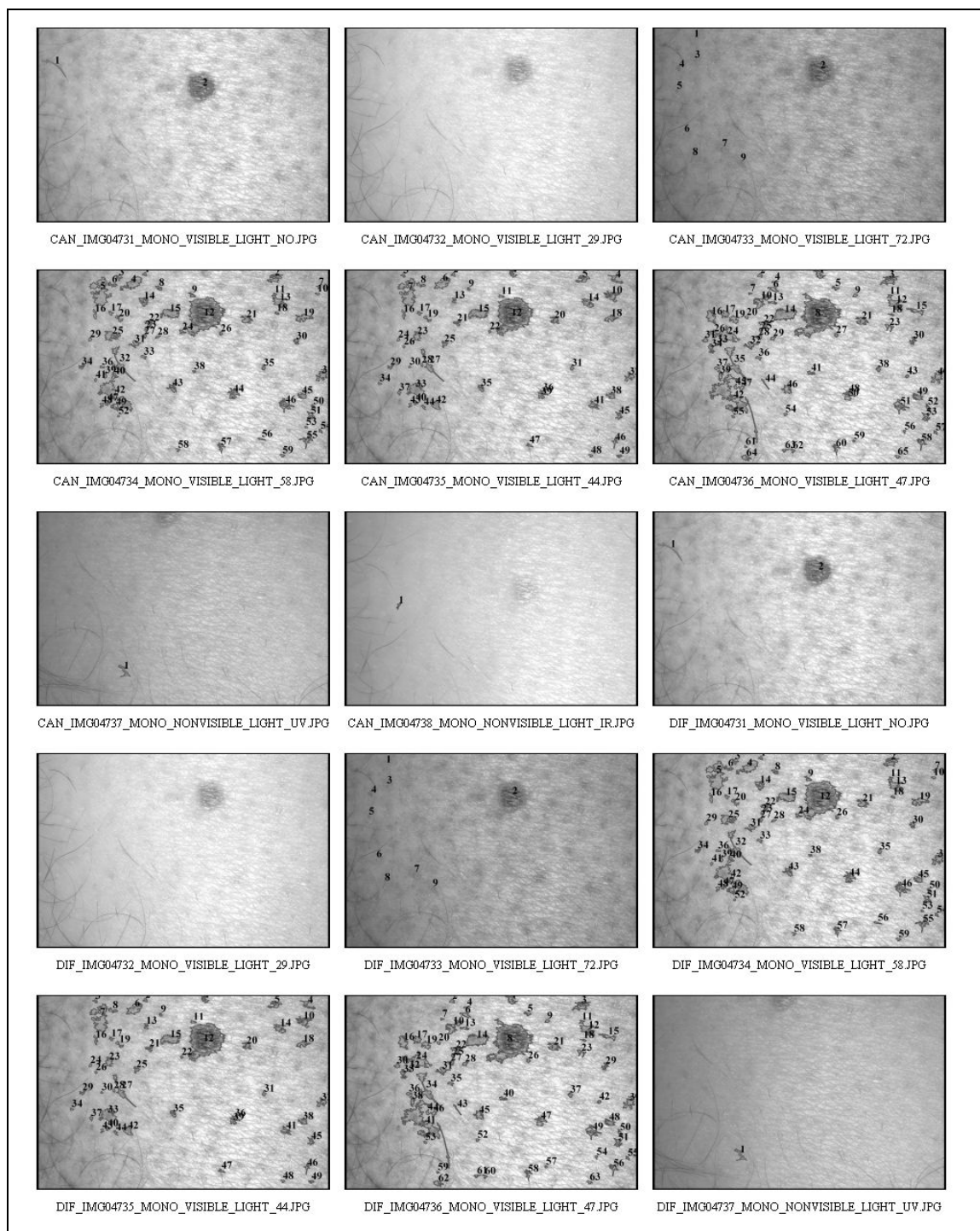


Figure 144. Lesion 473X Processed Sheet 1

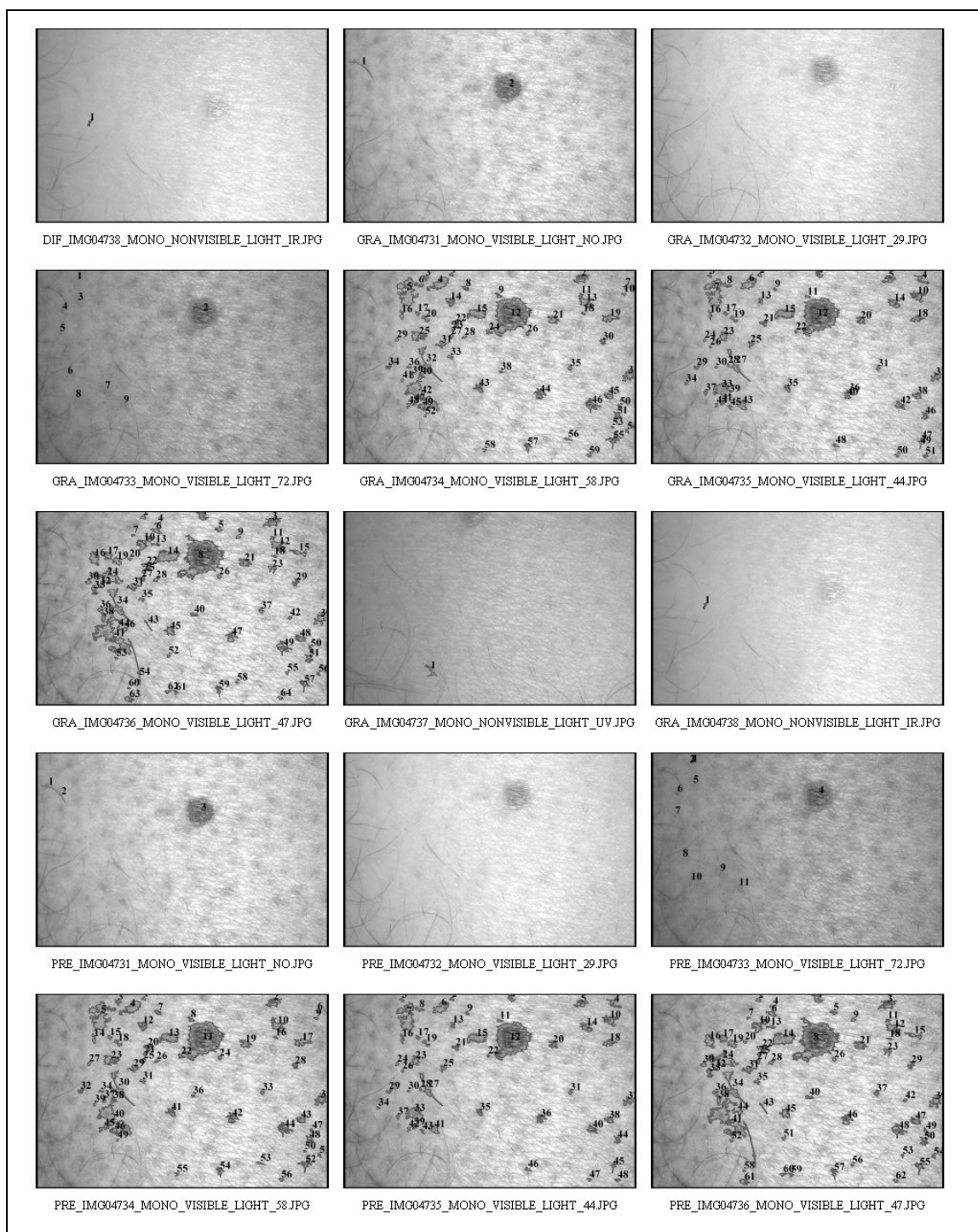


Figure 145. Lesion 473X Processed Sheet 2

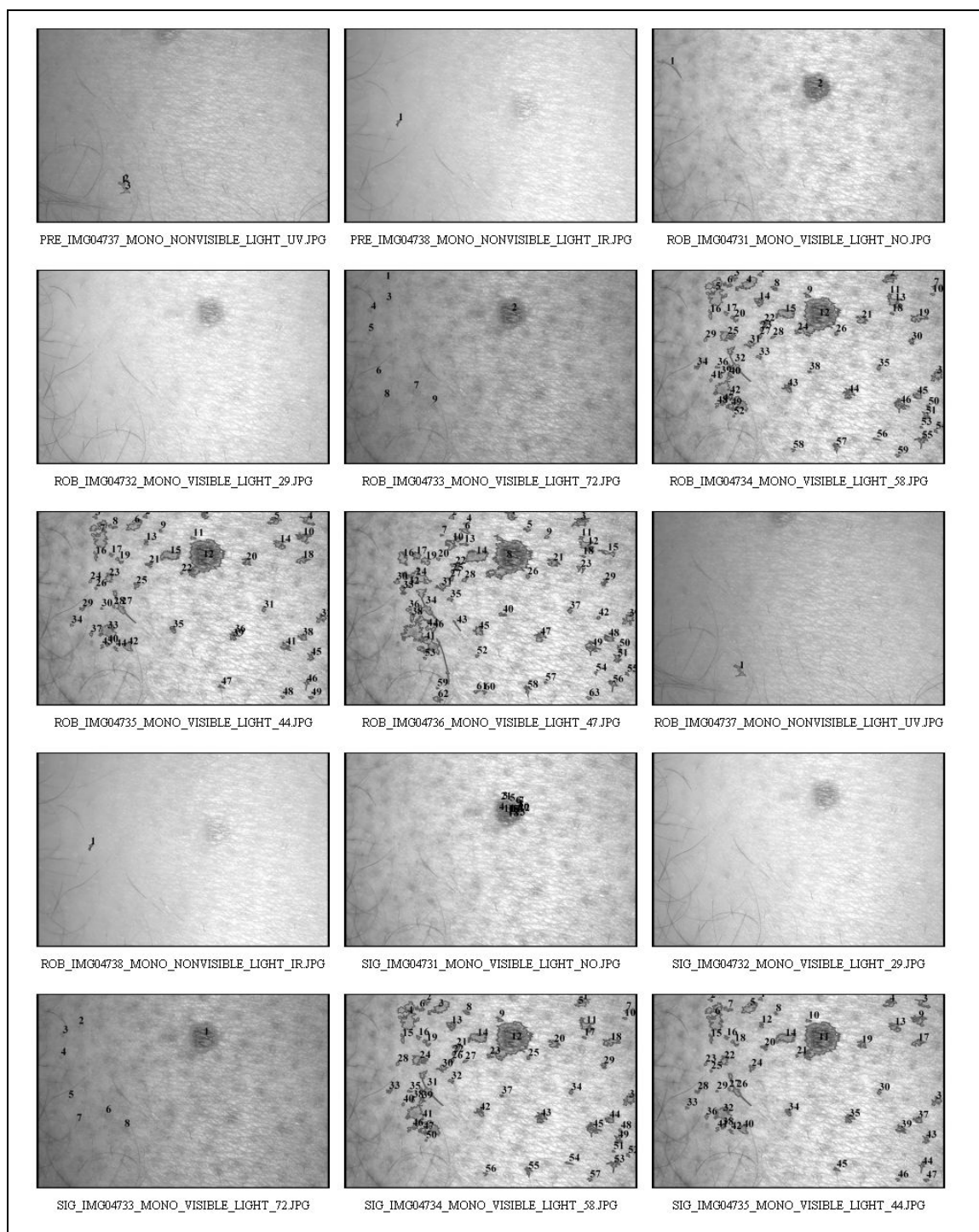


Figure 146. Lesion 473X Processed Sheet 3

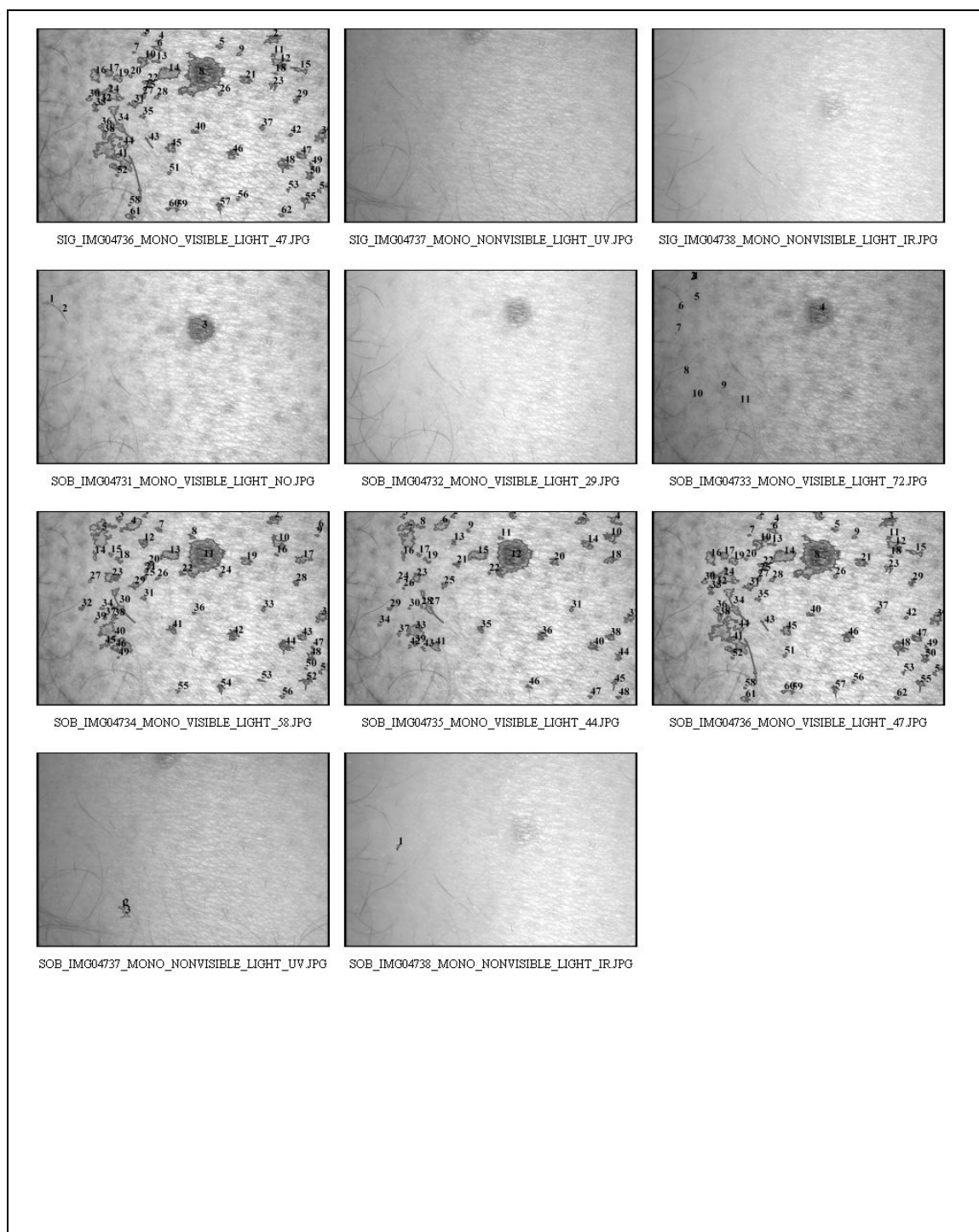


Figure 147. Lesion 473X Processed Sheet 4

Lesion 474X

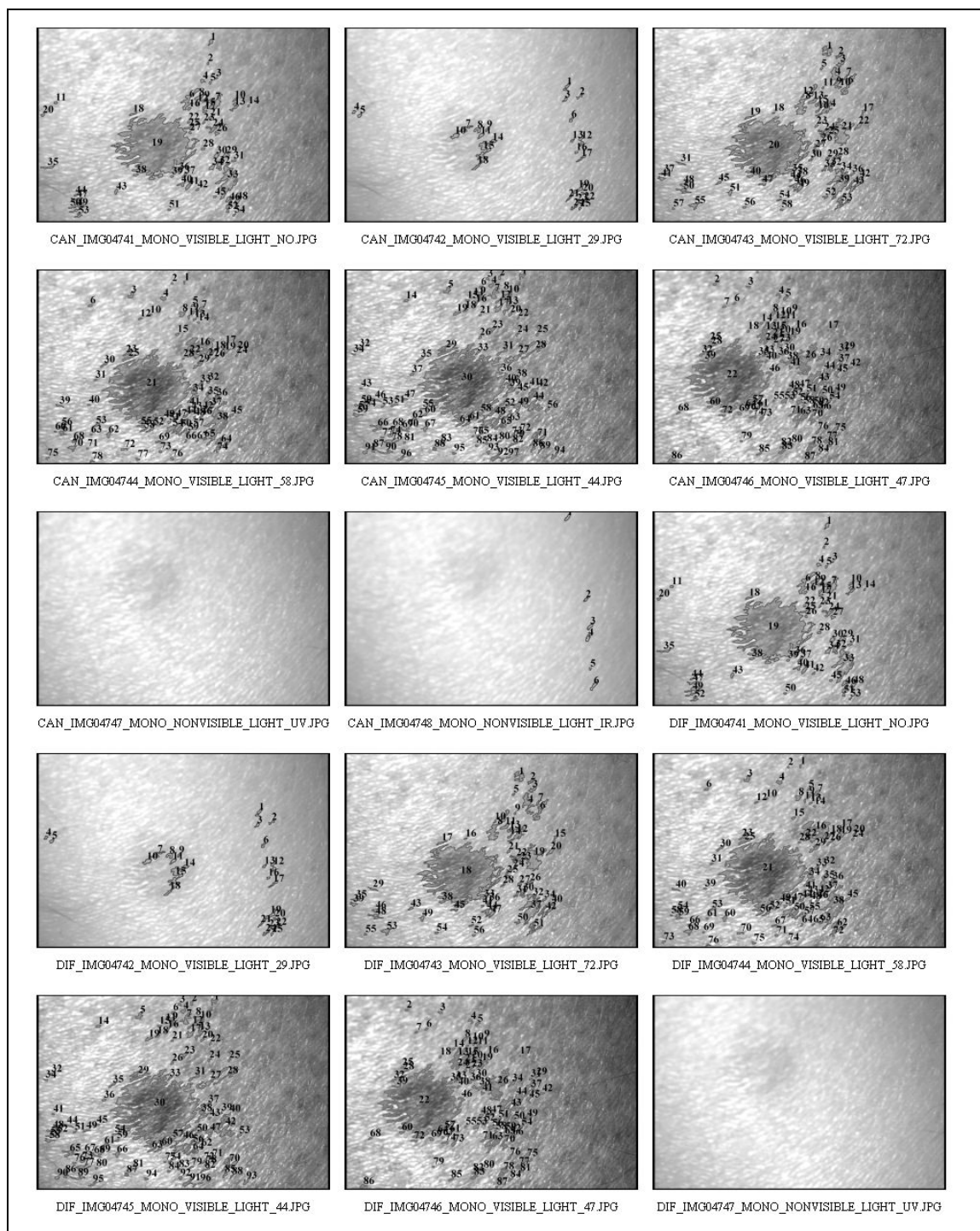


Figure 148. Lesion 474X Processed Sheet 1

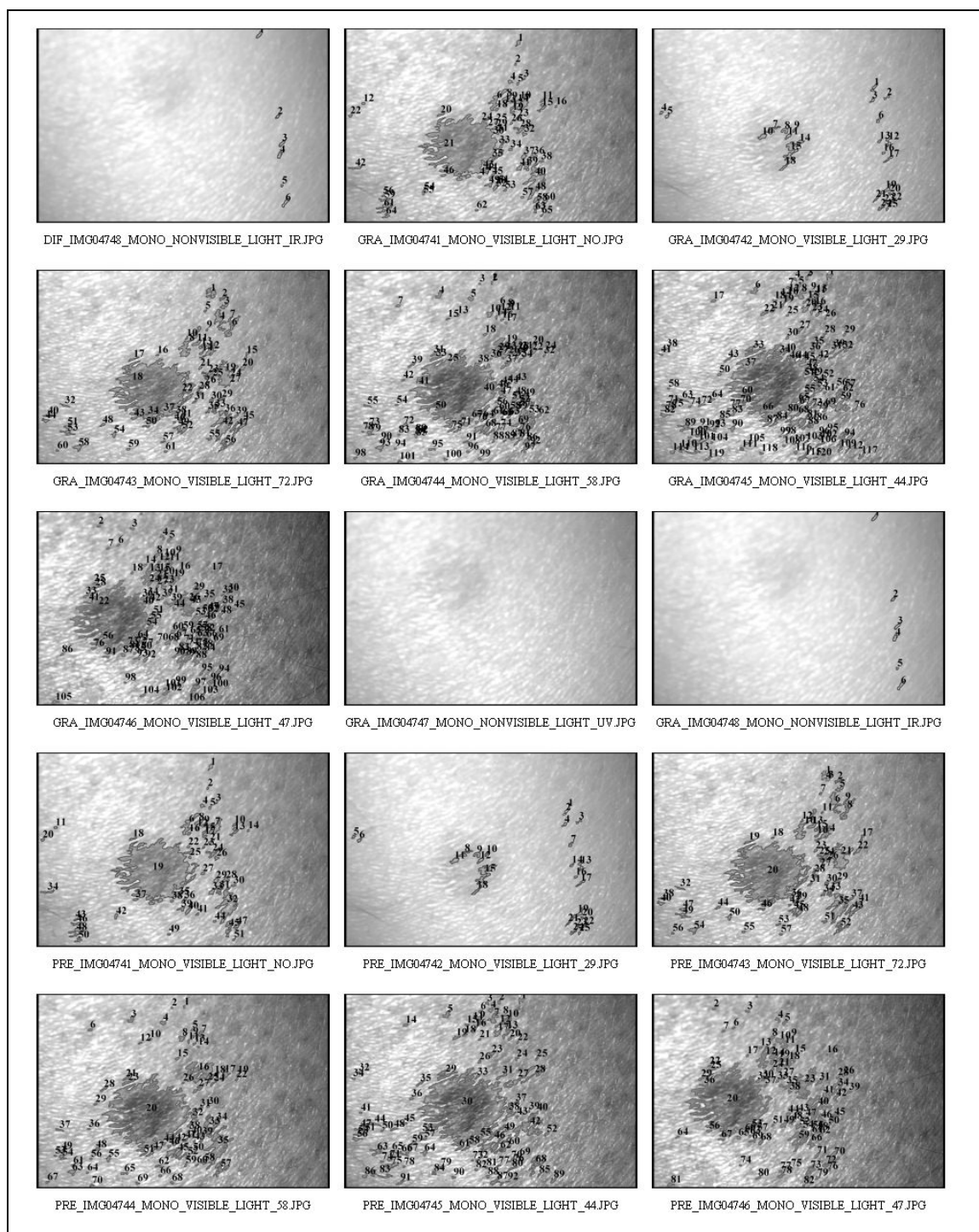


Figure 149. Lesion 474X Processed Sheet 2

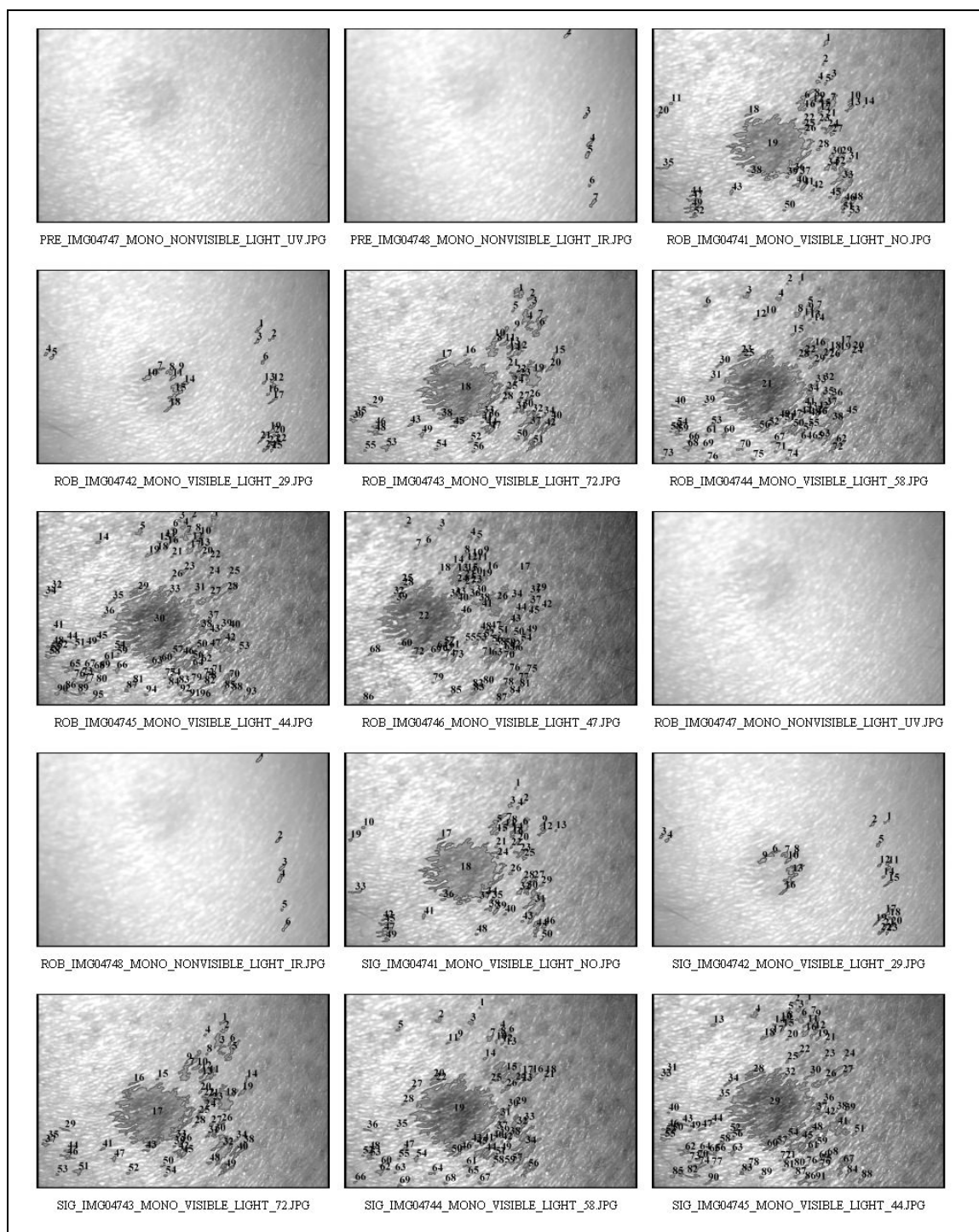


Figure 150. Lesion 474X Processed Sheet 3

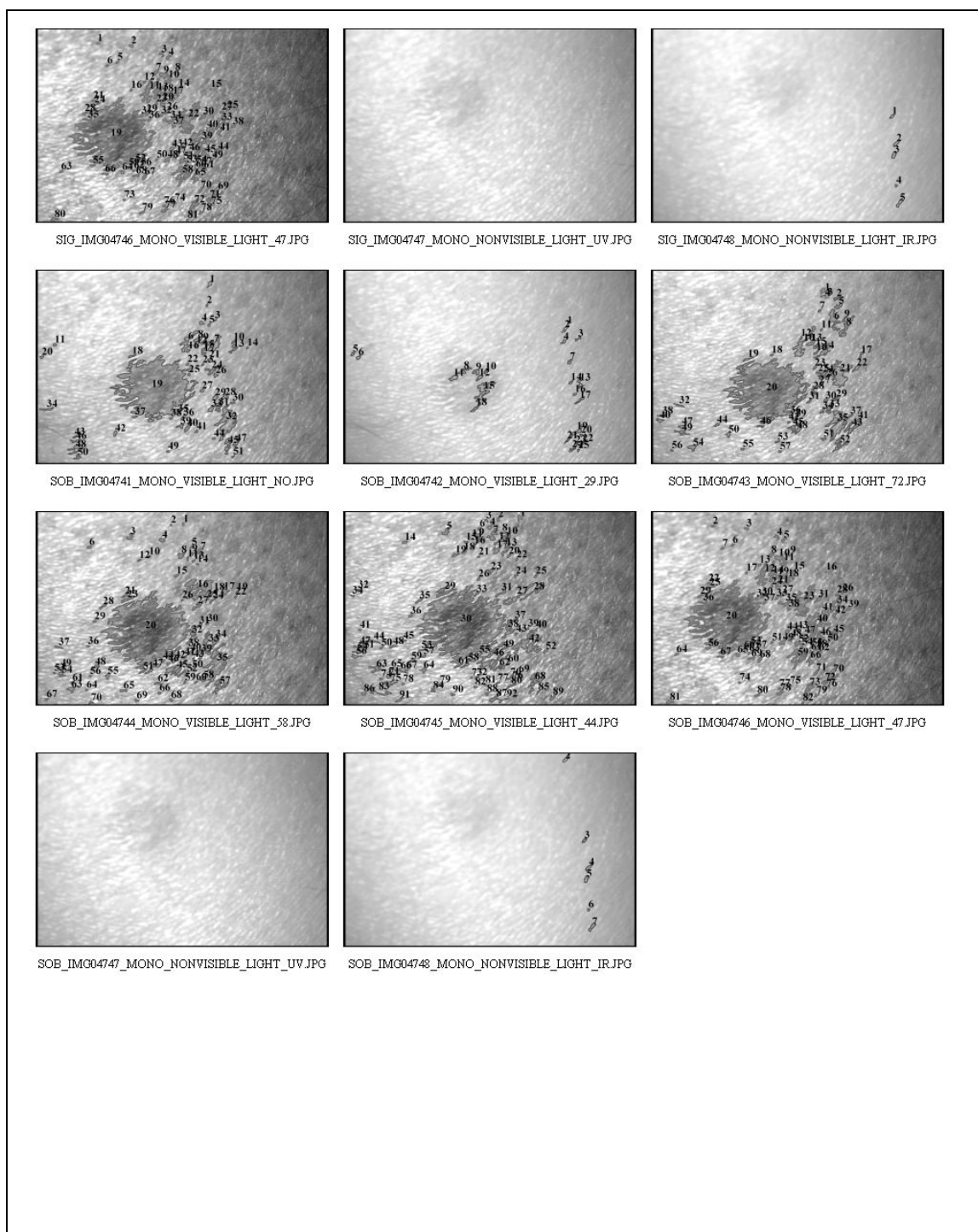


Figure 151. Lesion 474X Processed Sheet 4

Lesion 475X

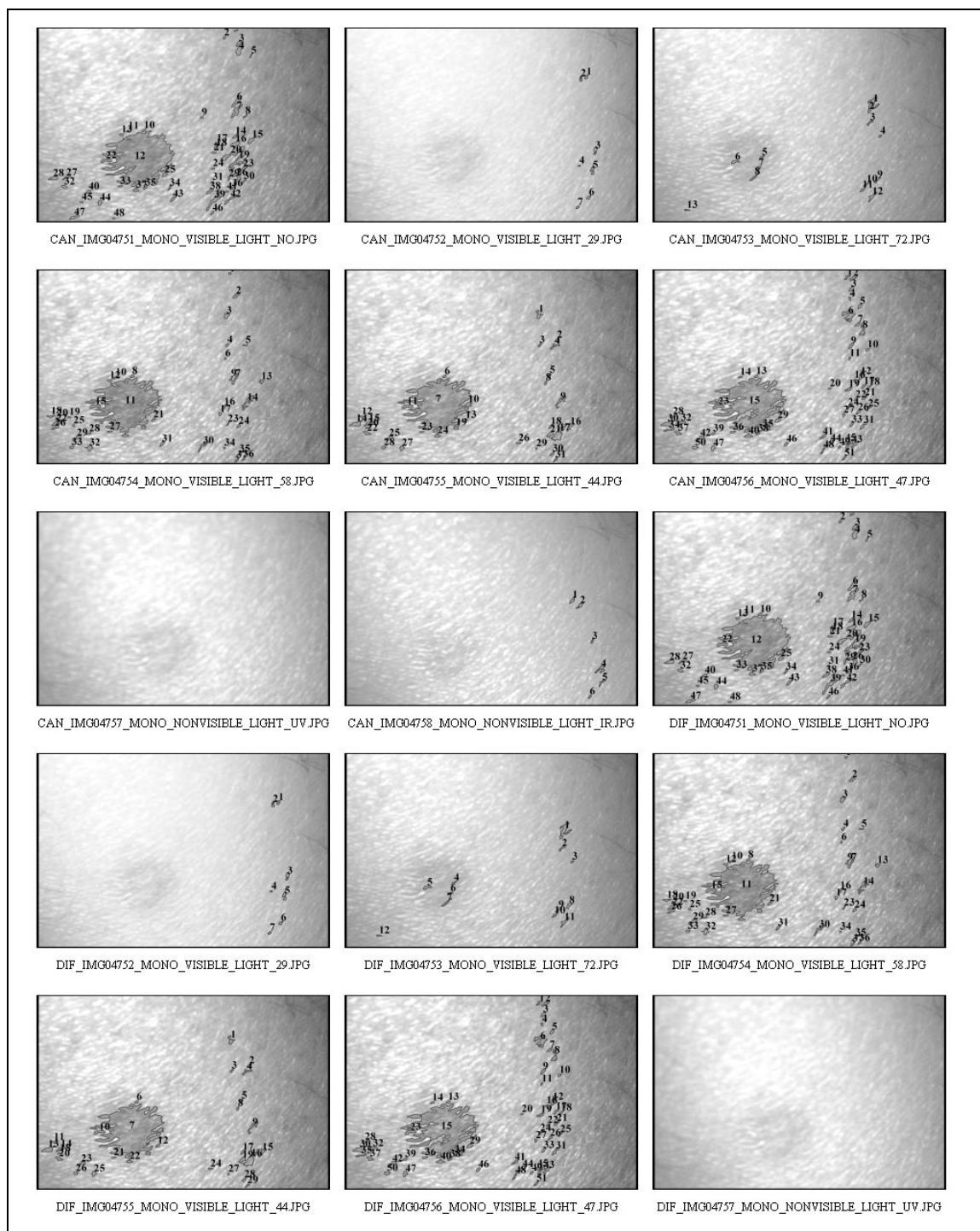


Figure 152. Lesion 475X Processed Sheet 1

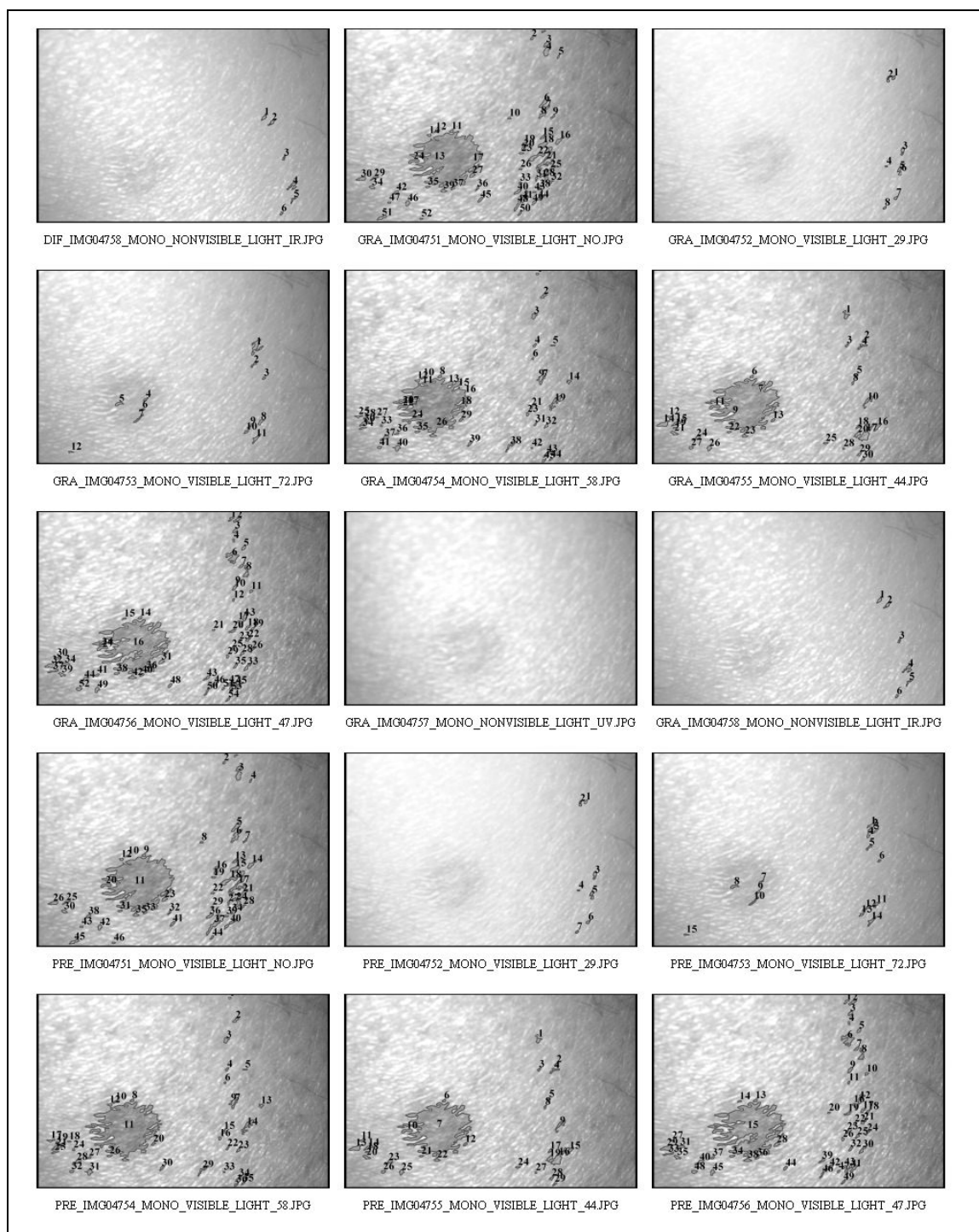


Figure 153. Lesion 475X Processed Sheet 2

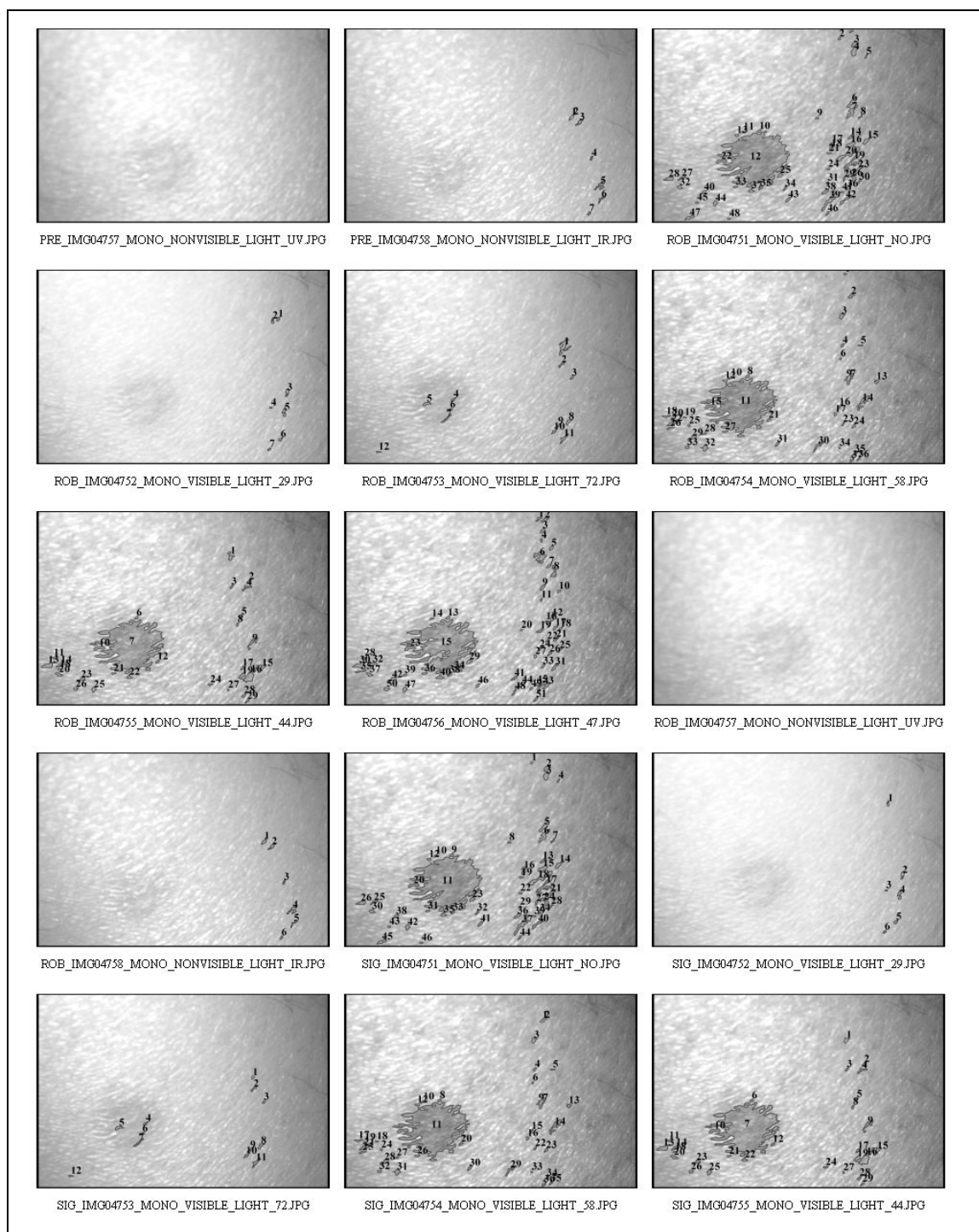


Figure 154. Lesion 475X Processed Sheet 3

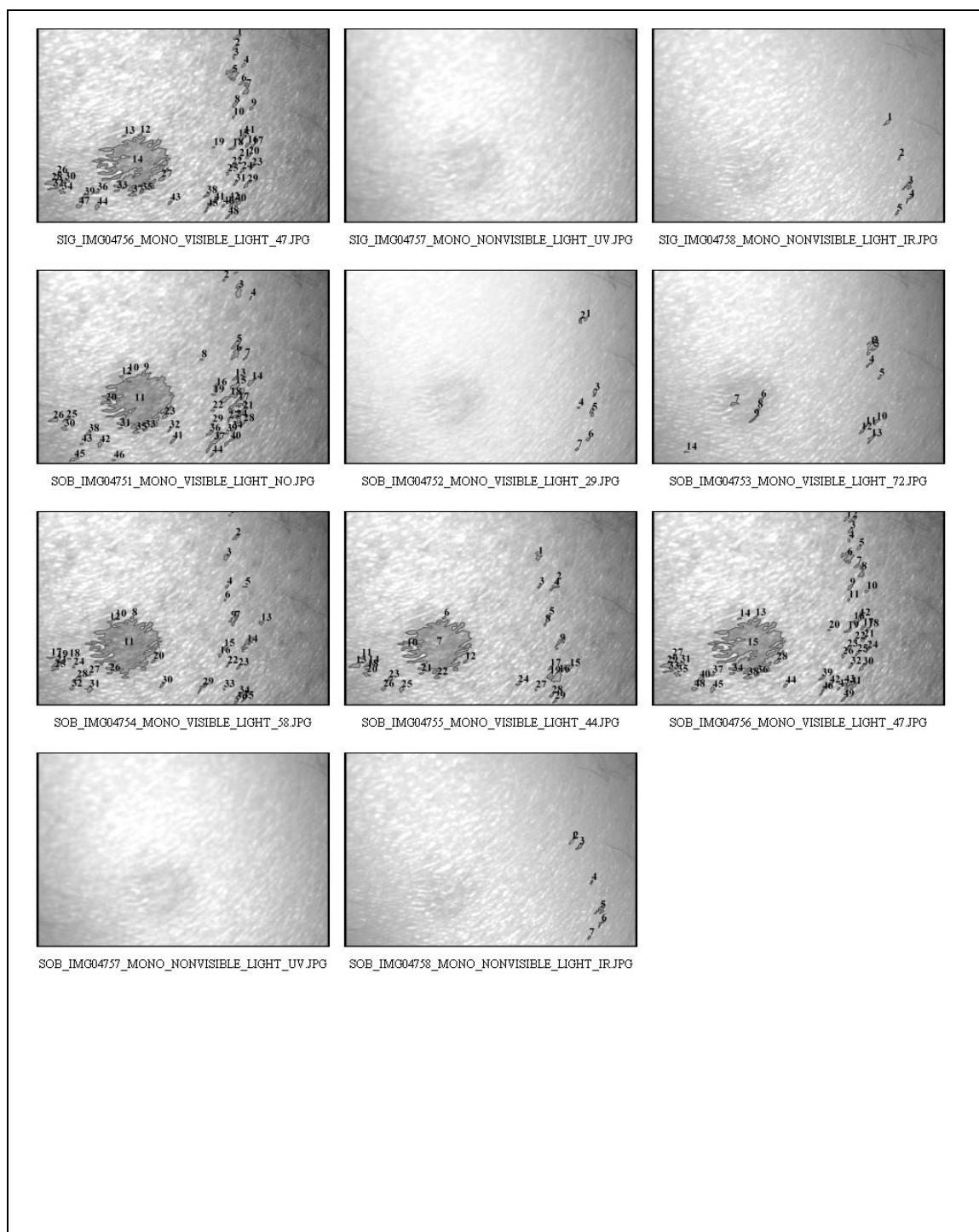
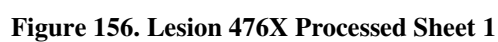


Figure 155. Lesion 475X Processed Sheet 4



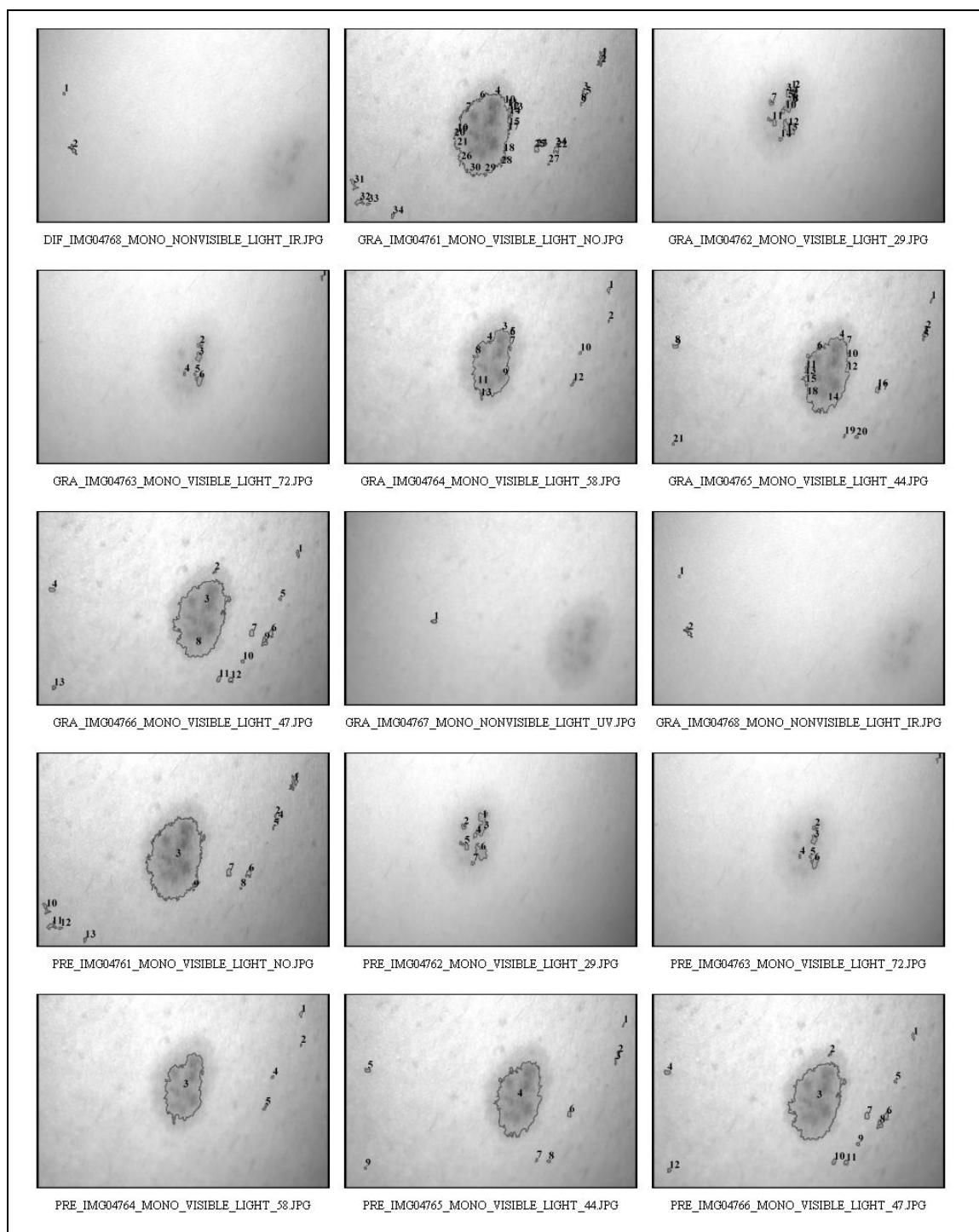


Figure 157. Lesion 476X Processed Sheet 2

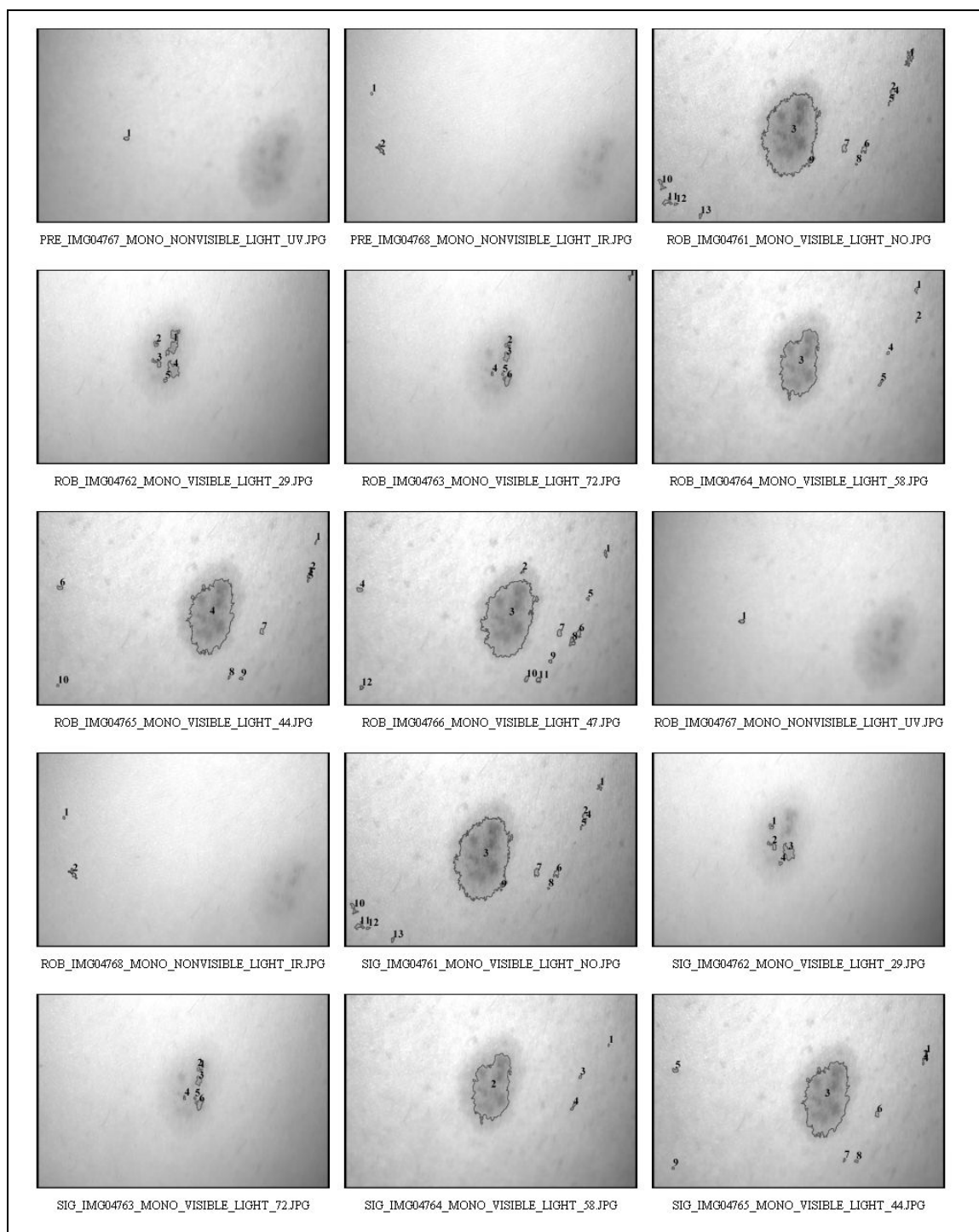


Figure 158. Lesion 476X Processed Sheet 3

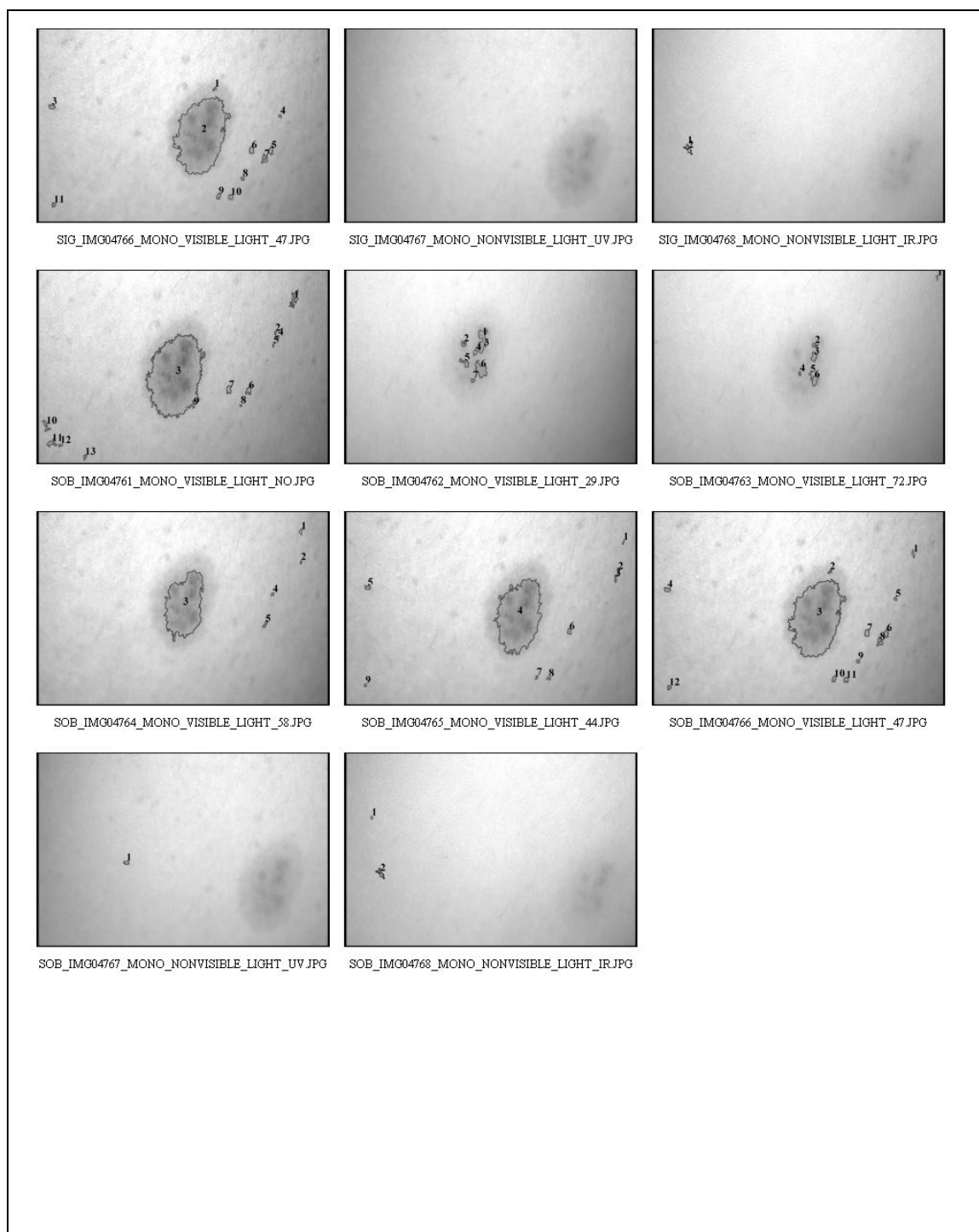


Figure 159. Lesion 476X Processed Sheet 4

Lesion 477X

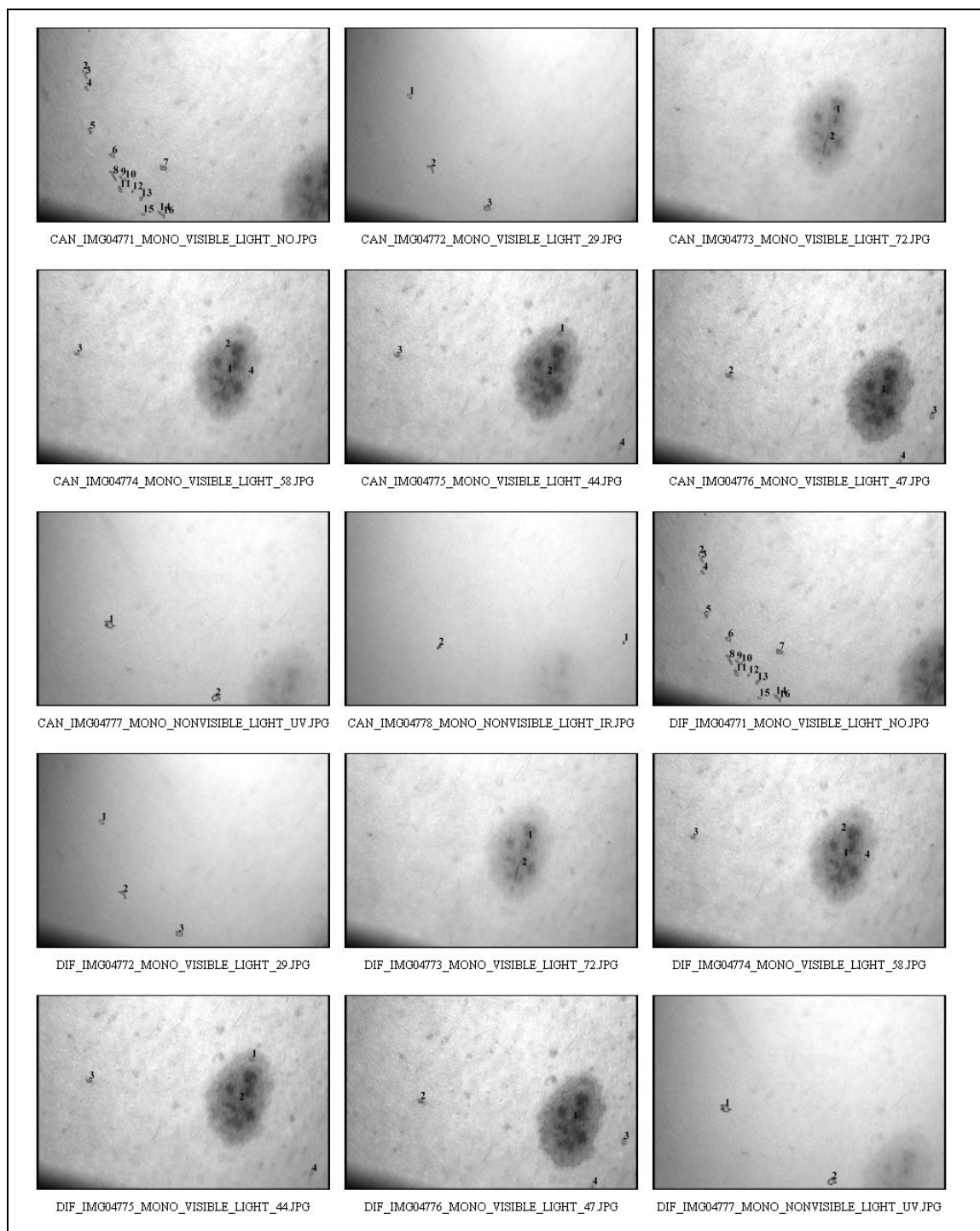


Figure 160. Lesion 477X Processed Sheet 1

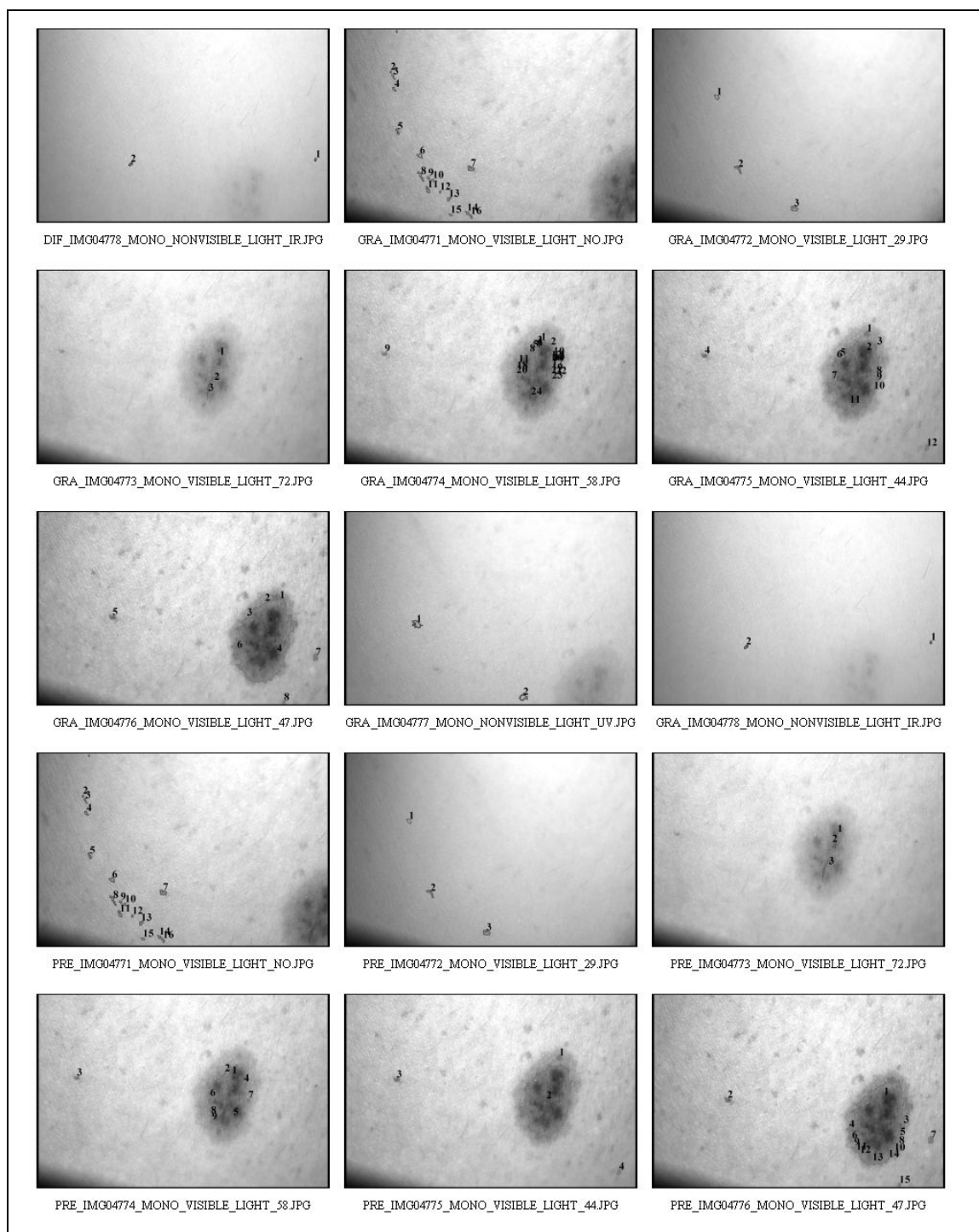


Figure 161. Lesion 477X Processed Sheet 2

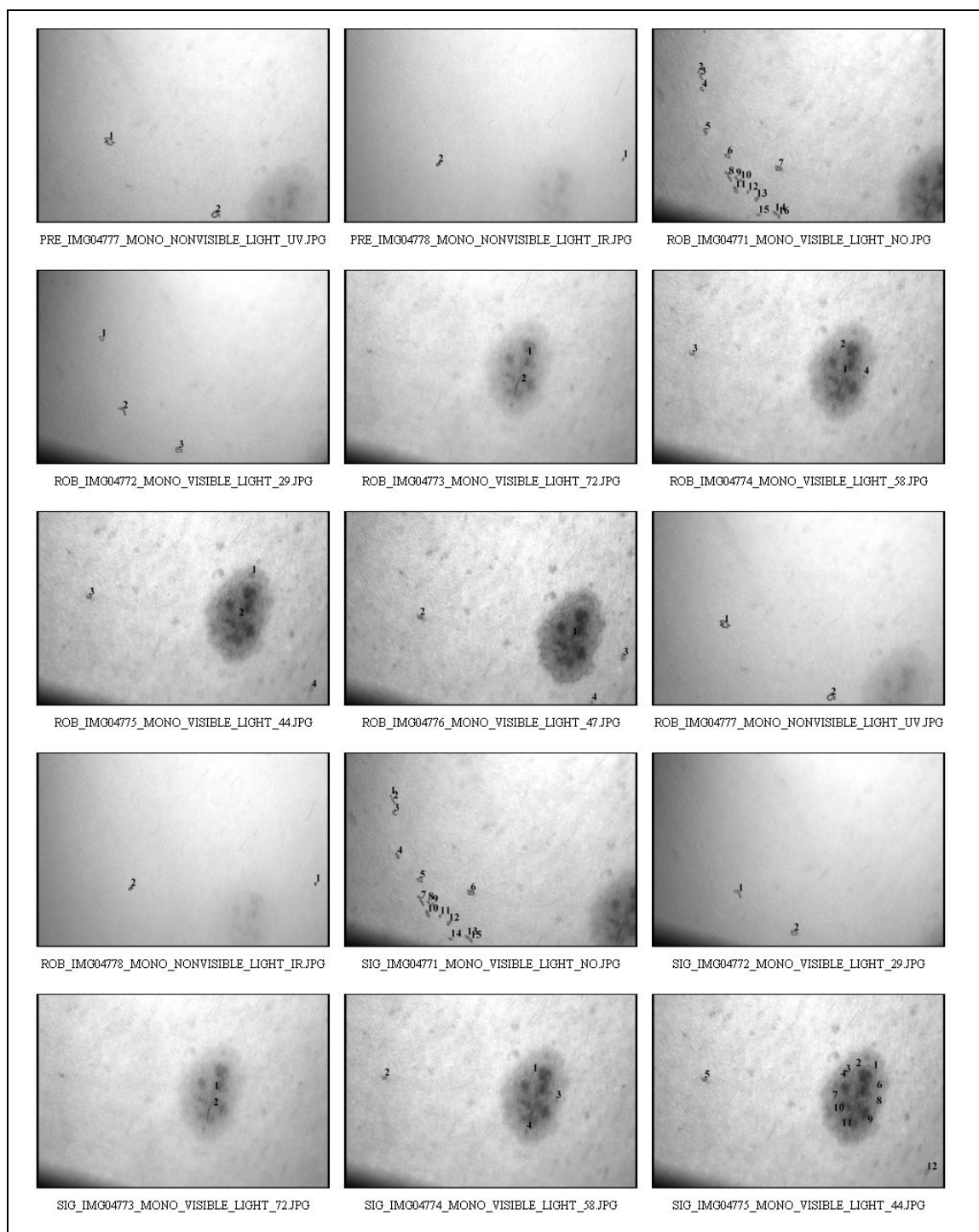


Figure 162. Lesion 477X Processed Sheet 3

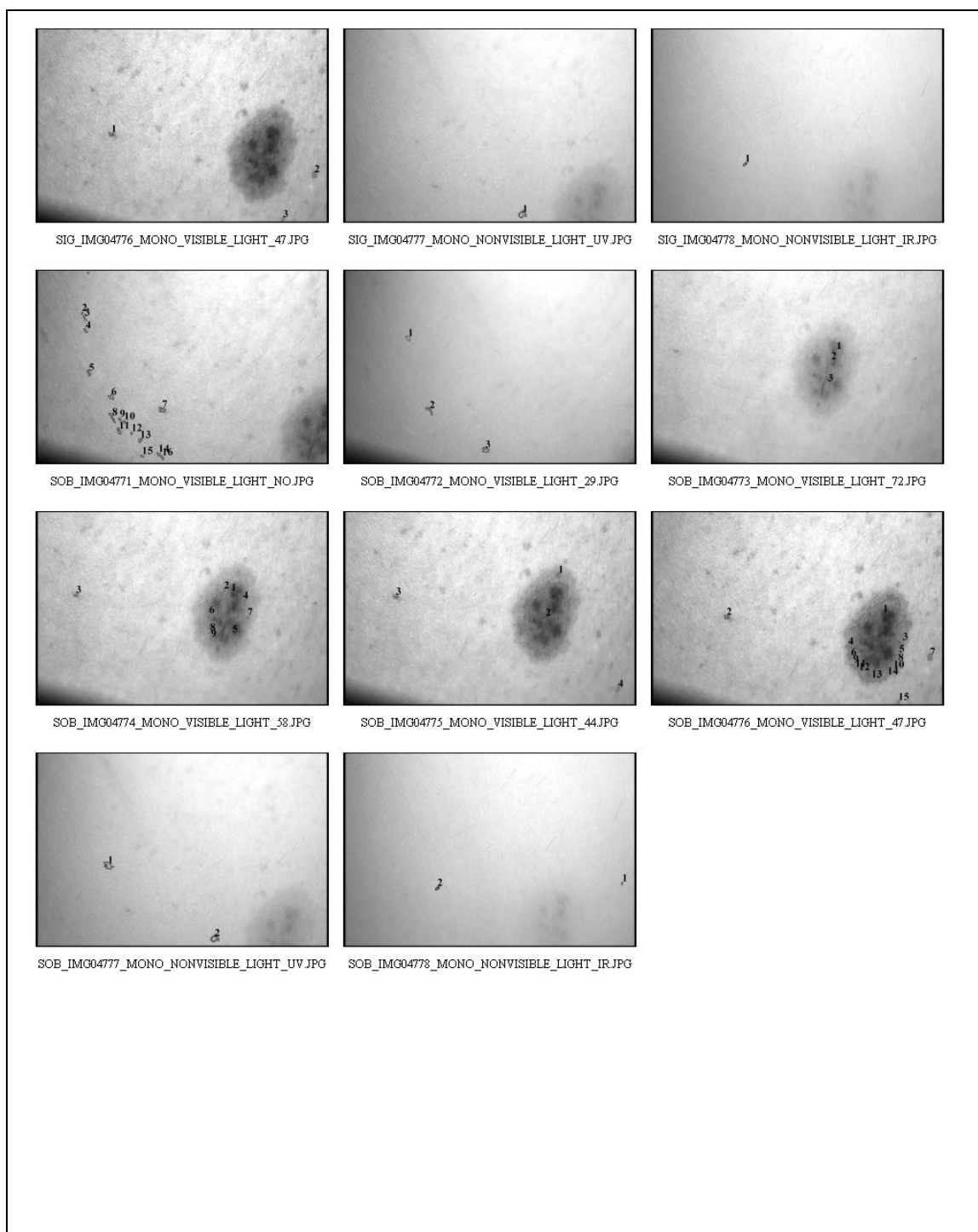


Figure 163. Lesion 477X Processed Sheet 4

Lesion 479X

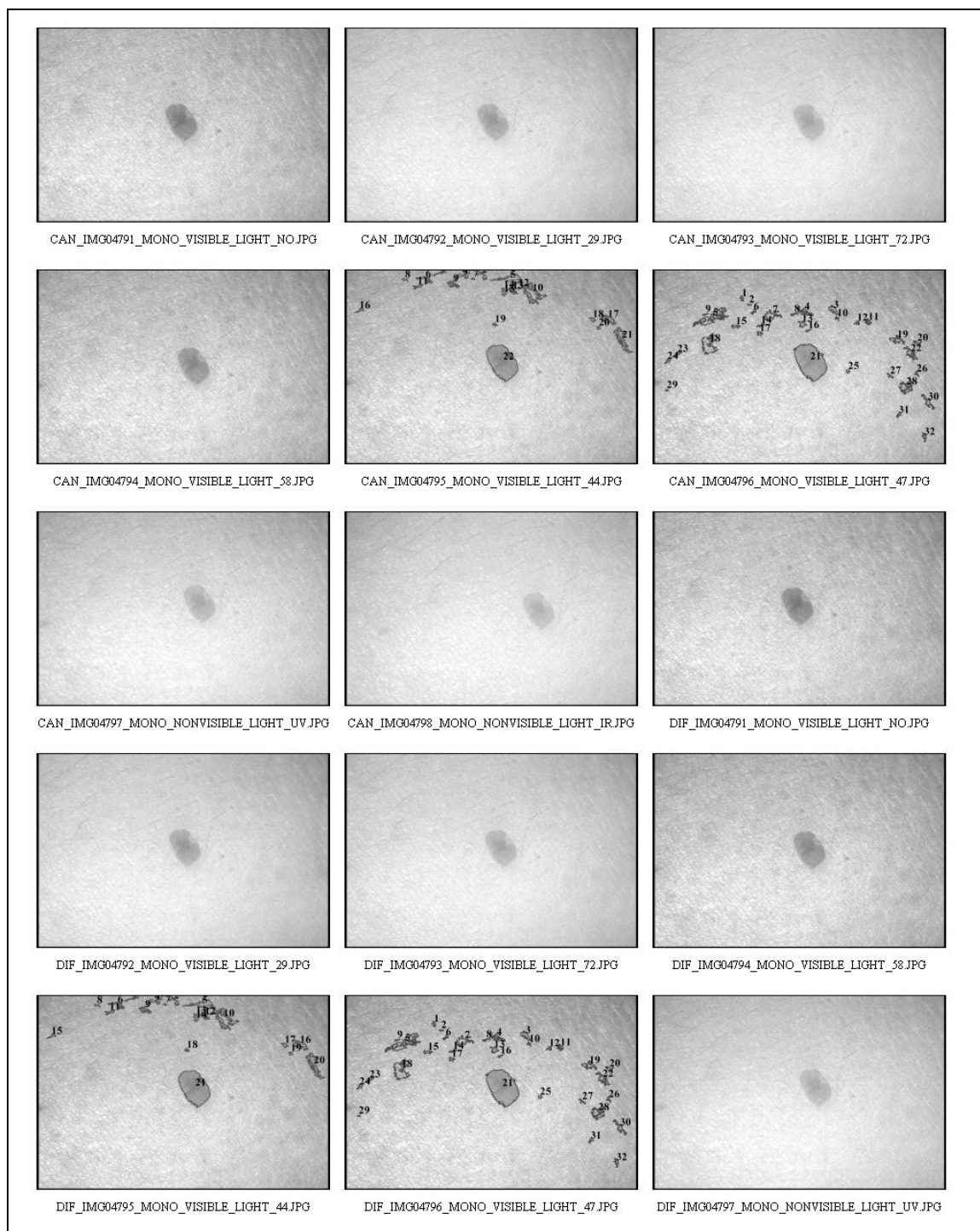


Figure 164. Lesion 479X Processed Sheet 1

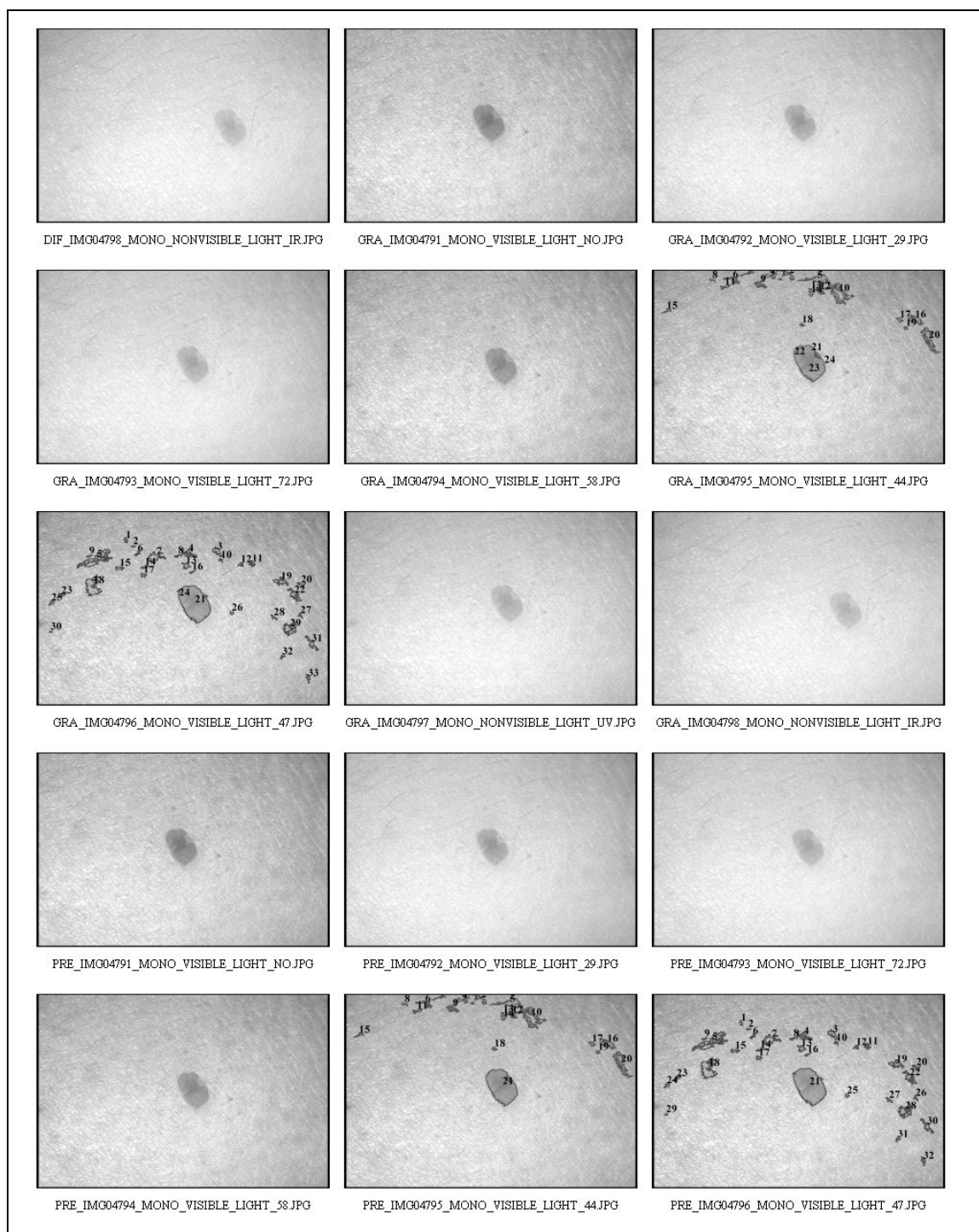


Figure 165. Lesion 479X Processed Sheet 2

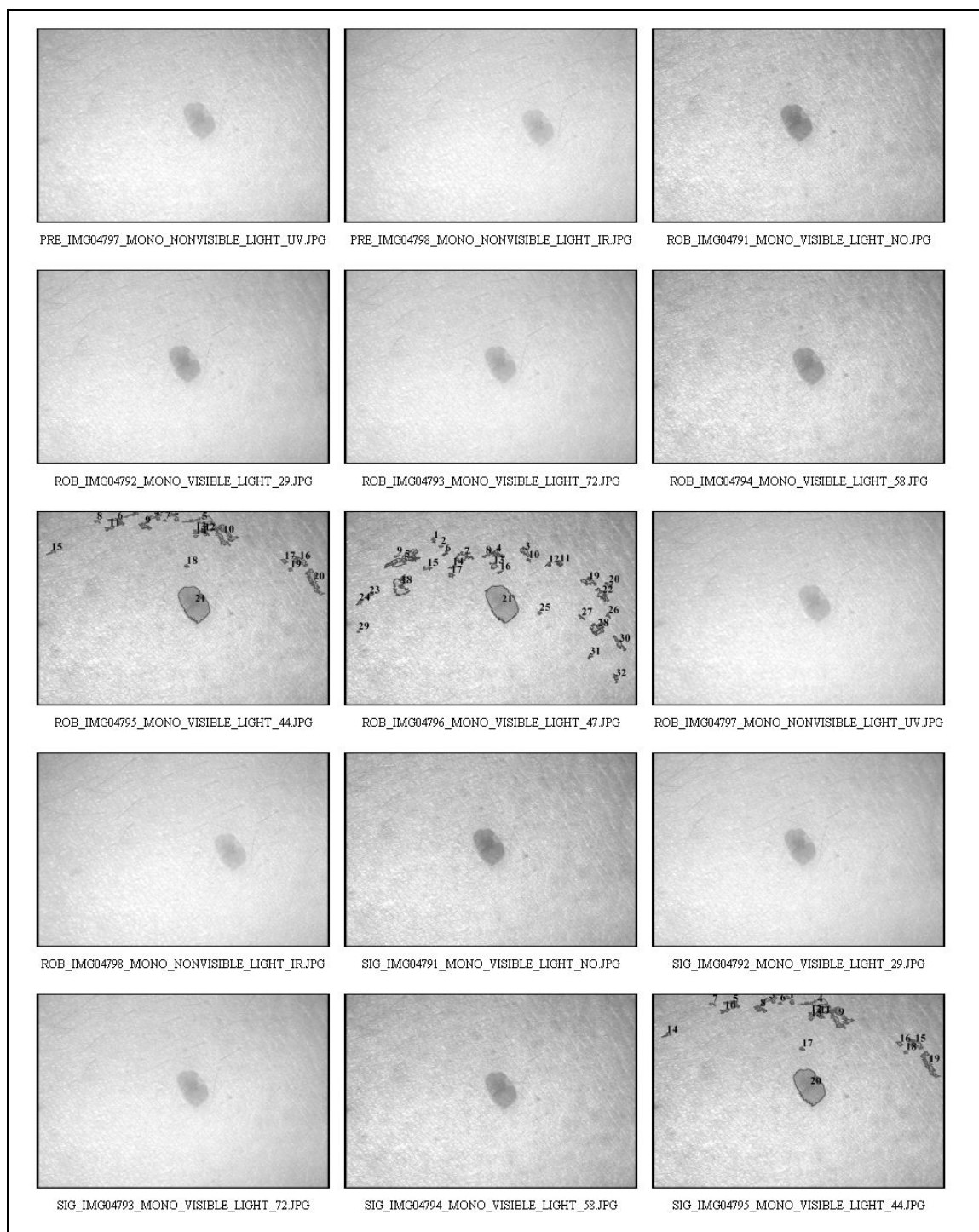


Figure 166. Lesion 479X Processed Sheet 3

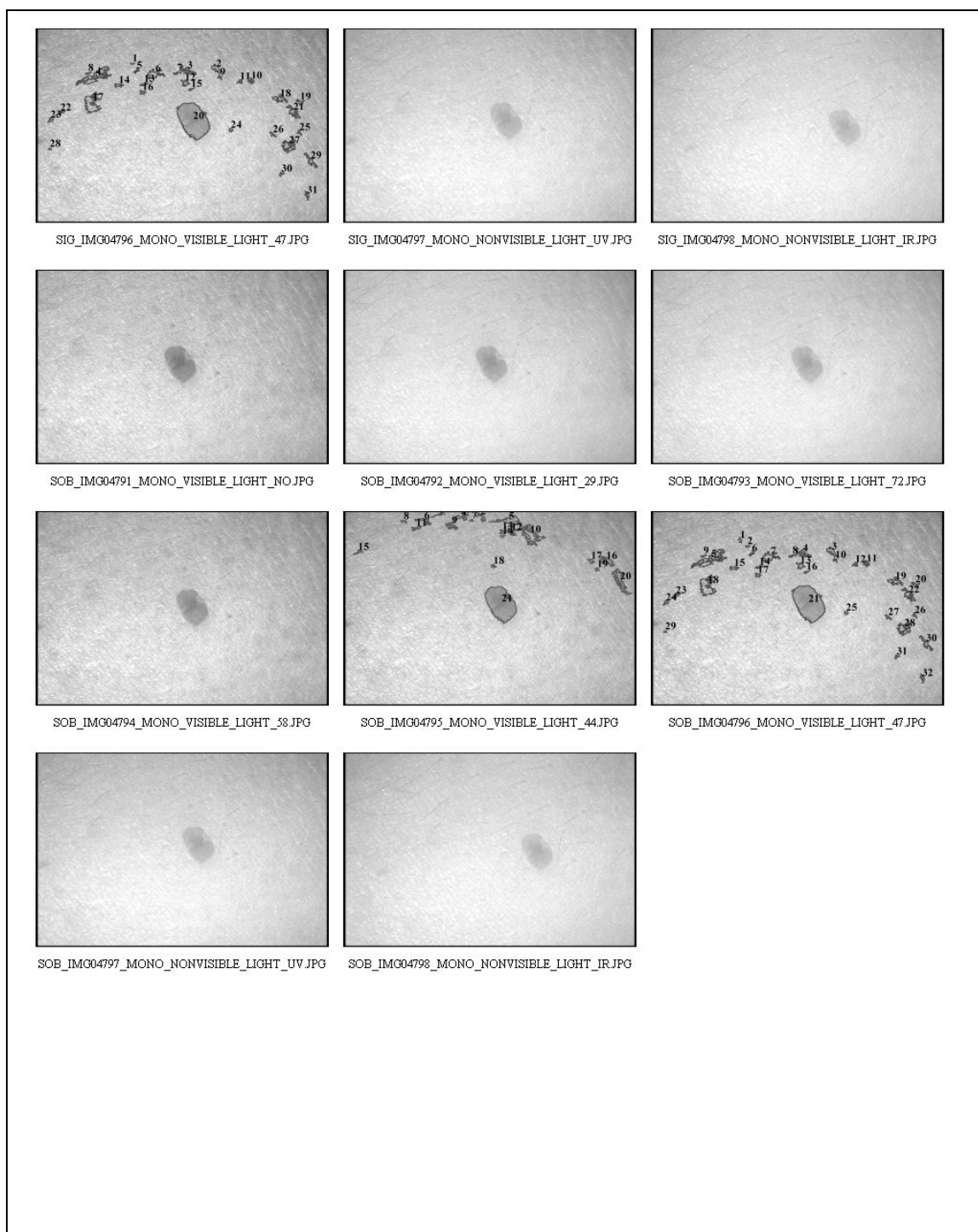


Figure 167. Lesion 479X Processed Sheet 4

Lesion 480X

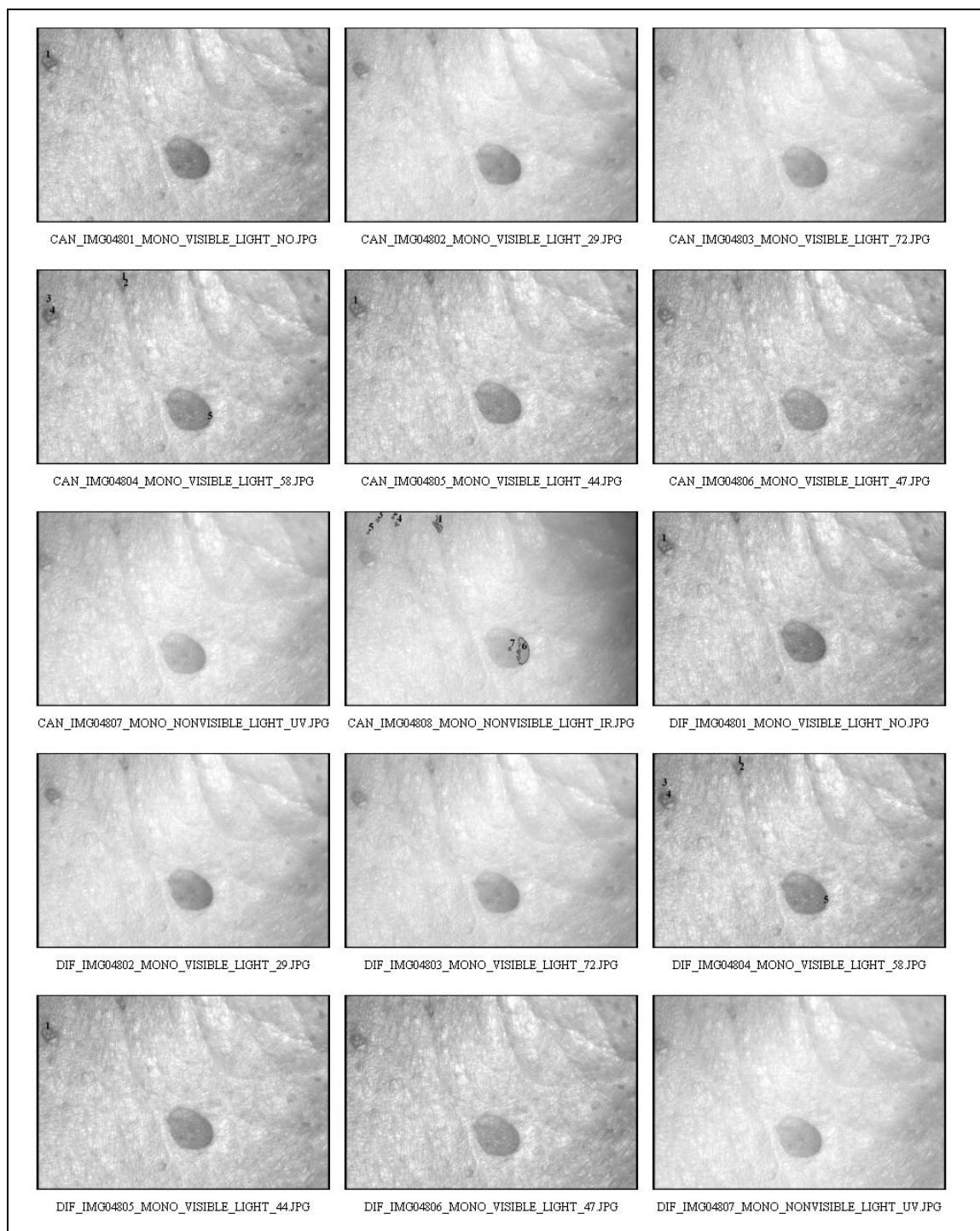


Figure 168. Lesion 480X Processed Sheet 1

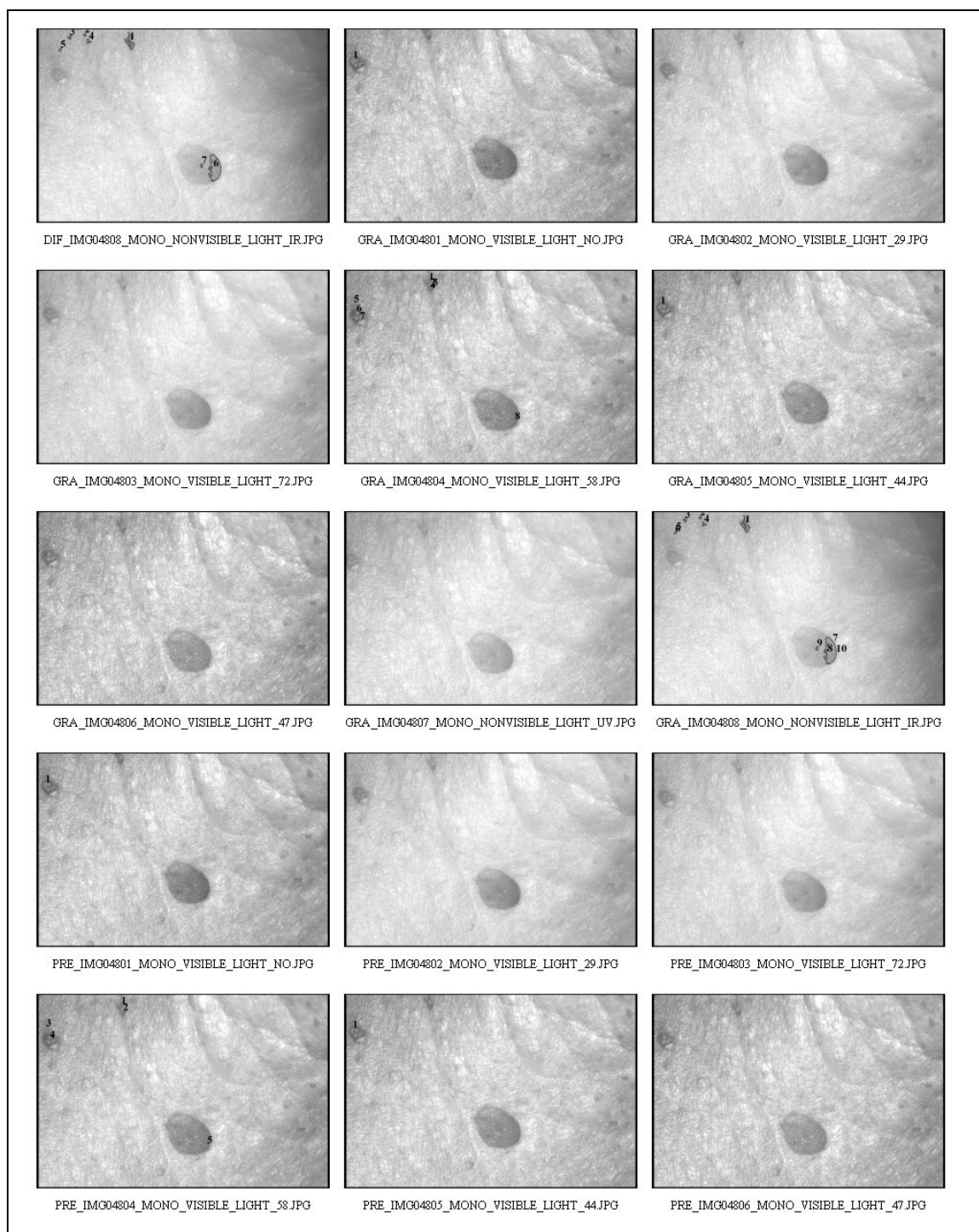


Figure 169. Lesion 480X Processed Sheet 2

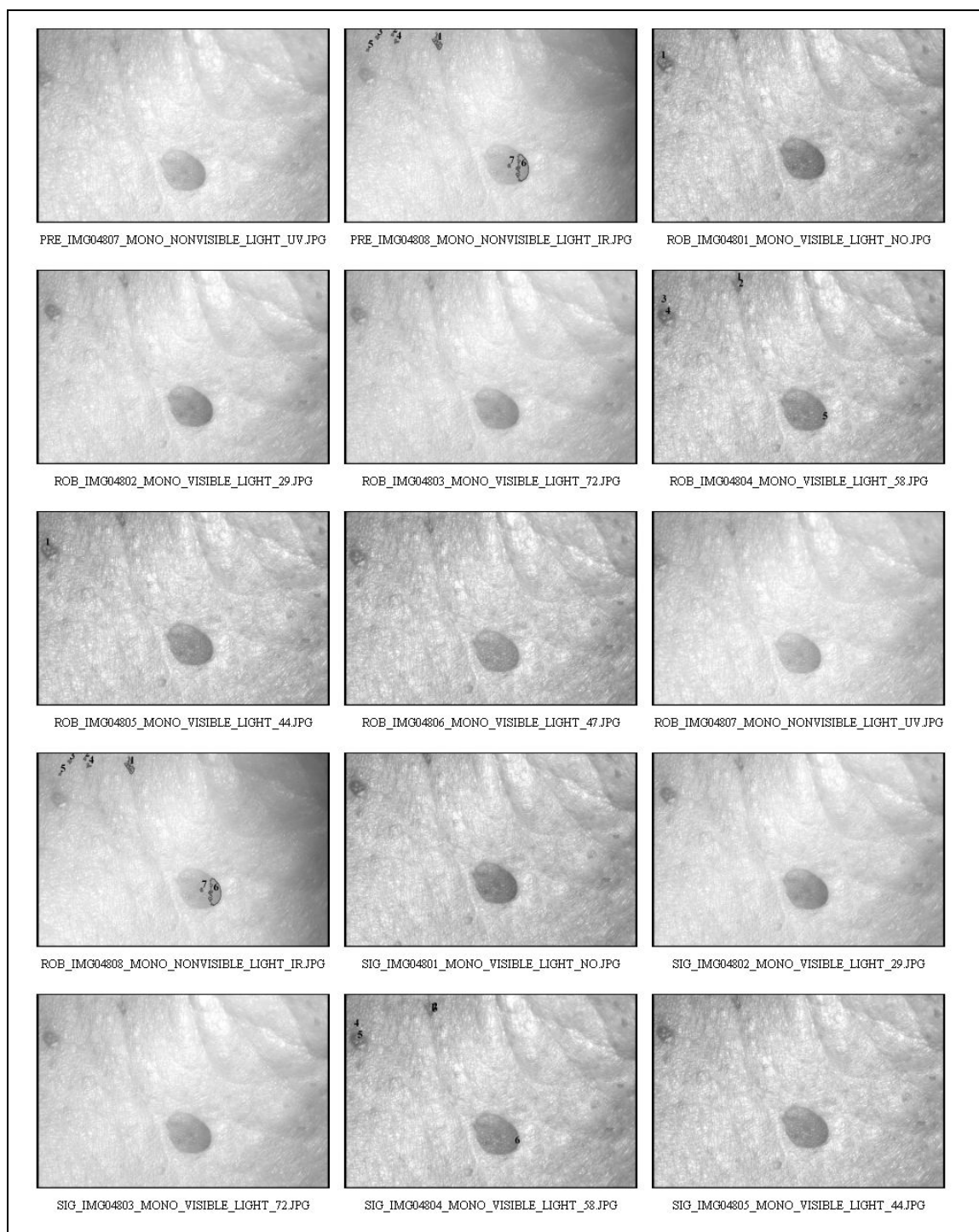


Figure 170. Lesion 480X Processed Sheet 3

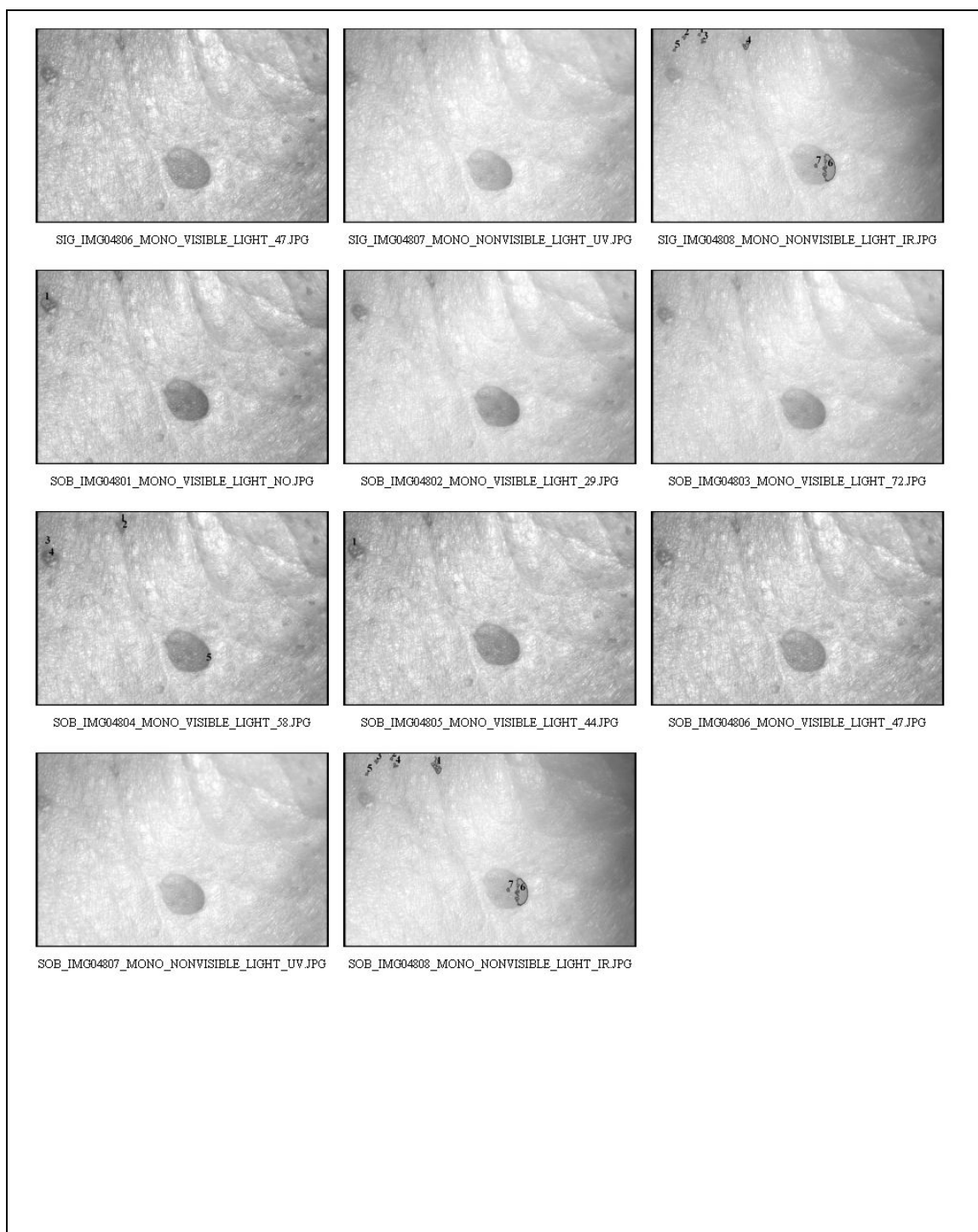


Figure 171. Lesion 480X Processed Sheet 4

Lesion 481X

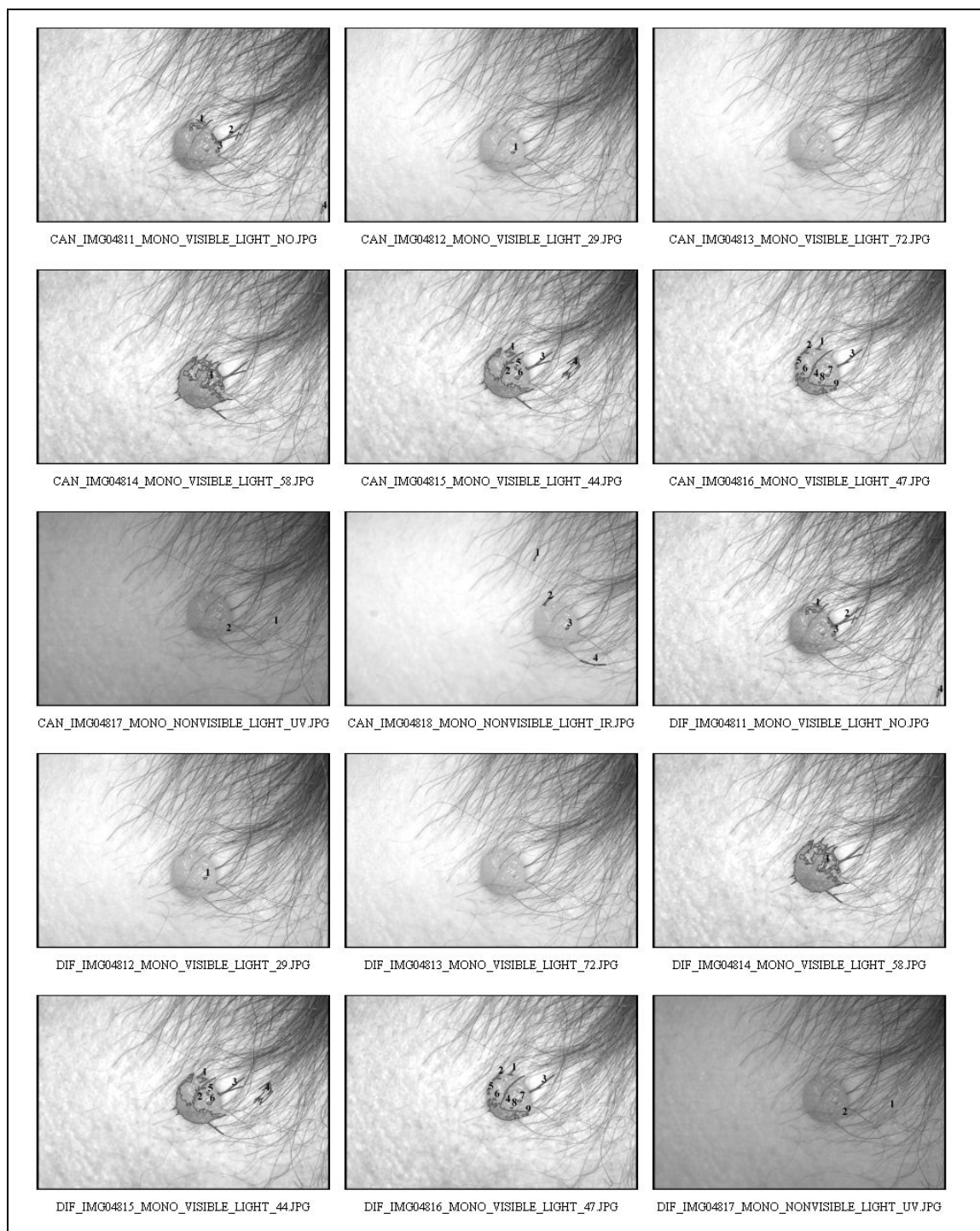


Figure 172. Lesion 481X Processed Sheet 1

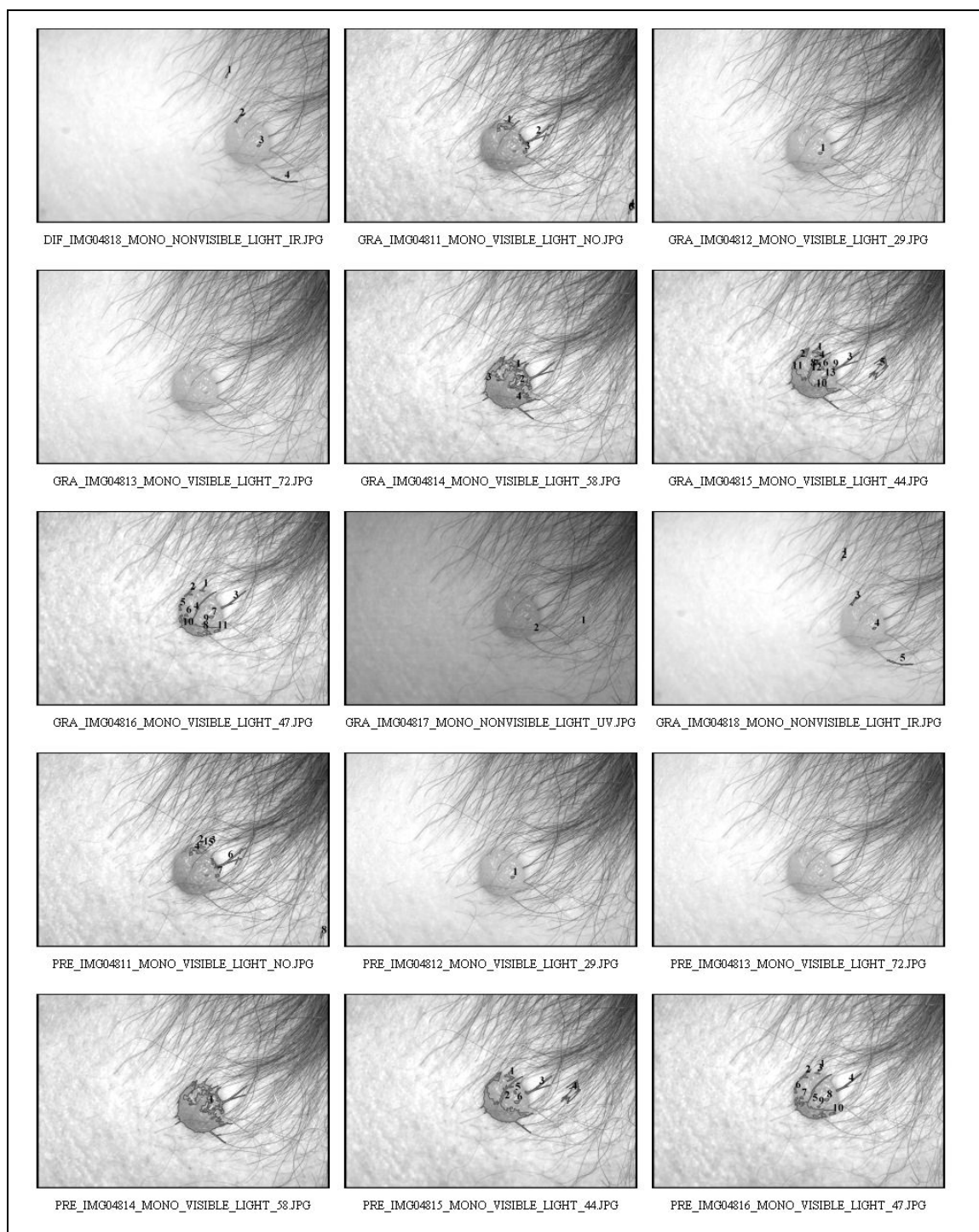


Figure 173. Lesion 481X Processed Sheet 2

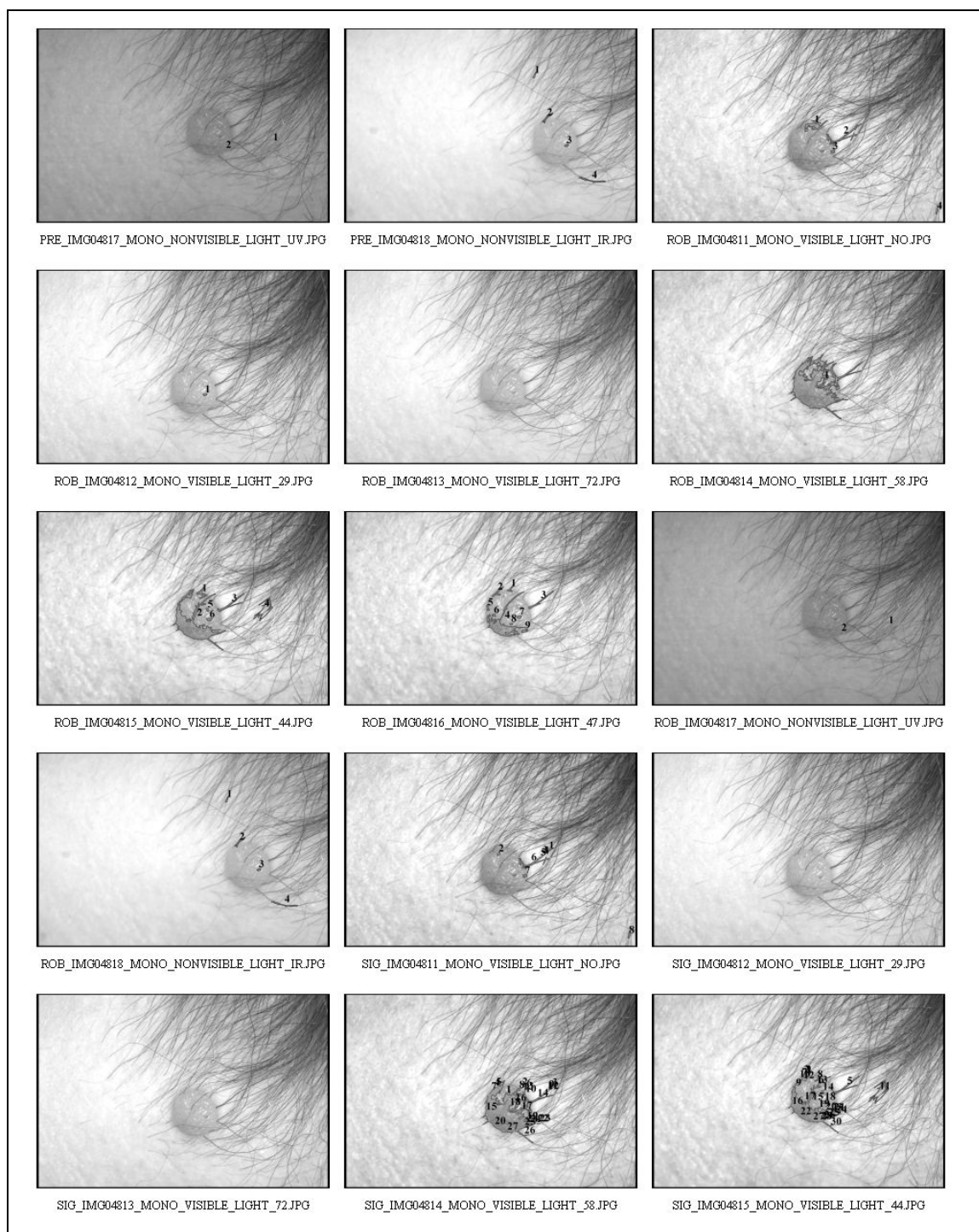


Figure 174. Lesion 481X Processed Sheet 3

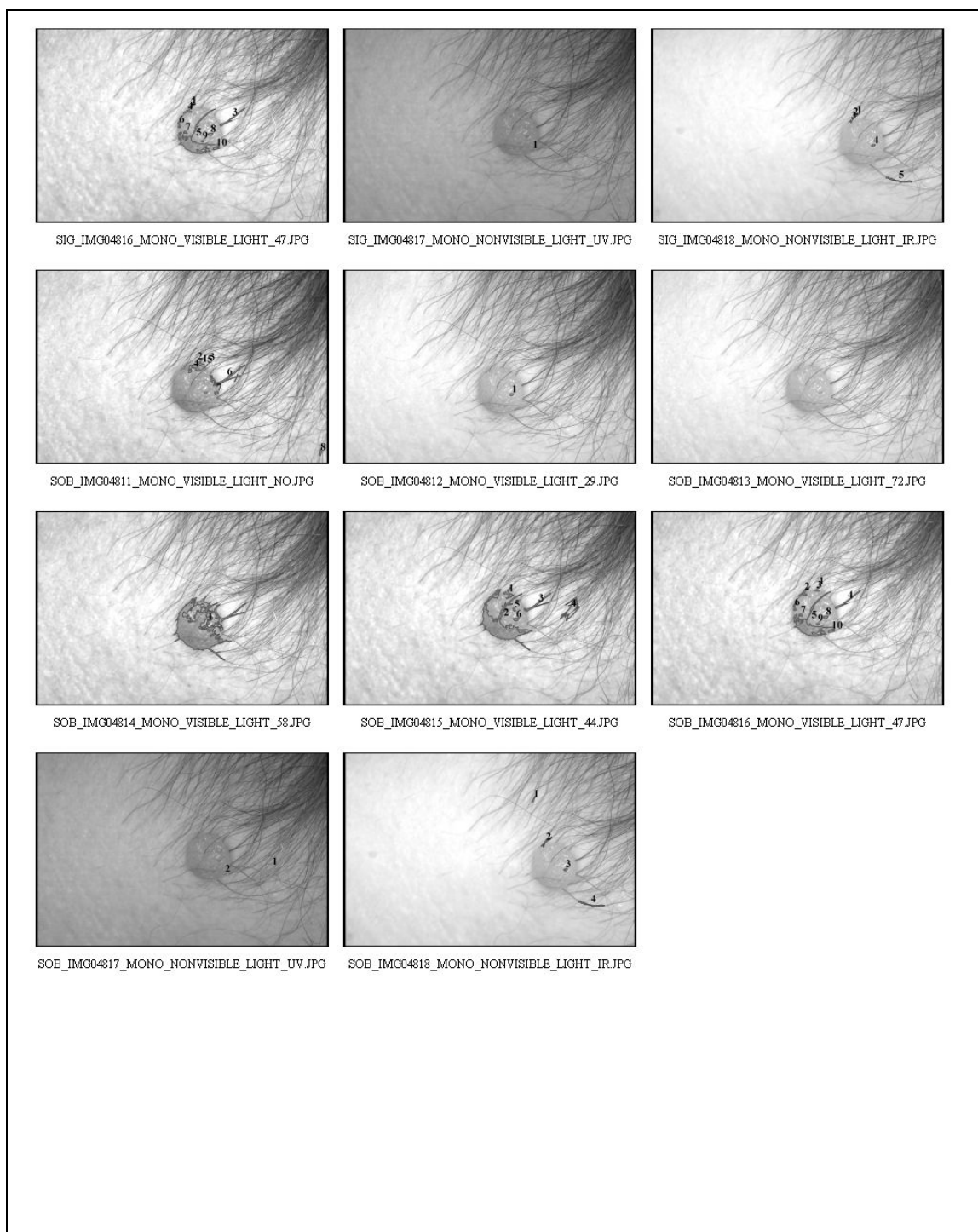


Figure 175. Lesion 481X Processed Sheet 4

Lesion 482X

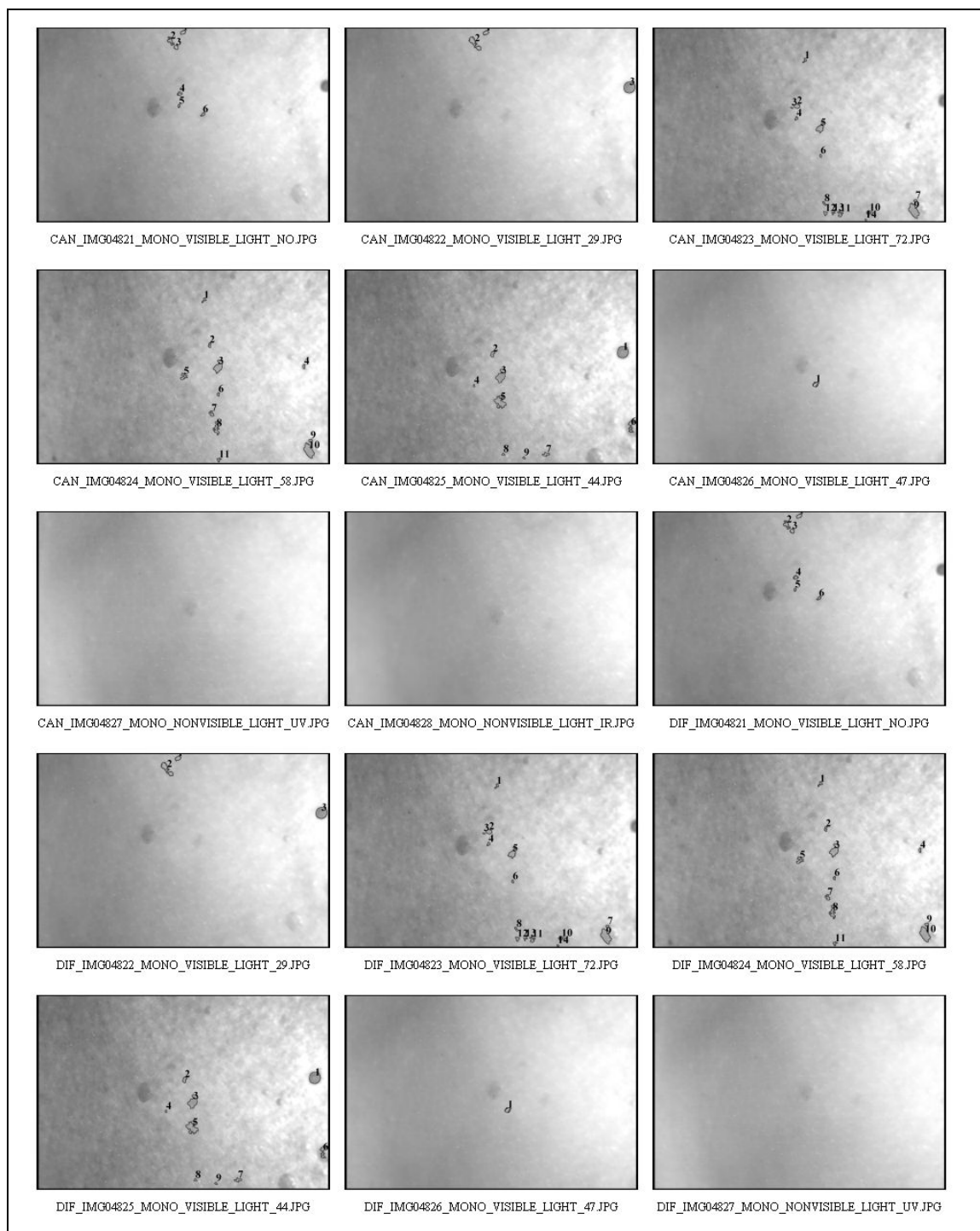


Figure 176. Lesion 482X Processed Sheet 1

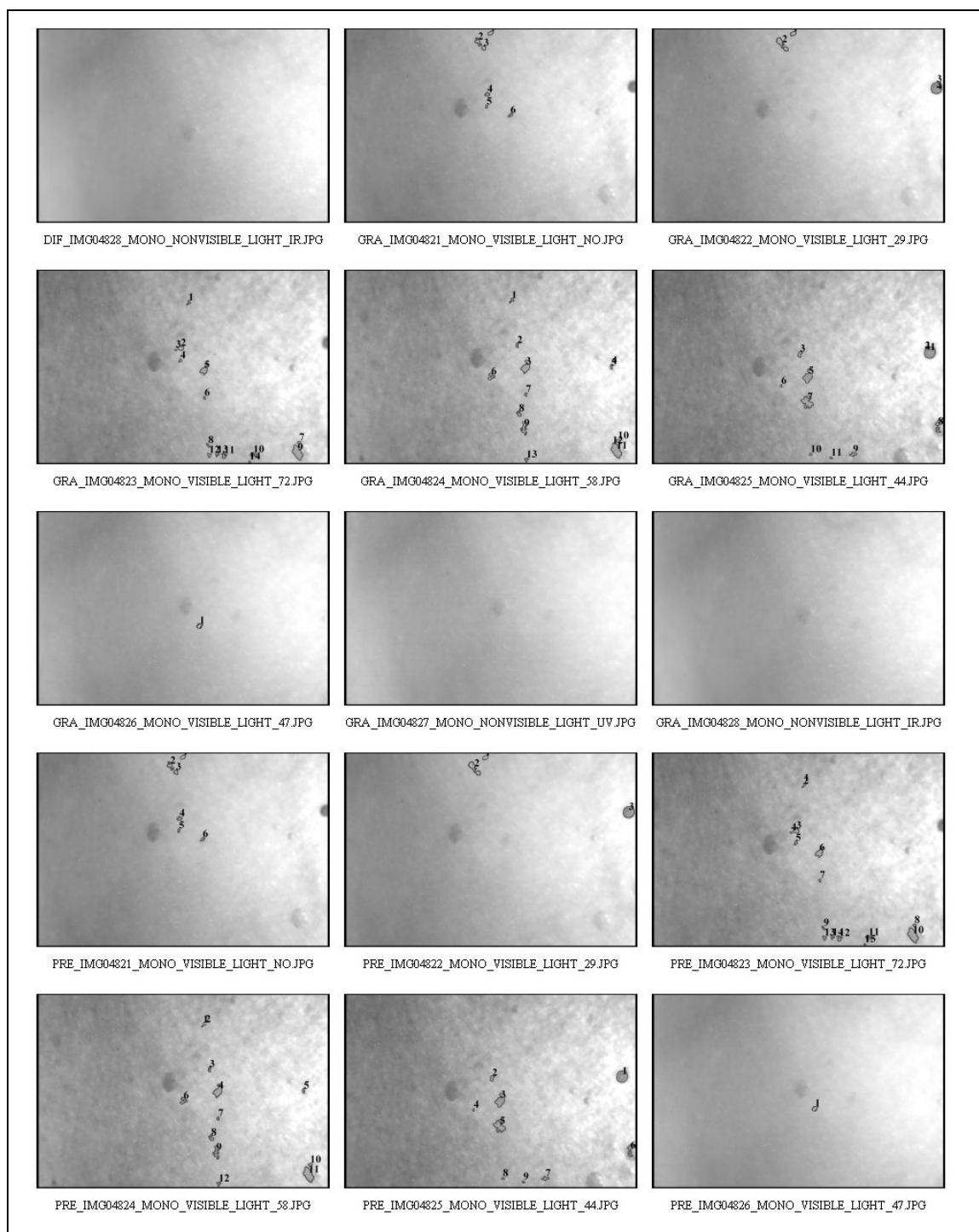


Figure 177. Lesion 482X Processed Sheet 2

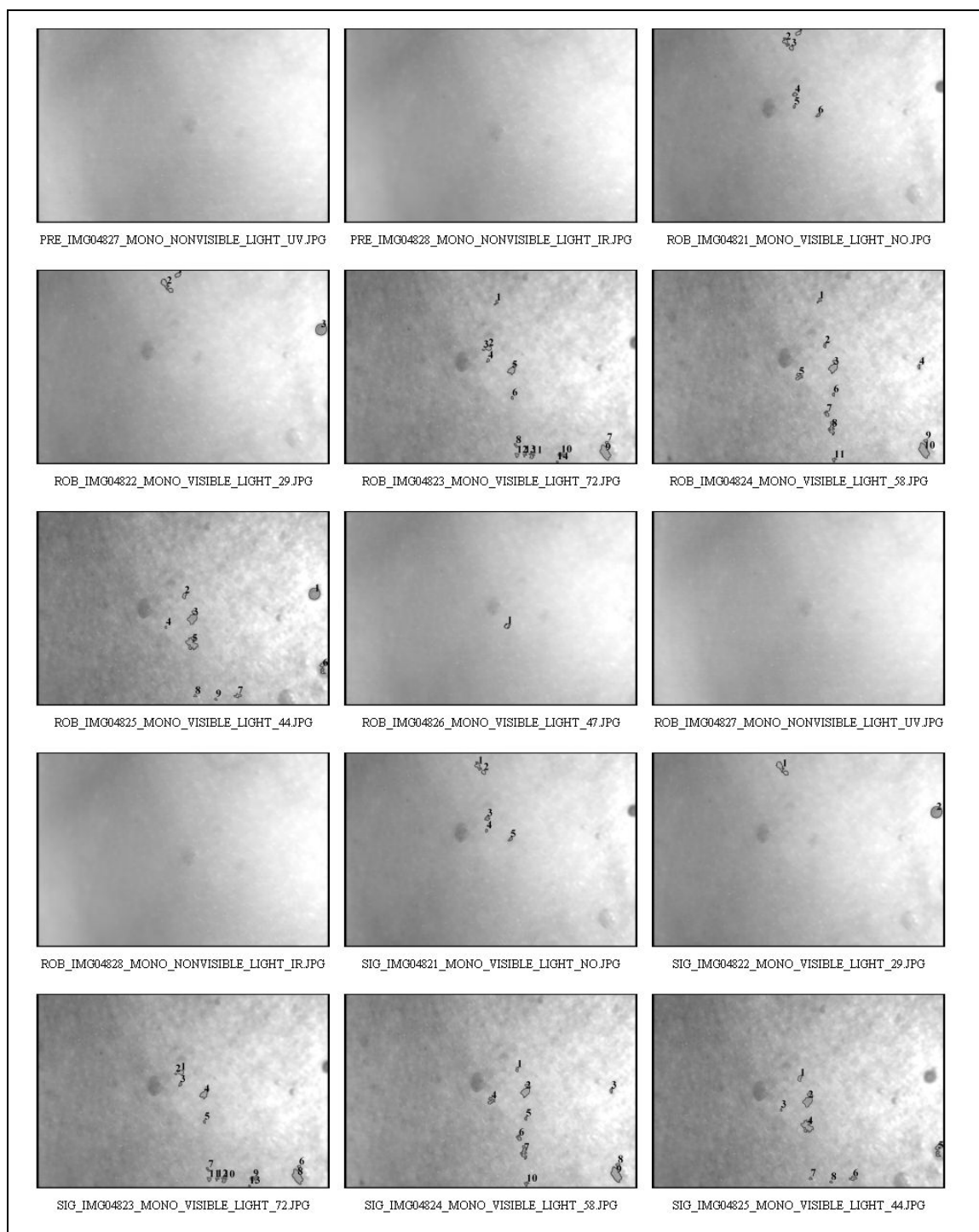


Figure 178. Lesion 482X Processed Sheet 3

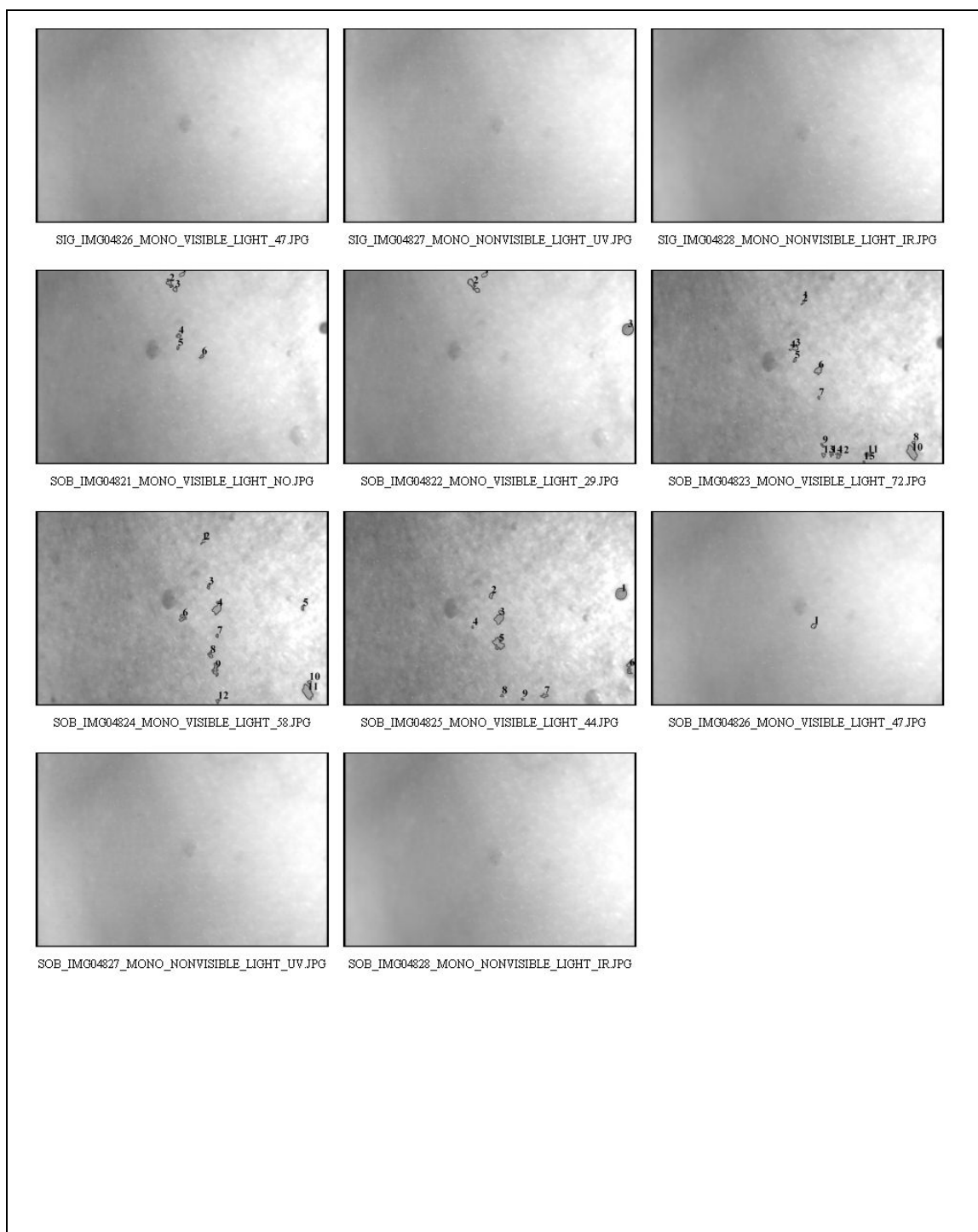


Figure 179. Lesion 482X Processed Sheet 4

Appendix R

Lesion Measurement Reports

Lesion 453X

Table 22. Lesion 453X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	1	1	48	6	3	1	1	1
Parts Found	1	1	70	61	5	1	1	1
Elongation	2.17	2.07	3.99	3.23	2.08	2.20	2.17	2.23
Compactness	0.10	0.12	0.20	0.10	0.09	0.09	0.11	0.12
Perimeter	775.49	1043.98	1500.21	3204.44	933.49	752.90	767.85	789.48
Heywood Cir.	3.01	3.23	3.75	5.08	3.32	3.00	2.97	2.93
Area	5273	8314	12756	31625	6309	5020	5333	5784

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	1	1	48	5	3	1	1	1
Parts Found	1	1	65	57	5	1	1	1
Elongation	2.17	2.05	3.58	3.24	2.08	2.20	2.16	2.23
Compactness	0.10	0.13	0.22	0.10	0.09	0.09	0.11	0.12
Perimeter	780.92	1045.18	1796.06	3205.04	944.52	766.87	776.87	784.88
Heywood Cir.	3.04	3.17	4.05	4.95	3.32	3.00	2.95	2.84
Area	5254	8650	15624	33376	6432	5212	5505	6058

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	1	1	50	17	3	1	4	1
Parts Found	3	1	69	66	7	1	4	1
Elongation	2.17	2.05	3.58	3.85	2.72	2.20	3.33	2.23
Compactness	0.09	0.13	0.22	0.08	0.06	0.09	0.14	0.12
Perimeter	1425.73	1045.18	2302.59	2522.09	1165.53	1485.36	667.94	785.67
Heywood Cir.	5.71	3.16	5.20	5.38	5.11	5.81	3.93	2.84
Area	4958	8719	15612	17458	4133	5198	2294	6078

Table 23. Lesion 453X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt	Heliopan 8125							
Largest Part	1	1	48	5	3	2	1	1
Parts Found	3	9	63	52	5	2	2	3
Elongation	2.30	2.24	3.74	3.21	2.08	1.97	2.31	2.43
Compactness	0.08	0.10	0.20	0.12	0.10	0.07	0.09	0.07
Perimeter	1135.43	851.85	2196.25	3371.38	944.23	1139.38	1273.56	1112.65
Heywood Cir.	5.23	4.20	4.26	4.78	3.07	5.49	5.59	5.17
Area	3749	3274	21111	39595	7518	3427	4124	3692
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Roberts	Heliopan 8125							
Largest Part	1	1	48	5	3	1	1	1
Parts Found	1	1	65	57	5	1	1	1
Elongation	2.17	2.05	3.58	3.24	2.08	2.20	2.16	2.23
Compactness	0.10	0.13	0.22	0.10	0.09	0.09	0.11	0.12
Perimeter	780.92	1045.18	1796.06	3205.04	944.52	766.87	776.87	784.88
Heywood Cir.	3.04	3.16	4.05	4.95	3.32	3.00	2.95	2.84
Area	5254	8721	15632	33383	6433	5215	5506	6077
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sigma	Heliopan 8125							
Largest Part	0	0	47	6	2	0	0	0
Parts Found	0	0	62	53	4	0	0	0
Elongation	0.00	0.00	3.74	3.21	2.08	0.00	0.00	0.00
Compactness	0.00	0.00	0.20	0.12	0.09	0.00	0.00	0.00
Perimeter	0.00	0.00	2196.25	3371.38	933.32	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	4.29	4.79	3.30	0.00	0.00	0.00
Area	0	0	20846	39482	6351	0	0	0
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sobel	Heliopan 8125							
Largest Part	1	1	48	5	3	2	1	1
Parts Found	3	9	63	52	5	2	2	3
Elongation	2.30	2.24	3.74	3.21	2.08	1.97	2.31	2.43
Compactness	0.08	0.10	0.20	0.12	0.10	0.07	0.09	0.07
Perimeter	1135.43	851.85	2196.25	3371.38	945.35	1139.38	1273.56	1112.65
Heywood Cir.	5.23	4.20	4.26	4.78	3.19	5.49	5.59	5.17
Area	3749	3274	21116	39588	6980	3427	4124	3692

Lesion 454X

Table 24. Lesion 454X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	4	1	11	13	11	1	3	1
Parts Found	6	1	13	16	13	1	4	1
Elongation	2.36	2.68	2.48	2.36	2.35	2.39	2.35	2.03
Compactness	0.20	0.40	0.32	0.22	0.22	0.45	0.27	0.54
Perimeter	836.15	750.53	923.87	830.12	875.09	208.91	860.35	173.96
Heywood Cir. Area	2.75 7336	2.21 9195	2.58 10167	2.59 8187	2.75 8050	1.53 1488	2.80 7533	1.43 1172

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	4	1	11	13	11	1	3	1
Parts Found	6	1	13	16	13	1	4	1
Elongation	2.37	2.76	2.49	2.37	2.35	2.34	2.37	1.96
Compactness	0.20	0.40	0.32	0.22	0.22	0.45	0.27	0.53
Perimeter	788.95	742.21	900.69	826.26	881.74	214.74	813.11	167.95
Heywood Cir. Area	2.60 7311	2.17 9268	2.53 10059	2.58 8160	2.77 8073	1.53 1568	2.61 7734	1.35 1229

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	4	1	11	13	11	1	3	1
Parts Found	6	1	13	16	13	1	4	1
Elongation	2.37	2.76	2.49	2.37	2.35	2.34	2.37	1.96
Compactness	0.20	0.40	0.32	0.22	0.22	0.45	0.27	0.54
Perimeter	788.95	742.21	900.69	826.26	881.74	214.74	813.11	167.95
Heywood Cir. Area	2.60 7311	2.16 9381	2.53 10061	2.58 8162	2.77 8074	1.53 1568	2.61 7735	1.35 1238

Table 25. Lesion 454X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt	Heliopan 8125							
Largest Part	4	3	11	13	11	1	3	1
Parts Found	6	3	13	16	13	1	4	1
Elongation	2.36	2.35	2.47	2.36	2.34	2.32	2.36	2.00
Compactness	0.21	0.51	0.34	0.23	0.24	0.43	0.29	0.47
Perimeter	758.31	433.00	870.30	766.60	807.10	193.47	788.75	266.71
Heywood Cir.	2.39	1.82	2.36	2.31	2.43	1.48	2.41	2.36
Area	7988	4523	10858	8743	8807	1358	8499	1014
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Roberts	Heliopan 8125							
Largest Part	4	1	11	13	11	1	3	1
Parts Found	6	1	13	16	13	1	4	1
Elongation	2.37	2.76	2.49	2.37	2.35	2.34	2.37	1.96
Compactness	0.20	0.40	0.32	0.22	0.22	0.45	0.27	0.54
Perimeter	788.95	742.21	900.69	826.26	881.74	214.74	813.11	167.95
Heywood Cir.	2.60	2.16	2.53	2.58	2.77	1.53	2.61	1.34
Area	7311	9374	10062	8160	8073	1571	7734	1251
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sigma	Heliopan 8125							
Largest Part	3	0	10	12	12	0	2	0
Parts Found	5	0	12	15	14	0	3	0
Elongation	2.37	0.00	2.47	2.36	2.34	0.00	2.36	0.00
Compactness	0.21	0.00	0.33	0.23	0.23	0.00	0.27	0.00
Perimeter	773.31	0.00	870.30	766.60	807.10	0.00	811.27	0.00
Heywood Cir.	2.48	0.00	2.37	2.33	2.44	0.00	2.62	0.00
Area	7715	0	10724	8579	8676	0	7638	0
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sobel	Heliopan 8125							
Largest Part	4	3	11	13	11	1	3	1
Parts Found	6	3	13	16	13	1	4	1
Elongation	2.36	2.35	2.47	2.36	2.34	2.32	2.37	2.00
Compactness	0.21	0.51	0.34	0.23	0.24	0.43	0.29	0.47
Perimeter	758.31	433.00	870.30	766.60	807.10	193.47	798.37	266.71
Heywood Cir.	2.39	1.82	2.36	2.31	2.43	1.48	2.46	2.36
Area	7988	4523	10858	8743	8807	1358	8378	1014

Lesion 455X

Table 26. Lesion 455X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	3	0	1	2	1	0	1	0
Parts Found	4	0	1	2	1	0	1	0
Elongation	1.51	0.00	2.64	1.62	1.77	0.00	2.02	0.00
Compactness	0.23	0.00	0.59	0.34	0.33	0.00	0.37	0.00
Perimeter	698.76	0.00	83.82	537.12	531.57	0.00	320.31	0.00
Heywood Cir.	2.59	0.00	1.21	2.20	2.33	0.00	1.83	0.00
Area	5774	0	385	4735	4146	0	2437	0

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	3	0	1	2	1	0	1	0
Parts Found	4	0	1	2	1	0	1	0
Elongation	1.51	0.00	2.53	1.62	1.77	0.00	2.05	0.00
Compactness	0.23	0.00	0.62	0.35	0.35	0.00	0.38	0.00
Perimeter	707.28	0.00	88.32	541.36	490.38	0.00	325.67	0.00
Heywood Cir.	2.59	0.00	1.22	2.19	2.10	0.00	1.81	0.00
Area	5947	0	417	4860	4338	0	2569	0

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	3	0	1	2	1	0	1	0
Parts Found	7	0	1	2	1	0	1	0
Elongation	3.69	0.00	2.53	1.62	1.77	0.00	2.05	0.00
Compactness	0.36	0.00	0.62	0.35	0.35	0.00	0.38	0.00
Perimeter	475.66	0.00	88.32	930.91	490.38	0.00	374.49	0.00
Heywood Cir.	2.80	0.00	1.22	3.78	2.10	0.00	2.09	0.00
Area	2293	0	418	4835	4342	0	2562	0

Table 27. Lesion 455X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt								
Largest Part	3	0	1	2	1	0	1	0
Parts Found	4	0	1	2	1	0	1	0
Elongation	1.51	0.00	2.53	1.63	1.81	0.00	1.99	0.00
Compactness	0.26	0.00	0.60	0.37	0.31	0.00	0.34	0.00
Perimeter	681.27	0.00	81.33	513.09	506.18	0.00	315.29	0.00
Heywood Cir.	2.35	0.00	1.26	2.04	2.27	0.00	1.88	0.00
Area	6690	0	330	5053	3961	0	2247	0
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Roberts								
Largest Part	3	0	1	2	1	0	1	0
Parts Found	4	0	1	2	1	0	1	0
Elongation	1.51	0.00	2.53	1.62	1.77	0.00	2.05	0.00
Compactness	0.23	0.00	0.62	0.35	0.35	0.00	0.38	0.00
Perimeter	707.28	0.00	88.32	541.36	490.38	0.00	325.67	0.00
Heywood Cir.	2.59	0.00	1.22	2.19	2.10	0.00	1.81	0.00
Area	5948	0	418	4860	4338	0	2571	0
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sigma								
Largest Part	2	0	0	1	1	0	0	0
Parts Found	3	0	0	1	1	0	0	0
Elongation	1.51	0.00	0.00	1.63	2.83	0.00	0.00	0.00
Compactness	0.23	0.00	0.00	0.31	0.53	0.00	0.00	0.00
Perimeter	694.20	0.00	0.00	1018.94	175.77	0.00	0.00	0.00
Heywood Cir.	2.55	0.00	0.00	4.46	1.94	0.00	0.00	0.00
Area	5887	0	0	4156	650	0	0	0
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sobel								
Largest Part	3	0	1	2	1	0	1	0
Parts Found	4	0	1	2	1	0	1	0
Elongation	1.50	0.00	2.53	1.62	1.80	0.00	1.99	0.00
Compactness	0.25	0.00	0.60	0.37	0.32	0.00	0.34	0.00
Perimeter	679.09	0.00	81.33	532.55	514.40	0.00	315.29	0.00
Heywood Cir.	2.38	0.00	1.26	2.08	2.29	0.00	1.88	0.00
Area	6474	0	330	5194	4000	0	2247	0

Lesion 456X

Table 28. Lesion 456X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	7	0	17	19	12	2	5	1
Parts Found	42	0	33	39	31	19	25	5
Elongation	4.06	0.00	2.39	4.87	3.75	4.29	4.66	4.32
Compactness	0.19	0.00	0.26	0.28	0.49	0.27	0.18	0.34
Perimeter	761.26	0.00	1311.85	1394.40	356.94	320.07	509.03	467.01
Heywood Cir. Area	2.85 5688	0.00 0	3.44 11592	4.04 9479	1.81 3101	1.90 2259	2.49 3333	2.25 3434

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	40	0	17	11	12	2	5	1
Parts Found	41	0	32	38	30	19	24	5
Elongation	1.78	0.00	2.39	5.08	3.69	4.23	4.56	4.22
Compactness	0.35	0.00	0.28	0.17	0.49	0.28	0.19	0.36
Perimeter	792.19	0.00	1273.24	1610.10	362.13	322.64	522.28	476.01
Heywood Cir. Area	2.85 6141	0.00 0	3.23 12392	4.03 12702	1.80 3214	1.87 2363	2.53 3397	2.22 3663

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	54	0	19	17	16	2	5	1
Parts Found	55	0	37	54	36	21	29	5
Elongation	1.78	0.00	2.39	4.99	3.69	4.23	4.56	4.22
Compactness	0.35	0.00	0.28	0.21	0.48	0.28	0.19	0.36
Perimeter	1042.10	0.00	2142.10	1588.86	526.16	322.64	618.14	490.46
Heywood Cir. Area	3.77 6083	0.00 0	5.45 12307	5.06 7834	2.66 3113	1.87 2364	3.00 3371	2.29 3663

Table 29. Lesion 456X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Prewitt	Heliopan 8125	UG1						UG1
Largest Part	38	0	17	11	12	10	5	7
Parts Found	39	0	32	37	30	19	24	7
Elongation	1.78	0.00	2.38	5.02	3.62	2.86	4.47	3.51
Compactness	0.37	0.00	0.29	0.19	0.52	0.46	0.20	0.31
Perimeter	782.66	0.00	1112.58	1466.89	357.15	380.69	512.52	414.27
Heywood Cir.	2.71	0.00	2.75	3.52	1.71	2.05	2.40	2.11
Area	6658	0	13063	13821	3476	2756	3632	3058
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Roberts	Heliopan 8125	UG1						UG1
Largest Part	40	0	17	11	12	2	5	1
Parts Found	41	0	32	38	30	19	24	5
Elongation	1.78	0.00	2.39	5.08	3.69	4.23	4.56	4.22
Compactness	0.35	0.00	0.28	0.17	0.49	0.28	0.19	0.36
Perimeter	792.19	0.00	1273.24	1610.10	362.13	322.64	522.28	476.01
Heywood Cir.	2.85	0.00	3.22	4.03	1.80	1.87	2.53	2.22
Area	6141	0	12406	12703	3217	2366	3397	3670
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sigma	Heliopan 8125	UG1						UG1
Largest Part	38	0	16	11	11	8	4	5
Parts Found	39	0	31	37	29	17	23	5
Elongation	1.78	0.00	2.38	5.02	3.62	2.86	4.57	3.53
Compactness	0.37	0.00	0.29	0.19	0.52	0.46	0.19	0.30
Perimeter	782.66	0.00	1112.58	1466.89	357.15	380.69	523.97	405.36
Heywood Cir.	2.72	0.00	2.76	3.53	1.72	2.05	2.51	2.12
Area	6609	0	12936	13769	3441	2742	3474	2915
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sobel	Heliopan 8125	UG1						UG1
Largest Part	38	0	17	11	12	10	5	7
Parts Found	39	0	32	37	30	19	24	7
Elongation	1.78	0.00	2.38	5.02	3.62	2.86	4.47	3.51
Compactness	0.37	0.00	0.29	0.19	0.52	0.46	0.20	0.31
Perimeter	782.66	0.00	1112.58	1466.89	357.15	380.69	512.52	414.27
Heywood Cir.	2.71	0.00	2.75	3.52	1.71	2.05	2.40	2.11
Area	6658	0	13054	13818	3476	2756	3632	3063

Lesion 457X

Table 30. Lesion 457X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	7	1	3	6	8	3	10	0
Parts Found	43	2	17	20	24	9	11	0
Elongation	1.84	1.82	2.25	1.96	1.96	2.27	1.52	0.00
Compactness	0.15	0.35	0.18	0.20	0.20	0.21	0.25	0.00
Perimeter	1027.12	598.48	863.98	867.59	879.86	961.28	933.49	0.00
Heywood Cir.	3.33	2.05	3.04	2.77	2.81	3.32	3.12	0.00
Area	7581	6753	6428	7806	7776	6666	7133	0

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	7	1	3	6	8	3	10	0
Parts Found	43	2	15	20	24	9	11	0
Elongation	1.82	1.83	2.25	1.95	1.96	2.27	1.52	0.00
Compactness	0.16	0.37	0.19	0.20	0.19	0.21	0.25	0.00
Perimeter	1021.72	597.61	862.82	886.75	879.43	953.50	936.38	0.00
Heywood Cir.	3.20	2.02	3.00	2.86	2.86	3.28	3.10	0.00
Area	8099	6963	6596	7660	7539	6730	7284	0

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	7	1	14	6	10	3	14	0
Parts Found	68	2	18	29	33	10	16	0
Elongation	1.81	1.83	1.96	1.82	3.65	2.27	1.52	0.00
Compactness	0.12	0.37	0.13	0.19	0.18	0.21	0.24	0.00
Perimeter	1469.55	597.61	909.68	1315.33	880.23	953.50	1666.41	0.00
Heywood Cir.	5.38	2.01	4.38	4.74	3.84	3.28	5.61	0.00
Area	5936	7011	3431	6126	4185	6724	7022	0

Table 31. Lesion 457X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Prewitt	Heliopan 8125	UG1						UG1
Largest Part	7	1	3	6	8	3	11	0
Parts Found	43	3	15	19	24	9	12	0
Elongation	1.82	2.38	2.24	1.95	1.96	2.26	1.52	0.00
Compactness	0.17	0.31	0.21	0.22	0.21	0.23	0.28	0.00
Perimeter	1012.85	909.58	841.36	867.52	865.63	763.21	589.11	0.00
Heywood Cir.	2.99	3.74	2.76	2.65	2.66	2.47	1.83	0.00
Area	9121	4697	7410	8514	8398	7587	8254	0
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Roberts	Heliopan 8125	UG1						UG1
Largest Part	7	1	3	6	8	3	10	0
Parts Found	43	2	15	20	24	9	11	0
Elongation	1.82	1.83	2.25	1.95	1.96	2.27	1.52	0.00
Compactness	0.16	0.37	0.19	0.20	0.19	0.21	0.25	0.00
Perimeter	1021.72	597.61	862.82	886.75	879.43	953.50	936.38	0.00
Heywood Cir.	3.20	2.01	3.00	2.86	2.86	3.28	3.10	0.00
Area	8099	7006	6596	7660	7543	6731	7284	0
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sigma	Heliopan 8125	UG1						UG1
Largest Part	6	2	2	9	7	7	10	0
Parts Found	42	2	14	22	23	8	11	0
Elongation	1.82	2.35	2.26	1.96	1.96	1.74	1.52	0.00
Compactness	0.17	0.21	0.18	0.21	0.21	0.31	0.28	0.00
Perimeter	1004.13	470.51	842.26	870.63	865.63	866.56	589.11	0.00
Heywood Cir.	3.06	2.22	2.96	2.73	2.68	2.97	1.83	0.00
Area	8570	3574	6452	8092	8316	6755	8211	0
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sobel	Heliopan 8125	UG1						UG1
Largest Part	7	1	3	6	8	3	11	0
Parts Found	43	3	15	19	24	9	12	0
Elongation	1.82	2.37	2.25	1.95	1.96	2.27	1.52	0.00
Compactness	0.17	0.32	0.20	0.22	0.21	0.23	0.28	0.00
Perimeter	1012.85	897.37	852.53	867.52	865.63	770.49	589.11	0.00
Heywood Cir.	2.99	3.65	2.84	2.65	2.66	2.53	1.83	0.00
Area	9121	4821	7186	8514	8398	7409	8250	0

Lesion 458X

Table 32. Lesion 458X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	0	0	0	0	0	0	0	0
Parts Found	0	0	0	0	0	0	0	0
Elongation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Area	0	0	0	0	0	0	0	0

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	0	0	0	0	0	0	0	0
Parts Found	0	0	0	0	0	0	0	0
Elongation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Area	0	0	0	0	0	0	0	0

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	0	0	0	0	0	0	0	0
Parts Found	0	0	0	0	0	0	0	0
Elongation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Area	0	0	0	0	0	0	0	0

Table 33. Lesion 458X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Prewitt	Heliopan 8125	UG1						UG1
Largest Part	0	0	0	0	0	0	0	0
Parts Found	0	0	0	0	0	0	0	0
Elongation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Area	0	0	0	0	0	0	0	0
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Roberts	Heliopan 8125	UG1						UG1
Largest Part	0	0	0	0	0	0	0	0
Parts Found	0	0	0	0	0	0	0	0
Elongation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Area	0	0	0	0	0	0	0	0
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sigma	Heliopan 8125	UG1						UG1
Largest Part	0	0	0	0	0	0	0	0
Parts Found	0	0	0	0	0	0	0	0
Elongation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Area	0	0	0	0	0	0	0	0
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sobel	Heliopan 8125	UG1						UG1
Largest Part	0	0	0	0	0	0	0	0
Parts Found	0	0	0	0	0	0	0	0
Elongation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Area	0	0	0	0	0	0	0	0

Lesion 459X

Table 34. Lesion 459X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	12	1	10	2	5	3	6	2
Parts Found	21	2	31	20	20	5	8	4
Elongation	3.43	2.95	5.94	2.95	4.59	15.45	2.26	3.95
Compactness	0.23	0.47	0.22	0.23	0.20	0.11	0.45	0.20
Perimeter	1374.34	203.75	553.43	949.03	818.56	511.60	402.34	610.24
Heywood Cir. Area	3.57 11786	1.35 1803	2.22 4952	3.31 6532	2.98 5989	2.82 2625	2.11 2902	2.69 4088

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	12	1	10	2	5	3	6	2
Parts Found	21	2	31	20	20	5	8	4
Elongation	3.45	2.96	5.93	2.95	4.57	14.96	2.27	3.95
Compactness	0.23	0.48	0.22	0.23	0.20	0.11	0.46	0.21
Perimeter	1393.75	204.20	551.27	957.56	817.59	512.16	399.91	632.04
Heywood Cir. Area	3.58 12070	1.33 1869	2.20 5015	3.30 6687	2.97 6025	2.79 2679	2.07 2961	2.75 4195

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	12	1	10	2	5	3	6	2
Parts Found	22	2	32	20	21	5	8	4
Elongation	3.45	2.96	5.93	2.95	4.57	14.96	2.27	3.95
Compactness	0.23	0.49	0.22	0.23	0.20	0.11	0.46	0.21
Perimeter	1400.27	204.20	551.27	957.56	817.59	512.16	399.91	632.04
Heywood Cir. Area	3.60 12068	1.32 1904	2.20 5016	3.30 6688	2.97 6026	2.79 2679	2.07 2962	2.75 4198

Table 35. Lesion 459X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Prewitt	Heliopan 8125	UG1						UG1
Largest Part	12	1	10	2	5	3	6	2
Parts Found	21	2	31	20	20	5	8	4
Elongation	3.42	3.02	5.79	2.92	4.50	13.97	2.25	3.91
Compactness	0.25	0.44	0.23	0.25	0.22	0.12	0.47	0.21
Perimeter	1271.83	216.20	552.04	886.72	816.00	514.94	401.10	609.62
Heywood Cir.	3.11	1.51	2.15	2.91	2.83	2.70	2.02	2.62
Area	13266	1636	5257	7366	6622	2898	3144	4293
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Roberts	Heliopan 8125	UG1						UG1
Largest Part	12	1	10	2	5	3	6	2
Parts Found	21	2	31	20	20	5	8	4
Elongation	3.45	2.96	5.93	2.95	4.57	14.96	2.27	3.95
Compactness	0.23	0.49	0.22	0.23	0.20	0.11	0.46	0.21
Perimeter	1393.75	204.20	551.27	957.56	817.59	512.16	399.91	632.04
Heywood Cir.	3.58	1.32	2.20	3.30	2.97	2.79	2.07	2.75
Area	12075	1891	5017	6687	6027	2679	2963	4210
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sigma	Heliopan 8125	UG1						UG1
Largest Part	12	1	12	1	4	2	5	1
Parts Found	21	1	33	20	19	4	7	3
Elongation	3.42	3.54	5.79	2.96	4.52	15.40	2.25	4.00
Compactness	0.25	0.53	0.23	0.24	0.21	0.11	0.47	0.18
Perimeter	1271.83	172.32	552.04	987.26	815.08	510.03	396.83	672.73
Heywood Cir.	3.13	1.89	2.17	3.37	2.89	2.83	2.01	3.17
Area	13174	662	5142	6825	6311	2579	3110	3589
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sobel	Heliopan 8125	UG1						UG1
Largest Part	12	1	10	2	5	3	6	2
Parts Found	21	2	31	20	20	5	8	4
Elongation	3.42	3.02	5.79	2.92	4.50	14.57	2.25	3.91
Compactness	0.25	0.44	0.23	0.25	0.22	0.11	0.47	0.22
Perimeter	1271.83	216.20	552.04	892.18	816.00	513.54	401.10	612.34
Heywood Cir.	3.11	1.51	2.15	2.94	2.83	2.74	2.02	2.59
Area	13273	1636	5257	7351	6622	2798	3144	4462

Lesion 460X

Table 36. Lesion 460X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	28	1	3	38	31	12	14	1
Parts Found	53	2	45	49	43	19	24	1
Elongation	1.58	1.82	3.00	4.56	3.37	1.81	1.67	1.69
Compactness	0.19	0.16	0.19	0.17	0.23	0.15	0.28	0.56
Perimeter	1366.11	871.37	1813.52	1765.25	1457.78	771.43	1052.38	249.39
Heywood Cir.	3.37	2.85	4.22	3.99	3.69	2.80	3.07	1.50
Area	13065	7455	14698	15612	12435	6032	9360	2213
Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	28	1	1	38	31	12	14	1
Parts Found	52	2	44	47	42	19	24	1
Elongation	1.58	1.82	2.47	4.53	3.37	1.80	1.66	1.69
Compactness	0.20	0.17	0.19	0.18	0.24	0.16	0.28	0.57
Perimeter	1377.09	853.66	2132.22	1770.87	1456.94	781.22	1041.76	257.46
Heywood Cir.	3.31	2.72	4.42	3.89	3.57	2.82	3.01	1.50
Area	13771	7826	18538	16512	13222	6128	9535	2335
Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	32	1	6	64	44	12	14	1
Parts Found	69	2	69	74	57	20	37	1
Elongation	1.58	1.82	2.41	3.33	3.53	1.80	1.66	1.69
Compactness	0.19	0.17	0.24	0.22	0.28	0.16	0.28	0.57
Perimeter	2611.06	1571.13	2200.08	2221.91	1809.03	1451.64	1603.34	365.90
Heywood Cir.	6.36	5.00	5.28	5.72	5.44	5.23	4.64	2.14
Area	13406	7854	13839	12020	8792	6126	9491	2334

Table 37. Lesion 460X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Prewitt	Heliopan 8125	UG1						UG1
Largest Part	27	1	1	36	30	12	13	1
Parts Found	51	4	42	45	41	19	23	1
Elongation	1.58	2.48	2.46	4.50	3.34	1.80	1.65	1.69
Compactness	0.21	0.11	0.20	0.19	0.26	0.17	0.31	0.51
Perimeter	1324.02	903.79	1977.88	1706.05	1450.18	769.05	1005.81	266.81
Heywood Cir.	3.05	4.44	3.97	3.59	3.40	2.64	2.78	1.66
Area	15036	3301	19732	18005	14478	6754	10403	2058
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Roberts	Heliopan 8125	UG1						UG1
Largest Part	28	1	1	38	31	12	14	1
Parts Found	52	2	44	47	42	19	24	1
Elongation	1.58	1.82	2.47	4.53	3.37	1.80	1.66	1.69
Compactness	0.20	0.17	0.19	0.18	0.24	0.16	0.28	0.57
Perimeter	1377.09	853.66	2132.22	1770.87	1456.94	781.22	1041.76	257.46
Heywood Cir.	3.31	2.72	4.42	3.89	3.57	2.82	3.01	1.50
Area	13774	7864	18555	16514	13224	6128	9542	2335
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sigma	Heliopan 8125	UG1						UG1
Largest Part	28	1	2	36	30	11	12	0
Parts Found	52	1	42	45	41	18	22	0
Elongation	1.58	2.60	2.70	4.50	3.34	1.80	1.65	0.00
Compactness	0.21	0.52	0.19	0.19	0.26	0.17	0.30	0.00
Perimeter	1324.02	151.76	1712.45	1706.05	1450.18	769.05	1005.81	0.00
Heywood Cir.	3.06	1.47	3.69	3.60	3.42	2.65	2.79	0.00
Area	14904	850	17125	17851	14341	6696	10308	0
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sobel	Heliopan 8125	UG1						UG1
Largest Part	27	1	1	36	30	12	13	1
Parts Found	51	4	42	45	41	19	23	1
Elongation	1.58	2.48	2.46	4.50	3.34	1.80	1.65	1.69
Compactness	0.21	0.11	0.20	0.19	0.26	0.17	0.31	0.51
Perimeter	1324.02	903.79	1980.49	1706.05	1450.18	769.05	1005.81	266.81
Heywood Cir.	3.05	4.44	3.98	3.59	3.40	2.64	2.78	1.66
Area	15033	3301	19723	18002	14473	6754	10396	2058

Lesion 472X

Table 38. Lesion 472X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	0	3	5	3	1	1	0
Parts Found	7	0	13	12	10	1	4	0
Elongation	1.55	0.00	1.53	1.54	1.45	1.51	1.49	0.00
Compactness	0.16	0.00	0.22	0.16	0.18	0.40	0.31	0.00
Perimeter	1029.20	0.00	1147.74	1114.51	1030.75	1176.38	1018.61	0.00
Heywood Cir.	3.00	0.00	2.90	3.22	2.84	3.41	3.14	0.00
Area	9343	0	12497	9546	10468	9493	8387	0

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	0	3	5	3	1	1	0
Parts Found	7	0	13	12	10	1	4	0
Elongation	1.55	0.00	1.53	1.54	1.46	1.51	1.49	0.00
Compactness	0.16	0.00	0.22	0.16	0.18	0.40	0.32	0.00
Perimeter	1046.92	0.00	1146.93	1120.09	1027.33	1086.77	967.65	0.00
Heywood Cir.	3.04	0.00	2.89	3.23	2.80	3.11	2.95	0.00
Area	9455	0	12524	9562	10701	9724	8588	0

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	0	3	5	3	1	1	0
Parts Found	7	0	13	12	12	1	4	0
Elongation	1.55	0.00	1.53	1.54	1.46	1.51	1.49	0.00
Compactness	0.16	0.00	0.22	0.16	0.18	0.40	0.32	0.00
Perimeter	1974.40	0.00	1146.93	1119.37	1046.85	1086.77	1664.48	0.00
Heywood Cir.	5.73	0.00	2.89	3.23	2.86	3.11	5.07	0.00
Area	9441	0	12526	9558	10697	9727	8584	0

Table 39. Lesion 472X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Prewitt	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	0	3	5	3	1	1	0
Parts Found	7	0	11	12	10	1	4	0
Elongation	1.55	0.00	1.53	1.54	1.46	1.51	1.49	0.00
Compactness	0.17	0.00	0.24	0.17	0.20	0.40	0.29	0.00
Perimeter	1013.78	0.00	1132.90	1051.88	1016.53	1061.94	1088.29	0.00
Heywood Cir.	2.81	0.00	2.74	2.90	2.66	3.04	3.46	0.00
Area	10378	0	13633	10470	11629	9684	7870	0
Roberts	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	0	3	5	3	1	1	0
Parts Found	7	0	13	12	10	1	4	0
Elongation	1.55	0.00	1.53	1.54	1.46	1.51	1.49	0.00
Compactness	0.16	0.00	0.22	0.16	0.18	0.40	0.32	0.00
Perimeter	1046.92	0.00	1146.93	1120.09	1027.33	1086.77	967.65	0.00
Heywood Cir.	3.04	0.00	2.89	3.23	2.80	3.11	2.95	0.00
Area	9455	0	12524	9562	10705	9725	8588	0
Sigma	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	0	5	4	2	1	2	0
Parts Found	7	0	13	11	9	5	3	0
Elongation	1.56	0.00	1.52	1.55	1.46	2.77	2.51	0.00
Compactness	0.16	0.00	0.23	0.16	0.18	0.33	0.31	0.00
Perimeter	1040.35	0.00	1136.84	1062.91	1015.12	536.43	278.36	0.00
Heywood Cir.	3.05	0.00	2.80	3.01	2.79	2.52	1.79	0.00
Area	9286	0	13126	9927	10551	3604	1914	0
Sobel	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	0	3	5	3	1	1	0
Parts Found	7	0	11	12	10	1	4	0
Elongation	1.55	0.00	1.53	1.54	1.45	1.51	1.49	0.00
Compactness	0.17	0.00	0.24	0.17	0.19	0.41	0.29	0.00
Perimeter	1016.37	0.00	1132.90	1051.88	1024.73	1052.09	1088.29	0.00
Heywood Cir.	2.84	0.00	2.74	2.90	2.70	3.00	3.46	0.00
Area	10161	0	13633	10470	11504	9775	7870	0

Lesion 473X

Table 40. Lesion 473X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	1	42	12	12	2	0	1
Parts Found	2	1	65	49	59	9	0	1
Elongation	1.69	2.59	3.52	1.70	1.77	1.52	0.00	3.20
Compactness	0.30	0.30	0.11	0.14	0.13	0.23	0.00	0.42
Perimeter	840.22	450.87	3079.16	1397.68	1538.68	1001.51	0.00	173.17
Heywood Cir.	2.25	2.30	5.63	3.48	3.75	2.52	0.00	1.54
Area	11129	3059	23791	12850	13425	12546	0	1000

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	1	41	12	12	2	0	1
Parts Found	2	1	63	49	59	9	0	1
Elongation	1.69	2.60	3.50	1.70	1.78	1.52	0.00	3.09
Compactness	0.30	0.31	0.12	0.14	0.13	0.23	0.00	0.44
Perimeter	840.86	423.30	3004.14	1378.49	1543.10	992.88	0.00	179.07
Heywood Cir.	2.23	2.12	5.34	3.35	3.68	2.50	0.00	1.53
Area	11317	3158	25218	13486	14024	12554	0	1084

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	2	1	41	12	12	2	0	1
Parts Found	2	1	64	51	59	9	0	1
Elongation	1.69	2.60	3.06	1.70	1.78	1.52	0.00	3.09
Compactness	0.30	0.31	0.14	0.14	0.13	0.23	0.00	0.44
Perimeter	840.86	423.30	3518.63	2704.47	3010.12	992.88	0.00	179.07
Heywood Cir.	2.23	2.11	6.51	6.57	7.17	2.50	0.00	1.53
Area	11315	3199	23260	13481	14020	12564	0	1088

Table 41. Lesion 473X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt	Heliopan 8125							
Largest Part	3	3	41	12	11	4	0	1
Parts Found	3	3	62	48	56	11	0	1
Elongation	1.69	2.21	3.49	1.70	1.78	1.52	0.00	3.37
Compactness	0.31	0.24	0.12	0.15	0.14	0.24	0.00	0.38
Perimeter	817.97	349.57	2869.28	1360.46	1525.79	956.30	0.00	175.56
Heywood Cir.	2.11	2.77	4.96	3.18	3.49	2.35	0.00	1.68
Area	11975	1269	26615	14604	15253	13181	0	872
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Roberts	Heliopan 8125							
Largest Part	2	1	41	12	12	2	0	1
Parts Found	2	1	63	49	59	9	0	1
Elongation	1.69	2.60	3.50	1.70	1.78	1.52	0.00	3.09
Compactness	0.30	0.31	0.12	0.14	0.13	0.23	0.00	0.44
Perimeter	840.86	423.30	3004.14	1378.49	1543.10	992.88	0.00	179.07
Heywood Cir.	2.23	2.11	5.33	3.35	3.68	2.50	0.00	1.53
Area	11317	3190	25245	13487	14025	12559	0	1087
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sigma	Heliopan 8125							
Largest Part	13	0	41	11	12	1	0	0
Parts Found	18	0	62	47	57	8	0	0
Elongation	2.99	0.00	3.49	1.70	1.78	1.52	0.00	0.00
Compactness	0.32	0.00	0.12	0.15	0.14	0.23	0.00	0.00
Perimeter	705.60	0.00	2869.28	1360.46	1525.79	970.88	0.00	0.00
Heywood Cir.	3.46	0.00	5.00	3.20	3.50	2.43	0.00	0.00
Area	3316	0	26243	14428	15096	12697	0	0
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sobel	Heliopan 8125							
Largest Part	3	3	41	12	11	4	0	1
Parts Found	3	3	62	48	56	11	0	1
Elongation	1.68	2.21	3.49	1.70	1.78	1.52	0.00	3.37
Compactness	0.32	0.24	0.12	0.15	0.14	0.24	0.00	0.38
Perimeter	842.76	349.57	2869.28	1360.46	1525.79	962.20	0.00	175.56
Heywood Cir.	2.16	2.77	4.96	3.18	3.49	2.36	0.00	1.68
Area	12157	1269	26610	14604	15253	13218	0	872

Lesion 474X

Table 42. Lesion 474X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	19	0	22	30	21	20	15	6
Parts Found	54	0	87	97	78	58	25	6
Elongation	1.89	0.00	1.64	1.67	1.70	1.88	2.14	3.38
Compactness	0.10	0.00	0.10	0.09	0.09	0.12	0.27	0.29
Perimeter	5522.23	0.00	5446.46	5466.53	5312.19	5112.28	748.34	209.91
Heywood Cir.	8.15	0.00	8.01	7.88	7.80	6.90	2.98	1.61
Area	36539	0	36836	38341	36954	43633	5018	1354

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	19	0	22	30	21	18	15	6
Parts Found	53	0	87	96	76	56	25	6
Elongation	1.89	0.00	1.64	1.68	1.68	1.88	2.13	3.23
Compactness	0.10	0.00	0.10	0.09	0.09	0.13	0.27	0.28
Perimeter	5547.04	0.00	5061.64	5552.45	5233.33	5080.41	744.57	212.28
Heywood Cir.	7.99	0.00	7.24	7.77	7.41	6.65	2.96	1.61
Area	38326	0	38870	40594	39640	46420	5048	1391

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	21	0	22	59	40	18	15	6
Parts Found	65	0	106	120	101	61	25	6
Elongation	1.72	0.00	2.81	1.50	3.49	2.92	2.13	3.23
Compactness	0.11	0.00	0.08	0.29	0.09	0.09	0.27	0.28
Perimeter	6732.22	0.00	5164.72	1683.91	3242.31	5255.63	1210.30	212.28
Heywood Cir.	11.87	0.00	10.77	4.91	8.16	10.12	4.81	1.60
Area	25586	0	18298	9342	12579	21473	5035	1393

Table 43. Lesion 474X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Prewitt	Heliopan 8125	UG1						UG1
Largest Part	19	0	20	30	20	20	15	7
Parts Found	51	0	82	92	70	57	25	7
Elongation	1.86	0.00	1.75	1.67	1.67	1.85	2.82	3.15
Compactness	0.12	0.00	0.11	0.11	0.11	0.15	0.25	0.31
Perimeter	5546.81	0.00	5081.59	5223.04	5052.18	5117.01	957.03	216.87
Heywood Cir.	7.30	0.00	6.68	6.76	6.61	6.27	3.17	1.55
Area	45974	0	46015	47484	46516	52920	7250	1562
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Roberts	Heliopan 8125	UG1						UG1
Largest Part	19	0	22	30	21	18	15	6
Parts Found	53	0	87	96	76	56	25	6
Elongation	1.89	0.00	1.64	1.68	1.68	1.88	2.13	3.23
Compactness	0.10	0.00	0.10	0.09	0.09	0.13	0.27	0.28
Perimeter	5547.04	0.00	5061.64	5552.45	5233.33	5080.41	744.57	212.28
Heywood Cir.	7.99	0.00	7.24	7.77	7.41	6.65	2.96	1.60
Area	38329	0	38884	40595	39642	46463	5048	1394
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sigma	Heliopan 8125	UG1						UG1
Largest Part	18	0	19	29	19	17	13	5
Parts Found	50	0	81	91	69	54	23	5
Elongation	1.86	0.00	1.75	1.67	1.67	1.85	2.82	3.29
Compactness	0.12	0.00	0.11	0.11	0.11	0.15	0.25	0.30
Perimeter	5546.81	0.00	5081.59	5223.04	5052.18	5117.01	957.03	211.42
Heywood Cir.	7.30	0.00	6.69	6.76	6.61	6.30	3.18	1.58
Area	45891	0	45896	47471	46477	52485	7229	1432
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sobel	Heliopan 8125	UG1						UG1
Largest Part	19	0	20	30	20	20	15	7
Parts Found	51	0	82	92	70	57	25	7
Elongation	1.86	0.00	1.75	1.67	1.67	1.85	2.82	3.15
Compactness	0.12	0.00	0.11	0.11	0.11	0.15	0.25	0.31
Perimeter	5546.81	0.00	5081.59	5223.04	5052.18	5117.01	957.03	216.87
Heywood Cir.	7.30	0.00	6.68	6.76	6.61	6.28	3.17	1.55
Area	45974	0	46004	47484	46511	52910	7250	1566

Lesion 475X

Table 44. Lesion 475X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	12	0	15	7	11	1	5	4
Parts Found	48	0	51	31	37	13	7	6
Elongation	1.74	0.00	1.90	1.88	1.83	2.04	2.93	3.11
Compactness	0.10	0.00	0.13	0.11	0.11	0.33	0.49	0.36
Perimeter	3901.70	0.00	5251.58	4261.28	4531.17	465.37	235.36	353.26
Heywood Cir.	6.89	0.00	7.84	7.10	7.20	2.34	1.84	2.07
Area	25492	0	35693	28668	31539	3141	1309	2322

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	12	0	15	7	11	1	5	4
Parts Found	48	0	51	29	37	12	7	6
Elongation	1.75	0.00	1.90	1.82	1.83	2.69	2.81	3.06
Compactness	0.10	0.00	0.14	0.12	0.11	0.30	0.47	0.36
Perimeter	3910.54	0.00	5148.37	4586.48	4457.77	560.89	233.72	354.58
Heywood Cir.	6.74	0.00	7.49	7.45	7.05	2.53	1.79	2.06
Area	26765	0	37575	30128	31776	3924	1361	2355

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	13	0	16	9	17	1	5	4
Parts Found	52	0	54	30	45	12	8	6
Elongation	1.84	0.00	1.90	3.02	2.11	2.69	2.82	3.06
Compactness	0.09	0.00	0.14	0.11	0.18	0.30	0.44	0.36
Perimeter	6212.86	0.00	5148.37	4553.86	2164.44	796.48	275.74	354.58
Heywood Cir.	12.10	0.00	7.49	10.17	7.13	3.59	2.16	2.06
Area	20967	0	37597	15956	7341	3914	1296	2368

Table 45. Lesion 475X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt	Heliopan 8125							
Largest Part	11	0	15	7	11	14	5	5
Parts Found	46	0	49	29	36	15	7	7
Elongation	1.74	0.00	1.89	1.82	1.83	4.46	2.75	3.02
Compactness	0.12	0.00	0.17	0.14	0.14	0.30	0.51	0.37
Perimeter	3746.62	0.00	5320.37	4554.00	4613.79	253.82	222.88	362.28
Heywood Cir.	5.98	0.00	7.05	6.87	6.63	1.67	1.60	2.03
Area	31209	0	45312	35000	38539	1849	1546	2533
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Roberts	Heliopan 8125							
Largest Part	12	0	15	7	11	1	5	4
Parts Found	48	0	51	29	37	12	7	6
Elongation	1.75	0.00	1.90	1.82	1.83	2.69	2.81	3.06
Compactness	0.10	0.00	0.14	0.12	0.11	0.30	0.47	0.36
Perimeter	3910.54	0.00	5148.37	4586.48	4457.77	560.89	233.72	354.58
Heywood Cir.	6.74	0.00	7.49	7.45	7.05	2.52	1.79	2.05
Area	26767	0	37603	30129	31779	3935	1361	2371
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sigma	Heliopan 8125							
Largest Part	11	0	14	7	11	11	4	3
Parts Found	46	0	48	29	36	12	6	5
Elongation	1.74	0.00	1.89	1.82	1.83	4.46	2.81	3.05
Compactness	0.12	0.00	0.17	0.14	0.14	0.30	0.50	0.36
Perimeter	3746.62	0.00	5320.37	4554.00	4613.79	253.82	236.40	354.64
Heywood Cir.	5.98	0.00	7.06	6.88	6.63	1.67	1.76	2.04
Area	31194	0	45211	34912	38486	1843	1432	2408
		B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Sobel	Heliopan 8125							
Largest Part	11	0	15	7	11	1	5	5
Parts Found	46	0	49	29	36	14	7	7
Elongation	1.74	0.00	1.89	1.82	1.83	4.06	2.75	3.02
Compactness	0.12	0.00	0.17	0.14	0.14	0.20	0.51	0.38
Perimeter	3746.62	0.00	5320.37	4554.00	4613.79	542.65	222.88	362.28
Heywood Cir.	5.98	0.00	7.05	6.87	6.63	3.34	1.60	2.03
Area	31209	0	45311	35000	38545	2103	1546	2542

Lesion 476X

Table 46. Lesion 476X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	3	1	3	4	3	6	1	3
Parts Found	13	1	12	10	5	6	5	3
Elongation	2.01	2.16	2.10	2.28	2.60	2.38	3.52	3.48
Compactness	0.07	0.56	0.07	0.08	0.08	0.29	0.20	0.32
Perimeter	2793.76	147.03	2401.49	2207.04	1932.10	286.76	708.10	249.04
Heywood Cir.	5.13	1.32	4.92	4.69	4.62	1.82	2.89	1.69
Area	23623	981	18946	17586	13932	1986	4775	1718

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	3	1	3	4	3	6	1	2
Parts Found	13	1	12	10	5	6	5	2
Elongation	2.01	2.07	2.10	2.28	2.59	2.35	3.49	2.63
Compactness	0.08	0.57	0.07	0.08	0.08	0.31	0.21	0.33
Perimeter	2775.15	148.13	2384.06	2189.83	1921.80	284.73	713.62	343.72
Heywood Cir.	5.03	1.31	4.76	4.56	4.47	1.72	2.84	2.02
Area	24235	1023	19966	18355	14705	2181	5026	2293

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	18	1	3	14	9	6	12	2
Parts Found	34	1	13	21	13	6	14	2
Elongation	6.31	2.07	1.97	3.47	4.88	2.35	2.20	2.63
Compactness	0.13	0.57	0.07	0.06	0.06	0.31	0.21	0.33
Perimeter	1038.80	148.13	3120.13	1549.33	1130.77	552.48	832.94	343.72
Heywood Cir.	4.40	1.30	7.45	5.36	4.90	3.35	4.30	2.02
Area	4445	1033	13954	6647	4244	2168	2984	2305

Table 47. Lesion 476X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Prewitt	Heliopan 8125	UG1						UG1
Largest Part	3	1	3	4	3	6	6	2
Parts Found	13	1	12	9	5	6	7	2
Elongation	2.00	2.03	2.10	2.28	2.59	2.32	2.19	2.58
Compactness	0.08	0.52	0.07	0.09	0.09	0.33	0.24	0.33
Perimeter	2676.97	139.25	2347.12	2188.51	1914.21	285.43	466.16	338.21
Heywood Cir.	4.64	1.36	4.56	4.38	4.25	1.65	2.24	1.98
Area	26511	837	21084	19910	16159	2368	3437	2319
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Roberts	Heliopan 8125	UG1						UG1
Largest Part	3	1	3	4	3	6	1	2
Parts Found	13	1	12	10	5	6	5	2
Elongation	2.01	2.07	2.10	2.28	2.59	2.35	3.49	2.63
Compactness	0.08	0.58	0.07	0.08	0.08	0.31	0.21	0.33
Perimeter	2775.15	148.13	2384.06	2189.83	1921.80	284.73	713.62	343.72
Heywood Cir.	5.03	1.30	4.75	4.56	4.47	1.72	2.84	2.02
Area	24240	1039	20067	18392	14733	2184	5026	2311
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sigma	Heliopan 8125	UG1						UG1
Largest Part	3	0	2	3	2	6	3	2
Parts Found	13	0	11	9	4	6	4	2
Elongation	2.01	0.00	2.10	2.28	2.59	2.38	2.20	3.51
Compactness	0.08	0.00	0.07	0.08	0.08	0.31	0.23	0.32
Perimeter	2742.38	0.00	2399.07	2183.16	1924.75	285.82	459.97	248.23
Heywood Cir.	4.86	0.00	4.95	4.49	4.61	1.72	2.30	1.71
Area	25312	0	18667	18773	13897	2195	3170	1675
		B+W 403	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403
Sobel	Heliopan 8125	UG1						UG1
Largest Part	3	1	3	4	3	6	6	2
Parts Found	13	1	12	9	5	6	7	2
Elongation	2.00	2.03	2.10	2.28	2.59	2.32	2.19	2.63
Compactness	0.08	0.52	0.08	0.09	0.09	0.33	0.24	0.35
Perimeter	2676.97	139.25	2361.44	2188.51	1918.25	285.43	466.16	343.65
Heywood Cir.	4.64	1.36	4.50	4.37	4.26	1.65	2.24	1.94
Area	26514	837	21879	19918	16107	2368	3433	2497

Lesion 477X

Table 48. Lesion 477X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	8	1	1	2	1	2	2	2
Parts Found	16	2	4	4	4	2	3	2
Elongation	4.65	2.39	2.12	2.08	2.50	1.76	3.61	2.47
Compactness	0.30	0.40	0.06	0.08	0.08	0.19	0.32	0.60
Perimeter	234.03	300.48	2779.29	2512.70	1940.02	953.81	218.85	126.40
Heywood Cir. Area	1.75 1429	1.79 2232	5.33 21601	5.17 18794	4.70 13555	3.27 6758	1.70 1319	1.34 711

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	8	1	1	2	1	2	2	2
Parts Found	16	2	4	4	4	2	3	2
Elongation	4.40	2.37	2.12	2.09	2.49	1.76	3.49	2.38
Compactness	0.31	0.40	0.06	0.08	0.09	0.20	0.34	0.57
Perimeter	237.71	301.80	2682.60	2468.73	1956.26	944.65	222.25	132.36
Heywood Cir. Area	1.73 1499	1.76 2333	4.99 23007	4.95 19778	4.59 14450	3.16 7115	1.67 1408	1.35 762

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	8	1	4	2	24	2	2	2
Parts Found	16	2	8	12	24	3	3	2
Elongation	4.40	2.37	2.95	1.88	1.85	1.82	3.49	2.38
Compactness	0.31	0.40	0.04	0.08	0.08	0.22	0.34	0.58
Perimeter	317.91	301.80	2563.43	1754.78	1573.04	1531.58	222.25	132.36
Heywood Cir. Area	2.33 1479	1.75 2365	7.07 10464	5.80 7281	5.73 5991	5.50 6160	1.67 1409	1.35 767

Table 49. Lesion 477X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
Canny	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	8	1	1	2	1	2	2	2
Parts Found	16	2	4	4	4	2	3	2
Elongation	4.65	2.39	2.12	2.08	2.50	1.76	3.61	2.47
Compactness	0.30	0.40	0.06	0.08	0.08	0.19	0.32	0.60
Perimeter	234.03	300.48	2779.29	2512.70	1940.02	953.81	218.85	126.40
Heywood Cir.	1.75	1.79	5.33	5.17	4.70	3.27	1.70	1.34
Area	1429	2232	21601	18794	13555	6758	1319	711

Differentiation	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	8	1	1	2	1	2	2	2
Parts Found	16	2	4	4	4	2	3	2
Elongation	4.40	2.37	2.12	2.09	2.49	1.76	3.49	2.38
Compactness	0.31	0.40	0.06	0.08	0.09	0.20	0.34	0.57
Perimeter	237.71	301.80	2682.60	2468.73	1956.26	944.65	222.25	132.36
Heywood Cir.	1.73	1.76	4.99	4.95	4.59	3.16	1.67	1.35
Area	1499	2333	23007	19778	14450	7115	1408	762

Gradient	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Largest Part	8	1	4	2	24	2	2	2
Parts Found	16	2	8	12	24	3	3	2
Elongation	4.40	2.37	2.95	1.88	1.85	1.82	3.49	2.38
Compactness	0.31	0.40	0.04	0.08	0.08	0.22	0.34	0.58
Perimeter	317.91	301.80	2563.43	1754.78	1573.04	1531.58	222.25	132.36
Heywood Cir.	2.33	1.75	7.07	5.80	5.73	5.50	1.67	1.35
Area	1479	2365	10464	7281	5991	6160	1409	767

Lesion 479X**Table 50. Lesion 479X Measurement Reports**

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue-Grn 420-570	Green 470-610	Dk Or-Yel 590-650	Dk Red 610-700	IR 690-1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Canny								
Largest Part	0	0	5	10	0	0	0	0
Parts Found	0	0	32	22	0	0	0	0
Elongation	0.00	0.00	4.18	2.20	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.27	0.30	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	998.34	1238.58	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	2.57	3.34	0.00	0.00	0.00	0.00
Area	0	0	12019	10932	0	0	0	0
Differentiation	Control	UV	47	44	58	72B	29	IR
Largest Part	0	0	5	10	0	0	0	0
Parts Found	0	0	32	21	0	0	0	0
Elongation	0.00	0.00	4.13	2.52	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.27	0.27	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	993.70	1350.48	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	2.55	3.52	0.00	0.00	0.00	0.00
Area	0	0	12039	11694	0	0	0	0
Gradient	Control	UV	47	44	58	72B	29	IR
Largest Part	0	0	5	10	0	0	0	0
Parts Found	0	0	33	24	0	0	0	0
Elongation	0.00	0.00	4.13	2.52	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.27	0.27	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	993.70	1546.27	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	2.55	4.04	0.00	0.00	0.00	0.00
Area	0	0	12043	11663	0	0	0	0

Table 51. Lesion 479X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue-Grn 420-570	Green 470-610	Dk Or-Yel 590-650	Dk Red 610-700	IR 690-1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt								
Largest Part	0	0	5	10	0	0	0	0
Parts Found	0	0	32	21	0	0	0	0
Elongation	0.00	0.00	4.08	2.50	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.28	0.29	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	987.09	1312.38	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	2.46	3.31	0.00	0.00	0.00	0.00
Area	0	0	12787	12543	0	0	0	0
Roberts	Control	UV	47	44	58	72B	29	IR
Largest Part	0	0	5	10	0	0	0	0
Parts Found	0	0	32	21	0	0	0	0
Elongation	0.00	0.00	4.13	2.52	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.27	0.27	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	993.70	1350.48	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	2.55	3.52	0.00	0.00	0.00	0.00
Area	0	0	12043	11697	0	0	0	0
Sigma	Control	UV	47	44	58	72B	29	IR
Largest Part	0	0	4	9	0	0	0	0
Parts Found	0	0	31	20	0	0	0	0
Elongation	0.00	0.00	4.12	2.50	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.28	0.28	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	994.92	1312.38	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	2.52	3.32	0.00	0.00	0.00	0.00
Area	0	0	12401	12447	0	0	0	0
Sobel	Control	UV	47	44	58	72B	29	IR
Largest Part	0	0	5	10	0	0	0	0
Parts Found	0	0	32	21	0	0	0	0
Elongation	0.00	0.00	4.08	2.50	0.00	0.00	0.00	0.00
Compactness	0.00	0.00	0.28	0.29	0.00	0.00	0.00	0.00
Perimeter	0.00	0.00	987.09	1312.38	0.00	0.00	0.00	0.00
Heywood Cir.	0.00	0.00	2.46	3.31	0.00	0.00	0.00	0.00
Area	0	0	12787	12531	0	0	0	0

Lesion 480X

Table 52. Lesion 480X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Canny								
Largest Part	1	0	0	1	4	0	0	6
Parts Found	1	0	0	1	5	0	0	7
Elongation	2.00	0.00	0.00	2.21	1.49	0.00	0.00	2.77
Compactness	0.55	0.00	0.00	0.59	0.18	0.00	0.00	0.22
Perimeter	142.83	0.00	0.00	126.79	492.40	0.00	0.00	702.03
Heywood Cir.	1.32	0.00	0.00	1.38	2.32	0.00	0.00	2.83
Area	925	0	0	670	3571	0	0	4912
Differentiation	Control	UV	47	44	58	72B	29	IR
Largest Part	1	0	0	1	4	0	0	6
Parts Found	1	0	0	1	5	0	0	7
Elongation	1.95	0.00	0.00	2.20	1.50	0.00	0.00	2.77
Compactness	0.56	0.00	0.00	0.57	0.18	0.00	0.00	0.22
Perimeter	147.91	0.00	0.00	130.90	496.84	0.00	0.00	647.47
Heywood Cir.	1.34	0.00	0.00	1.39	2.32	0.00	0.00	2.55
Area	967	0	0	705	3652	0	0	5111
Gradient	Control	UV	47	44	58	72B	29	IR
Largest Part	1	0	0	1	6	0	0	1
Parts Found	1	0	0	1	8	0	0	10
Elongation	1.95	0.00	0.00	2.20	1.77	0.00	0.00	2.84
Compactness	0.56	0.00	0.00	0.57	0.15	0.00	0.00	0.32
Perimeter	147.91	0.00	0.00	130.90	665.60	0.00	0.00	754.89
Heywood Cir.	1.34	0.00	0.00	1.39	3.76	0.00	0.00	3.44
Area	967	0	0	705	2500	0	0	3836

Table 53. Lesion 480X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue-Grn 420-570	Green 470-610	Dk Or-Yel 590-650	Dk Red 610-700	IR 690-1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt								
Largest Part	1	0	0	1	4	0	0	6
Parts Found	1	0	0	1	5	0	0	7
Elongation	2.04	0.00	0.00	2.30	1.50	0.00	0.00	2.74
Compactness	0.53	0.00	0.00	0.52	0.20	0.00	0.00	0.25
Perimeter	148.24	0.00	0.00	124.02	490.02	0.00	0.00	634.92
Heywood Cir.	1.41	0.00	0.00	1.40	2.16	0.00	0.00	2.36
Area	874	0	0	626	4092	0	0	5748
Roberts	Control	UV	47	44	58	72B	29	IR
Largest Part	1	0	0	1	4	0	0	6
Parts Found	1	0	0	1	5	0	0	7
Elongation	1.95	0.00	0.00	2.20	1.50	0.00	0.00	2.77
Compactness	0.56	0.00	0.00	0.57	0.18	0.00	0.00	0.22
Perimeter	147.91	0.00	0.00	130.90	496.84	0.00	0.00	647.47
Heywood Cir.	1.34	0.00	0.00	1.39	2.32	0.00	0.00	2.55
Area	967	0	0	705	3652	0	0	5111
Sigma	Control	UV	47	44	58	72B	29	IR
Largest Part	0	0	0	0	5	0	0	6
Parts Found	0	0	0	0	6	0	0	7
Elongation	0.00	0.00	0.00	0.00	1.50	0.00	0.00	2.75
Compactness	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.23
Perimeter	0.00	0.00	0.00	0.00	484.73	0.00	0.00	638.28
Heywood Cir.	0.00	0.00	0.00	0.00	2.20	0.00	0.00	2.45
Area	0	0	0	0	3862	0	0	5402
Sobel	Control	UV	47	44	58	72B	29	IR
Largest Part	1	0	0	1	4	0	0	6
Parts Found	1	0	0	1	5	0	0	7
Elongation	2.04	0.00	0.00	2.30	1.50	0.00	0.00	2.74
Compactness	0.53	0.00	0.00	0.52	0.20	0.00	0.00	0.25
Perimeter	148.24	0.00	0.00	124.02	490.02	0.00	0.00	634.92
Heywood Cir.	1.41	0.00	0.00	1.40	2.16	0.00	0.00	2.36
Area	874	0	0	626	4092	0	0	5748

Lesion 481X

Table 54. Lesion 481X Measurement Reports

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Canny								
Largest Part	2	1	4	2	1	0	1	4
Parts Found	4	2	9	6	1	0	1	4
Elongation	3.50	5.94	2.22	2.17	2.08	0.00	2.48	9.38
Compactness	0.15	0.15	0.11	0.11	0.14	0.00	0.61	0.25
Perimeter	1198.27	716.14	1714.71	3041.70	3538.28	0.00	96.49	455.86
Heywood Cir.	3.89	3.02	4.26	5.86	4.94	0.00	1.28	2.54
Area	7542	4471	12875	21452	40833	0	451	2556
Differentiation	Control	UV	47	44	58	72B	29	IR
Largest Part	2	1	4	2	1	0	1	4
Parts Found	4	2	9	6	1	0	1	4
Elongation	3.51	5.84	2.21	2.17	2.07	0.00	2.50	9.22
Compactness	0.15	0.15	0.11	0.11	0.14	0.00	0.60	0.25
Perimeter	1178.76	725.98	1714.44	3015.72	3472.79	0.00	99.32	461.49
Heywood Cir.	3.79	3.00	4.24	5.74	4.81	0.00	1.28	2.53
Area	7693	4668	13035	21933	41483	0	482	2638
Gradient	Control	UV	47	44	58	72B	29	IR
Largest Part	2	1	4	10	1	0	1	5
Parts Found	6	2	11	13	4	0	1	5
Elongation	3.51	5.84	6.29	3.02	3.79	0.00	2.50	9.22
Compactness	0.15	0.15	0.09	0.10	0.19	0.00	0.60	0.25
Perimeter	1201.93	725.98	1191.96	2931.55	3833.35	0.00	99.32	461.49
Heywood Cir.	3.87	3.00	4.04	7.39	7.21	0.00	1.28	2.53
Area	7662	4671	6917	12507	22519	0	482	2638

Table 55. Lesion 481X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue-Grn 420-570	Green 470-610	Dk Or-Yel 590-650	Dk Red 610-700	IR 690-1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt								
Largest Part	6	1	5	2	1	0	1	4
Parts Found	8	2	10	6	1	0	1	4
Elongation	3.51	5.95	2.21	2.17	2.07	0.00	2.37	8.85
Compactness	0.16	0.14	0.12	0.11	0.15	0.00	0.58	0.27
Perimeter	1161.57	770.11	1699.09	3046.89	3473.66	0.00	99.15	460.15
Heywood Cir.	3.66	3.47	4.02	5.66	4.73	0.00	1.29	2.40
Area	8016	3911	14212	23053	42883	0	469	2916
Roberts	Control	UV	47	44	58	72B	29	IR
Largest Part	2	1	4	2	1	0	1	4
Parts Found	4	2	9	6	1	0	1	4
Elongation	3.51	5.84	2.21	2.17	2.07	0.00	2.50	9.22
Compactness	0.15	0.15	0.11	0.11	0.14	0.00	0.60	0.25
Perimeter	1178.76	725.98	1714.44	3015.72	3472.79	0.00	99.32	461.49
Heywood Cir.	3.79	3.00	4.23	5.74	4.81	0.00	1.28	2.53
Area	7693	4673	13057	21941	41492	0	482	2638
Sigma	Control	UV	47	44	58	72B	29	IR
Largest Part	6	1	5	11	1	0	0	5
Parts Found	8	1	10	30	27	0	0	5
Elongation	3.55	3.25	2.22	2.94	1.92	0.00	0.00	8.92
Compactness	0.20	0.38	0.12	0.25	0.16	0.00	0.00	0.26
Perimeter	944.29	270.49	1699.53	881.16	2251.01	0.00	0.00	459.24
Heywood Cir.	3.78	2.63	4.14	2.92	6.94	0.00	0.00	2.47
Area	4964	843	13406	7237	8384	0	0	2752
Sobel	Control	UV	47	44	58	72B	29	IR
Largest Part	6	1	5	2	1	0	1	4
Parts Found	8	2	10	6	1	0	1	4
Elongation	3.49	5.95	2.21	2.16	2.07	0.00	2.37	8.85
Compactness	0.16	0.14	0.12	0.11	0.15	0.00	0.58	0.27
Perimeter	1175.63	770.11	1699.09	3019.24	3487.00	0.00	99.15	460.15
Heywood Cir.	3.69	3.47	4.02	5.56	4.71	0.00	1.29	2.40
Area	8083	3911	14221	23464	43625	0	469	2916

Lesion 482X**Table 56. Lesion 482X Measurement Reports**

Wavelength	Control 310-700	UV 280- 410	Blue 400-500	Blue- Grn 420-570	Green 470-610	Dk Or- Yel 590-650	Dk Red 610-700	IR 690- 1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Canny								
Largest Part	2	0	1	5	8	9	2	0
Parts Found	6	0	1	9	11	14	3	0
Elongation	2.49	0.00	1.93	1.57	2.82	2.70	3.19	0.00
Compactness	0.41	0.00	0.51	0.31	0.43	0.19	0.25	0.00
Perimeter	247.07	0.00	160.27	463.18	330.51	332.64	384.20	0.00
Heywood Cir.	1.61	0.00	1.30	2.23	1.85	2.01	2.01	0.00
Area	1869	0	1201	3422	2539	2179	2895	0
Differentiation	Control	UV	47	44	58	72B	29	IR
Largest Part	2	0	1	5	8	9	2	0
Parts Found	6	0	1	9	11	14	3	0
Elongation	2.40	0.00	1.96	1.57	2.73	2.69	3.21	0.00
Compactness	0.42	0.00	0.51	0.32	0.43	0.19	0.26	0.00
Perimeter	247.94	0.00	171.19	460.58	339.43	339.04	382.90	0.00
Heywood Cir.	1.61	0.00	1.36	2.17	1.86	2.02	1.99	0.00
Area	1889	0	1253	3594	2644	2240	2958	0
Gradient	Control	UV	47	44	58	72B	29	IR
Largest Part	2	0	1	7	9	9	2	0
Parts Found	6	0	1	11	13	14	4	0
Elongation	2.40	0.00	1.96	1.57	2.73	2.69	3.21	0.00
Compactness	0.42	0.00	0.51	0.32	0.43	0.19	0.26	0.00
Perimeter	247.94	0.00	171.19	460.58	339.43	339.04	382.90	0.00
Heywood Cir.	1.60	0.00	1.36	2.16	1.86	2.02	1.98	0.00
Area	1907	0	1262	3608	2645	2240	2979	0

Table 57. Lesion 482X Measurement Reports (cont'd)

Wavelength	Control 310-700	UV 280-410	Blue 400-500	Blue-Grn 420-570	Green 470-610	Dk Or-Yel 590-650	Dk Red 610-700	IR 690-1100
	Heliopan 8125	B+W 403 UG1	Wratten 47	Wratten 44	Wratten 58	Wratten 72B	Wratten 29	B+W 403 UG1
Prewitt								
Largest Part	2	0	1	5	9	10	2	0
Parts Found	6	0	1	9	12	15	3	0
Elongation	2.34	0.00	1.96	1.57	2.69	2.66	3.16	0.00
Compactness	0.43	0.00	0.45	0.34	0.44	0.21	0.26	0.00
Perimeter	249.21	0.00	168.48	445.96	336.87	343.46	380.19	0.00
Heywood Cir.	1.59	0.00	1.47	2.03	1.79	1.92	1.94	0.00
Area	1944	0	1050	3844	2817	2534	3065	0
Roberts	Control	UV	47	44	58	72B	29	IR
Largest Part	2	0	1	5	8	9	2	0
Parts Found	6	0	1	9	11	14	3	0
Elongation	2.40	0.00	1.96	1.57	2.73	2.69	3.21	0.00
Compactness	0.42	0.00	0.51	0.32	0.43	0.19	0.26	0.00
Perimeter	247.94	0.00	171.19	460.58	339.43	339.04	382.90	0.00
Heywood Cir.	1.61	0.00	1.36	2.16	1.86	2.02	1.98	0.00
Area	1894	0	1258	3612	2647	2240	2976	0
Sigma	Control	UV	47	44	58	72B	29	IR
Largest Part	1	0	0	4	7	8	1	0
Parts Found	5	0	0	8	10	13	2	0
Elongation	2.42	0.00	0.00	1.56	2.69	2.66	3.26	0.00
Compactness	0.38	0.00	0.00	0.32	0.44	0.21	0.24	0.00
Perimeter	244.13	0.00	0.00	451.30	336.87	343.46	567.27	0.00
Heywood Cir.	1.68	0.00	0.00	2.12	1.80	1.92	3.10	0.00
Area	1685	0	0	3591	2802	2534	2670	0
Sobel	Control	UV	47	44	58	72B	29	IR
Largest Part	2	0	1	5	9	10	2	0
Parts Found	6	0	1	9	12	15	3	0
Elongation	2.37	0.00	1.96	1.57	2.69	2.66	3.18	0.00
Compactness	0.44	0.00	0.45	0.34	0.44	0.21	0.28	0.00
Perimeter	242.94	0.00	168.48	445.96	336.87	343.46	383.03	0.00
Heywood Cir.	1.51	0.00	1.47	2.03	1.79	1.92	1.90	0.00
Area	2058	0	1050	3855	2823	2534	3238	0

Appendix S

Lesion Analysis Graphs

Lesion 453X

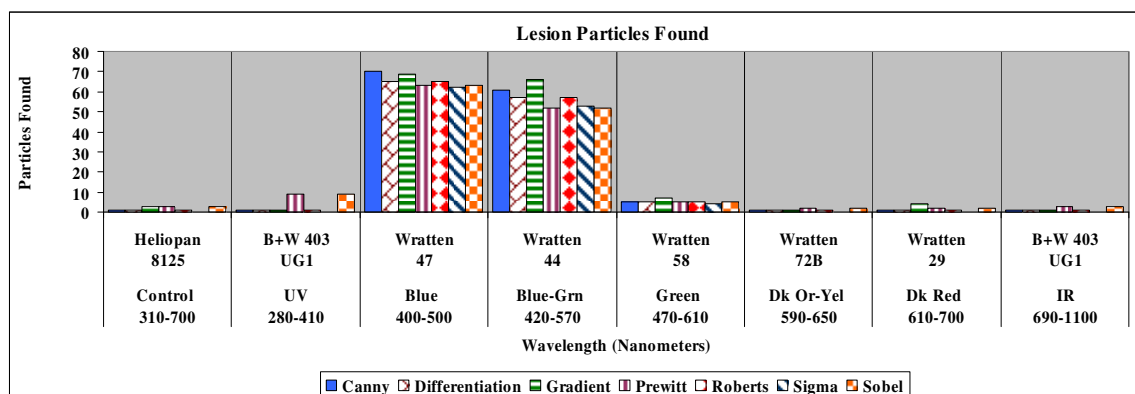


Figure 180. Lesion 453X Particles Found

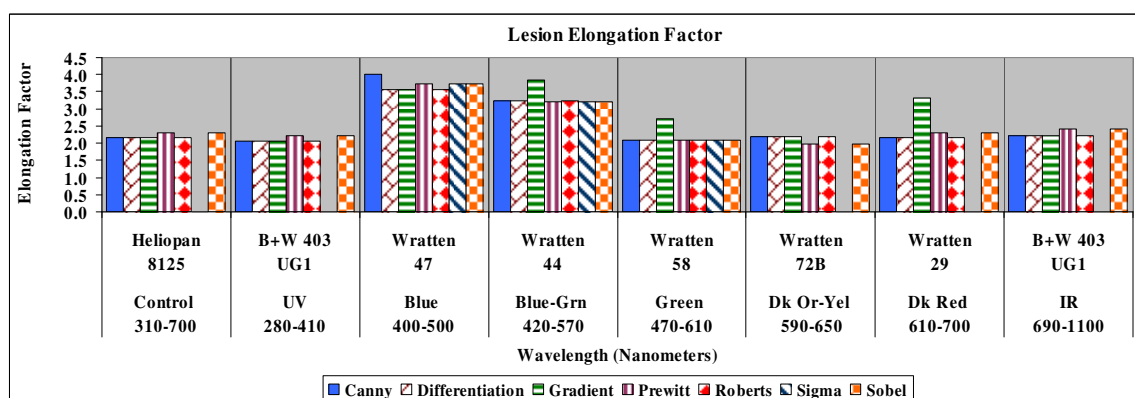


Figure 181. Lesion 453X Elongation Factor

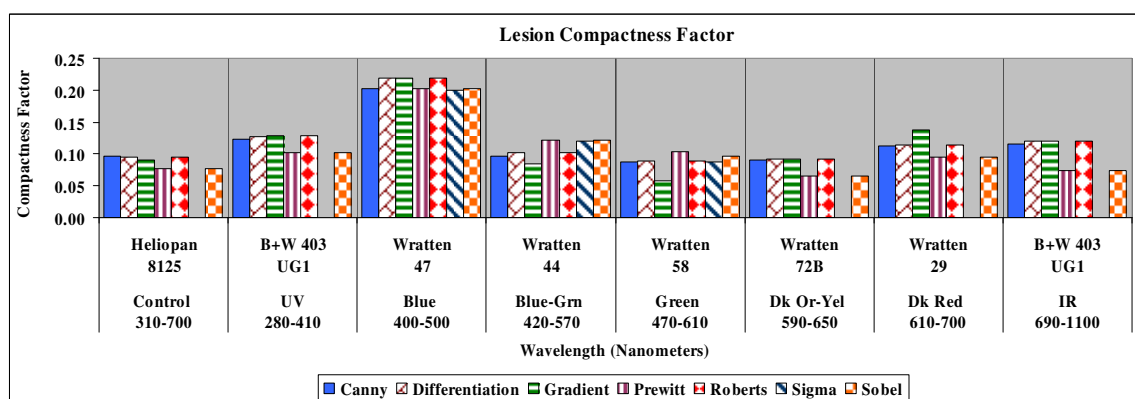


Figure 182. Lesion 453X Compactness Factor

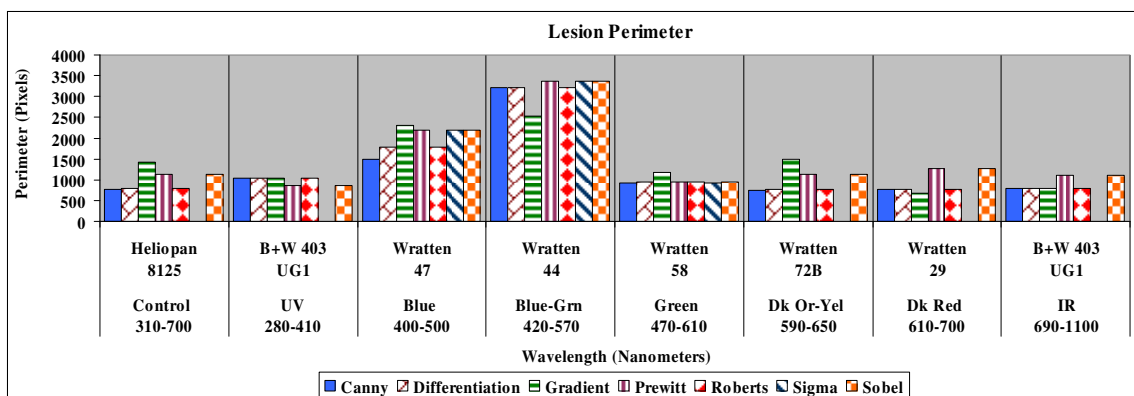


Figure 183. Lesion 453X Perimeter

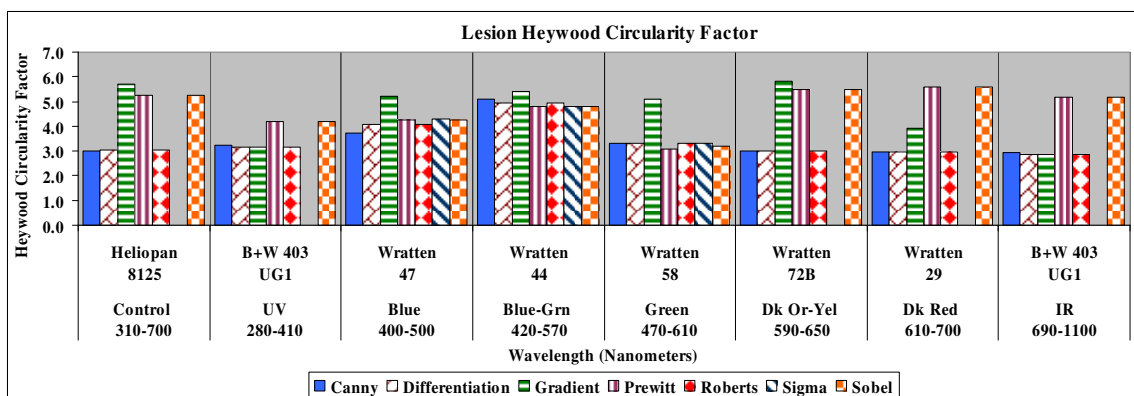


Figure 184. Lesion 453X Heywood Circularity Factor

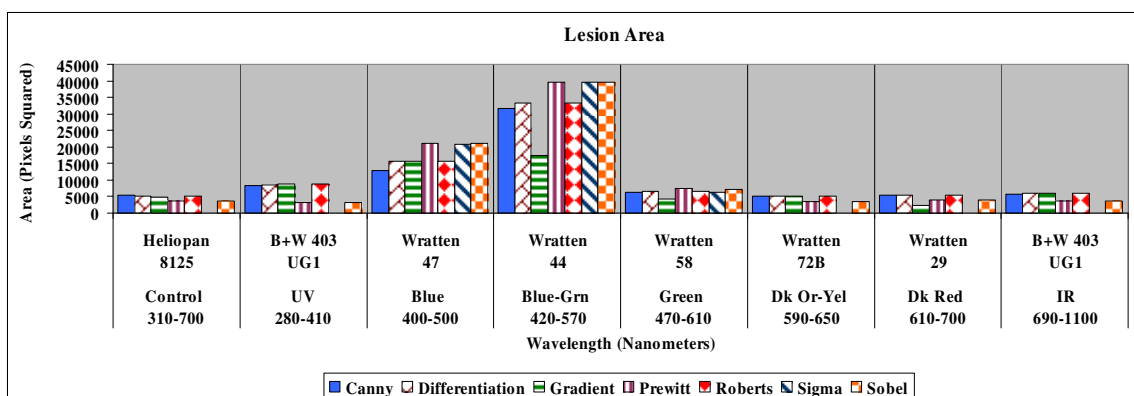


Figure 185. Lesion 453X Area

Lesion 454X

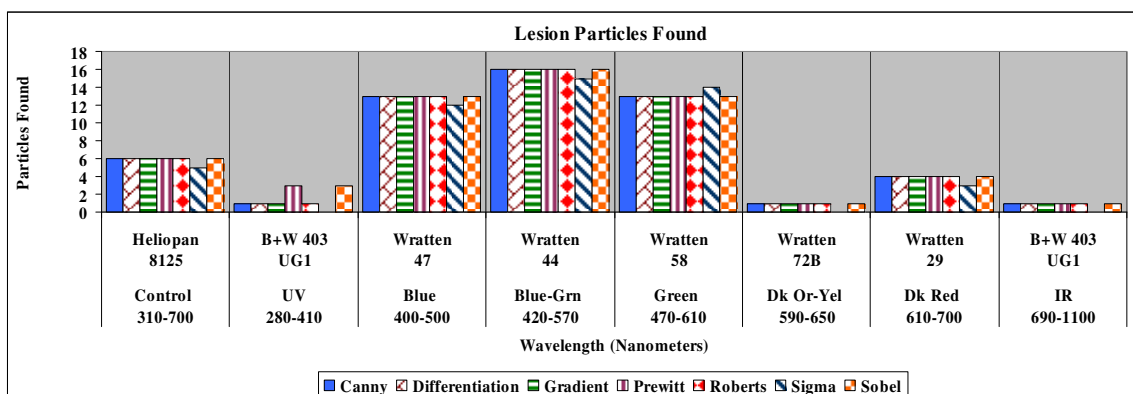


Figure 186. Lesion 454X Particles Found

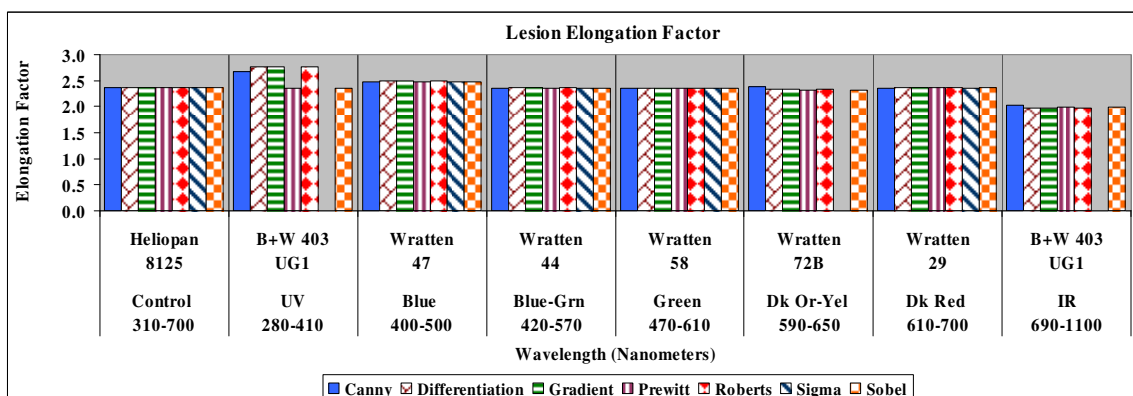


Figure 187. Lesion 454X Elongation Factor

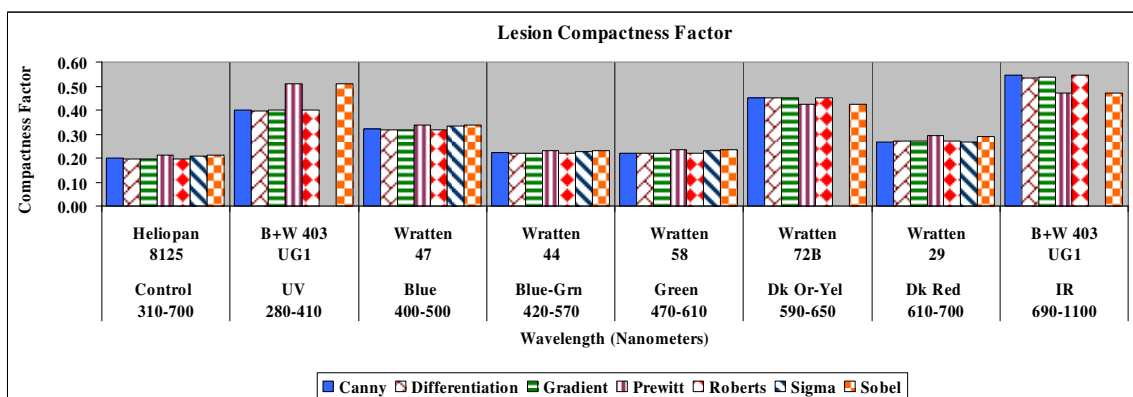


Figure 188. Lesion 454X Compactness Factor

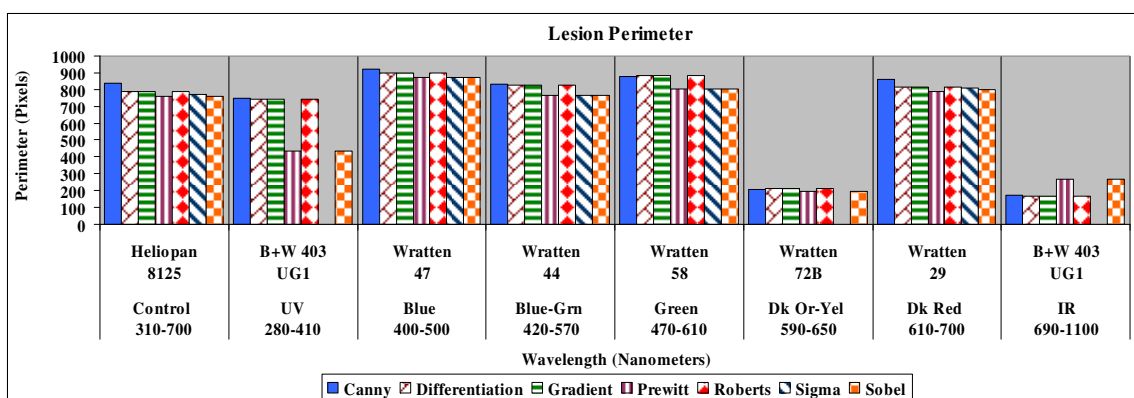


Figure 189. Lesion 454X Perimeter

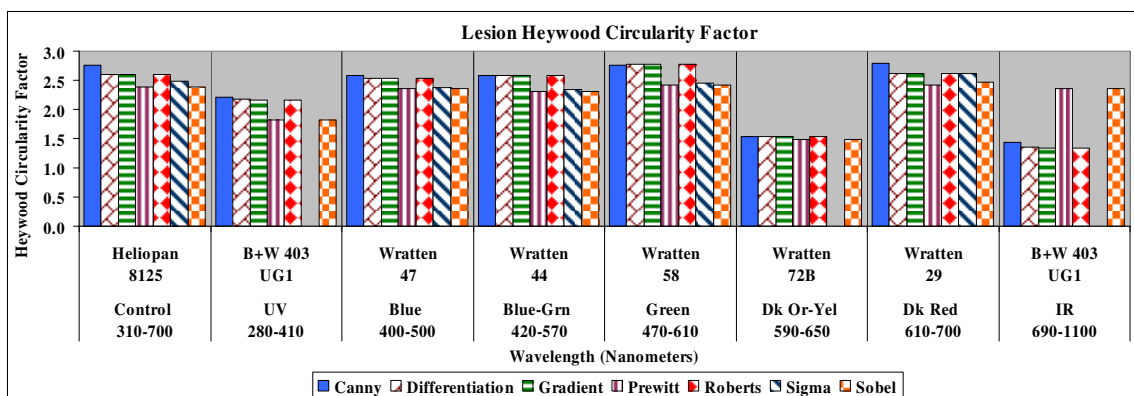


Figure 190. Lesion 454X Heywood Circularity Factor

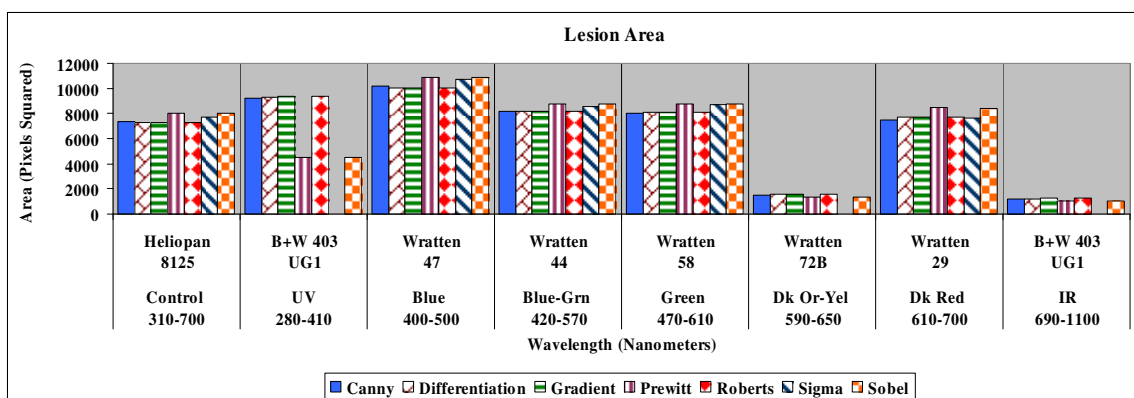


Figure 191. Lesion 454X Area

Lesion 455X

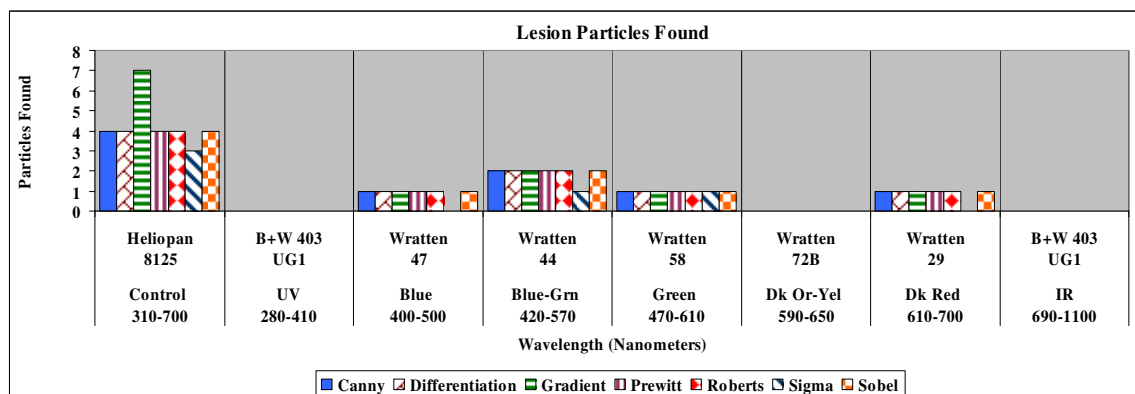


Figure 192. Lesion 455X Particles Found

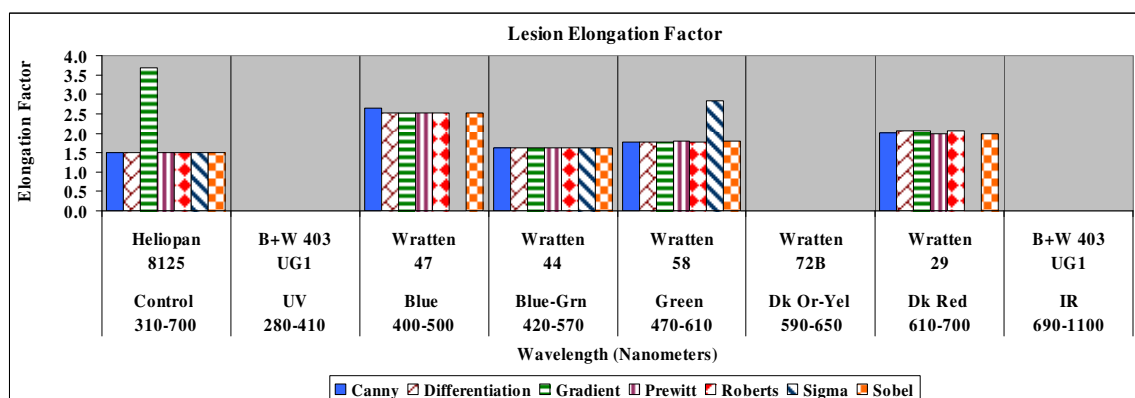


Figure 193. Lesion 455X Elongation Factor

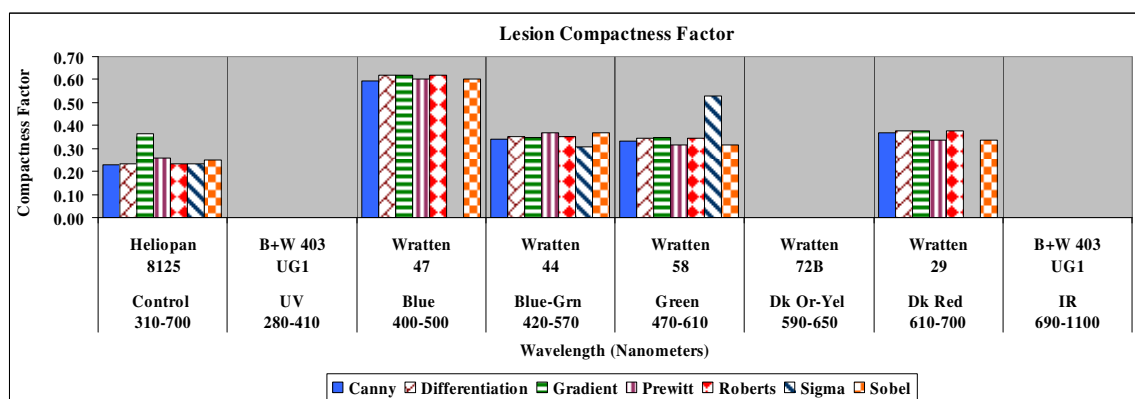


Figure 194. Lesion 455X Compactness Factor

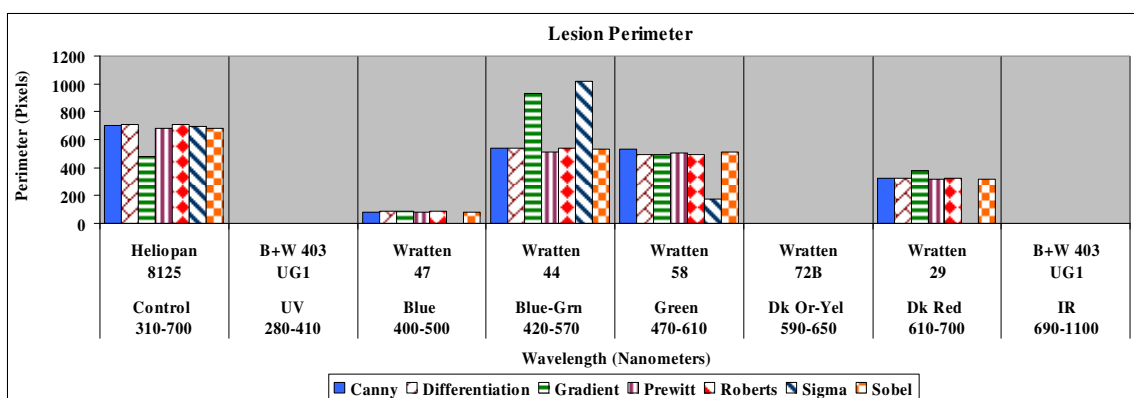


Figure 195. Lesion 455X Perimeter

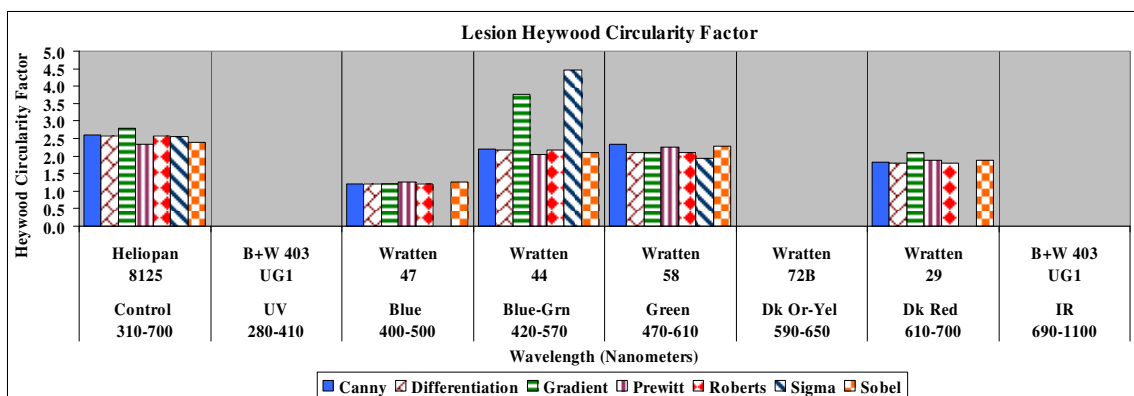


Figure 196. Lesion 455X Heywood Circularity Factor

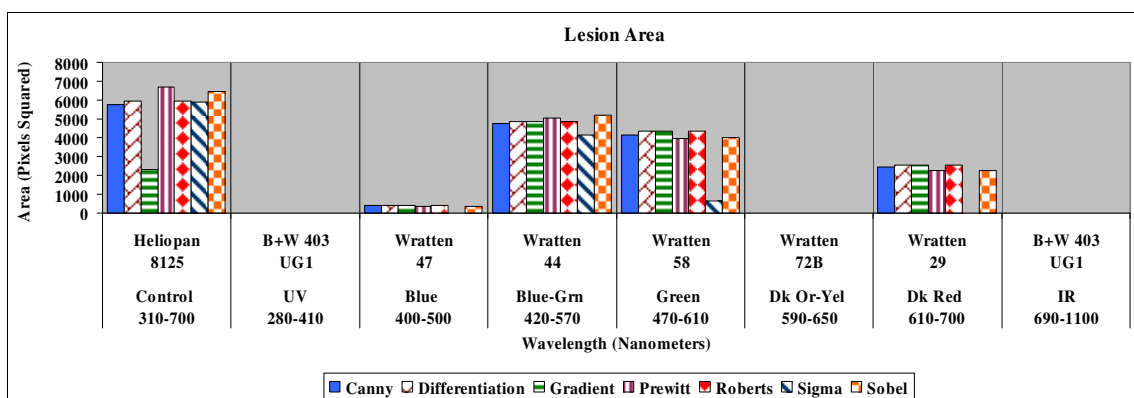


Figure 197. Lesion 455X Area

Lesion 456X

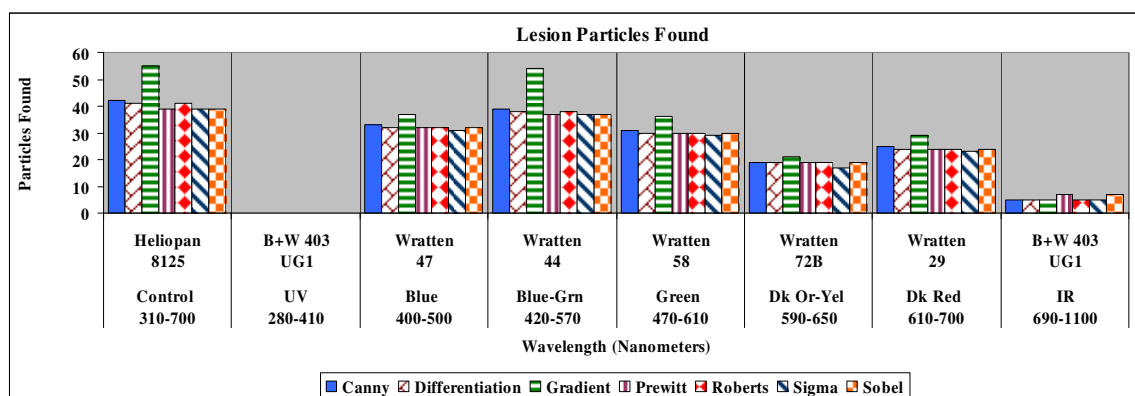


Figure 198. Lesion 456X Particles Found

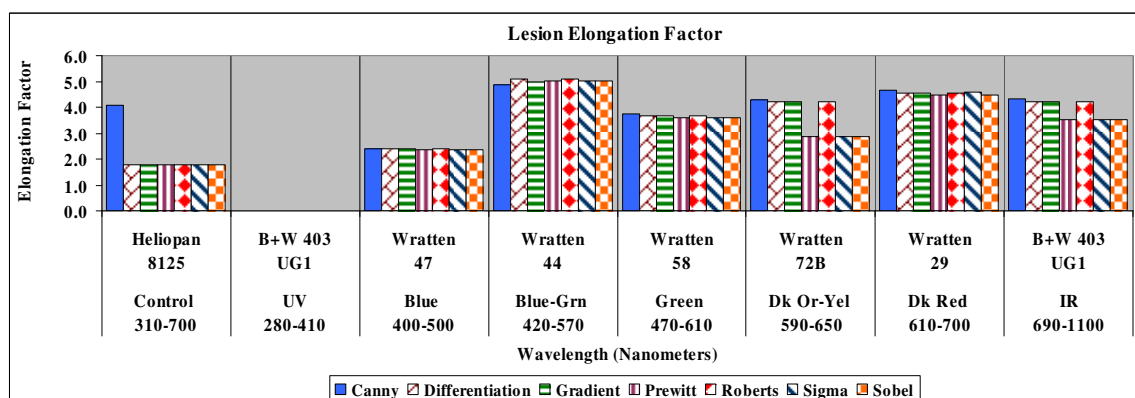


Figure 199. Lesion 456X Elongation Factor

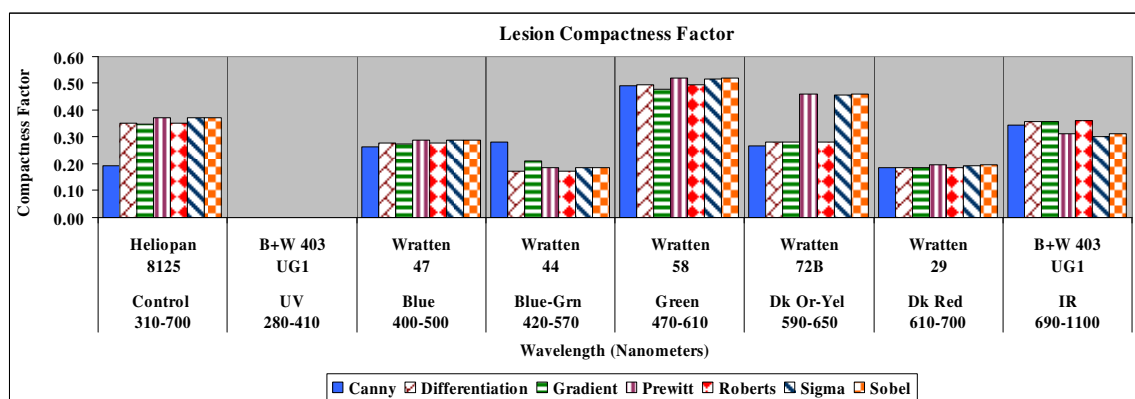


Figure 200. Lesion 456X Compactness Factor

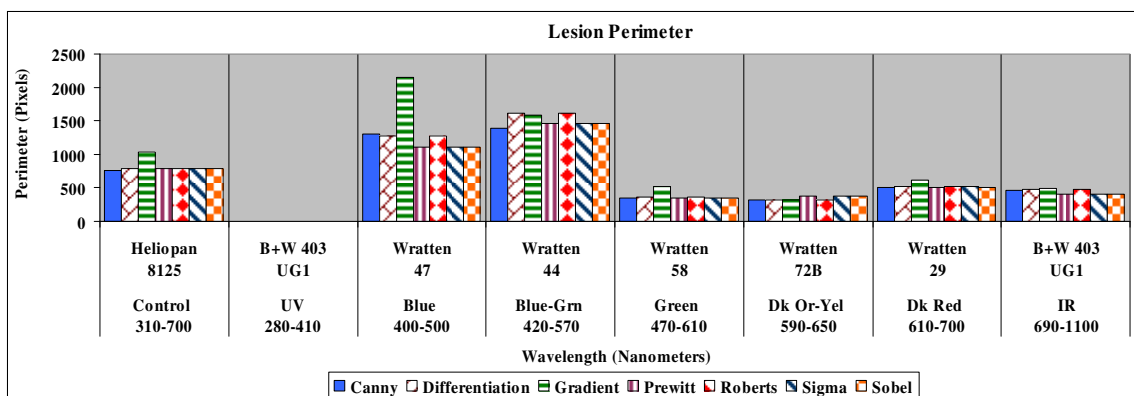


Figure 201. Lesion 456X Perimeter

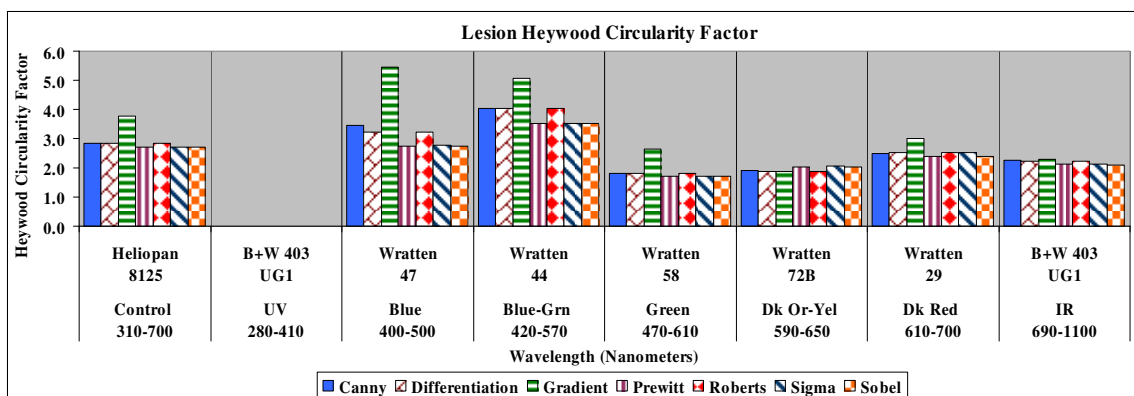


Figure 202. Lesion 456X Heywood Circularity Factor

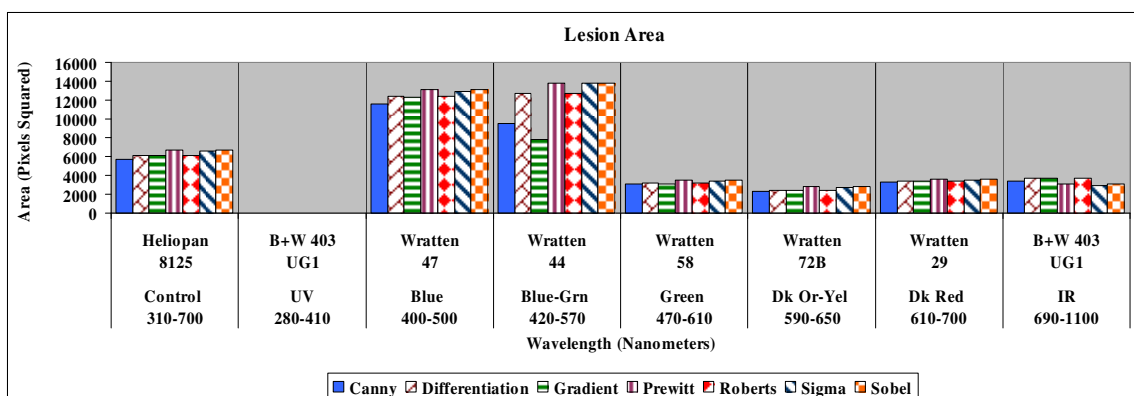


Figure 203. Lesion 456X Area

Lesion 457X

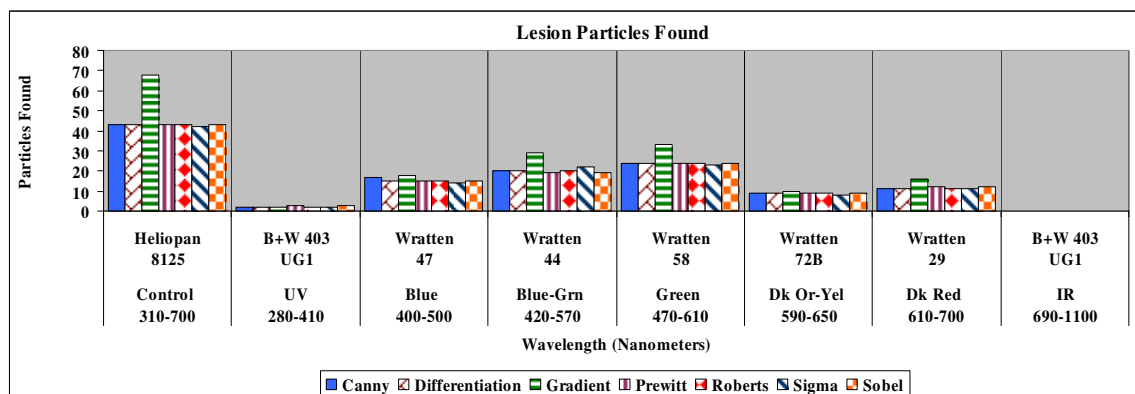


Figure 204. Lesion 457X Particles Found

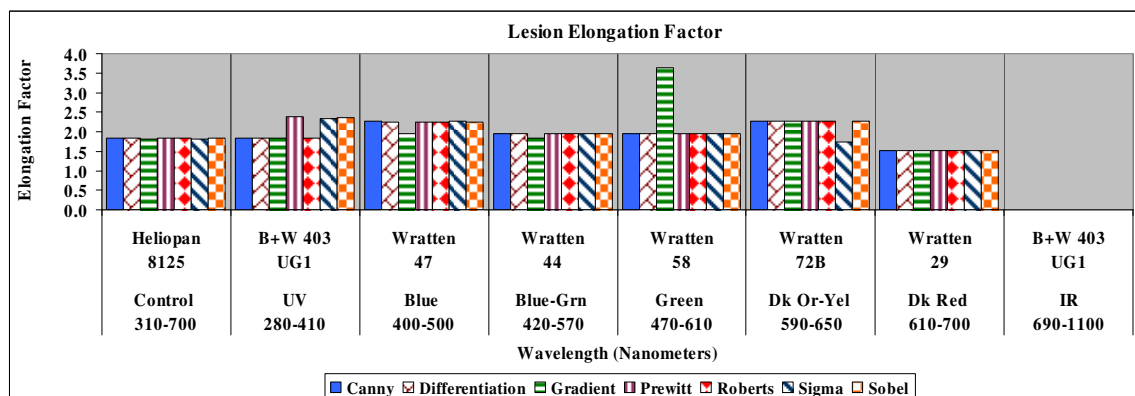


Figure 205. Lesion 457X Elongation Factor

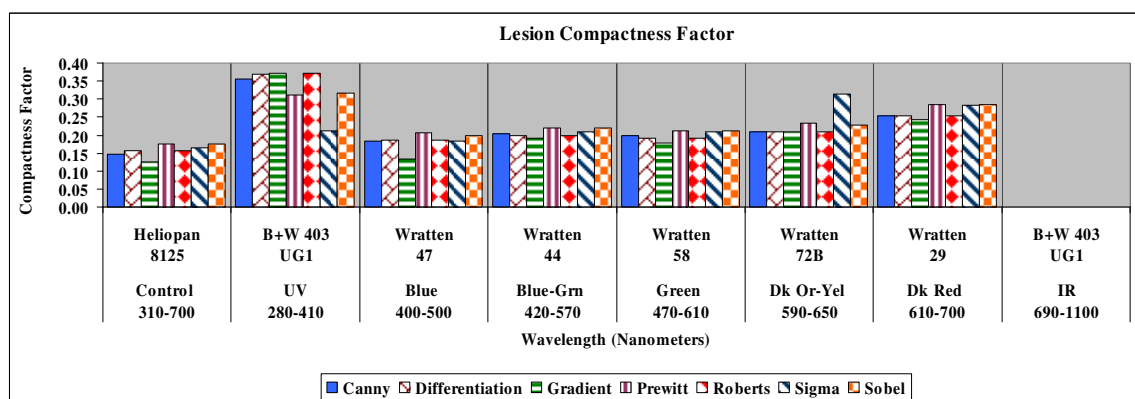


Figure 206. Lesion 457X Compactness Factor

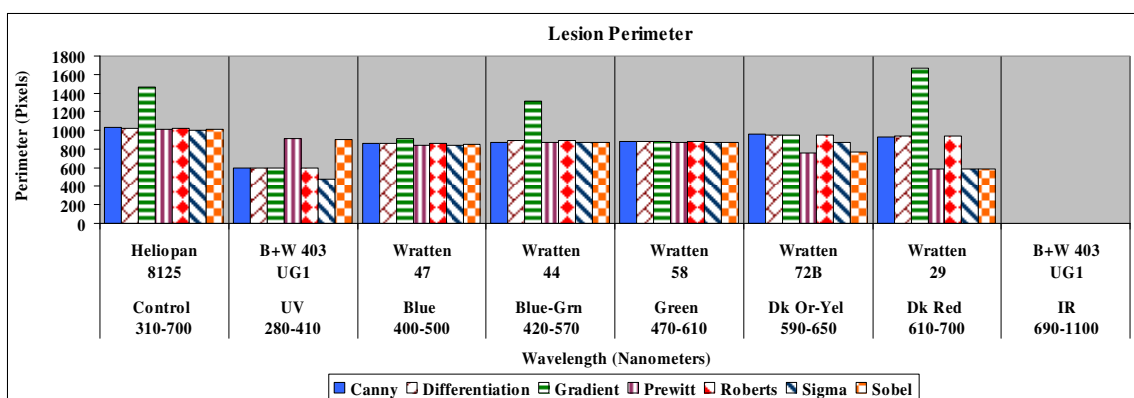


Figure 207. Lesion 457X Perimeter

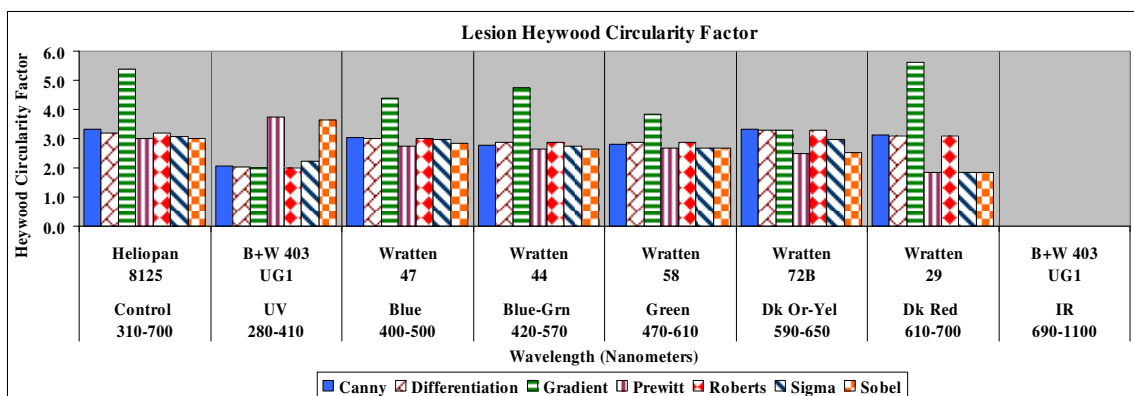


Figure 208. Lesion 457X Heywood Circularity Factor

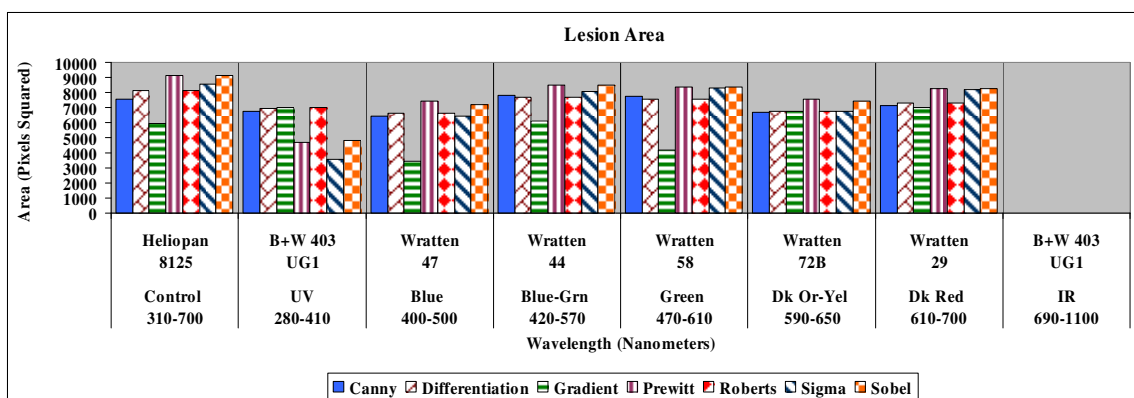


Figure 209. Lesion 457X Area

Lesion 458X

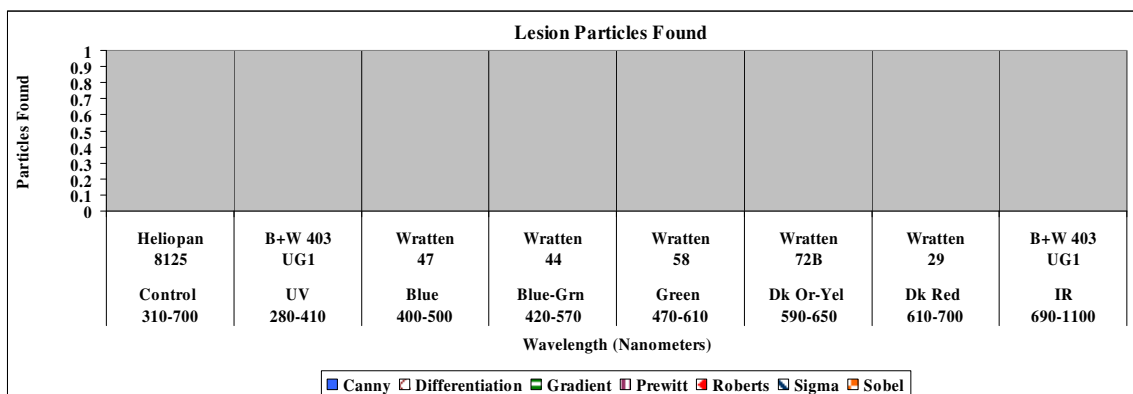


Figure 210. Lesion 458X Particles Found

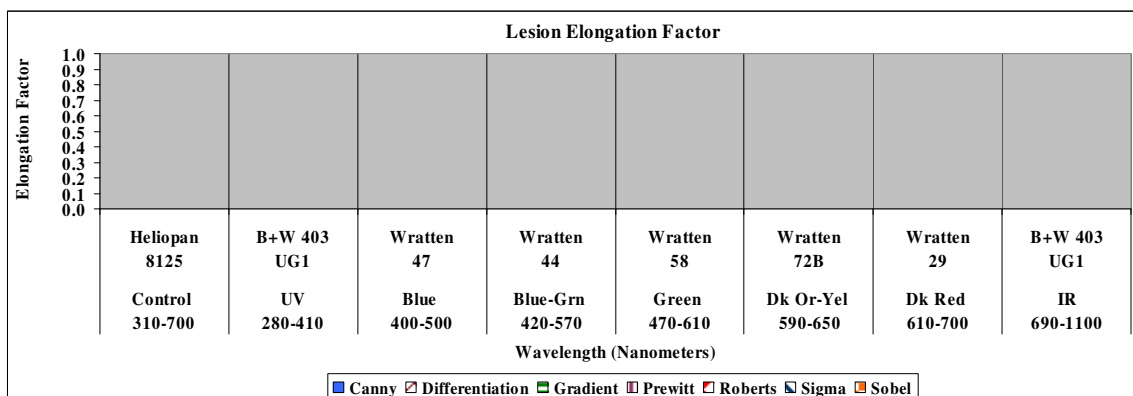


Figure 211. Lesion 458X Elongation Factor

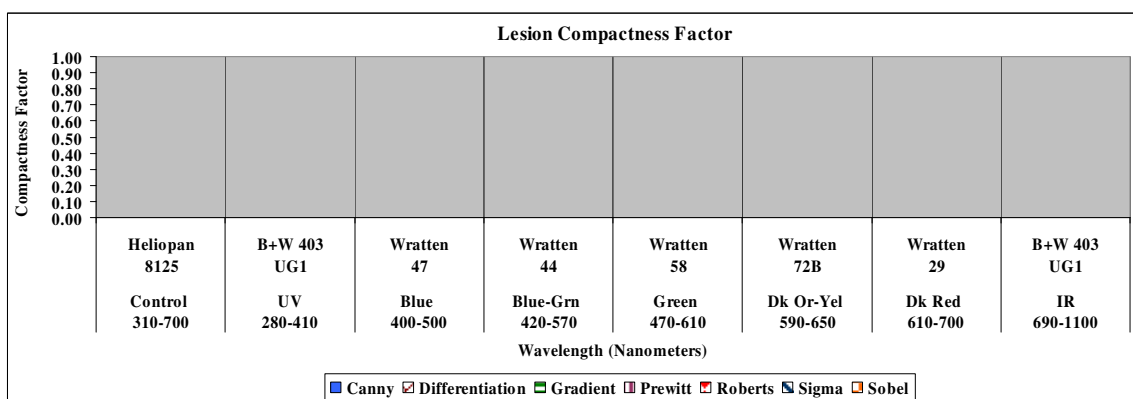


Figure 212. Lesion 458X Compactness Factor

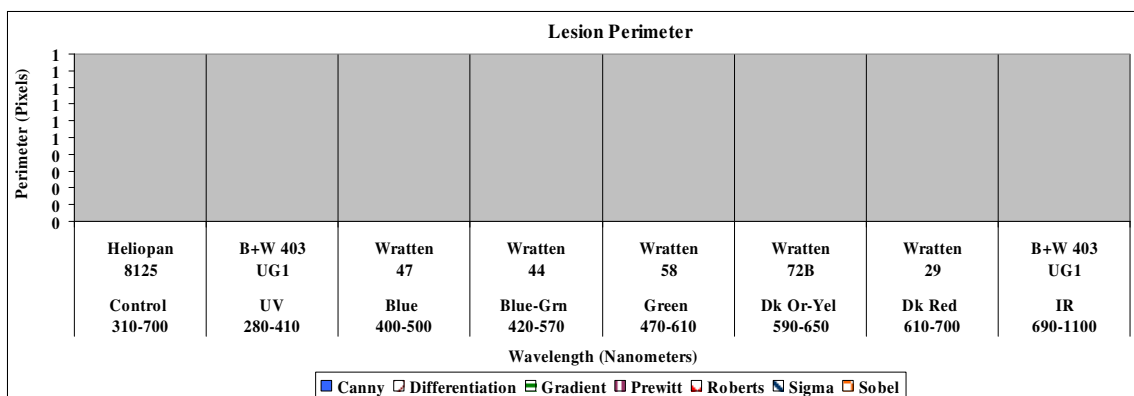


Figure 213. Lesion 458X Perimeter

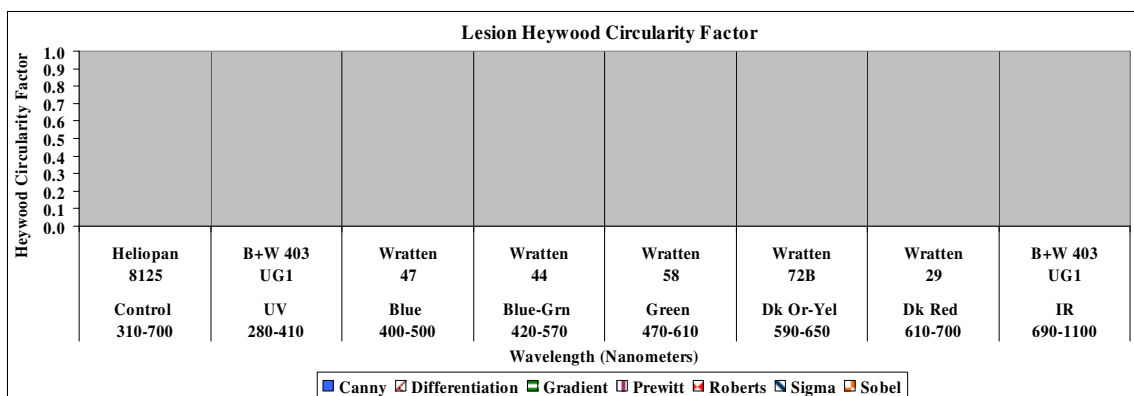


Figure 214. Lesion 458X Heywood Circularity Factor

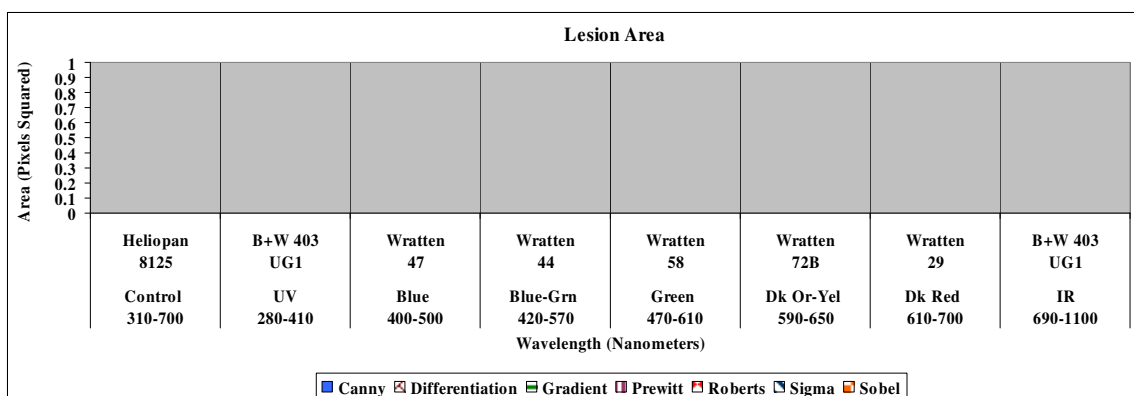


Figure 215. Lesion 458X Area

Lesion 459X

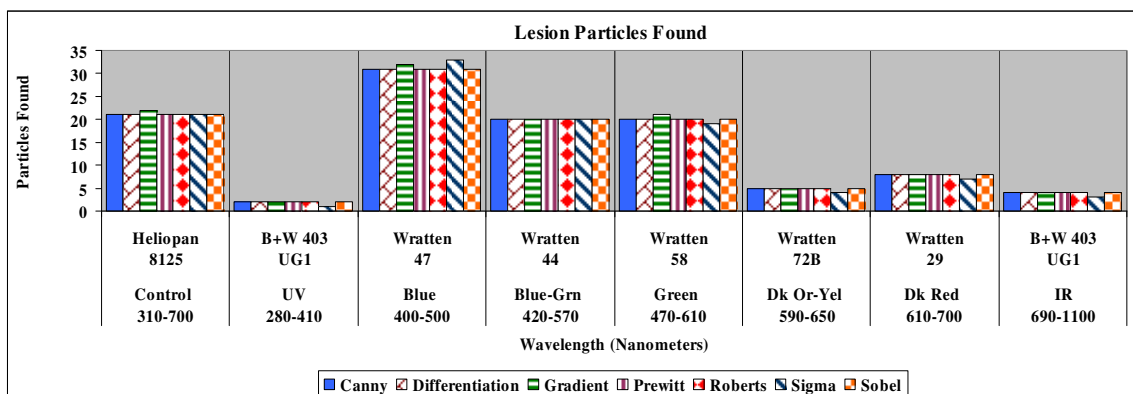


Figure 216. Lesion 459X Particles Found

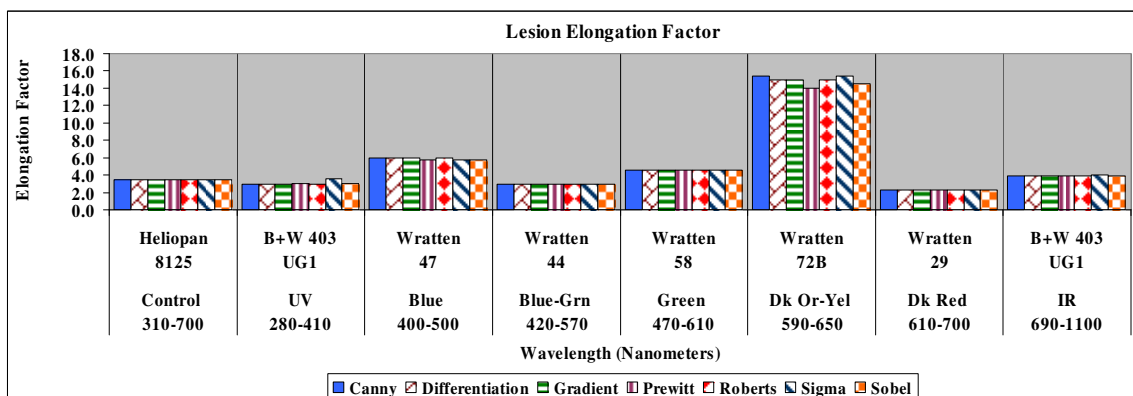


Figure 217. Lesion 459X Elongation Factor

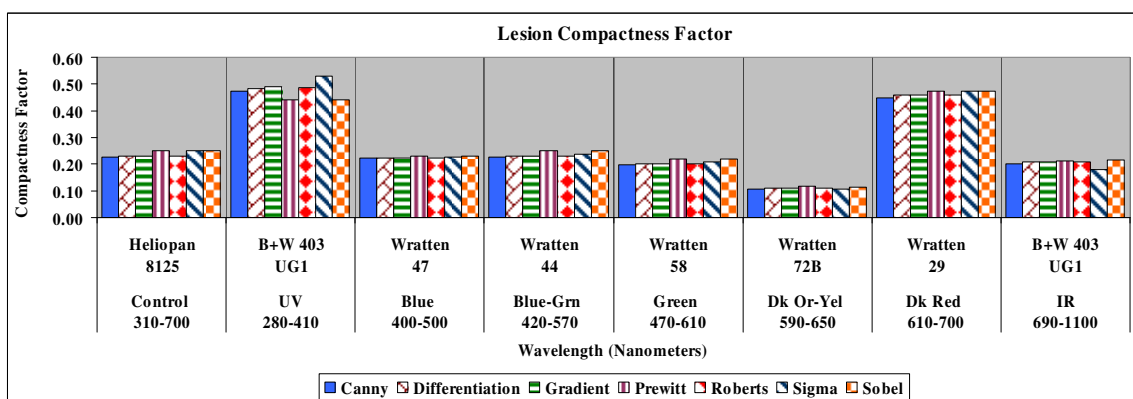


Figure 218. Lesion 459X Compactness Factor

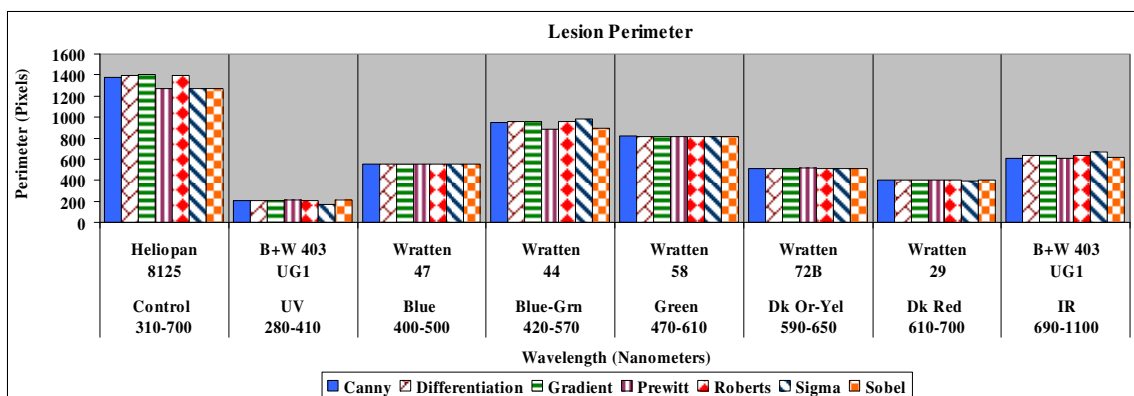


Figure 219. Lesion 459X Perimeter

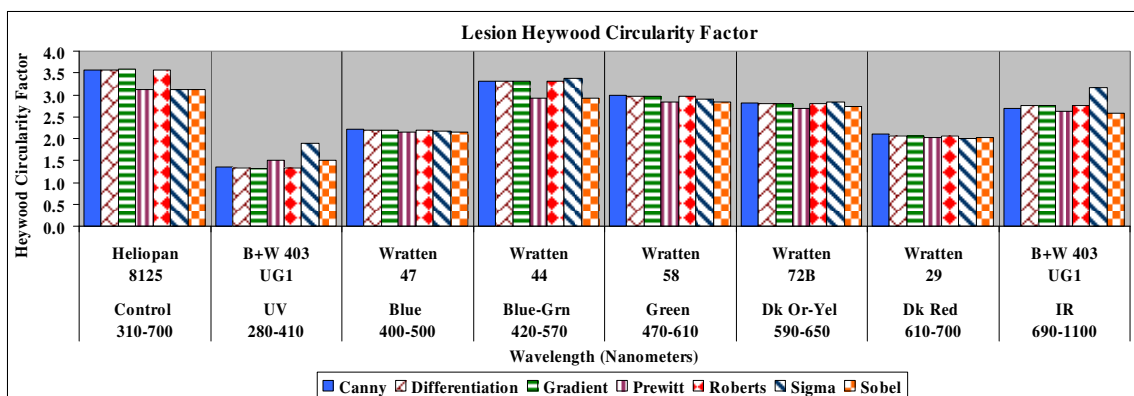


Figure 220. Lesion 459X Heywood Circularity Factor

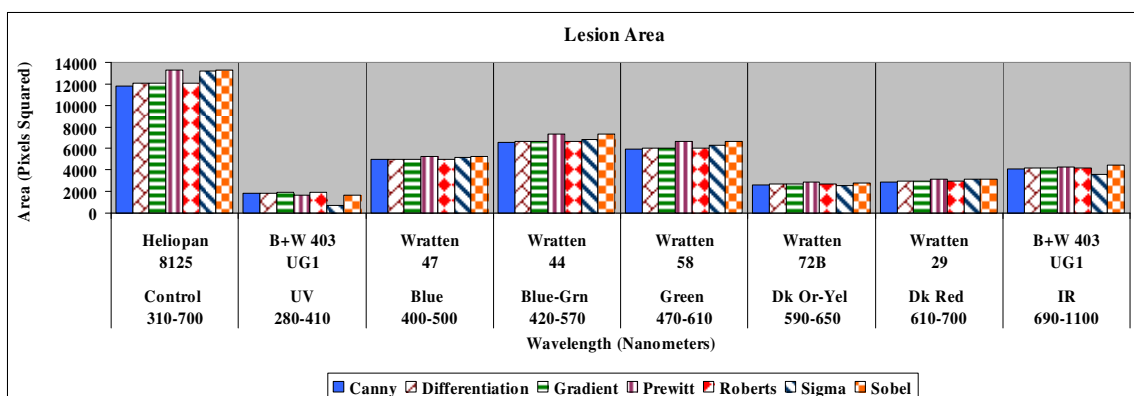


Figure 221. Lesion 459X Area

Lesion 460X

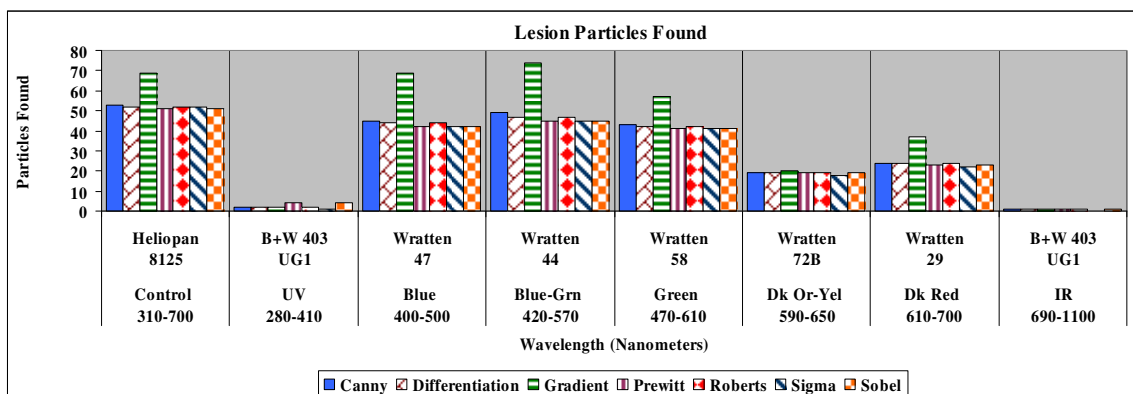


Figure 222. Lesion 460X Particles Found

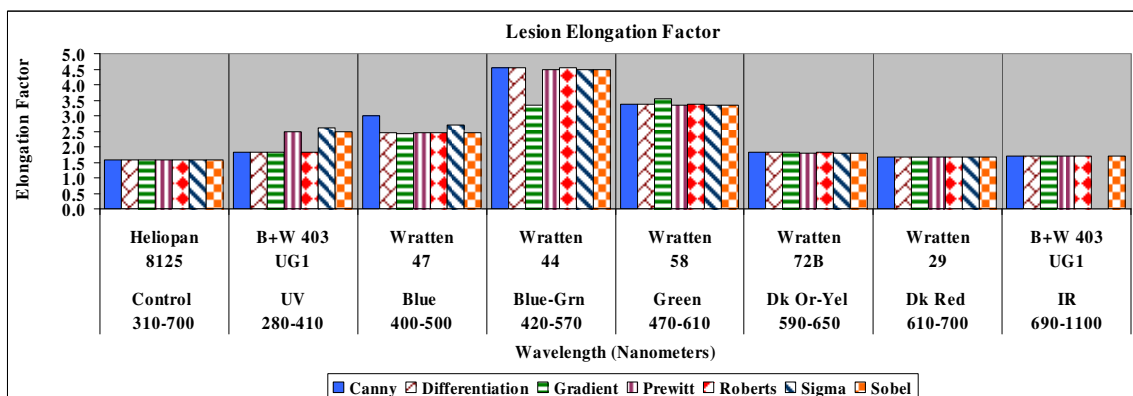


Figure 223. Lesion 460X Elongation Factor

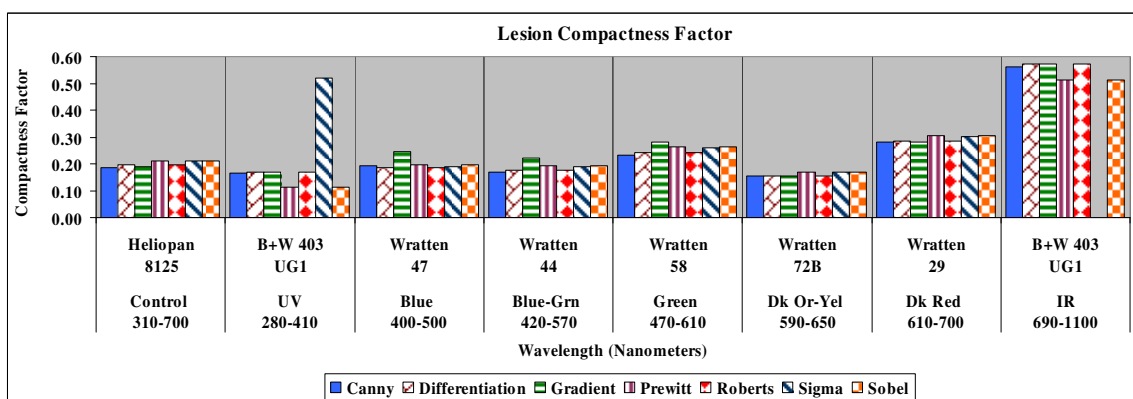


Figure 224. Lesion 460X Compactness Factor

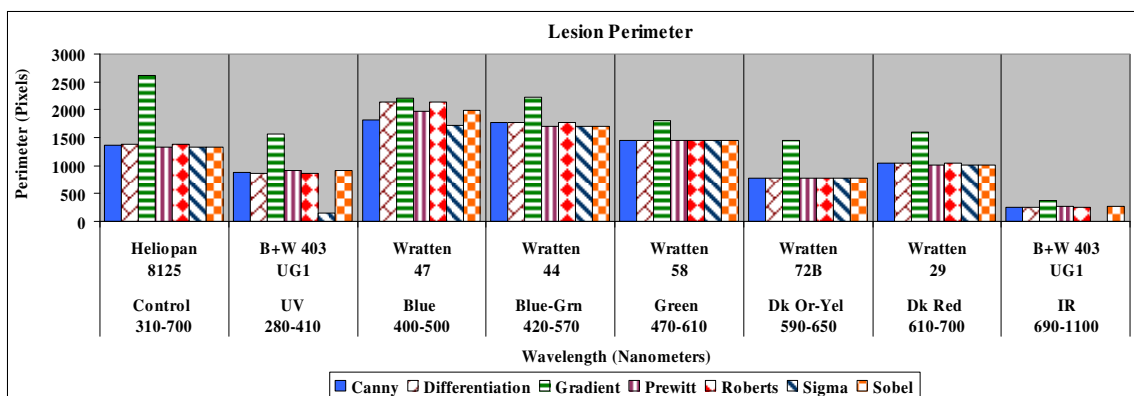


Figure 225. Lesion 460X Perimeter

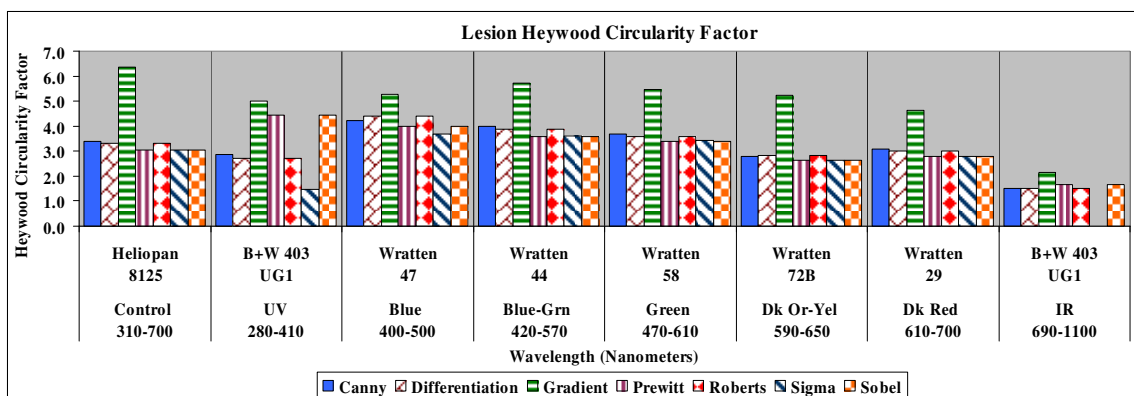


Figure 226. Lesion 460X Heywood Circularity Factor

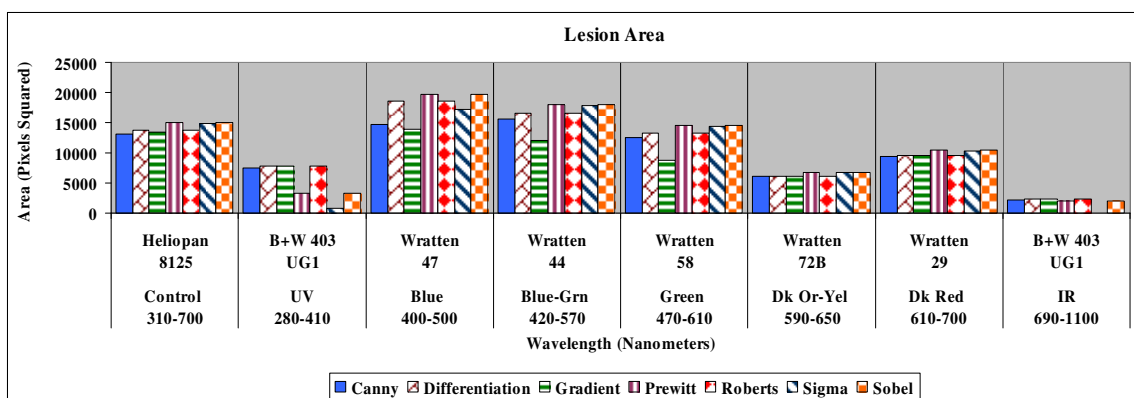


Figure 227. Lesion 460X Area

Lesion 472X

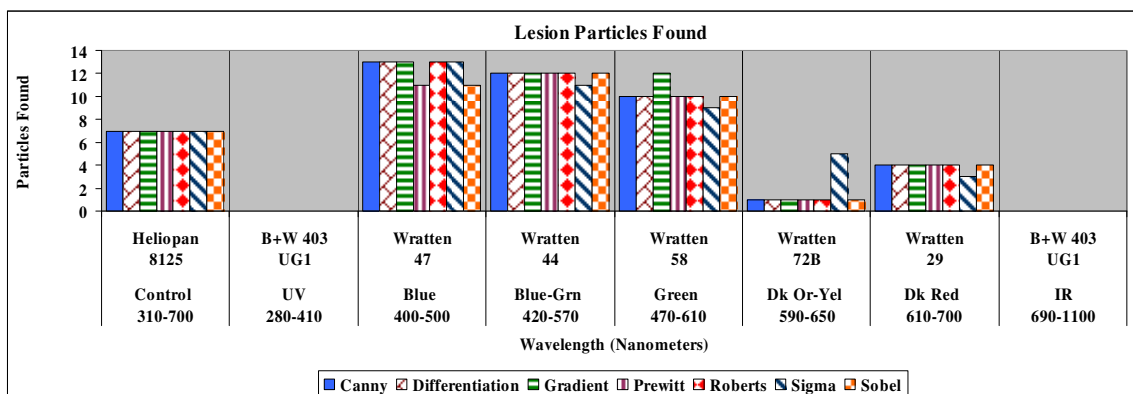


Figure 228. Lesion 472X Particles Found

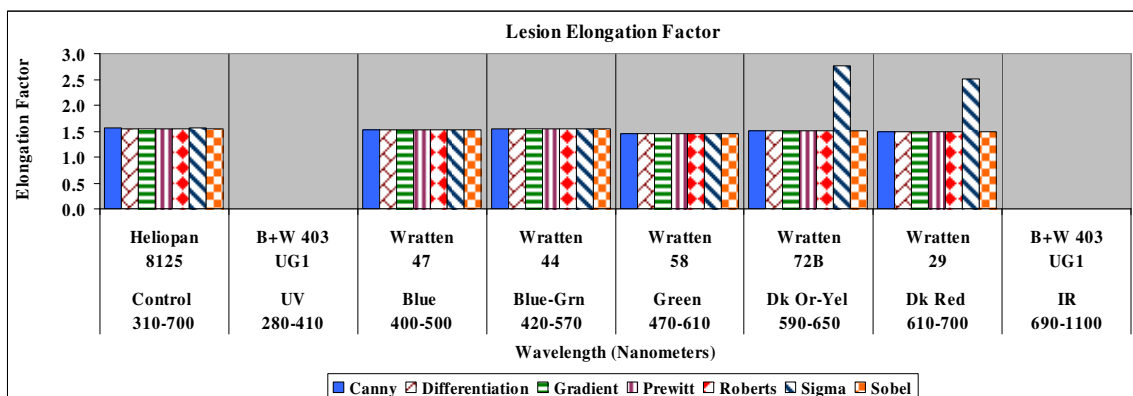


Figure 229. Lesion 472X Elongation Factor

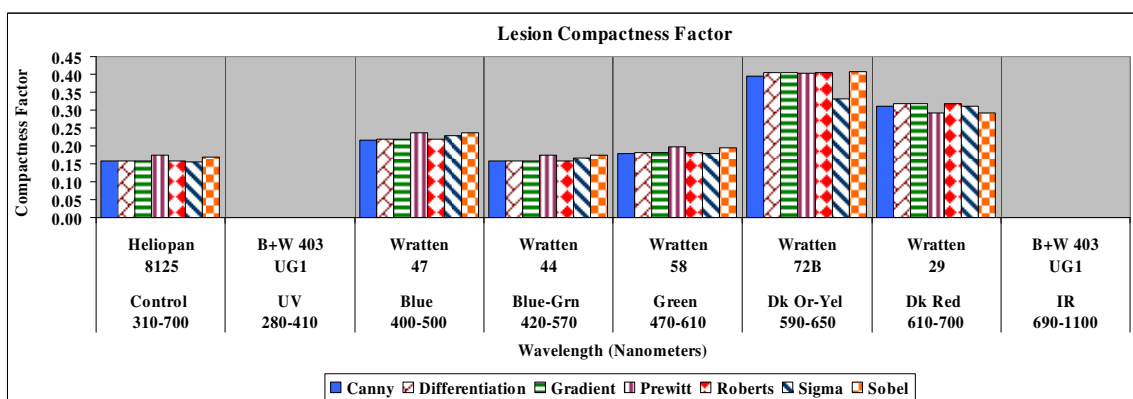


Figure 230. Lesion 472X Compactness Factor

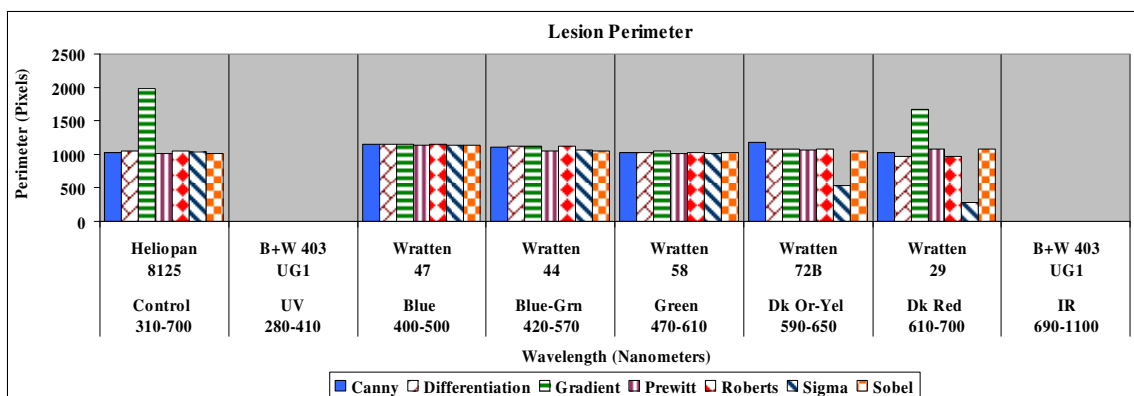


Figure 231. Lesion 472X Perimeter

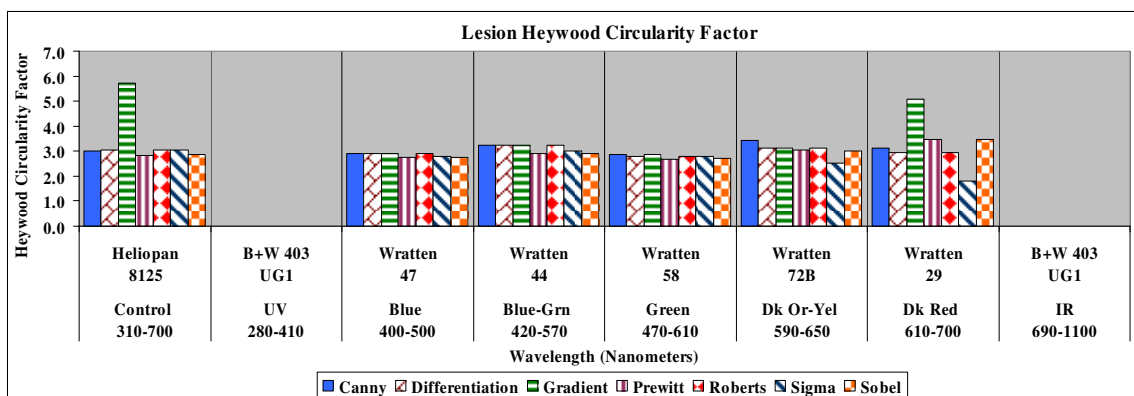


Figure 232. Lesion 472X Heywood Circularity Factor

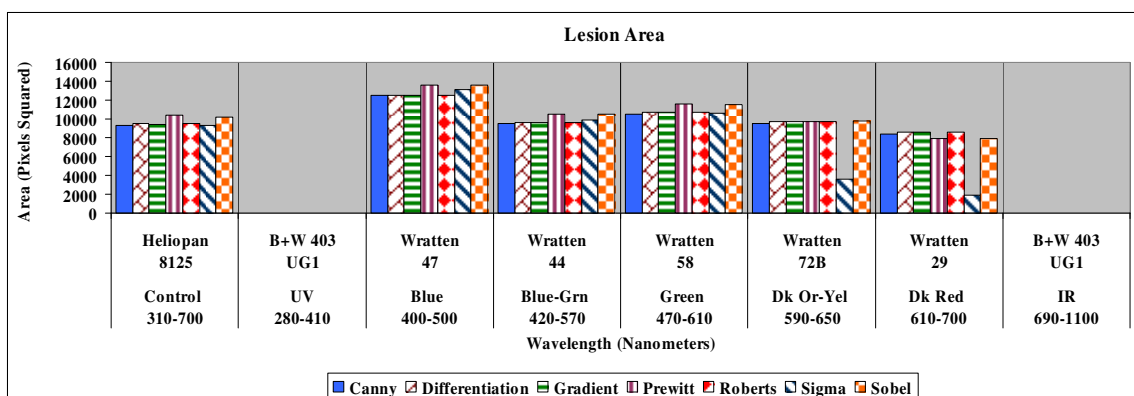


Figure 233. Lesion 472X Area

Lesion 473X

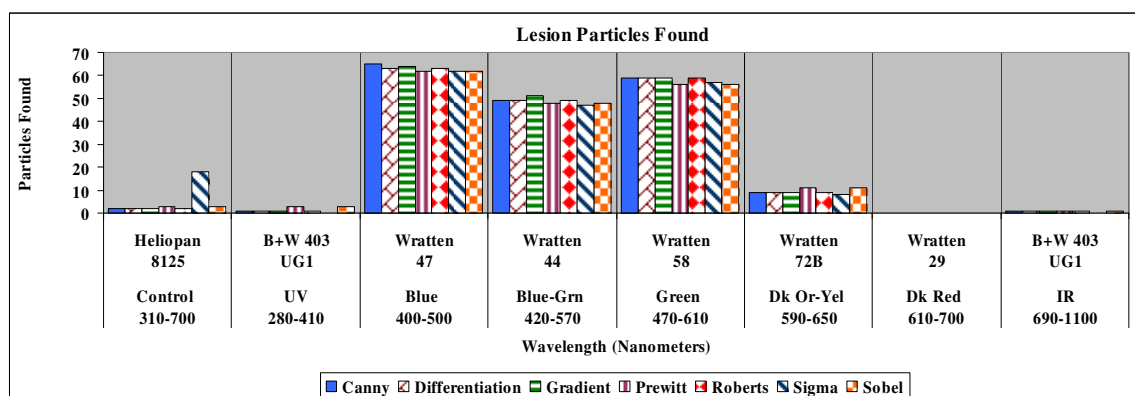


Figure 234. Lesion 473X Particles Found

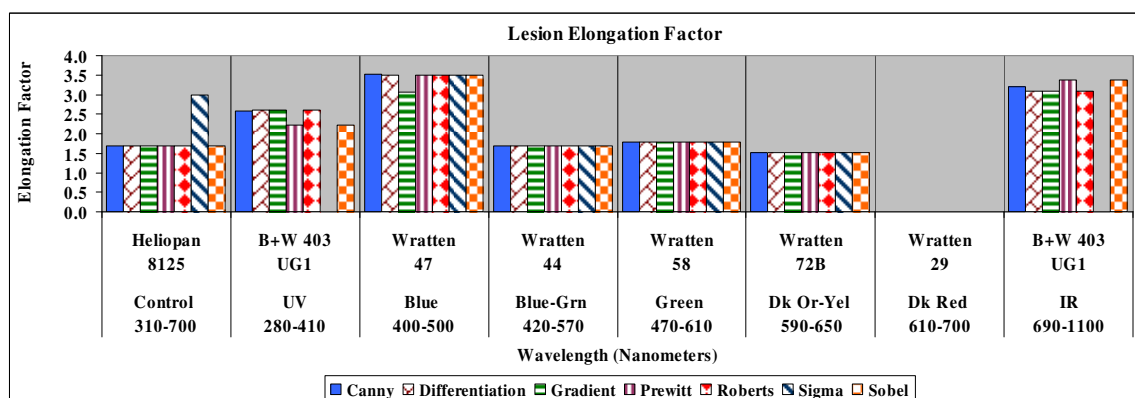


Figure 235. Lesion 473X Elongation Factor

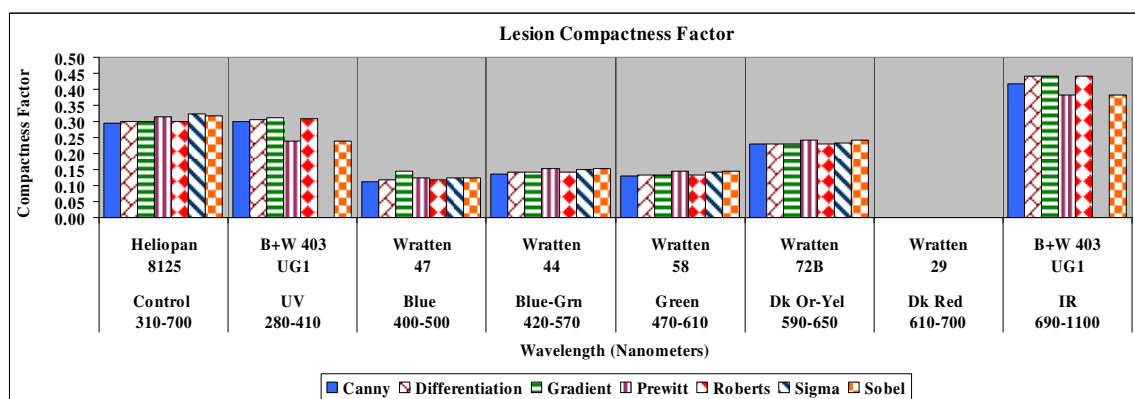


Figure 236. Lesion 473X Compactness Factor

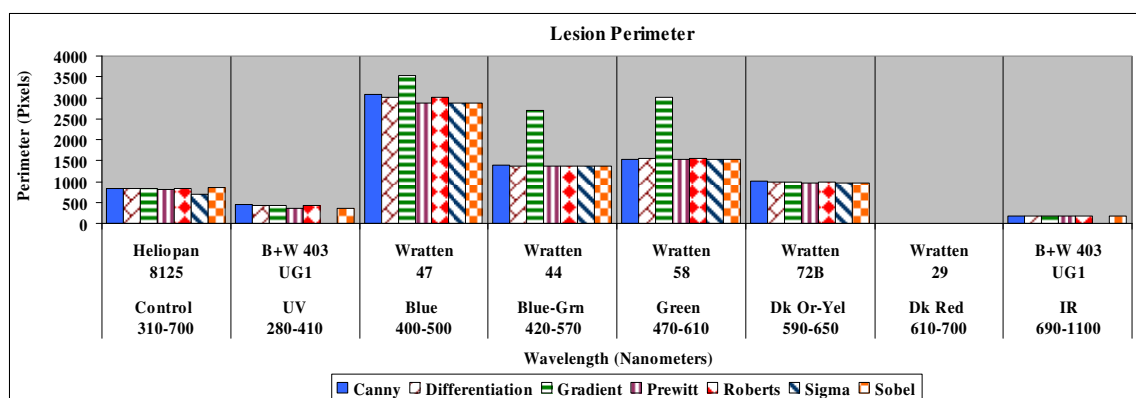


Figure 237. Lesion 473X Perimeter

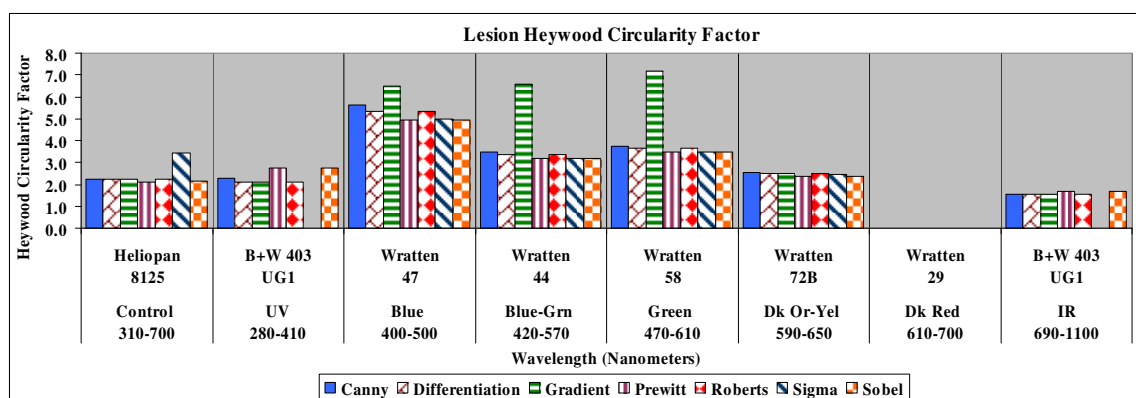


Figure 238. Lesion 473X Heywood Circularity Factor

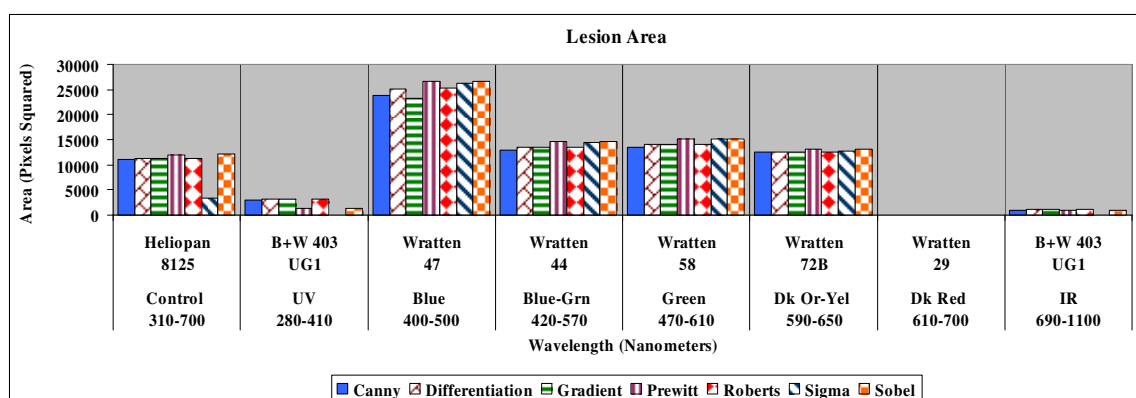


Figure 239. Lesion 473X Area

Lesion 474X

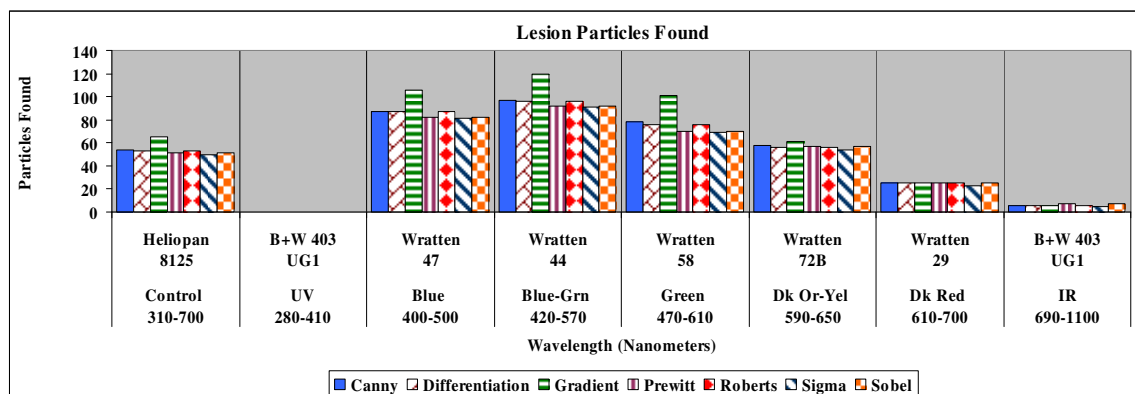


Figure 240. Lesion 474X Particles Found

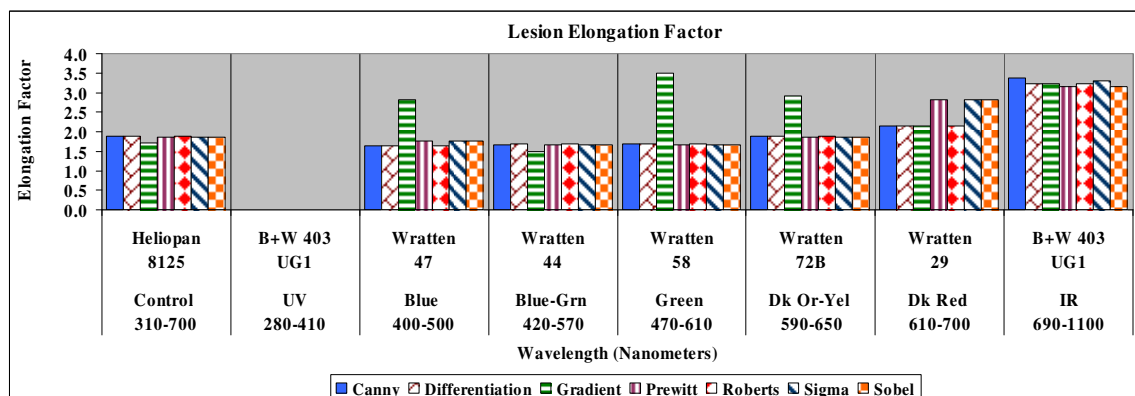


Figure 241. Lesion 474X Elongation Factor

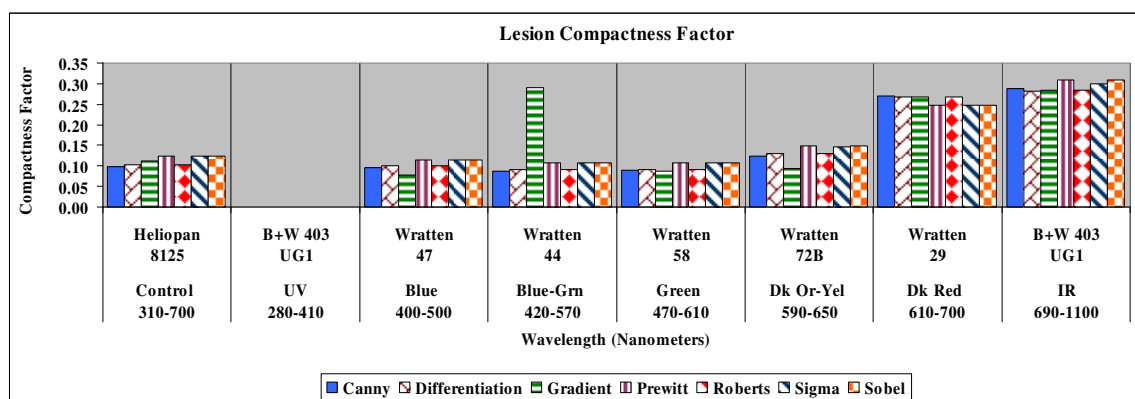


Figure 242. Lesion 474X Compactness Factor

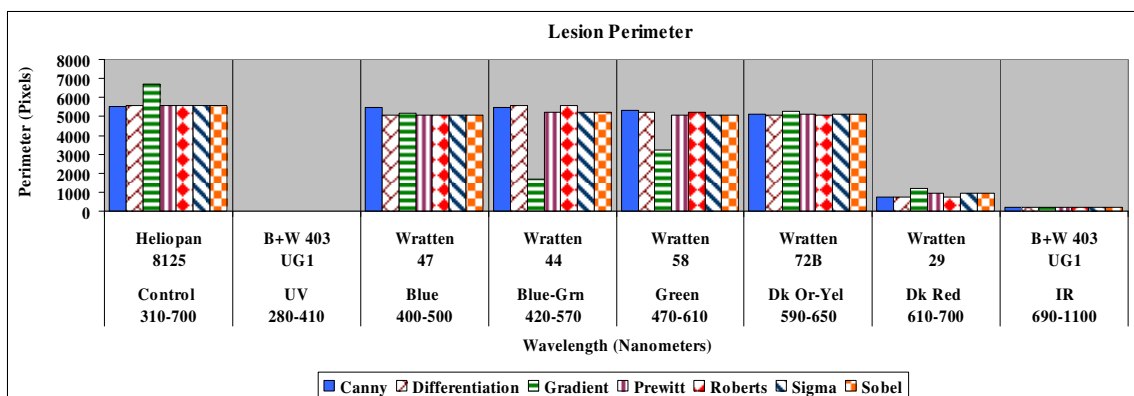


Figure 243. Lesion 474X Perimeter

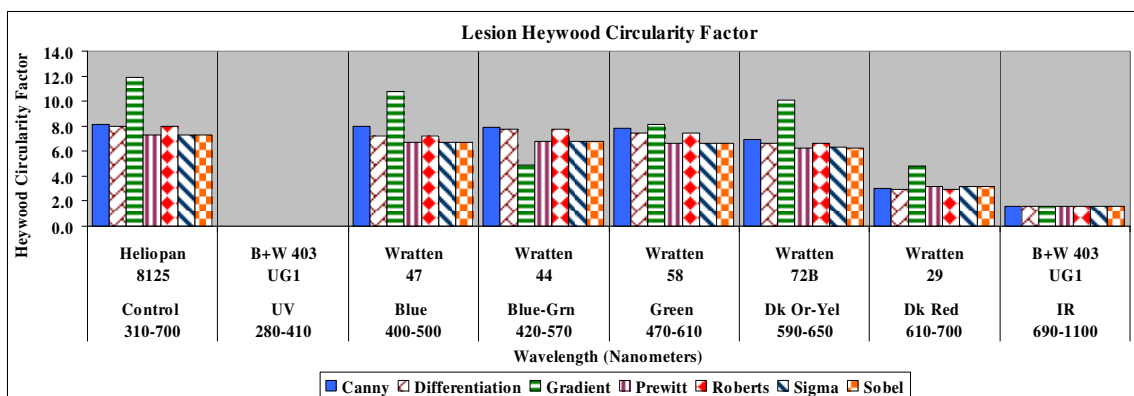


Figure 244. Lesion 474X Heywood Circularity Factor

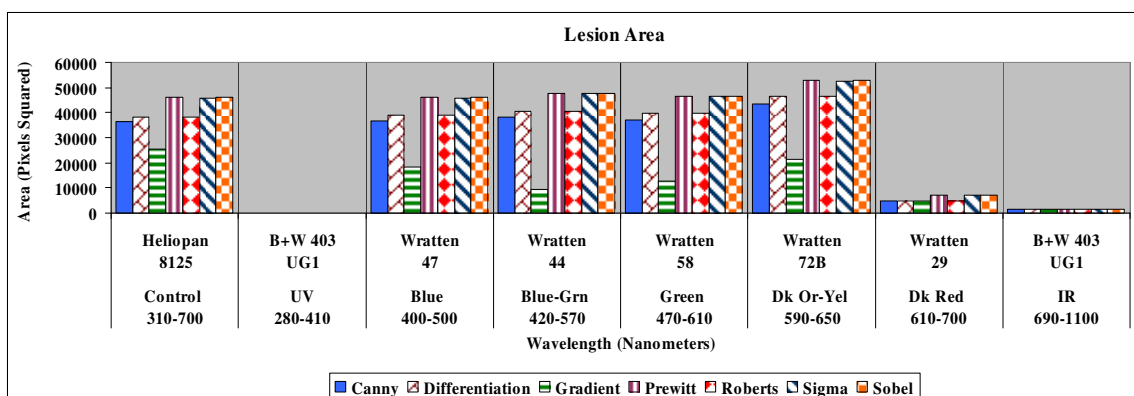


Figure 245. Lesion 474X Area

Lesion 475X

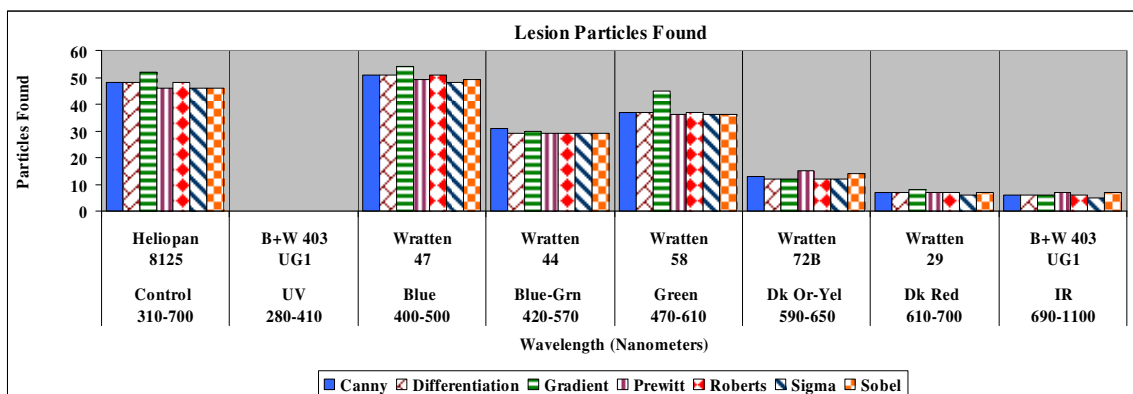


Figure 246. Lesion 475X Particles Found

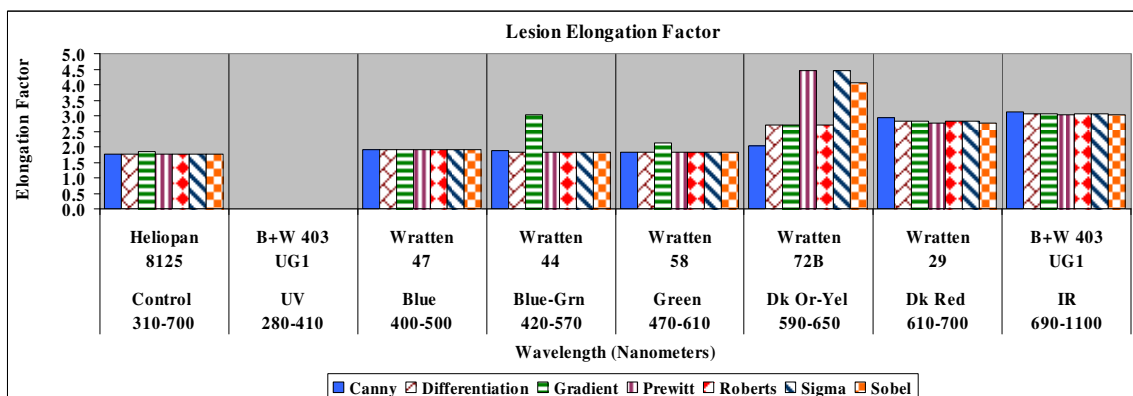


Figure 247. Lesion 475X Elongation Factor

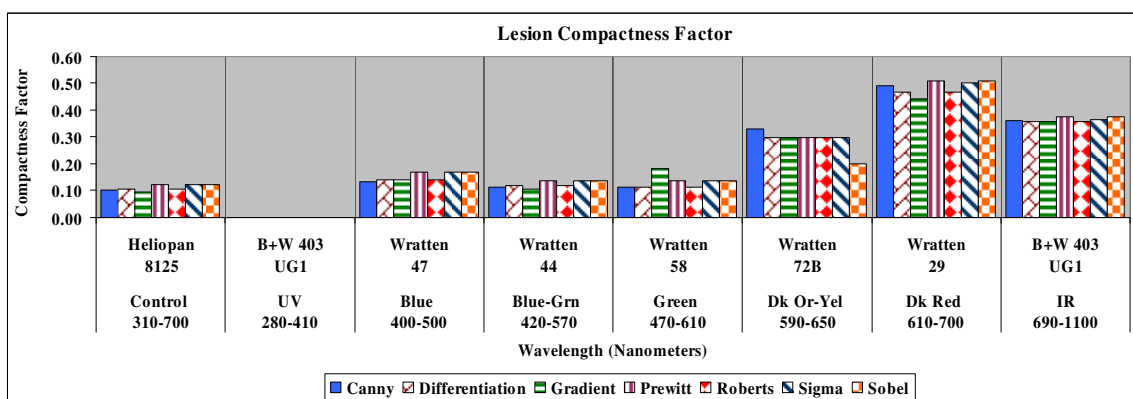


Figure 248. Lesion 475X Compactness Factor

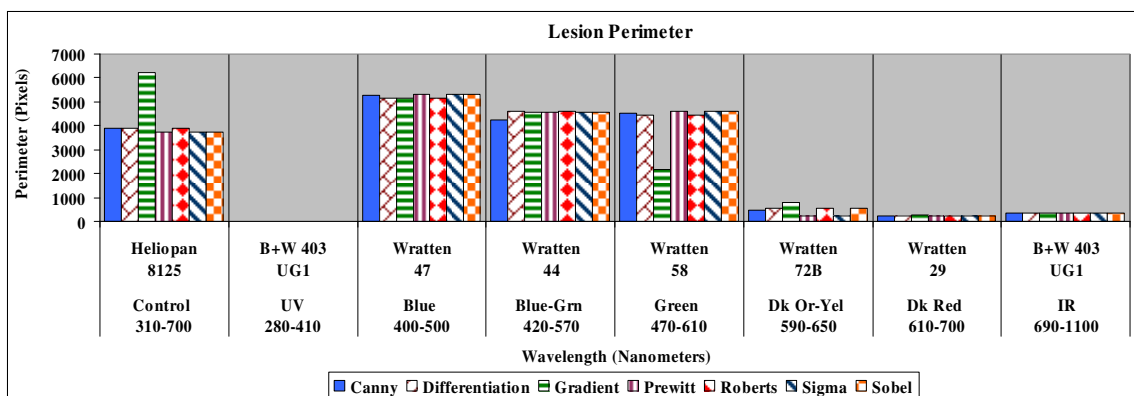


Figure 249. Lesion 475X Perimeter

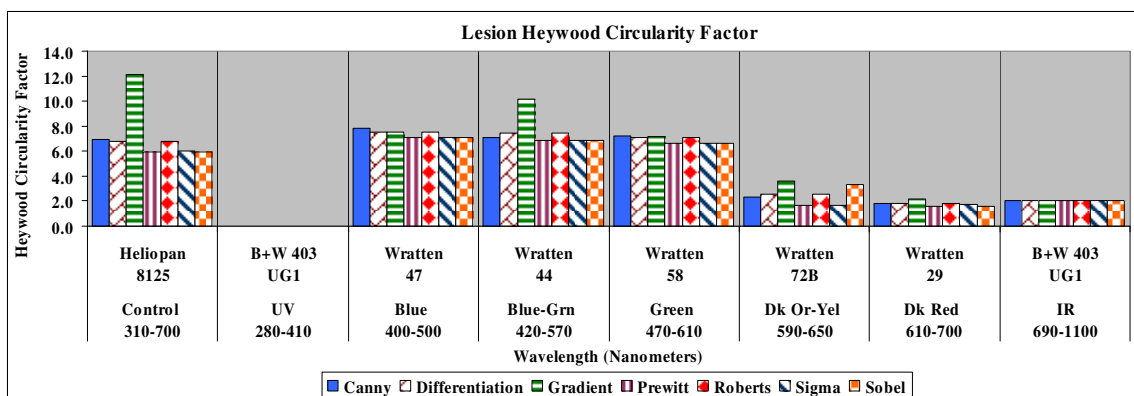


Figure 250. Lesion 475X Heywood Circularity Factor

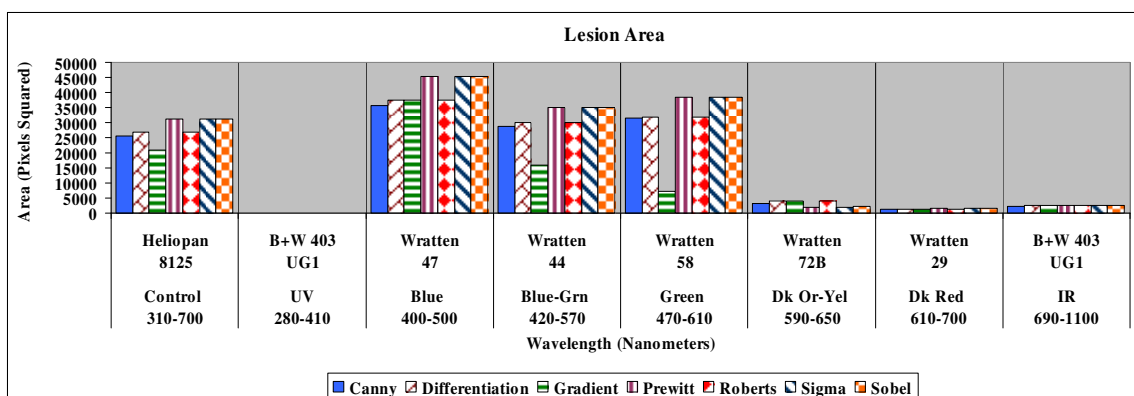


Figure 251. Lesion 475X Area

Lesion 476X

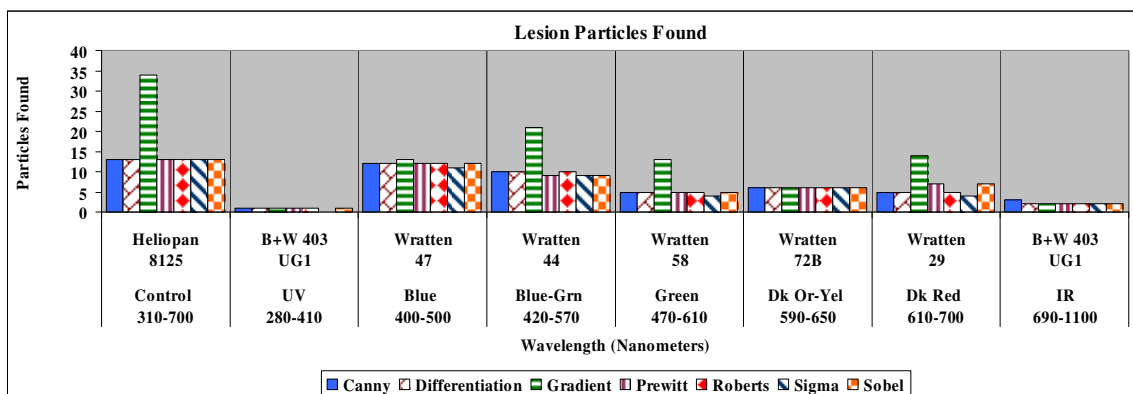


Figure 252. Lesion 476X Particles Found

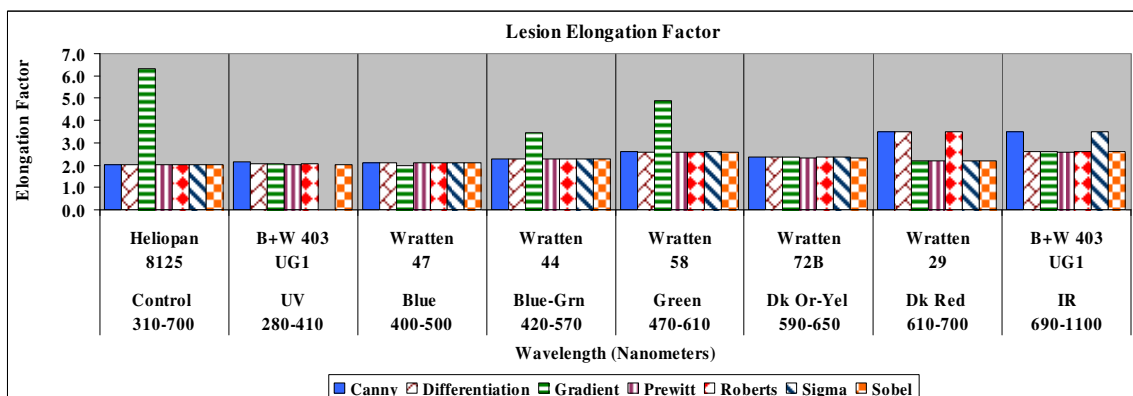


Figure 253. Lesion 476X Elongation Factor

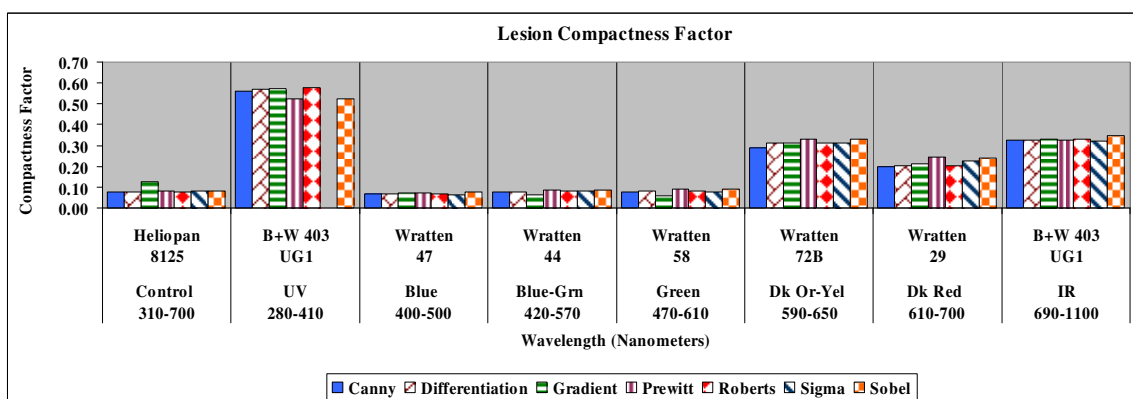


Figure 254. Lesion 476X Compactness Factor

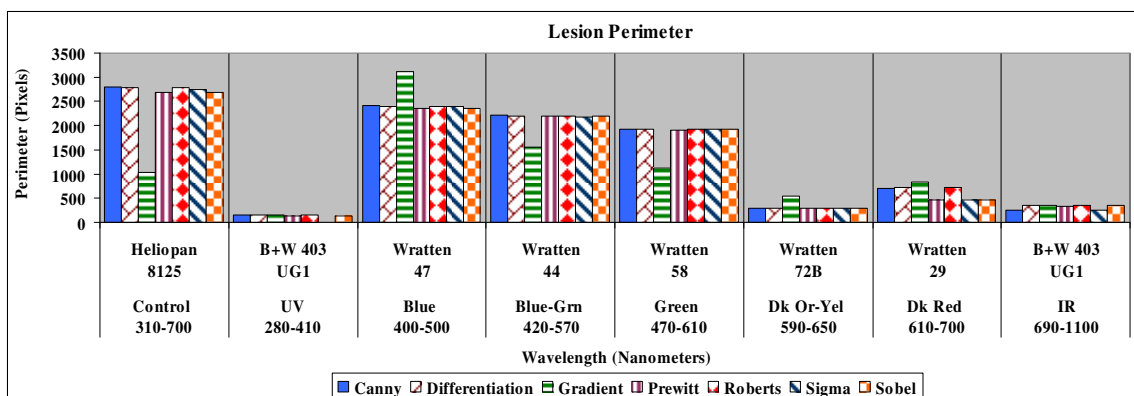


Figure 255. Lesion 476X Perimeter

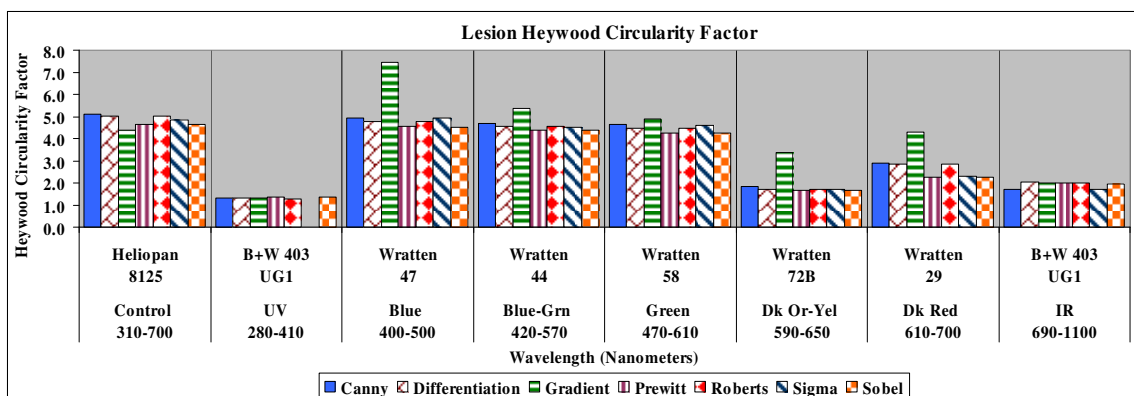


Figure 256. Lesion 476X Heywood Circularity Factor

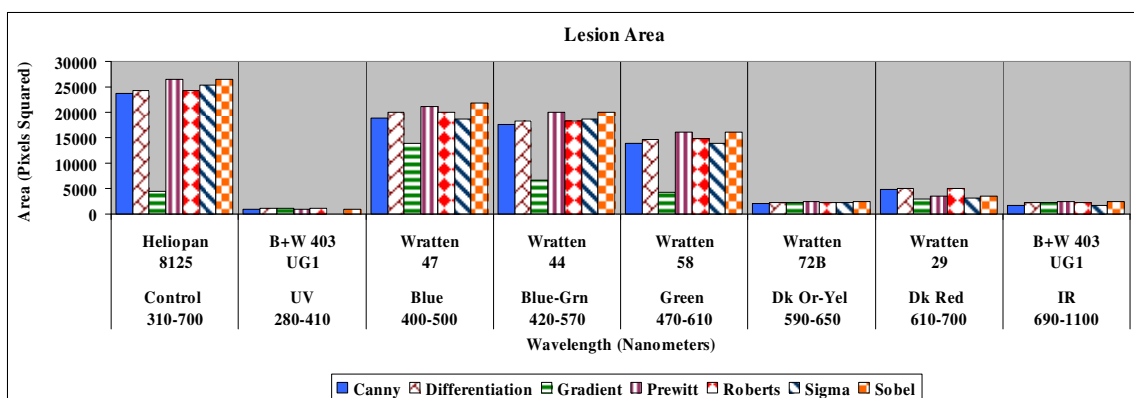


Figure 257. Lesion 476X Area

Lesion 477X

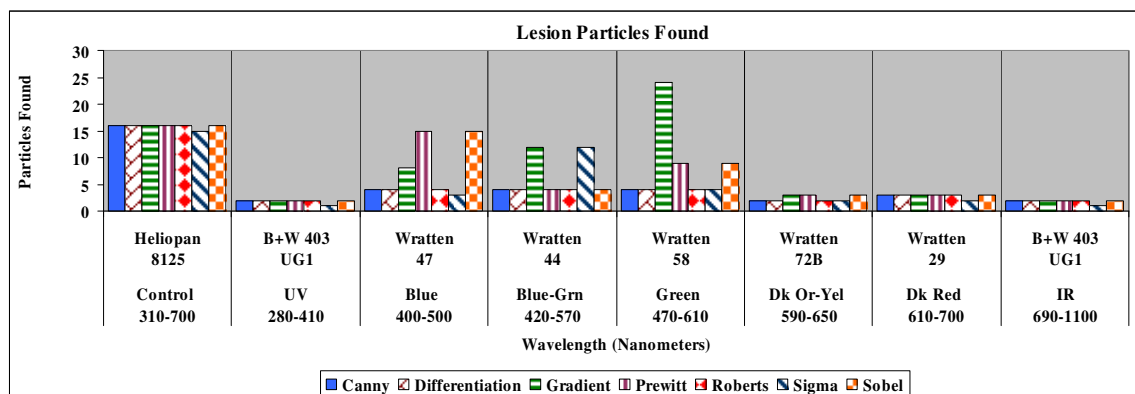


Figure 258. Lesion 477X Particles Found

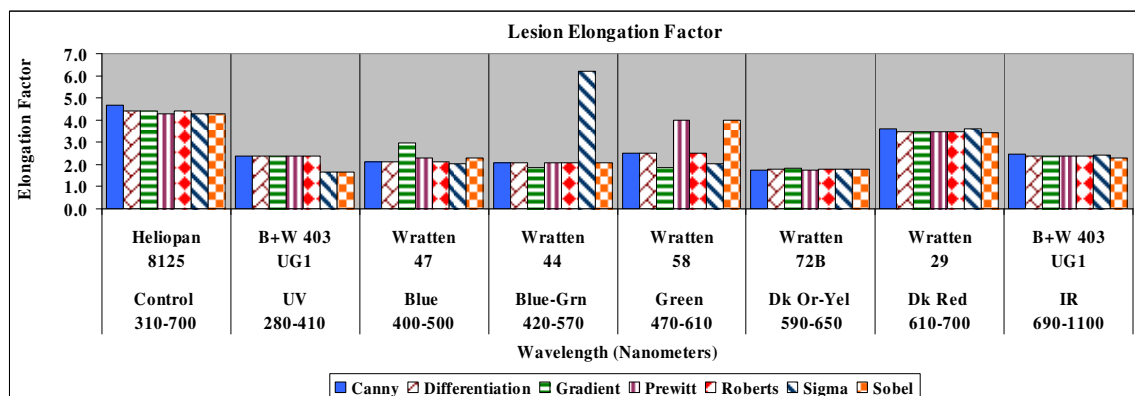


Figure 259. Lesion 477X Elongation Factor

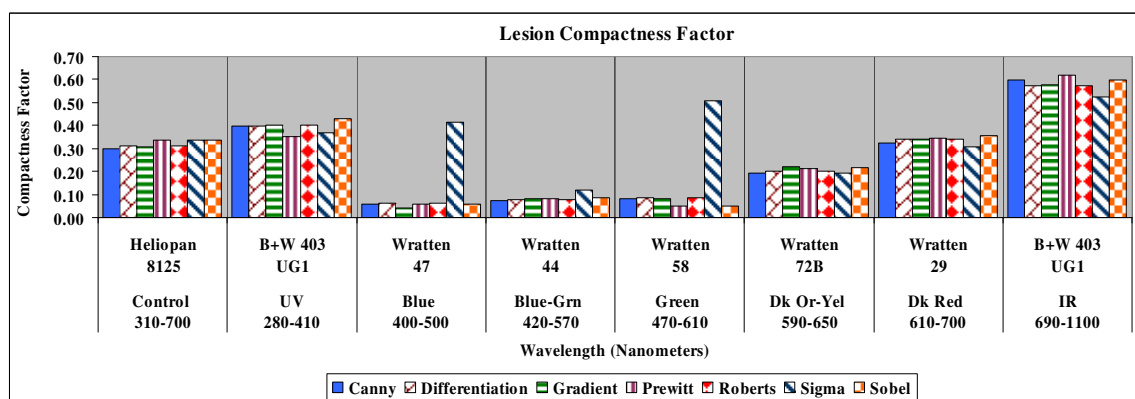


Figure 260. Lesion 477X Compactness Factor

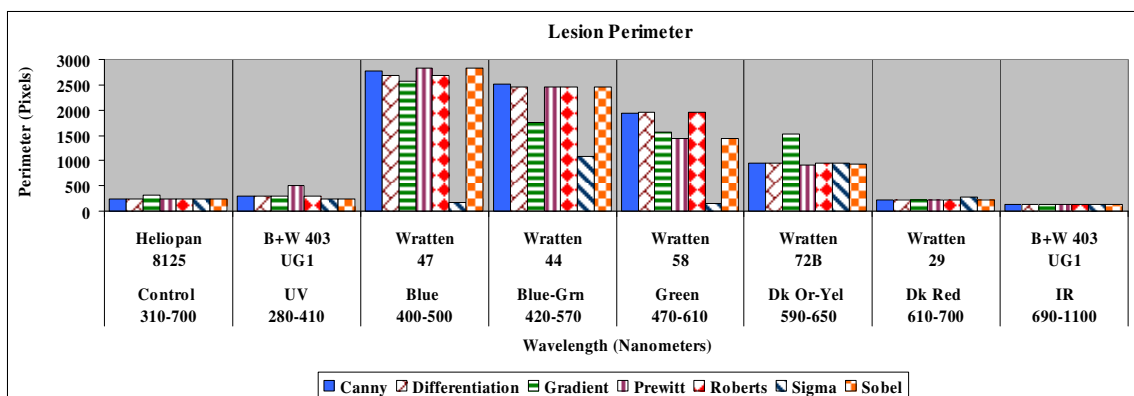


Figure 261. Lesion 477X Perimeter

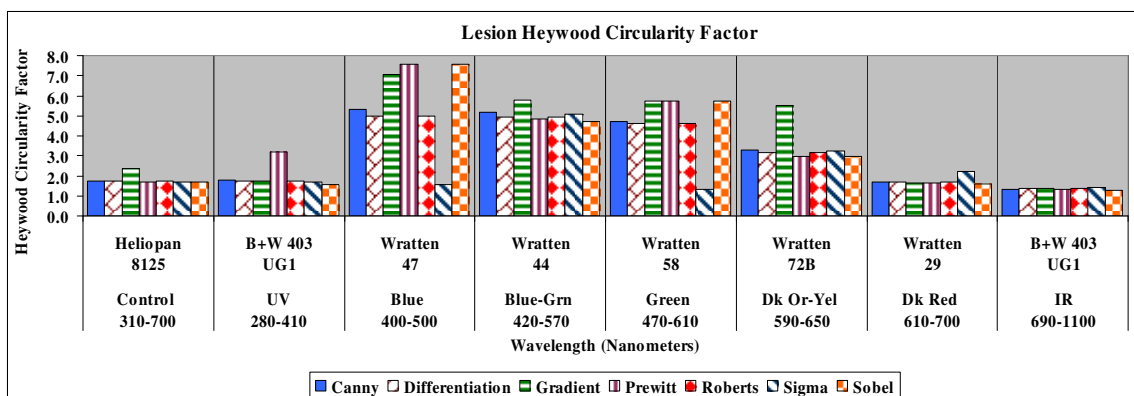


Figure 262. Lesion 477X Heywood Circularity Factor

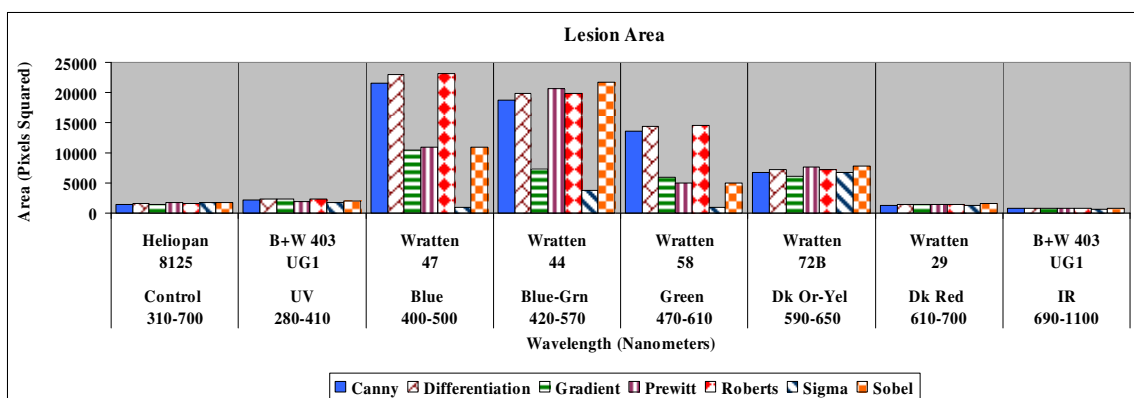


Figure 263. Lesion 477X Area

Lesion 479X

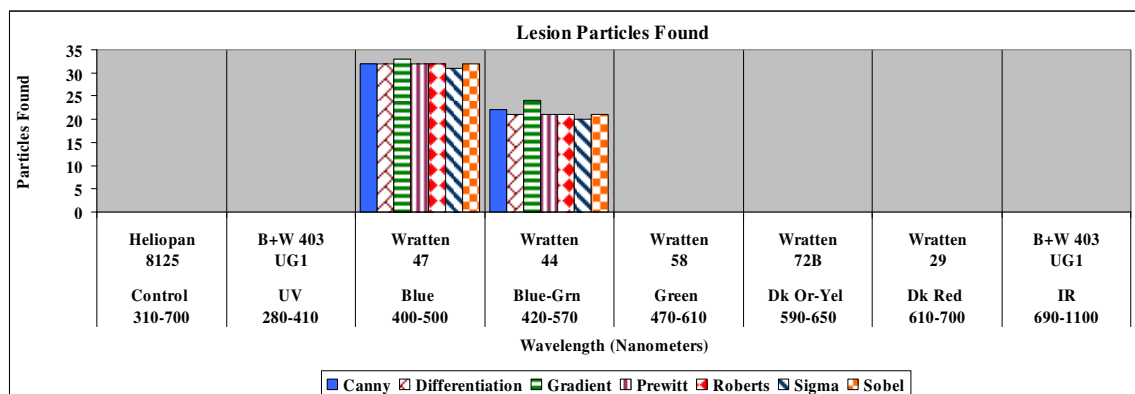


Figure 264. Lesion 479X Particles Found

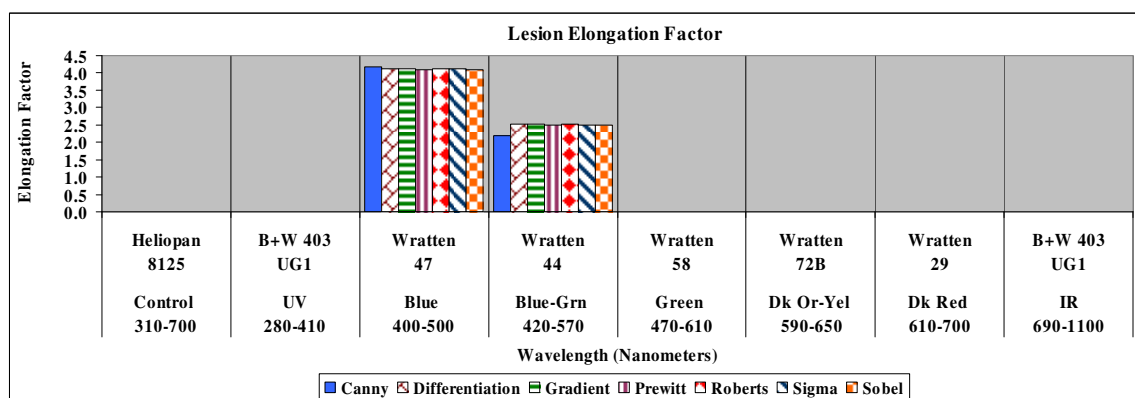


Figure 265. Lesion 479X Elongation Factor

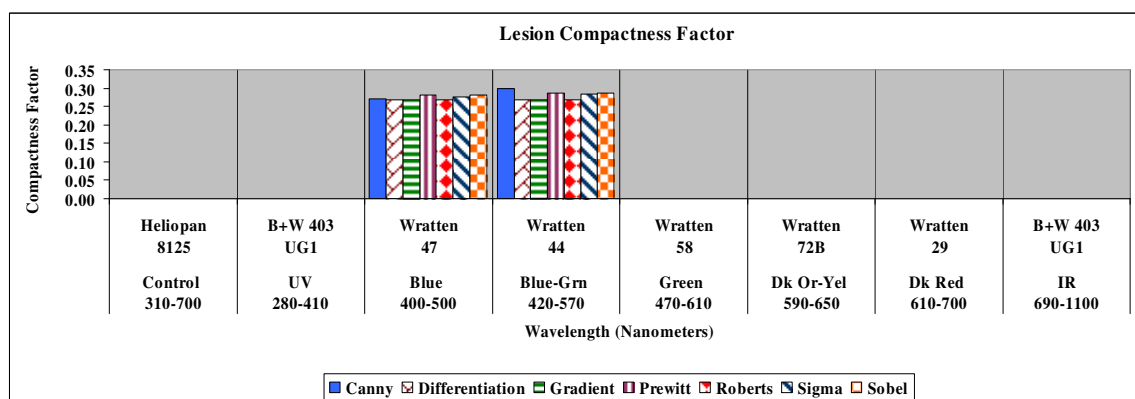


Figure 266. Lesion 479X Compactness Factor

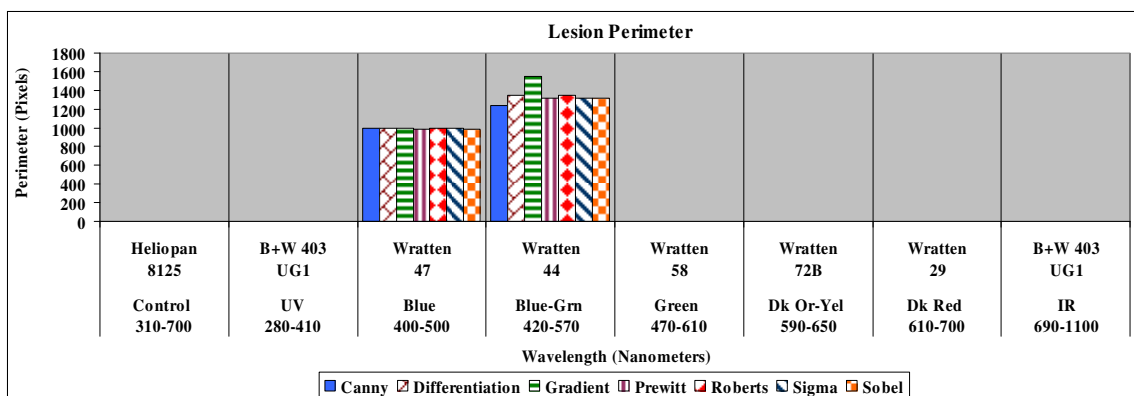


Figure 267. Lesion 479X Perimeter

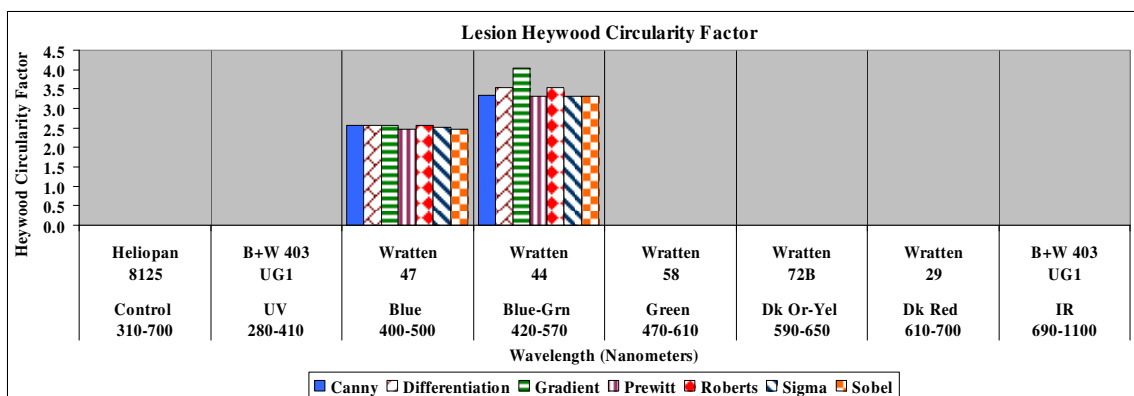


Figure 268. Lesion 479X Heywood Circularity Factor

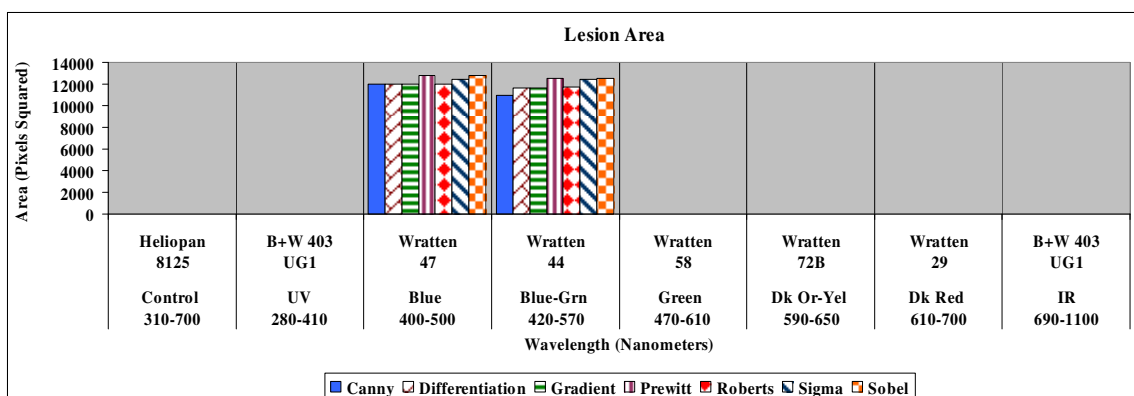


Figure 269. Lesion 479X Area

Lesion 480X

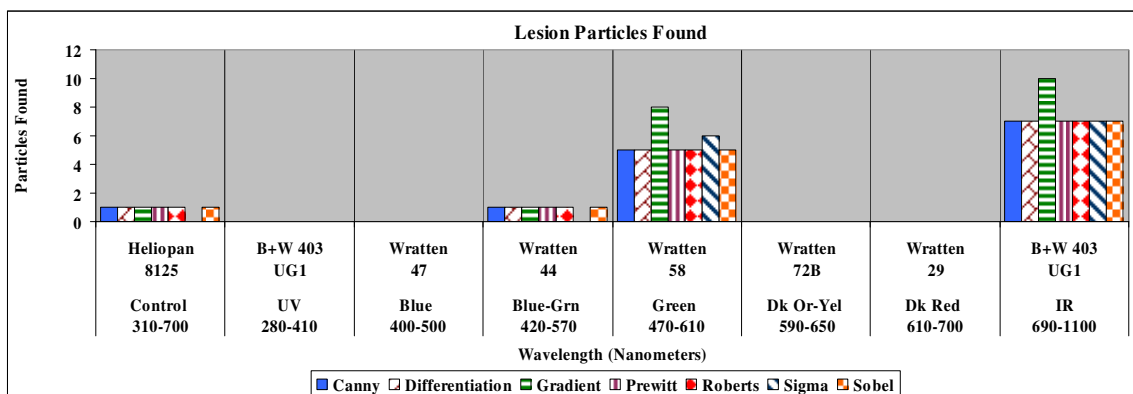


Figure 270. Lesion 480X Particles Found

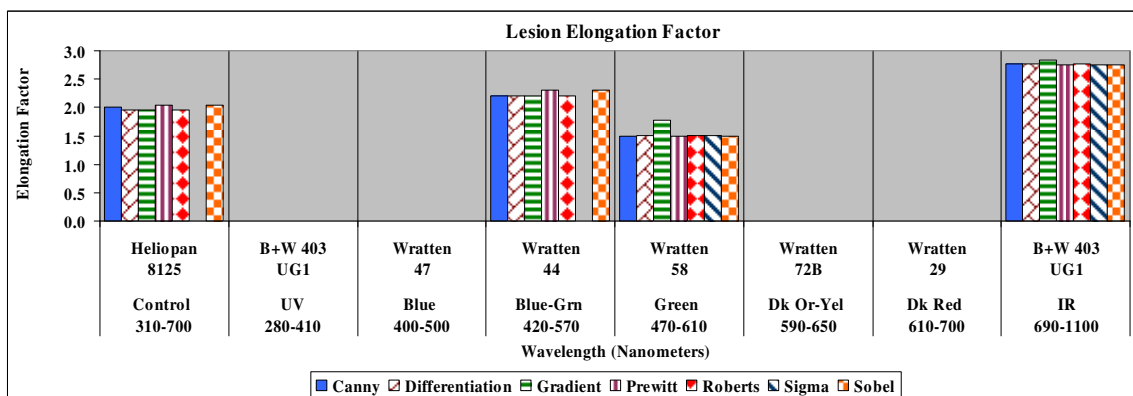


Figure 271. Lesion 480X Elongation Factor

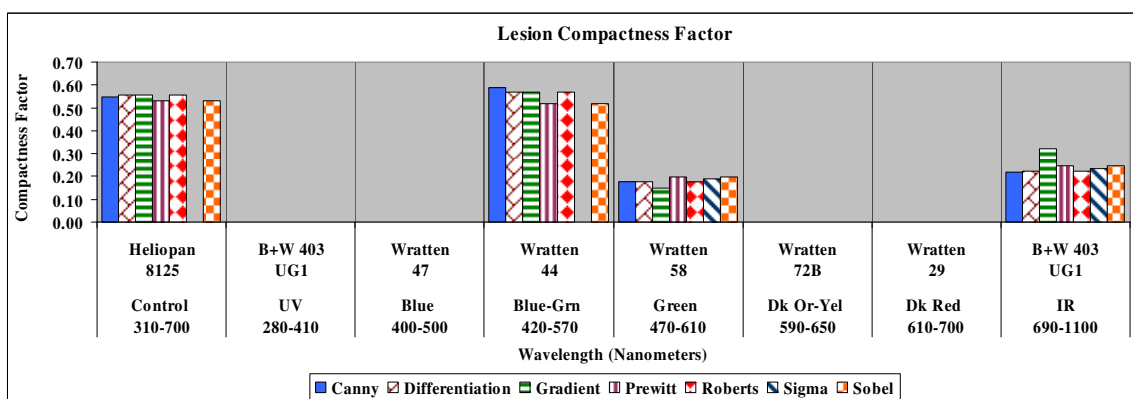


Figure 272. Lesion 480X Compactness Factor

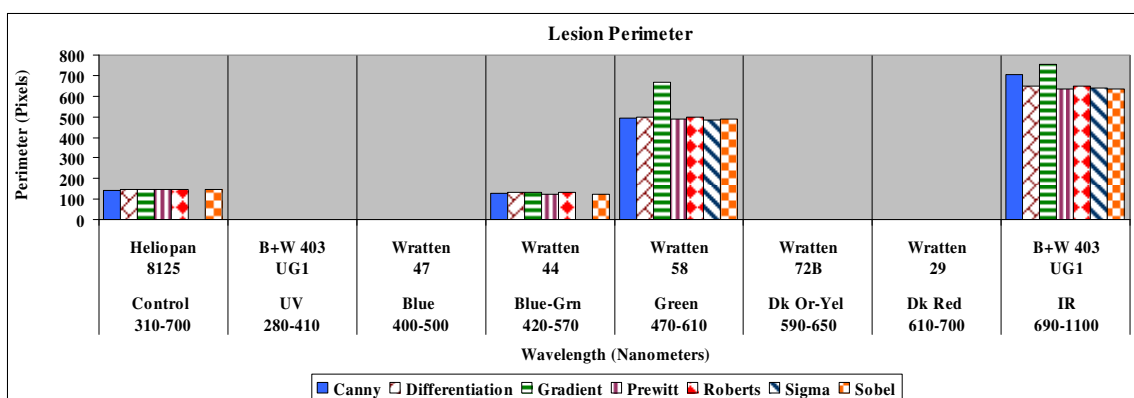


Figure 273. Lesion 480X Perimeter

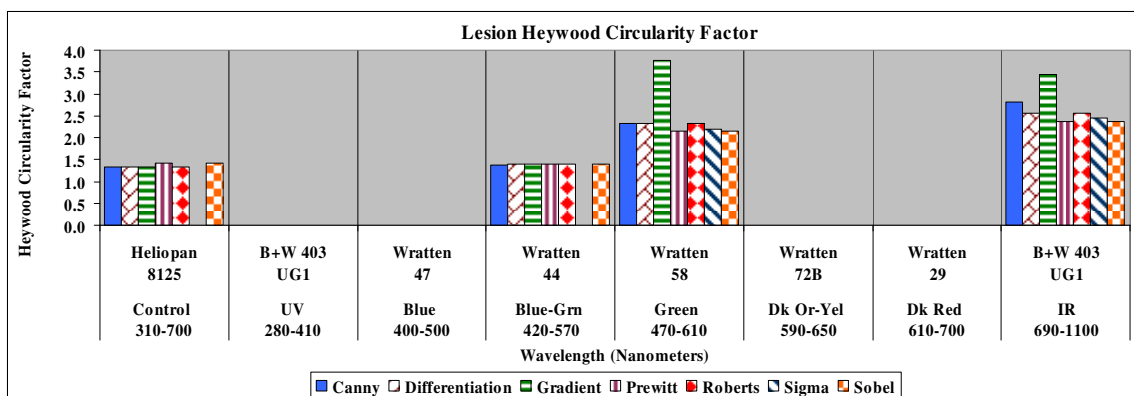


Figure 274. Lesion 480X Heywood Circularity Factor

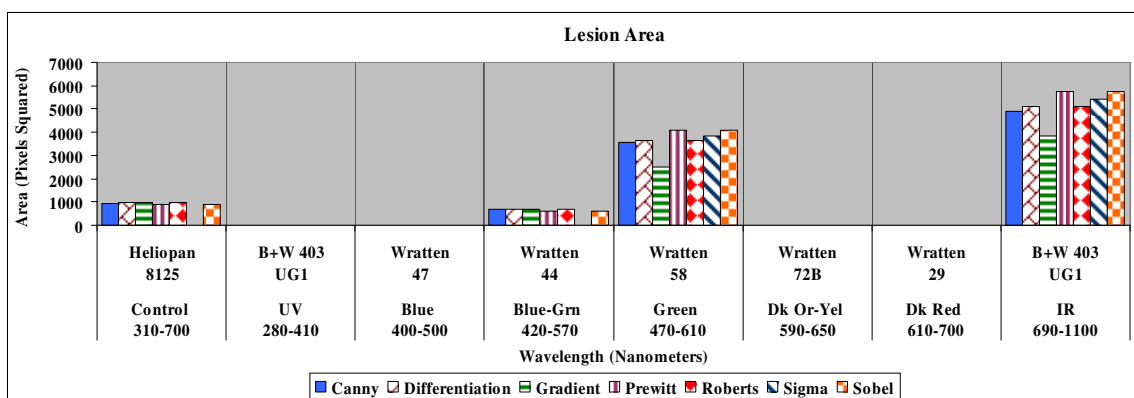


Figure 275. Lesion 480X Area

Lesion 481X

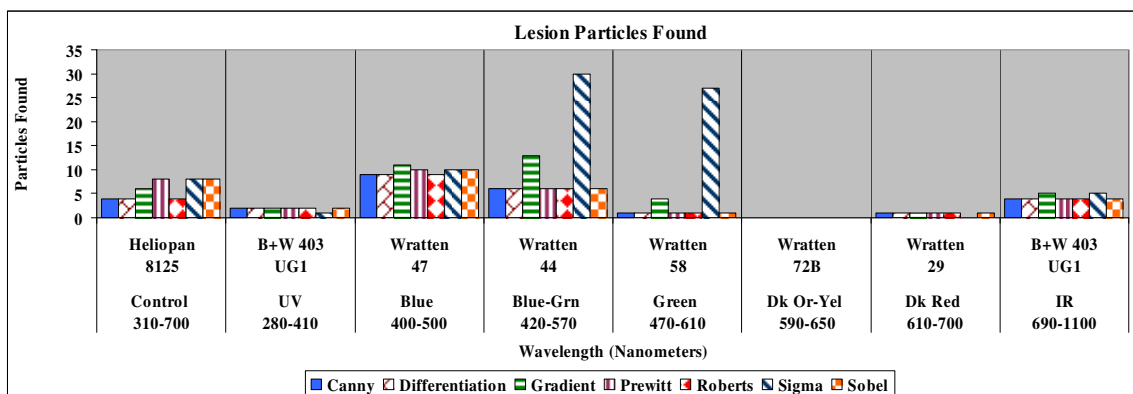


Figure 276. Lesion 481X Particles Found

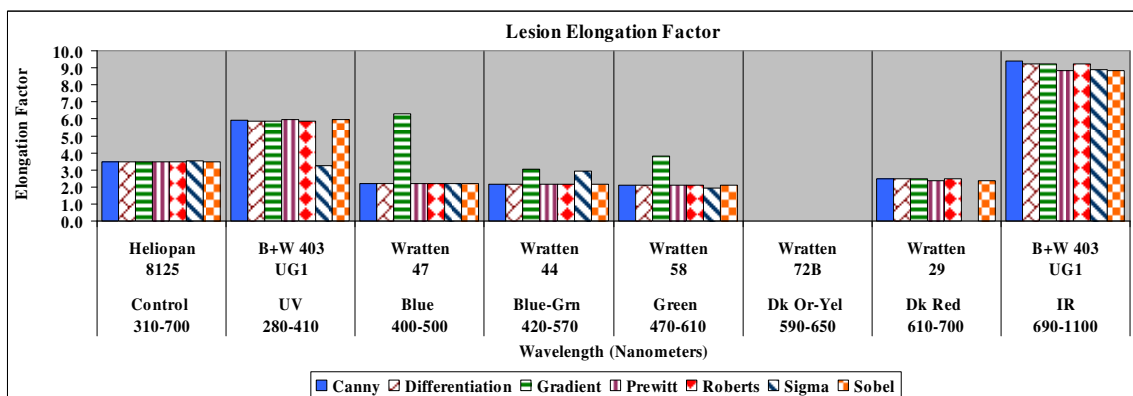


Figure 277. Lesion 481X Elongation Factor

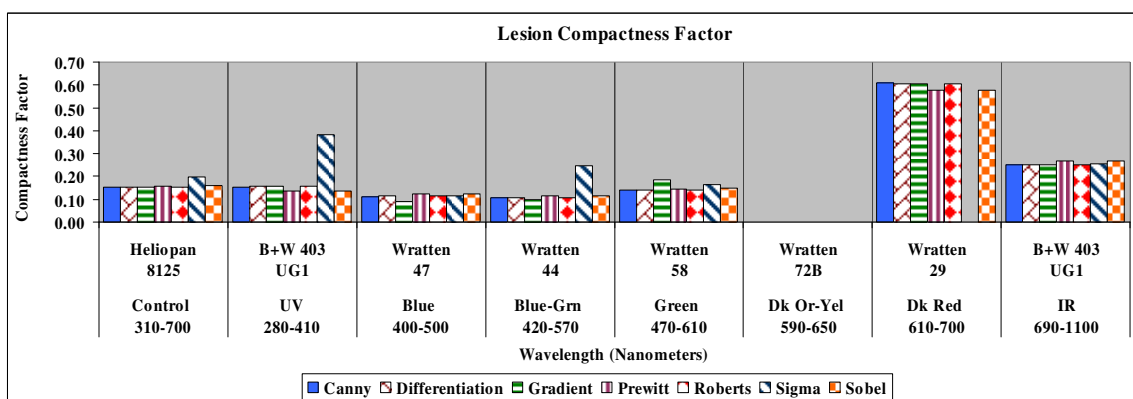


Figure 278. Lesion 481X Compactness Factor

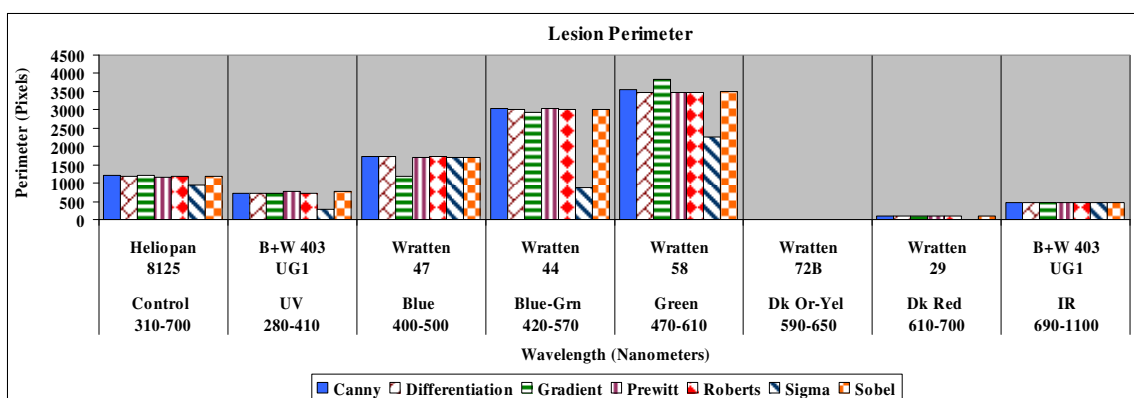


Figure 279. Lesion 481X Perimeter

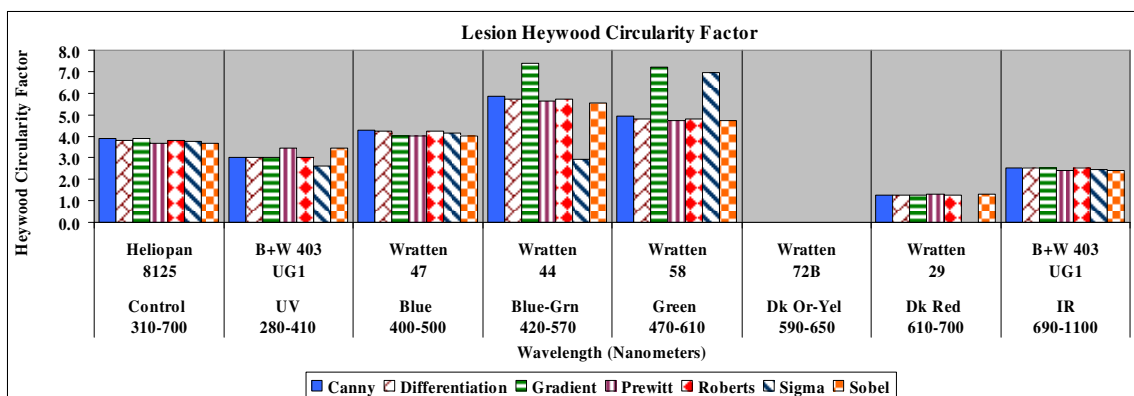


Figure 280. Lesion 481X Heywood Circularity Factor

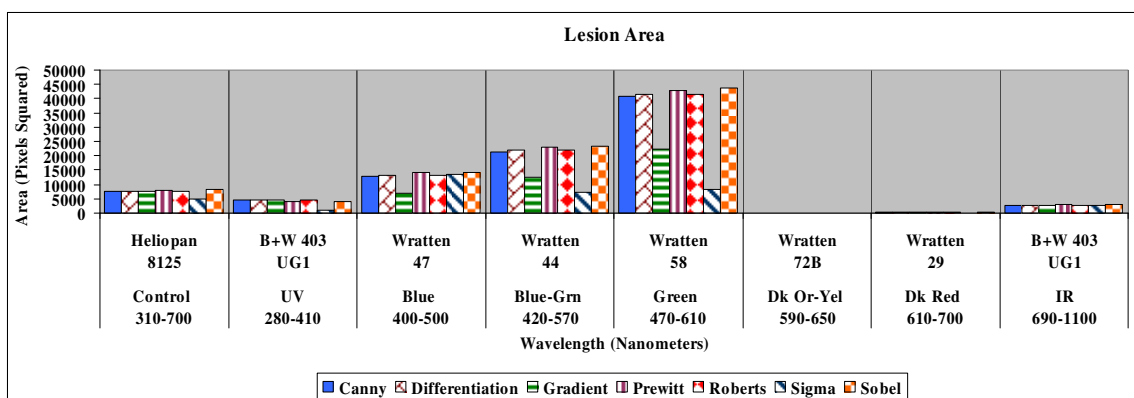


Figure 281. Lesion 481X Area

Lesion 482X

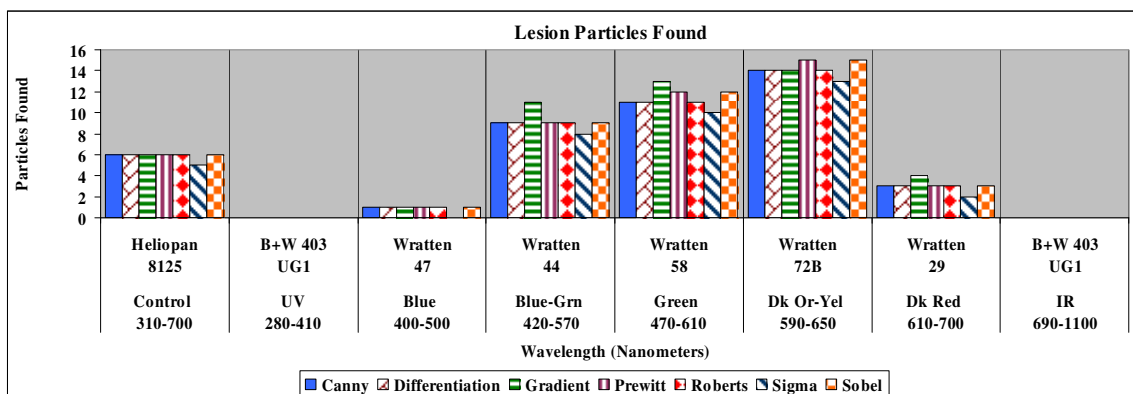


Figure 282. Lesion 482X Particles Found

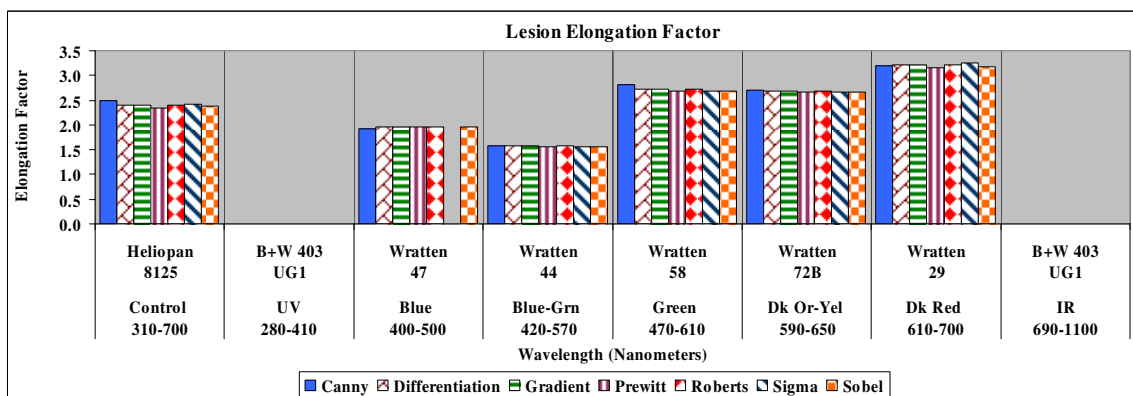


Figure 283. Lesion 482X Elongation Factor

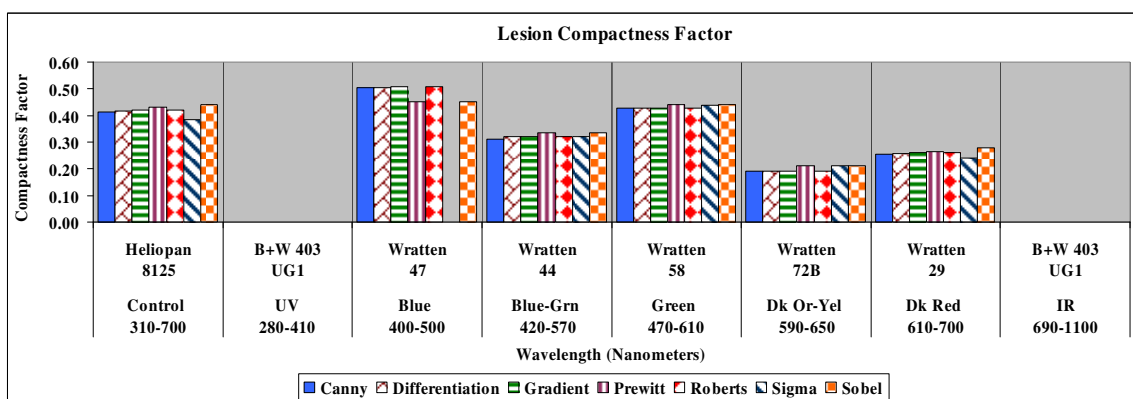


Figure 284. Lesion 482X Compactness Factor

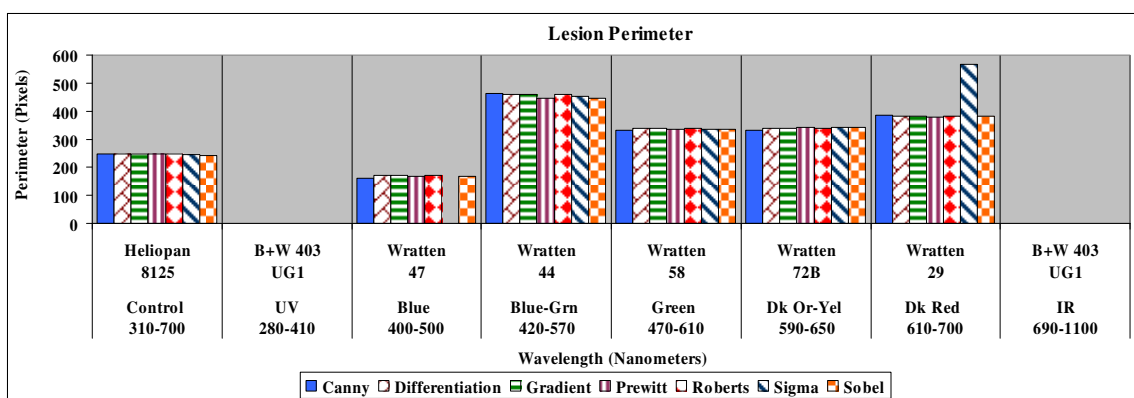


Figure 285. Lesion 482X Perimeter

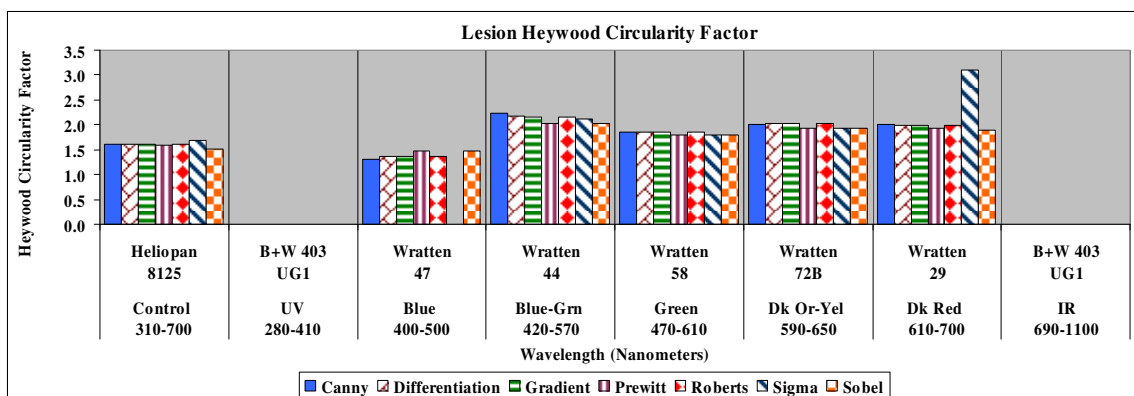


Figure 286. Lesion 482X Heywood Circularity Factor

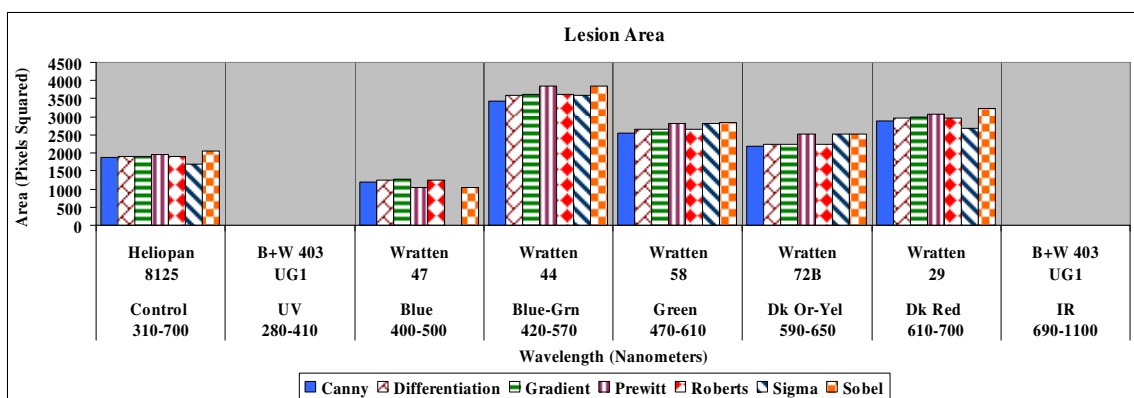


Figure 287. Lesion 482X Area

Glossary

Anti-Aliasing filter – This filter is typically used with a Bayer CFA. The Bayer CFA represents an inefficient use of silicon area and imposes constraints on the digital camera designer. Due to the sparse nature of the sampling, the Bayer CFA needs interpolation of the missing color data to create three complete color image planes (R, G, and B). An optical blur filter, also known as an Anti-Aliasing filter, or an optical low-pass filter, (OLPF), is usually designed into consumer and professional digital cameras. Blur filters reduce the color aliasing artifacts caused by spatial phase differences among the color channels. Two blur filters are typically placed in the optical path: one to blur in the horizontal direction, and the other one in the vertical direction. The blur filters reduce color aliasing at the expense of image sharpness (Guttosch, 2005).

Asymmetry – A characteristic used to distinguish benign moles from melanoma where half of the mole does not match the other half. Medically defined as unequal in size and shape around the axis (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Basal Cell Carcinoma – Tumors that usually appear as small, fleshy bumps or nodules on the head and neck, but can occur anywhere on your skin. This type of skin cancer is the most common skin cancer found among fair-skinned people. Basal cell carcinoma does not grow quickly, and rarely spreads to other parts of the body; however, it can penetrate below the skin to the bone and cause considerable local damage (EHSO, 2005).

Bayer Image Sensor – The technology that made digital photography a reality was the Charged Couple Device (CCD) image sensors. The sensor that made digital photography a reality was the Bayer-Pattern Image Sensor. This color CCD sensor was introduced by Bryce Bayer in 1976 and used mosaic patterns of filters (Lyon, 2002).

Benign – A medical condition which untreated will not become life-threatening. The biological behavior of benign tumors does not invade surrounding tissues nor does it metastasis to other parts of the body; however, treatment may eventually be required for health or cosmetic reasons (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Biopsy – A medical test involving the removal of a small piece of living tissue from an organ or other part of the body for microscopic examination to confirm or establish a diagnosis (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Border – A characteristic used to distinguish benign moles from melanoma where the border or edge of the mole is ragged or irregular (UMMC, 2004).

Cancer – A neoplasm characterized by the uncontrolled growth of anaplastic cells that tend to invade surrounding tissue. This disease is characterized by uncontrolled division of cells and the ability of these cells to invade other tissues. This cell invasion is by direct growth into adjacent tissue or by implantation into distant sites by metastasis. While cancer can affect people of all ages, the risk tends to increase with age. 80% of cancer cases are attributed to cigarette smoking, exposure to carcinogenic chemicals, ionizing radiation, or ultraviolet rays. In the United States, cancer is second only to heart disease as the leading cause of mortality (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

CAT or CT scan – See Computed Tomography

Color Filter Array (CFA) – Dr. Bryce Bayer, of the Eastman Kodak Company, invented the Bayer Color Filter Array (CFA) that fueled the recent explosion of digital image capture devices in both the DSC (Digital Still Camera) and the cell phone markets. The Bayer CFA is made up of a repeating array of red, green, and blue filter material deposited on top of each pixel in an array (Guttosch, 2004).

Computed Tomography (CT) (originally known as computed axial tomography (CAT or CT scan)), is a medical imaging method employing tomography where digital geometry processing is used to generate a three-dimensional image of the internals of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation. This procedure was first used in 1972 and is painless, non-invasive, and requires no special preparation. CT is 100 times more sensitive than conventional radiography and this is achieved by using a narrow collimated beam of x-rays that rotate in a full circle around the patient. The computer calculates the tissue absorption and produces a graphical representation of the densities of various structures (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Convolution Kernel – A convolution kernel is used when a grayscale image needs filtering to enhance the quality of the image. Filters are used to smooth an image, remove noise from an image, enhance the edge information in an image, etc. The convolution kernel is a structure whose coefficients define how the filtered value at each pixel is computed. The filtered output for each pixel is a weighted combination of its original value and the values of its neighboring pixels. The size of the convolution kernel determines the number of neighboring pixels that will be included in the filtering process. A new value is computed with the kernel at each pixel location (National Instruments, 2005).

- Convolution Filters** – Convolutions are divided into four families: gradient, Laplacian, smoothing, and Gaussian and is determined by the convolution kernel contents or the weight assigned to each pixel. The standard convolution kernels size is typically 3×3 , 5×5 , 7×7 , etc. (National Instruments, 2005).
- Color** – A characteristics used to distinguish benign moles from melanoma where the color of the mole varies throughout (UMMC, 2004).
- DermatoscopeTM** – A commonly used hand-held surface microscopes instrument that allow a fixed magnification of $\times 10$. Surface microscopy allows the epidermis to become translucent, and therefore permits a detailed examination of the pigmented structures (Westerhoff, Mccarthy, and Menzies, 2000).
- Differentiation Filter** – Produces continuous contours by highlighting each pixel where an intensity variation occurs between itself and its three upper-left neighbors (National Instruments, 2006).
- Edge Detection** – An algorithm that marks points in a digital image where the luminous intensity changes sharply. This process reduces the amount of data by filtering out information that may be regarded as less relevant and preserving the important structural properties of an image. The technique has become well known and used widely in digital image processing (Taner, 1999).
- Eigenvalues** – A special set of scalars associated with a linear system of equations that are sometimes also known as characteristic roots, characteristic values (Hoffman and Kunze 1971), proper values, or latent roots (Marcus and Minc 1988).
- Epidermis** – A layer of skin which forms a waterproof protective wrap over the body's surface. This layer is made up of stratified squamous epithelium with an underlying basal lamina. The epidermis contains no blood vessels and is nourished by diffusion from the dermis. The deepest layer is the stratum basale and anchors the superficial layers to the underlying tissue. In addition, the stratum basale provides new cells to replace those lost by abrasion from the outermost layer (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).
- Epiluminescence Imaging (ELM)** – a new methodology for early detection of skin cancer based on the analysis of a pair of cross-polarization and side-transillumination images to examine surface pigmentation and vascularization characteristics of a lesion (Zouridakis et al., 2005).

Episcope™ – A commonly used hand-held surface microscopes instrument that allow a fixed magnification of $\times 10$. Surface microscopy allows the epidermis to become translucent, and therefore permits a detailed examination of the pigmented structures (Westerhoff, McCarthy, and Menzies, 2000).

Foveon X3 Image Sensor – This image sensor has three layers of pixels and is similar to the layers of chemical emulsion used in color film (Foveon, 2005). The layers of pixels are stacked vertically and take advantage of the ability of silicon to absorb different wavelengths of light at different depths in silicon (Hubel, 2005).

Freckles – Small tan spots of melanin on the skin of people with fair complexions that result from exposure to sunlight. When the sun's rays penetrate the skin, they activate melanocytes which can cause freckles to become darker and more numerous. There is an inherited tendency to freckling, and it is most frequently seen in persons with red hair. Freckles are harmless but people who freckle easily should avoid excessive sun exposure or use protective sunscreens because they have a tendency toward development of more serious actinic skin changes. The scientific term *ephelides* is used to designate freckles in dermatology (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Gradient Filter – An edge detection algorithm that highlights the variations of light intensity along a specific direction, which has the effect of outlining edges and revealing texture (National Instruments, 2005).

Highpass Filter – Emphasizes the intensity variations in an image, detects edges boundaries, and enhances fine details in an image (National Instruments, 2005).

HSL – A color image is stored in memory as either a red, green, and blue (RGB) image or a hue, saturation, and luminance (HSL) image. Color image pixels are a composite of four values. HSL images store color information using 8 bits each for hue, saturation, and luminance (National Instruments, 2005).

Hue – Represents the dominant color of a pixel. The hue function is a continuous function that covers all the possible colors generated using the R, G, and B primaries (National Instruments, 2005).

Infrared (IR) – Red is the color of visible light with the longest wavelength. Infrared wavelengths span between approximately 750nm and 1mm. (Gilblom and Yoo, 2004).

Joint Photographic Experts Group (JPEG) – An image file format for storing 8-bit and color images with lossy compression. JPEG images have the file extension JPG (National Instruments, 2005).

JPEG – See Joint Photographic Experts Group.

Kernel – A structure that represents a pixel and its relationship to its neighbors where the relationship is specified by the weighted coefficients of each neighbor (National Instruments, 2005).

LabVIEWTM – Laboratory Virtual Instrument Engineering Workbench is a program development environment application based on the programming language G used commonly for test and measurement applications (National Instruments, 2005).

Lesion – A lesion is pathologic change in body tissue skin such as a wound, sore, rash, or boil. A lesion may be described as benign or cancerous (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Lossless Data Compression – This data compression algorithm allows the exact original data to be reconstructed from the compressed data. Lossless compression is used when it is important that the original data and decompressed data are identical (Clunie, 2000).

Lossy Data Compression – A lossy data compression method that involves deliberately discarding information that is not visually or diagnostically important. Unfortunately, lossy compression schemes may only achieve modest compression before significant information is lost. The lossy data compression also has a drawback called generation loss when a file is repeatedly compressed and decompressed in that the file will progressively lose quality (Clunie, 2000).

Lowpass Filter – Attenuates intensity variations in an image which can be used to smooth an image by eliminating fine details and blurring the edges (National Instruments, 2005).

Luminance – The brightness information in a picture. The luma amplitude varies in proportion to the brightness of the signal (National Instruments, 2005).

Lymphatic System – A complex network that consists of lymphoid organs, lymph nodes, lymph ducts, and lymph vessels that produce and transport lymph fluid from tissue to the circulatory system. The lymphatic system is a major component of the immune system and has three interrelated functions: removal of excess fluids from body tissues, absorption of fatty acids and subsequent transport to the circulatory system, and production of immune cells (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Magnetic Resonance Imaging (MRI) – Formerly referred to as Magnetic Resonance Tomography (MRT) or Nuclear Magnetic Resonance (NMR), is a method used to visualize the inside of living organisms. A MRI is able to detect the composition of geological structures and is primarily used to demonstrate pathological or other physiological alterations of living tissues. Medical imaging is based on the resonance of atomic nuclei in a strong magnetic field. The field causes those nuclei with an odd number of protons to align and rotate around the axis of the field. Application of a radiofrequency pulse causes the protons to resonate. When the pulse is terminated, the protons relax back to equilibrium. During this transition, the protons release energy that is detected as a radio signal. Analysis of the amplitude and frequency of the signals yields information about the number and position of nuclei in the tissue, from which the image is produced. MRI is the method of choice for a growing number of disease processes. Among its advantages are its superior soft-tissue contrast resolution, ability to image in multiple planes, and lack of ionizing radiation hazards. MRI is regarded as superior to computed tomography for the most central nervous system abnormalities. The procedure usually does not require a contrast medium but may use an IV injection of gadolinium. Patients must remain motionless for high-quality imaging (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Malignant Melanoma – A group of malignant neoplasms that originate in the skin and is composed of melanocytes. A melanocytic nevus may be acquired or congenital. The congenital melanocytic nevus is regarded as more likely to develop into malignant melanoma. Melanoma tends to develop over several months or years and occurs most commonly in fair skinned people with light colored eyes. While this form of skin cancer is rare it is responsible for most skin cancer-related deaths. Despite many years of intensive laboratory and clinical research, the most effective cure is surgical extraction of the tumor before it achieves a thickness greater than 1 mm. When the disease metastasizes to distant parts of the body and then proliferates it becomes extremely dangerous and patient survival rarely exceeds two years. In the early stages melanoma is difficult to diagnose since it looks identical to harmless moles. Any black or brown spot that has an irregular border; pigment that appears to radiate beyond the border; a red, black, and blue coloration observable on close examination; or a nodular surface is suggestive of melanoma. Moles that are irregular in color or shape are suspicious of a malignant melanoma and excised for a biopsy. Prognosis depends on the kind of melanoma; its size, depth of invasion and location; and the age and condition of the patient (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Melanin – A black or dark brown pigment that occurs naturally in the hair, skin, iris and choroid of the eye. In humans, melanin is the primary determinant of human skin color. Some humans have no or very little melanin in their bodies, which is a condition known as albinism (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Melanocytes – A cell located in the bottom layer of the skin's epidermis that produces melanin, the pigment in the skin. Melanocytes are distributed throughout the basal cell layer and form melanin pigment from tyrosine. Melanin granules are then transferred to adjacent basal cells and hair through a process called melanogenesis. The difference in skin color between fair people and dark people is not due to the number of melanocytes in their skin, but rather to the melanocytes' level of activity. Melanocyte-stimulating hormone (MSH) from the pituitary controls the amount of melanin produced. Albinos lack an enzyme called tyrosinase that is required for melanocytes to produce melanin (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Melanocyte-stimulating hormone (MSH) – A polypeptide hormone secreted by the pars intermedia of the pituitary gland, that controls the intensity of the pigmentation in pigmented cells (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Metastasis – The spread of cancer from its primary site to other places in the body (e.g., brain, liver). Cancer cells can break away from a primary tumor, penetrate into lymphatic and blood vessels, circulate through the bloodstream, and grow in normal tissues elsewhere in the body. Tumors are classified as either benign or malignant. Benign tumors cannot spread and only grow locally while malignant tumors can spread, invade, and metastasize into other human organs. The term cancer only applies only to malignant tumors. If a patient is diagnosed with cancer then they will want to know whether their disease is local or has spread to other locations. The ability to spread via the blood and/or the lymphatics system to other tissues and organs is what makes cancer a potentially life-threatening disease. When cancer cells spread to form a new tumor, it is called a secondary or metastatic tumor, and is very common in the later stages of cancer. A metastatic tumor and its cells are like those in the original tumor. For example, if breast cancer spreads (metastasizes) to the lung then the secondary tumor is made up of abnormal breast cells. The disease in the lung is metastatic breast cancer and not lung cancer (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Moles – A mole or melanocytic naevus is a small dark spot on the skin. A pigmented skin blemish that is usually benign but may become cancerous. They are a member of the family of skin lesions known as naevi. Moles may either be present at birth or develop later in life. Acquired moles are a form of benign neoplasm, while congenital moles are considered a minor malformation. Some scientists suspect that overexposure to ultraviolet light (including excessive sunlight) may play a role in the formation of acquired moles. Everyone needs to be checked regularly for any changes in their moles as well as noting any new moles (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

MRI – See Magnetic Resonance Imaging.

Neighbor – A pixel whose value affects the value of a nearby pixel when an image is processed where the neighbors of a pixel are usually defined by a kernel (National Instruments, 2005).

Nonlinear Filter – Replaces each pixel value with a nonlinear function of its surrounding pixels (National Instruments, 2005).

Nonlinear Gradient Filter – A highpass edge-extraction filter that favors vertical edges (National Instruments, 2005).

Nonlinear Prewitt Filter – A highpass edge-extraction filter based on 2D gradient information (National Instruments, 2005).

Optical Blur Filter – See Anti-Aliasing filter.

Optical Low-Pass Filter (OLPF) – See Anti-Aliasing filter.

Pigment – Skin color is determined by the amount and type of the pigment melanin in the skin. Melanin comes in two types: pheomelanin which produces skin color from red to yellow and eumelanin which produces skin color from dark brown to black (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

PNG – See Portable Network Graphic.

Portable Network Graphic (PNG) – An image file format for storing 8-bit, 16-bit, and color images with lossless compression. PNG images have the file extension PNG.

Prewitt Filter – An edge detection algorithm that extracts the contours in gray-level values using a 3×3 filter kernel (National Instruments, 2006).

RGB – A color image is stored in memory as either a red, green, and blue (RGB) image or a hue, saturation, and luminance (HSL) image. Color image pixels are a composite of four values. RGB images store color information using 8 bits each for the red, green, and blue planes (National Instruments, 2005).

Region of Interest (ROI) – An area of the image that is graphically selected from a window displaying the image and is for further processing (National Instruments, 2005).

Roberts Filter – An edge detection algorithm that extracts the contours in gray level, favoring diagonal edges (National Instruments, 2006).

ROI – See Region of Interest.

Saturation – The amount of white added to a pure color. Saturation relates to the richness of a color. A saturation of zero corresponds to a pure color with no white added. For example, pink is a red with low saturation (National Instruments, 2006).

Semantic Information – Deals with knowledge and meaning of the pixels meaning (Suetens, P., Fau, P., and Hanson, A., 1992).

Skin Cancer – A malignant growth on the skin and generally develops in the epidermis, the outermost layer of skin. Skin cancers are the most common and most curable malignancies. Since this tumor is usually clearly visible most skin cancers are detectable in their early stages. There are three common types of skin cancer each of which are named after the type of skin cell: Basal cell carcinoma (BCC), Squamous cell carcinoma (SCC) which may be locally disfiguring but unlikely to spread to other parts of the body, and malignant melanoma which can be fatal if not treated early. Basal cell carcinomas are typically raised hard reddish lesions with a pearly surface and rarely metastasize. Squamous cell tumors are typically scaly, slightly elevated growths with extensive ulceration and a nonhealing scab. A definitive diagnosis may be established by a incisional or excisional biopsy. Surgery is favored for the treatment because of the possibility of recurrence of cancer. Despite the curability of skin cancer, it causes many deaths because people fail to obtain treatment (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Sigma Filter – A highpass filter that outlines edges (National Instruments, 2005).

Sobel Filter – An edge detection algorithm that extracts the contours in gray-level values using a 3×3 filter kernel (National Instruments, 2005).

Squamous Cell Carcinoma – The second most common skin cancer found in fair-skinned people. Squamous cell carcinomas account for about 20% of non-melanoma skin cancers and usually develop in the epithelial layer of the skin and sometimes in various mucous membranes of the body. These tumors may appear as nodules or as red, scaly patches (EHSO, 2005). This cancer can develop into large masses, and unlike basal cell carcinoma, it can spread to other parts of the body (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Stratum Basale – The deepest of the five layers of the epidermis and is composed of cuboidal-shaped cells. This layer provides new cells by mitotic cell division to replenish the regular loss of skin by shedding from the surface (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Syntactic Information – Deals only with the pixel values themselves and not their meaning (Suetens, P., Fau, P., and Hanson, A., 1992).

Tagged Image File Format (TIFF) – A file format for mainly storing images, including photographs and line art. The first version of the TIFF specification was published by Aldus Corporation in the fall of 1986 (Adobe, 1992). This image format commonly used for encoding 8-bit, 16-bit, and color images. TIFF images have the file extension TIF. TIFF is a popular format for high color depth images, along with JPEG and PNG (National Instruments, 2006).

Threshold – Separates particles / lesions from the background by assigning all pixels with intensities within a specified range to the particle / lesions and the rest of the pixels to the background. The result is a binary image where particles particle / lesions are represented with a pixel intensity of 255 and the background is set to 0 (National Instruments, 2006).

TIFF – See Tagged Image File Format.

Transillumination – The transmission of light through tissues of the body. An example is the red glow produced by the light of a flashlight through the fingers. The main advantage of transillumination is its sensitivity to increased blood flow and vascularization and its ability to visualize the subsurface pigmentation in a nevus (Zouridakis, Doshi, Duvic and Mullani, 2005)

Tumors – A swelling or enlargement occurring in inflammatory conditions. A tumor is a new growth of tissue characterized by progressive, uncontrolled proliferation of cells. This growth can be either malignant or benign. Malignant tumors are cancerous and has the potential to invade and destroy neighboring tissues. Benign tumors do not invade neighboring tissues but may grow locally to large size. They typically do not return after surgical removal (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Tyrosine (Tyr) – An amino acid synthesized in the body from the essential amino acid phenylalanine. Tyrosine is found in most proteins and is the precursor of melanin and several hormones, including epinephrine and thyroxin melanin (Anderson, D., Anderson, K., Anderson, L., Glanze, W., 2005).

Ultraviolet (UV) – Violet is the color of visible light with the shortest wavelength. Ultraviolet wavelengths span between approximately 1 nm to 400 nm (Gilblom and Yoo, 2004).

Wratten Number – A labeling system for optical filters. They are named after the British inventor who came up with the system, Frederick Wratten. Wratten sold his company to Eastman Kodak in 1912. Today Wratten filters are still produced by the Tiffen Corporation under license from Kodak (Syosset Camera Club, 2004).

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