

Spring 2012

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Christopher Todd Kowalczyk

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A PRELIMINARY INVESTIGATION COMPARING CRANIOFACIAL METRIC
MEASUREMENTS AND 3D VIRTUAL MEASUREMENTS.

by

CHRISTOPHER T. KOWALCZYK

Under the Direction of Matthew Williamson

Abstract

The development and advancement of new laser scanning techniques enables the capture of 3D imaging which can be quantitatively assessed for use on the human skull. I used a Polhemus FastScan Scorpion scanner to scan 8 skulls and evaluated the standard 24 metric measurements in Delta analysis software in comparison to standard metric measurements. The scanned measurements were then compared to the standard metric measurements using the same landmarks. Of the original 48 measurements, 33 (68.75%) fail to reject the null and 10 (20.83%) reject the null with the remaining 5 (10.41%) being unknown due to n=1 because of skull damage. The measurements that proved highly reliable were those associated with specific landmarks, and not those measurements that are based on landmarks and feel and considered arbitrary in this study. This study indicates that the use of the laser scanner can be a useful tool for rapid acquisition of skeletal and anatomical surfaces however, accurate location of landmarks and operator skill are of utmost importance in achieving accurate and reliable results.

INDEX WORDS: Craniofacial, Metric measurements, Virtual measurements, Handheld laser scanners, Laser scanners, Geometric Morphometrics, Polhemus, Delta.

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MEASUREMENTS AND 3D VIRTUAL MEASUREMENTS.

by

CHRISTOPHER T. KOWALCZYK

Bachelors of Science, Georgia Southern University, July 24th 2009

A Thesis

Submitted to the Graduate Faculty of Georgia Southern University

In Partial Fulfillment

Of the Requirements for the Degree

MASTERS OF ARTS SOCIAL SCIENCE
IN ANTHROPOLOGY

STATESBORO, GEORGIA

May 11th 2012

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A PRELIMINARY INVESTIGATION COMPARING CRANIOFACIAL METRIC
MEASUREMENTS AND 3D VIRTUAL MEASUREMENTS.

by

Christopher T. Kowalczyk

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Electronic Version Approved:
May 2012

Dedication:

To my mom and dad Kathleen and Teddy Kowalczyk,
My wife Brittany Jade Kowalczyk, and My Daughter Anna Elizabeth Kowalczyk for without
their help, patience, belief and support this study as well as my collegiate career would not
have been possible.

Acknowledgements:

I would like to thank those who have died and have left their bodies behind, as a reminder of their lives on this earth for without this study would not have been possible.

I would also like to give special thanks to Dr. Matthew Williamson for all his help with this study, pushing me when I needed to be pushed, letting me run free when I could stand on my own, as well as being a friend and mentor. To Dr. Sue Moore for believing in my abilities even when I was stuck in my ways. To Dr. Stephen Hale for being open to new ideas, ways of thinking and allowing me to push the envelope of traditional studies. To Dr. Ray Chandler for giving me the tools to look at the world in a new perspective as well as being my statistical go to person. To Dr. James B. Claiborne for always having an open door and being a JMP guru.

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Chapter 1

Introduction

Anthropometry – (Greek – *anthropos* (άνθρωπος – man) and *metron* (μέτρον – measure) is the measurement of man or woman (Dorland's Medical Dictionary 2007). In today's world anthropometry plays many important roles in the study of fashion, industrial design and ergonomics as well as data collection in forensic anthropology and other scientific fields (See Figure 1).

In recent years skeletal and facial anthropometry has been increasingly studied in plastic surgery, orthodontics, craniofacial surgery and forensic anthropology (Eckert 1992). Since traditional skeletal anthropometry requires many direct cranial measurements that require considerable time to accomplish, it was decided to try an alternative to the traditional method. Moore-Jansen (1994) states that there are 24 cranial measurements that are to include 48 individual points on the cranium involved in the forensic or anthropometry and requires roughly 60 minutes to complete (Figure 2).

During the last decade the development of laser surface or optical surface laser scanners have become available and may provide an alternative to traditional or metric measure methods. The laser scanner uses light triangulation to rapidly and accurately digitize surface data. The facet framework of surface contour has a sub millimeter precision and allows for data to be collected through a non-contact process, which minimizes any potential contamination of the object or hazard to the operator.

During the scanning process surface data is immediately transferred to the computer and the resulting image can be seen in real time as the scan is being conducted, which is crucial in allowing for operator recognition and modifications of the scan while allowing for easy data retrieval and storage.

The aim of this study is four fold: (1) ease of data acquisition using the 3D scanner; (2) accuracy of measurements based on analysis software; (3) to determine the reliability of laser scan measurements by comparing them to identical measurements taken in the traditional manner; (4) problems and limitations associated with 3D laser measurement acquisition.

The Human Skull

In regards to all references of the skull the following shall be assumed. Directional and positional terms relating to the skull are in the context of the standard anatomical planes and perspectives. In reference to terminology, the skull refers to the entire skull including the mandible; the cranium is the skull without the mandible, and the calvarium is the cranium without the splanchnocranium (White And Folkens 2005).

The skull is a complex structure made up of 28 bones consisting of 8 unpaired, 6 paired and 2 sets of 3 small auditory ossicles with a purpose to house and protect the brain as well as the primary sight, smell, hearing, taste and mastication organs. It also supports the tissues and organs that allow breathing, swallowing and speech and serves as scaffolding for soft tissue that makes up facial structure and facial movement. It is comprised of two types of bone tissue the cortical and trabecular that contribute to the bones structural properties and behavior. Collagen is also present allowing for elasticity of the bone while calcium and phosphorous provide stiffness (White 2005).

Figure 1. "The Speaking Portrait", an article from "Pearson's Magazine", 1901, Alphonse Bertillon's Anthropometry.

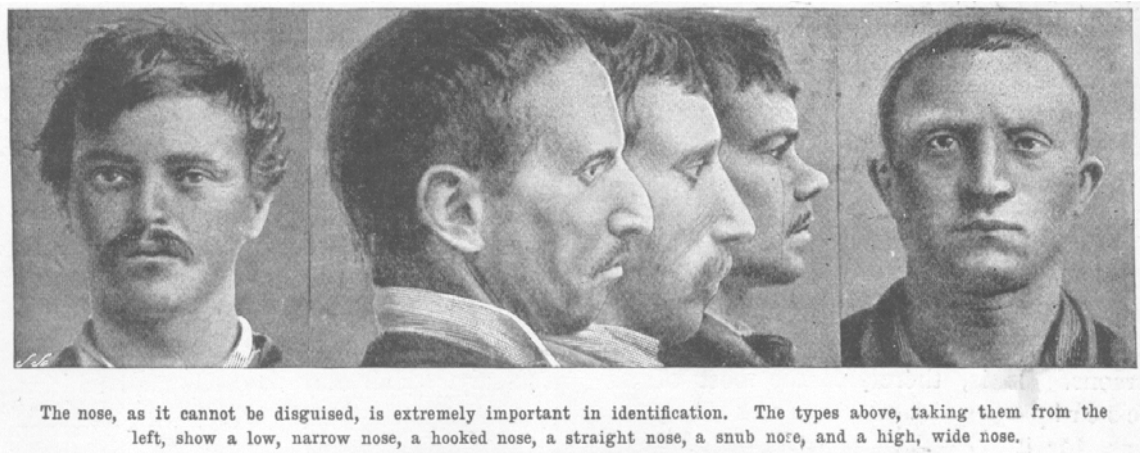
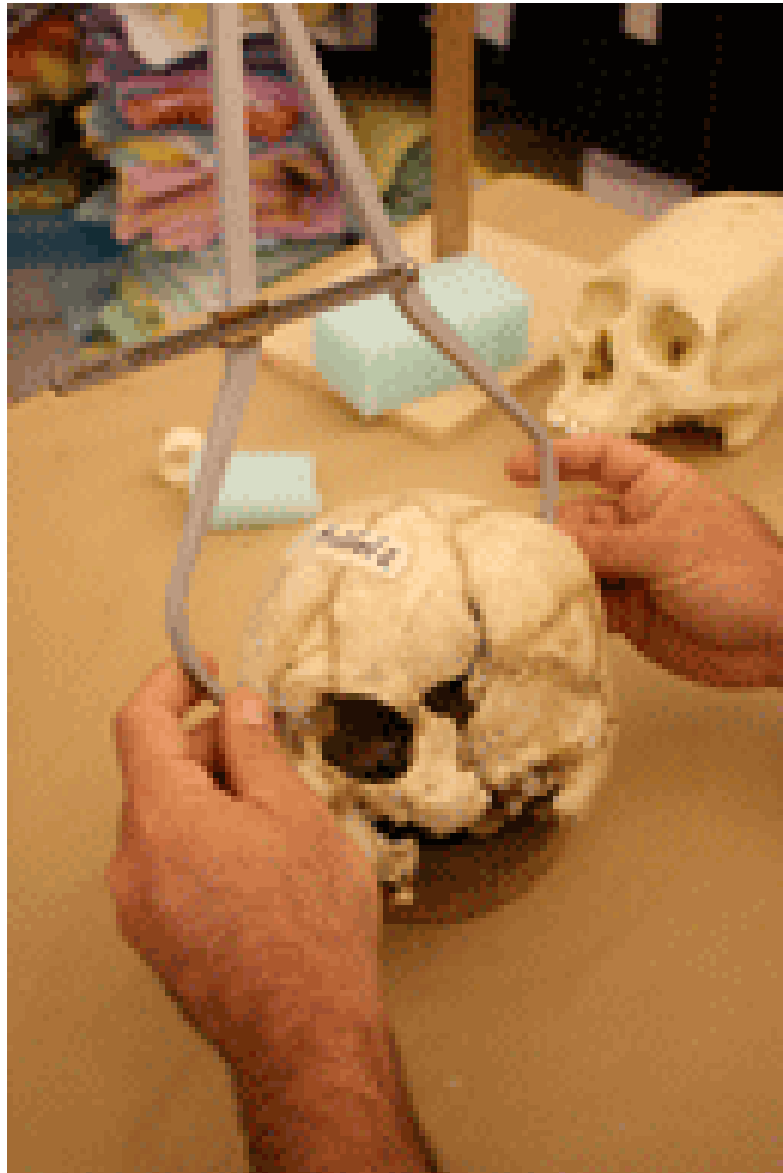


Figure 2. G-OP Metric measure on a Native American Provenience or date unknown. Recovered by GBI from a home in North Georgia (Verbal Communication Dr. Matthew Williamson). Picture by Brittany Jade Kowalczyk



Chapter 2

Literature Review

Osteological and Craniofacial Measurements

Common Uses:

Bass (1987) states that the reason to study bones can be for the study of fossil man, racial classification, biological comparison, ancient diseases and cause of death as well as modern forensic cases.

However, most osteological or cranial facial measurements deal with a wide array of both the living and the deceased. For many years orthodontists have used radiographs in determining cephalometric assessments in order to correct orthodontia malformations using braces and other appliances both internally and externally.

Growth and Development

Van Erum (et al. 1998) has used the process of skeletal evaluation to determine health and the potential to diagnosis malformations of the living by looking at the evaluation of growth and development of cranial growth and dental maturation of “small for gestational age” (SGA). In their research 77 cephalograms and orthopantomograms were studied in order to assess craniofacial growth through the use of high doses of growth hormone (GH) in SGA persons (Van Erum 1998).

Old Time Races and Sex

Bass describes the skull as the only area of the skeletal system that can accurately estimate the racial origin (Bass 1987). These determinations of the races has been limited to two major areas which consist of morphological and anatomical variations of the bone structure, as well as anthropometric measurements (Bass 1987)

Bass (1987) breaks down the “Old Time Races” into three major categories; Caucasoid, Negroid, and Mongoloid. Though each group is given a racial category anatomical specimens can also be broken down to fit within each of these groups. For instance, Caucasoid race is to include all white with European decent. Negroid or American Negroids is to include all specimens of the African-derived specimens.

Mongoloid however, consists of all Asian derived backgrounds to include Southwestern American Indians (Taylor 2001).

Forensic Anthropologists and forensic artists are able to use the data of given racial groups to determine the probable race of a given specimen. For instance the Caucasoid race has certain features that are present in higher quantities than in other races. Bass states that in the nasal sill area of the Caucasoid race there is usually a dam that will stop a pencil; however, in the Negroid skull there is no dam or nasal sill, and the pen will easily slide into the nasal aperture, where as Mongoloid skulls will range between the two extremes. Other examples of such differences are included in the Negroid race where anatomical traits are mainly associated only with the given race such as little or no nasal depression, rounded forehead, bregmatic depression, wide nasal opening, and a dense or “Ivory texture” to the bone. The same is similar in the Mongoloid race where certain anatomical traits are specific to the race. These traits include but not limited to: Inferior Zygomatic projection (the Zygomatic bones dip below the lower edge of the maxilla), nasal overgrowth (the nasal bones project forward beyond their junction with the frontal portion of the maxilla) (Bass 1987).

Even though these differences help in determining race, the skull is not ideal in determining the sex of a given individual. This is due to the fact that women can have masculinized facial features and men can have feminized facial features, which will skew the researchers ability to make an accurate determination.

Bass (1987) states that sex estimation of subadult bones is purely an educated guess due to the fact that secondary traits associated with sex identification do not become apparent until the individual reaches puberty. The measurements associated with sexing however are based on the sex differences in the long bones of an individual. Typically, the long bones of males are longer and larger (more massive) in size and weight as well as a larger head diameter of the humerus than a representative female bone and therefore implies a suggested sex for a given individual (Bass 1987, Krogman 1962).

Archival

Though Bass does not specifically address the topic of archival in a separate chapter, the entire “Human Osteology” book is based on the gathering of information for archival and study purposes by researchers. Specifically Bass goes in to depth in the act/art of excavating, transporting, cleaning, restoring, and handling skeletal material. Bass also supplies templates of burial forms as well as basic do’s and don’ts of skeletal handling. With this said however; all traditional aspects involve measurements and photography as well as drawings of individual bones and teeth. This process though accurate and valuable is where the problem lies. The 1st problem is how can a drawing be truly subjective? The 2nd is how much data is lost through a picture or measurement? The 3rd is how do we archive collected data?

Studies of Size and Shape

Merriam-Webster defines “Linear Measure” as 1: a measure of length or 2: a system of measure of length. Moore-Jansen (1994) and Bass (1987) describe linear measurement as measurement between groups. The skull group consists of 24 standardized landmarks on the human skull that are used by anthropologists for taking anthropometric measurements. As in all “Sciences” the measurements used by physical anthropologists are those most commonly used and accepted as a “Proven” method in bone analysis and therefore commonly used (Bass 1987). This method though highly valuable and common practice is where a potential problem lies. This is due to the fact that of these 24 landmarks 11 are somewhat arbitrary because they are not associated with sutures or exact points. For example, the maximum length of the skull is taken from the Glabella (g) to the Opisthocranium (op). In this instance (g) is not of major concern due to the fact that it is the “most forward point in the midline of the forehead at the level of the supra-orbital ridges and above the nasofrontal suture”, which is somewhat subjective but the point has a given value within certain landmarks, (op) on the other hand is “the most posterior point on the skull not on the external occipital protuberance” therefore it is not a fixed point within given landmarks and is instrumentally determined and opened to individual interpretation to some extent due to feel.

As we can see this is where the potential problem lies. If we are to assume that the current practice of measurement is the most accurate and new data points or measurements will never provide better degrees of accuracy or new information then we can assume that

there is no need for change. History on the other hand has proven the previous statement false, due to the fact that science only advances as old questions are re-analyzed and new technology allows us to gather, explore or measure in a way that until that time was unattainable.

Geometric Morphometrics Forerunners

Anatomical comparison of biological organisms has been a foundation of taxonomic classification and clarification in bio-diversity based on morphological forms since its inception by Carolus (Carl) Linnaeus in the 18th century. This method of classification lasted until the late nineteenth century when Hermon Bumpus used quantitative data for one or more measureable traits, which were then analyzed as mean values among groups (Bumpus 1899). D'Arcy Thompson suggested in 1917 that changes of biological form be both modeled and described as mathematical diffeomorphisms (deformations that are smooth and that have smooth inverses), in his publication of "On Growth and Form" which has been argued to be the possible first transition of morphometrics into a true discipline (Bookstein, 1991). It was not however until the mid 1970's that morphometrics was viewed as a standard application of multivariate analysis (Blackith, and Reyment, 1971). In the mid twentieth century modern morphometrics was able to stand alone as a separate field by combining morphological taxonomy and quantitative analysis into a statistical analysis to describe variation (Bookstein, 1991). This success can be directly related to the work done by Pearson (1895) regarding the correlation coefficient and principal components analysis (Pearson, 1901; Hotelling, 1933) along with analysis of variance done by R.A. Fisher (1935).

Early Geometric Morphometrics

During the early days of geometric morphometrics; quantitative assessment of shapes were almost entirely conducted with the aid of ratios of characters, where one character could be regarded as indicative of a given feature, and another character effectively standardized its variation by providing a measure of absolute size (Reyment, 1984 et. al). It is however; the standardization of variation where the weakness lies. "In the mid 70's the multivariate analysis of morphometrics dealt with "size measures" and "shape measures, "these distances and angles, presumably derived from biological forms in an unsupervised way" (Bookstein, 1991). This morphometric method dealt with the multivariate statistical

analysis of quantitative data in regards to length, width, height or position (Rohlf, and Bookstein, 1990; Bookstein, 1991). Bookstein (1991), however; identified problems with this method in regards to the collection of distances, angles or distance ratios because of the limitations of linear measurements in regards to the fact that they do not capture spatial arrangements of these points. Marcus (1990) stated that; “traditional morphometrics” tend to ignore the origins of data by not paying close attention to the shape or geometry of biological specimens or their images. Instead, these measurements of form were analyzed as distances rather than shape. Reyment et. al (1984) notes that: early quantitative assessment used ratios of characters. This process used one character as the indicator of the primary point and the second point standardized the set providing absolute size. The reasoning behind the use of ratios is the misconception that more than two characters cannot be handled at once and ratios best examine two characters (Reyment, 1984).

In Theoretical Biology “homology” or “homologous” structures are a correspondence between two structures in two different species; thus the bones of a bats wing have structurally the same bones as those in a human arm, and a whale’s pectoral fin. Bookstein (1991) states that; “this diction”, unmodified, empowers only the most rudimentary type of morphometrics, the invocation of variables that represent “extents” of homologous parts without any additional geometrical content. Morphometrics based on this primitive utilization of the notion of physical distance is generally known as “multivariate morphometrics” (cf. Reyment, et al., 1984). These variables usually are measured in cm (cm^2 or cm^3), log cm, log ratios (differences of log cm), or various nonlinear transformations of these (such as degrees of angle). However, the lengths and other elements that go into the integrals are not claimed separately to be homologous as extents upon the organism; they are simply conveniences in the computation of multiple integrals, which could be taken instead, according to Green’s theorem, by surface integrals of position around the boundary (Bookstein, 1991). If, instead, the length of a linear structure, such as a long bone, is to be taken as a proper morphometric value on its own, then the endpoints of the calipers that measure it must be themselves located upon homologous substructures: not, for instance, measured to the end of a bone spur on one form, a condyle on another (Bookstein, 1991).

However, the use of characters suggests prior knowledge of the subject at hand, which automatically raises concerns for the study. The following are three main concerns that deal with the weakness of ratios: “(1.) The fact that a ratio will not be constant for organisms of the same species unless these are also of the same size, by virtue of the almost universal occurrence of differential growth; of course, the effects of allometry may be small in relation to the differences between species. (2.) As generally used, ratios contain only two characters and thus afford a poor appreciation of what may turn out to be an involved contrast between forms. (3.) To compound two characters into a ratio implies that there is only one contrast of form to be studied, and that unique contrast is well assessed in terms of two characters of equal weights, but opposite in sign” (Reyment, 1984). Burnaby (1966) states that biological taxonomists are often reluctant to employ multivariate methods in cases where the organism continues to grow throughout life, such as, *foraminifera* (Hole-bearers), *gastropoda* (Snails and Slugs), *pelecypoda* (bivalves). Burnaby (1966) also states that growth is not the sole generator of “nuisance factors” in taxonomy, but that other components of variation, which the researcher may be uninterested in, may inhibit the investigation (Burnaby, 1966).

Morphometric Framework

An essential problem in morphometrics is to the degree of similarity of two forms (Reyment, 1984 et. al). Imagine two identical forms (A) and (B); (A) is the larger form and (B) is the smaller form with exactly all the same landmark structures. The growth pattern can be of any volume or any kind, so that marked points on (A) and (B) approach a homologue, and growth can travel at independent rates independent of each other (Reyment, 1984 et. al). Reyment, et. al (1984) states that; “If we consider the expansion of the smaller form as being accompanied by a displacement of every marked point, the vector of displacements of the marked points on the smaller form towards the homologous points on the larger form may be used as the basis for a measure of divergence between the forms.” This is the essence of all truly multivariate studies of the form (Reyment, 1984). Bookstein (1991) also states that; “All morphometric implementations of real physical distance within a multivariate statistical framework are governed by one crucial concept from biomathematicians, the notion of *homology*” (Bookstein, 1991). In Theoretical Biology “homology” or “homologous” structures are a correspondence between two structures in two different species; thus the

bones of a bats wing have structurally the same bones as those in a human arm, and a whale's pectoral fin. Bookstein (1991) states that; "this diction", unmodified, empowers only the most rudimentary type of morphometrics, the invocation of variables that represent "extents" of homologous parts without any additional geometrical content. Morphometrics based on this primitive utilization of the notion of physical distance is generally known as "multivariate morphometrics" (cf. Reyment, et al., 1984). These variables usually are measured in cm (cm² or cm³), log cm, log ratios (differences of log cm), or various nonlinear transformations of these (such as degrees of angle). However, the lengths and other elements that go into the integrals are not claimed separately to be homologous as extents upon the organism; they are simply conveniences in the computation of multiple integrals, which could be taken instead, according to Green's theorem, by surface integrals of position around the boundary (Bookstein, 1991). If, instead, the length of a linear structure, such as a long bone, is to be taken as a proper morphometric value on its own, then the endpoints of the calipers that measure it must be themselves located upon homologous substructures: not, for instance, measured to the end of a bone spur on one form, a condyle on another (Bookstein, 1991). It was also noted that coordinates of these landmarks concisely encode all the information of any subset or distance between them (Bookstein, 1991). One corner of this common foundation is the demonstration by elementary theorem (Bookstein, 1986) that the "Shape space" common to these schools incorporates the linearized multivariate statistics of all possible "traditional" shape measurements of the landmark locations (Bookstein, 1991). This theorem, for instance, leads to the demonstration (Bookstein, 1987) that the so-called finite-element methods, which display particular nonlinear transformations of biologically somewhat arbitrary linear manipulations of the land-mark coordinates, must lose statistical power against any general alternative hypothesis, so that the diagrams by which their findings are reported are seriously misleading in most applications (Bookstein, 1987).

3D Scanning The Beginning:

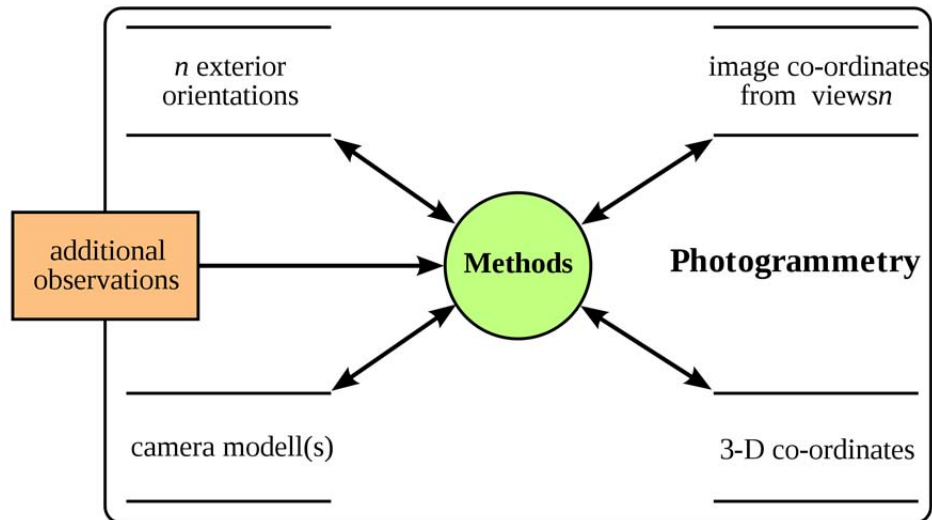
The Laser Idea

3D surface scanning is becoming more and more common for generating 3D data points to be used in many different applications. Unlike CT scanning 3D scanning collects surface information of any given object in order to create a 3D model in

computer or virtual space without aftermarket software such as Vitrea Lt (Amber Lewis). Zollikofer, et. al (2005) discuss “Photogrammetry” and “Laser Range Scanning” as two principal approaches to surface scanning.

Photogrammetry is the technology of determining geometric properties from image-based two-dimensional data (American Society for Photogrammetry and Remote Sensing) (ASPRS). ASPRS also states that if the distance between two points that lie on a plane parallel to the photographic image plane can be determined by calculating their distances of the image as long as the scale of the object is known (Figure 5). Stereophotogrammetry on the other hand involves a system with one or more camera that is used to estimate three-dimensional points of an object in space through triangulation (ASPRS). Though traditional Stereophotogrammetry uses more than one camera it is possible to reconstruct three-dimensional space through complicated algorithms and symmetries with one camera. The Levenberg-Marquardt algorithm or (LMA); $\mathcal{S}(\beta) = \sum_{i=1}^m [y_i - f(x_i, \beta)]^2$ is used as a solution to minimizing nonlinear or spatial parameters of functions, that arise in least square curve functions or nonlinear programming.

Figure 3. Photogrammetry (George Wiora 2005)



Laser Range Scanning; however, uses the reflections of focused laser light to estimate distance value coordinates of real space into 3D computer space (ASPRS). Feng (*et al* 2001) state; that in comparison to coordinate measuring machines (or CMM) laser range

scanning is only one magnitude less accurate in digitizing points in 3D space. The differences lie in the fact that CMM uses sensor probes that come in contact with the objects where as laser range scanning does not contact the object at all (Feng 2001).

Willems (*et al* 2005) has stated due to the fact that most surface scanners have been developed to serve specific needs of optical triangulation surface scanning; the operator must be careful in deciding which scanning method to use for desired outcomes. Zollikofer and Ponce de Leon (2005) state radar based lasers or laser range scanning are used for large structures such as buildings or large open are and that all optical triangulation systems are limited in that they only record line of sight data which requires constant movement. The Polhemus FastScan laser scanner offers a solution to the problem of acquiring complex spatial geometry by separating the wand from the transmitter and to essentially allow six degrees of freedom in 3D space and object movement with the use of a reference receiver. Through this method range-scanning lasers process the data as X, Y and Z Cartesian coordinates. The data is then transferred into point cloud data (Figure 6.), which represents real world objects in virtual space. Zollikofer and Ponce de Leon (2005) state that point cloud data is ideal for morphometric as well as other analysis software due to the ease of use in repositioning and reorientation through many platforms.

Harrison (*et al* 2004) has shown that in using the Polhemus FastScan in order to evaluate facial swelling for patients of oral surgeons, a 12.5 cm^3 standard deviation error can occur even when scanning the head of a mannequin several times as a set control. Furthermore, it was concluded that the main source of error is due to repositioning the head in the positioning assembly for comparative scans. Harrison (*et al* 2004) also noted that due to the lack of mechanical gantry complexity, ease of use, lack of radiation danger and low cost, the “FastScan” is a valuable tool in the clinical world.

Current Uses

Three-dimensional (3D) scanning has quickly branched out from its origins of the entertainment world of computer graphic and computer generation. Currently 3D scanning can be found in the art, cultural heritage, forensic anthropology, anthropometric and archaeological fields as well as many others not listed in this paper.

In the case of Art and 3D scanning one of the best-known cases is that of the “The Digital Michelangelo Project: 3D Scanning of Large Statues” by Levoy *et al* (2000). The scan sequence of “David” consisted of the largest single dataset to be comprised of two billion polygons and 7,000 color images. Though exact accuracy is not given, Levoy states that an accuracy of ¼ mm or better was necessary in order to obtain chisel mark data required for the study. Other examples can be those indicated by El-Hakim *et al* (2005) wherein frescoed walls of Italy have been scanned and digitized allowing for a closer analysis and protection from modern contaminants and mold while still allowing visitors to view the paintings. Ahmon (*et al* 2004) state that the process of making molds, castings or other reproductions that require the item to be touched causes damage to the precious cultural resources.

Scanning may also be used in order to obtain data to build a recreation of objects that may not be suitable for display to the general public due to their fragility. Taylor (*et al* 2002) and others note that 3D scanning is invaluable in the preservation of material in order to preserve Cultural Heritage items that are not capable of being on display in a museum setting.

Forensic Anthropology is fast becoming fond of 3D scanning in the recreation of museum models and study material as well as crime scene analysis and recreation of skeletal information; tire tracks, footprints and facial reconstruction. The College of Brooklyn has also applied this technology in the “Cuneiform Forensics – 3D digital Analysis of Cuneiform Tablet Production.” Park (*et al* 2006) also showed the possibilities of this technology in the analysis of craniometry in their paper “Use of hand-held laser scanning in the assessment of craniometry”. Park *et al* (2006) state that; “ In forensic and physical anthropology, there are many potential benefits of the ability to map the facial soft or hard tissues of a subject, while at the same time retaining accuracy and reliability in an office or in the field. It is also beneficial to collect and store the associated three-dimensional (3D) data for future analysis”.

Anthropometric analysis traditionally used calipers and other mechanical devices in order to obtain measurements of human shape. The problem here lies in that only certain measurements are taken at any given time and if the researcher is in need of points that are not acquired at the time of measurement the data is essentially lost. With the use of 3D

scanning the number of scanned points are nearly infinite and are also stored in virtual space which can be examined at later times. Fowles (2000) states that 3D scanning should be part of any conservation especially those of archaeology since the artifact is usually removed from the site. Fowles (2000) also states that the data obtained is an invaluable resource of information before restoration and removal.

Problems and Errors of Data Capture

Though scanning and creation of virtual replicas is an accurate solution to non-contact data acquisition, it is still inherently filled with technical and general issues. The initial obstacle to overcome is the price of the scanner itself. The Polhemus FastScan Scorpion lies in the \$35,000.00 range just for hardware. The software for 3D analysis can range from several hundred dollars to well over \$50,000.00 for software capable of handling point-clouds of one hundred million. Other issues lie in the use of the equipment itself. Creating 3D models is achieved by passing a handheld laser scanner over a given object. During this process the user must be sure to hold a roughly equal distance and speed while passing over the object. If the distance is too great or the speed is too fast corrupt data is received by the wand unit. Though this is of concern; the operator can easily overcome user errors. Once physical scanning is completed; the image is generated in real time and requires little processing in order to generate an image; however, extensive post-processing is required in order to generate the 3D analysis from the point-cloud.

During data capture errors can occur from many different areas; however, two aspects of errors are of much importance, these are superfluous light or systematic problems such as calibration or data capture errors which have also been recognized by Feng (*et al* 2001) as well. Within these limitations one is prevalent in all 3D laser scanners; that is, certain objects are not capable of being scanned due to the object themselves. For example, objects such as shiny, mirrored, certain colors or transparent items show inherent problems due to the fact that the beam is not reflected back correctly. These problems can be overcome by coating the object in a fine white powder. Feng (*et al* 2001) have also experienced problems such as mine in that black objects absorb light and therefore the laser is not reflected back to the recording camera and therefore no data points are received. By adjusting laser intensity it is possible to overcome issues with light or specimen color.

Additional problems such as specular noise or reflection interference can cause issues with scans (Polhemus). Systematic errors are those that occur during the interpretation of data within the device itself. This can happen for many reasons due to the triangulation methods where accuracy can be lost when the laser hits the edge or corner of an object. These results in two separate reflections are sent back for one laser pulse, which Simulate a dual image. Others such as possible noise or metal interference between the wand transmitter and reference receiver can deliver multiple images or deleted areas of a scan. As well as possible problems with incident angles of light or projected fields due to calibration discontinuity (Polhemus 2009).

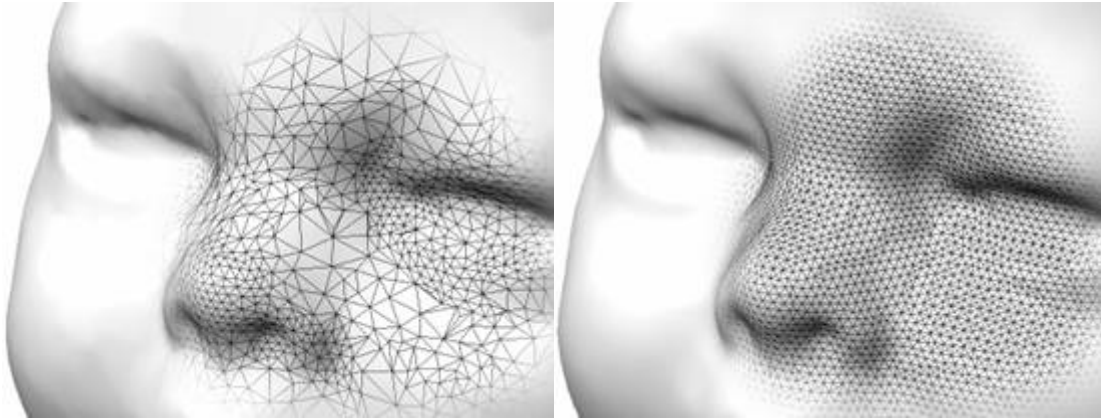
Virtual Models, Virtual Data, Virtual Reality

What is the importance of virtual (VR) in regards to computer assisted data acquisition? Or as we asked, “What is the relationship between VR data and the real bone?”

The creation of virtual models from hard data requires the conversion of point cloud data into surface representation algorithm, which allows 3D visualization. Virtual surfaces can be created in four ways (See figure 4): “Points” which show the individual data that make up the scan, “Wireframe” displays the surface triangular mesh, created by linking the point data, “Solid” displays the scanned object as a solid surface and “Outlined” which displays the object as a solid surface with the wireframe overlaid upon it (Polhemus Manual 2010).

Throughout history we have been taught that “Scientific Examination” has revolved around the dissection of deceased bodies or the exploratory examination of living bodies by cutting through layers to access different tissue layers. In recent years MRI, MRA, cat scans and VR have made exploratory surgeries archaic in most instances allowing doctors and researchers to see inside the body in computer generated pictures. The world of VR is a computer-generated graphic that gathers real world data and processes it into numerical data, which is then re-assembled into the VR world as a digital representation of the original form.

Figure 4. Virtual Surfaces (Polhemus.com)



Surfaces can be created using many different methods. Export formats can be created using either “NURBS” (non-uniform rational B-spline), 3D Studio Max® (.3ds), ASCII (.txt), AutoCAD® (.dxf), IGES® (.igs), LightWave® (.lwo), MATLAB® (.mat), STL (.stl), Virtual Reality Modeling Language (.wrl), Wavefront® (.obj), Open Inventor® (.iv), Visualization

Toolkit (.vtk) Polyworks® Scan (.psl), Stanford Polygon (.ply) and optional AAOP file format (Boehler *et al* 2002, Polhemus 2009). All export formats are mathematical representations of surface features. Boehler (*et al* 2002), states that NURBS is a simpler approach due to the smaller file sizes compared to that of surface mesh and provide a better representation of curved surfaces due to the fact that points are not allocated in the algorithm.

The more complex representation is that of “Wireframe” which is comprised of point-cloud data in a triangular configuration, where as each given point has six adjoining points in relation to the given point. With this information in mind, the researcher must understand that due to the numerous methods in both generating and analysis of surface mesh, each one holds a certain place in its use and on the quality of data captured. Due to the fact that the strengths and weaknesses of all capture and analysis software are outside the realm of this paper the following examination will only deal with the strengths and weaknesses of capture and analysis of data through the use of the “Polhemus FastScan Scorpion”.

Polhemus (2010) considers the scanned data or point-cloud data to be “Raw data” as it is viewed on the monitor screen. Lin and Liang (2002) states that, the “adaptive fitting technique” averages points of a range therefore “fitting” lines to an average for a given area of data. Polhemus calls this process “smoothing”, which is part of the “Basic Surface” analysis, which simplifies or smooth’s over data points. The smoothing parameter controls the degree of smoothing when aligning sweeps. Simplification, on the other hand, removes points within given areas and therefore allows for a virtual representation which is less representative of the given object (Lin and Liang 2002). Polhemus uses increasing or decreasing “Decimation” to generate surface detail. In this it is similar to that of “Simplification” stated by Lin and Liang (2002) in that an increased Decimation value reduces the number of points and triangles; and a decreased Decimation value will generate a subsequent increase of points and triangles (Polhemus 2009).

Chapter 3

Purpose

Given the benefits of scanning and importance of craniometry the purpose of this study is to explore the role of 3D laser scanning (3DLS) in craniofacial measurements. Understanding how this technology can be used in the field of anthropology, archaeology, and forensic sciences requires first understanding the three basic methodological considerations required in all 3DLS. First, the type of data acquisition used to create manipulable point clouds. Second the type of material being scanned and third, the precision and accuracy of the scanned subject in relation to the point cloud and solid works representation.

The first study will examine the use of traditional tools in acquiring measurements on both the unmodified (Study) skulls and the modified skulls. The choice of traditional measurement techniques is used to establish a base line using proven and accepted technique and problems or issues associated with such measurements in the following areas: Ease of data acquisition, Accuracy of measurements, Precision of measurements and Problems and limitations.

The second case study will examine the use of 3DLS for the creation of a digital replica. This study will look at the acquisition of data, precision and accuracy in comparison to traditional measurement techniques and determine the following: Ease of data acquisition, Accuracy of measurements, Precision of measurements and Problems and limitations.

Methods

Traditional

The process begins by taking measurements of distances between predetermined landmarks using spreading or sliding calipers. The landmarks used can be found in Tables 1, which identify and define standard landmarks on the human skull. Most landmarks refer to precise points on the surface or interior portions of the skull and therefore are easily recognizable. Traditional instruments used in this study are sliding calipers and hinge calipers both of which are described below and shown in figure 7.

A. Sliding Calipers (non-digital) – Best used when landmarks are relatively close together and cranial features do not interfere with straight-line measurements.

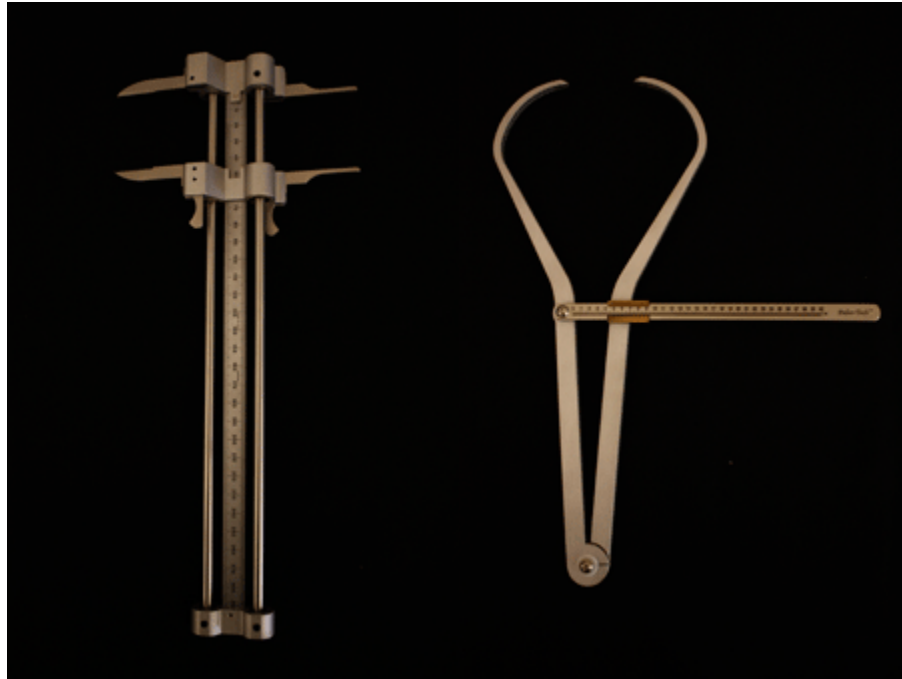
B. Hinge or Spreading Caliper (non-digital) – are the desired choice when cranial features make straight-line measurements impossible.

With the use of both of these instruments the researcher measures to the nearest mm were as decimal or sub-millimeter measurements are unnecessary.

Case Study I: Traditional Measuring Method

Using the information from Bass, W.M. (1987) *Human Osteology: A Laboratory and Field Manual*. 3rd edition. Missouri Archaeological Society Columbia a total of 24 measurements and Data Collection Procedures For Forensic Skeletal Material Report of Investigations no. 48 The University of Tennessee, Knoxville Department of Anthropology 1994, Peer M. Moore-Jansen, Stephen D. Ousley, Richard L. Jantz was used. These landmarks are listed and are know as; max length, max breadth, bizygomatic breadth, basion-bregma, cranial base length, basion-prosthion, max aveolar breadth, max aveolar length, biauricular breadth, upper facial height, minimum frontal breadth, upper facial breadth, nasal height, nasal breadth, orbital breadth, orbital height, biorbital breadth, interorbital breadth, frontal chord, parietal chord, occipital chord, foramen magnum length, foramen magnum breadth and mastoid height. These landmarks were chosen because they are accepted landmarks that are used in forensic anthropology in determining sex, race, and age.

Figure 5. Anthropometric measuring devices: A (Left), Sliding caliper; B (Right), Hinge caliper.



Case Study II: Polhemus FastScan Measurements

Polhemus FastScan Scorpion Method

The semiconductor lasers commonly referred to as “diode “ or “injection lasers” emit light through the use of semiconductor materials and electricity. This particular family of lasers is currently the hot topic in research known as “New” lasers at the current time. Most diode lasers operate in the ultraviolet to infrared range. Angelopoulou and Wright (1999) state that pulse operation is preferred due to the concerns of heat dissipation with semiconductor type lasers.

The laser scanner used in this study is the “Polhemus FastScan SCORPION”. This unit is a CLASS 3R Laser product with a peak power of 3.5mW and a wavelength of 670nm (Polhemus). Resolution of the “Scorpion” is 0.5mm at 200mm or (0.02 inches at 8 inches) range and as good as 0.1mm (Polhemus). The scanning rate is 50 lines / second, line-to-line resolution depends on movement of wand, typically 1mm at 50 mm / second (0.04 inches at 2 inches / second) (Polhemus). Scanning range is a user selectable radius up to .75mm or 75 cm (30 inches) wand to transmitter and / or receiver to transmitter range; longer range is available with optional 4-inch transmitter. The accuracy of the unit is an absolute accuracy within a 60” sphere centered around the reference source is 0.75mm (0.030 in.).

Practical accuracy is determined by scanning a bowling ball and calculating the variation in radius over the point cloud surface was found to be 0.13mm (0.005 in). In order to achieve these results several factors must be utilized in the scanning process

1. The object to be scanned should not be in direct sunlight.
2. The object cannot move at all.
3. The larger 2-inch transmitter may not move at all.

Figure 6: Polhemus FASTSCAN Scorpion Laser scanner and receivers (Polhemus Inc.).

2 Hardware and Software Setup

2.1 Components

You should have received the following components with your *FastSCAN™* package:

- Wand (1)
- Processing Unit (PU) (2)
- 2-inch Transmitter (large cube) (3)
- 1/2-inch Reference receiver (small cube) (4)
- Wand cable (color coded) (5)
- PU's power supply and power cable
- Wand pad
- USB cable
- *FastSCAN™* software install CD
- This manual.



Figure 1: The FastSCAN™ Cobra system with numbered components.

Optional Items

- Mechanical Stylus
- Optical Stylus
- Headband.

The intact cranium of four sample skulls and the three modified skulls were scanned individually. The way in which skulls were scanned did not vary between specimens: All skulls were placed on a wooden dowel wrapped with black fabric which was inserted into the foramen magnum until it touched the top portion of the skull near the bregma. This point provided a sturdy resting place free of un-wanted skull movement.

Scanner parameters were set as follows: smoothing is set at 1.00 and decimation is set at 0.50. This base line is chosen and kept for all scans in order to provide consistent data. Profile smoothing is set on low to provide highest accuracy. Sensitivity is set at 4 on a scale of 1 thru 6, where 1 is least sensitive and 6 is most sensitive, these numbers provided the best scan resolution in relationship to our study area and subjects. Maximum scanning distance was set to 750.00 mm and angles were set to 30.00 degrees, with a best scanning resolution set to .5mm, worst scanning resolution of 100.00mm, and a profile smoothing set to low. The 2-inch transmitter was placed on the dowel base approximately 3 inches above the table surface. The area was chosen to allow for a 3-foot metal free zone from any floor or wall rebar, which minimizes any interference in transmission and reception of the signal. The laptop was positioned on a separate table which helps minimize any movement of the object scanned and allows for easy visual reference of the scanning process as the wand was moved around the skull.

Files

The resulting scans were saved as FASTSCAN file (.fsn) to a folder on the laptop. Each file was named for the cranium from which it was scanned and is kept on the hard drive for further use. Upon completion of the scans the files were registered under “register sweeps” to determine if improved detail or reduced noise distortion was achieved. Visual comparison was used in assessing improvement or degradation between registered or unregistered sweeps. For the purposes of this study unregistered sweeps have been chosen due to the fact they are a more accurate representation of the object scanned. The next comparison is the “basic” sweep, which merges sweeps, changes filtering data, standardizes resolution, simplifies triangular mesh and limits the number of objects contained in a sweep. Upon visual comparison of the “Basic” sweeps it has been determined that “Basic” sweeps will not be used for this study due to the smoothing effect of the registered sweeps.

Measurements Analysis

Measurements analysis was provided by Polhemus “Delta” software. Though the program lists no reported accuracy, the publisher has determined that the accuracy is accurate to 0.005 mm. This was determined by scanning a known object that measured 1.00004 mm² with digital calipers. The object was then scanned and measured under Delta software and a measurement of 1.00504 mm² was obtained. This process was repeated 20 times until the publisher was confident that the accuracy and precision were quantified.

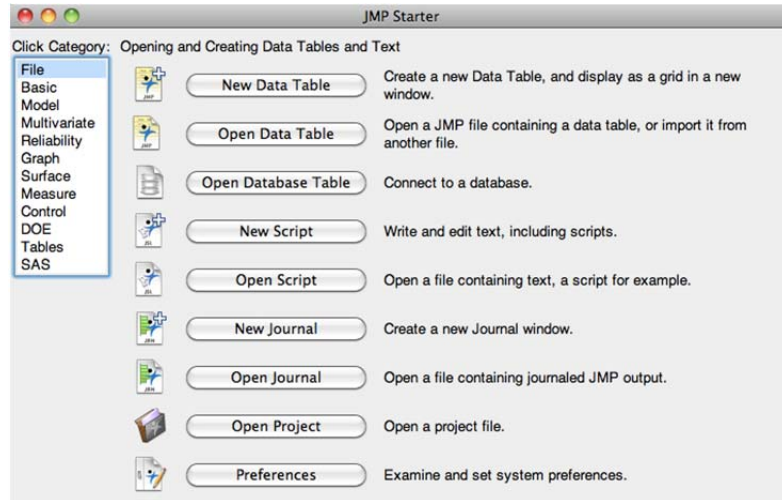
Statistical Analysis

Statistical analysis was performed using JMP software using Matched Pairs analysis. JMP is selected because it offers a special analysis platform for paired data. The Matched Pairs analysis compares means between two or more response columns using a paired *t-test* (JMP Manual 2011). The plot is broken down into two sections. The primary plot is a plot of the difference of the two responses on the *y-axis*, and the mean of the two responses on the *x-axis*. The graph produced in JMP is the same as a scatterplot of the two original variables except it is turned on a 45° rotation. It is this rotation that turns the original coordinates into two distinct categories known as difference and sum, which can be rescaled to show both difference and mean. The solid horizontal line is “zero” and the confidence interval is plotted above and below zero using a dashed line. If the confidence interval does not contain the “zero” solid line then the test comes back with a significant difference between the two responses.

Steps to access JMP Matched Pairs.

1. Access “New Data Table”

Figure 7: JMP Starter



2. Insert data in table and highlight two or more columns.

Figure 8: Data Table

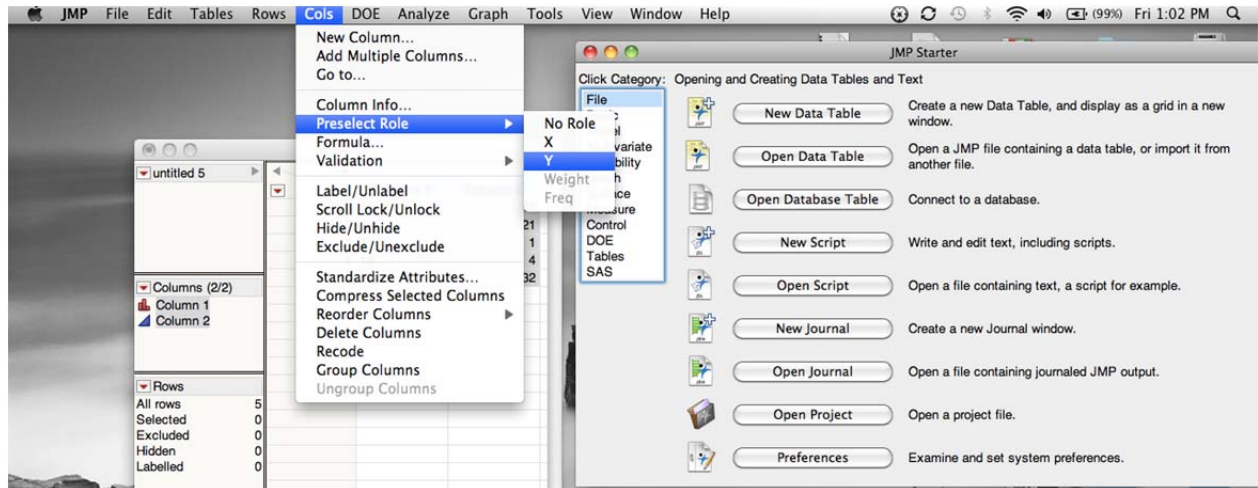
The screenshot shows the JMP Data Table window titled 'untitled 5'. The table has 5 rows and 2 columns. The first column is labeled 'Column 1' and the second column is labeled 'Column 2'. The data in the table is as follows:

	Column 1	Column 2
1	1	12
2	2	21
3	1	1
4	13	4
5	42	32

On the left side of the window, there are two panels. The top panel is titled 'Columns (2/2)' and shows 'Column 1' and 'Column 2'. The bottom panel is titled 'Rows' and shows 'All rows' (5), 'Selected' (0), 'Excluded' (0), 'Hidden' (0), and 'Labelled' (0).

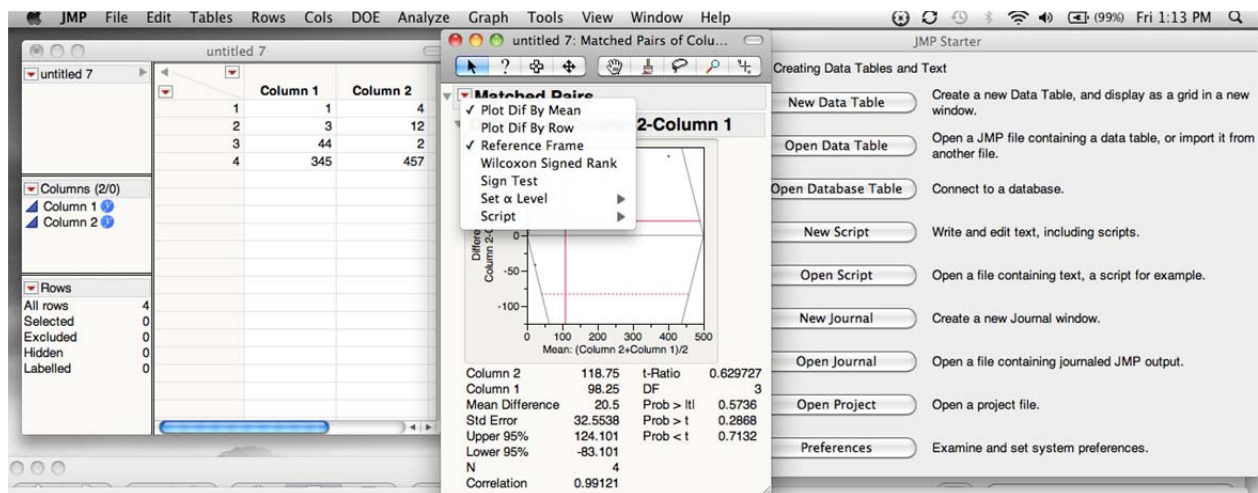
3. Scroll over “Cols” and choose “Preselect role” and set as “Y”.

Figure 9: Preselect Role



4. Select “Analyze” and choose “Matched Pairs”, “Plot Diff By Mean”, notice Columns have switched and are both set to “Y”.

Figure 10: Analyze Matched Pairs



The analysis draws the “zero” reference line, which is equal to the point at which both columns are equal. If the means of both columns are equal, then the points should be equally distributed above and below the zero line. All points above the solid line are greater than zero, in turn all numbers below the line are less than zero. In the example above the

parallel red line is displaced from the zero line by an amount equal to the difference of means between the responses; therefore sets the “Line of fit” for the sample. Which gives the means is equivalent to the line being non-significantly separated from the reference line of zero.

Described Unpaired and Paired Craniometric Landmark Definitions

The following definitions are taken from “Human Osteology A Laboratory and Field Manual” William M. Bass Third Edition (1987).

Table 1A: Landmark Definitions

1. Glabella (g) – The most forward projecting point in the midline of the forehead at the level of the supra-orbital ridges and above the nasofrontal suture.
2. Opisthocranium (op) – The most posterior point on the skull not on the external occipital protuberance. It is the posterior end point of maximum cranial length measured from glabella. It is thus not a fixed point but is instrumentally determined.
3. Euryon (eu) – The two points on the opposite sides of the skull that form the termini of the lines of greatest breadth, i.e., the most widely separated points on the two sides of the skull. The two points are determined instrumentally.
4. Zygion (zy) – The most lateral point of the Zygomatic arch; a point determined instrumentally.
5. Basion (ba) – The midpoint of the anterior margin of the foramen magnum most distant from the bregma. It is used to measure the height of the skull.
6. Bregma (b) – The intersection of the coronal and sagittal sutures, in the midline.
7. Nasion (n) – Intersection of the nasofrontal suture with the Midsagittal plane. Nasion is the uppermost landmark for the measure of facial height.
8. Prosthion (pr) – (prealveolar point) – Has often been confused with alveolare. Prosthion is the most anterior point in the midline on the upper alveolar process.
9. Maxillo-Alveolar Breadth (ect / ecm)- The maximum breadth across the alveolar borders of the maxilla measured on the lateral surfaces at the location of the second maxillary molar.
10. Alveolon (alv) – A point on the hard palate where a line drawn through the termini of the alveolar ridges crosses the median line.
11. Auriculare (au) – Not a standard landmark as defined here. Instead it is defined as a point on the lateral aspect of the root of the Zygomatic process at the deepest incurvature, wherever it may be.
12. Frontotemporale (ft) – The most medial point on the incurvature of the temporal ridge. The points lie on the frontal bones just above the zygomaticofrontal suture.
13. Upper facial breadth (fmt) – From nasion to alveolare. This gives the height of the face excluding the teeth and the mandible. It is used when the mandible is missing.
14. Nasospinale (ns) – The point where a line drawn between the lower margins of the right and left nasal apertures is intersected by the MSP (Midsagittal plane). NS is the lowest landmark for the measurement of nasal height.
15. Alare (al) – The instrumentally determined most lateral point on the nasal aperture taken perpendicular to the nasal height.
16. Orbital Breadth (width) – From maxillofrontale to ectoconchion. The maximum distance of the orbit from maxillofrontale to the middle of the lateral orbital

- border (ectoconchion). Measurement also can be taken from dacryon or lacrimale, but I prefer maxillofrontale since this is present most often. Since bones of the medial wall of the eye orbit are quite fragile; dacryon and lacrimale often are missing in archaeological specimens. To locate maxillofrontale, extend the medial edge of the eye orbit with a pencil line until the line crosses the frontomaxillary suture.
17. Orbital Height – The maximum height from the upper to the lower orbital borders perpendicular to the horizontal axis of the orbit and using the middle of the inferior border as a fixed point. Either or both orbits may be measured, but the left is the standard.
 18. Ectoconchion (ec) – The point where the orbital length line, parallel to the upper border, meets the outer rim. Ectoconchion is the point of maximum breadth on the lateral wall of the eye orbit.
 19. Interorbital Breadth –
 20. Lambda (l) – The intersection of the sagittal and lambdoidal sutures in the midline.
 21. Opisthion (o) – The midpoint of the posterior margin of the foramen magnum.

Table 1B: Described Unpaired and paired Craniometric landmarks

(Human Osteology A Laboratory Field Manual William M. Bass Third Edition 1987)

- | | |
|---------------------------------------|---------------------------------------|
| 1. Maximum length (g-op) [GOL] | 12. Upper Facial Br. (fmt-fmt) [UFBR] |
| 2. Maximum Breadth (eu-eu) [XCB] | 13. Nasal Height (n-ns) [NLT] |
| 3. Bizygomatic Breadth (zy-zy) [ZYB] | 14. Nasal Breadth (al-al) [NLB] |
| 4. Basion-Bregma (ba-b) [BBH] | 15. Orbital Breadth [OBB] |
| 5. Cranial base length (ba-n) [BNL] | 16. Orbital Height [OBH] |
| 6. Basion-Prosthion (ba-pr) [BPL] | 17. Biorbital Breadth (ec-ec) [EKB] |
| 7. Max. Alveolar Br. (ect-ect) [MAB] | 18. Interorbital Breadth [DKB] |
| 8. Max. Alveolar L. (pr-alv) [MAL] | 19. Frontal Chord (n-b) [FRC] |
| 9. Biauricular Breadth (au-au) [AUB] | 20. Parietal Chord (b-l) [PAC] |
| 10. Upper Facial Height (n-pr) [UFHT] | 21. Occipital Chord (l-o) [OCC] |
| 11. Min. Frontal Br. (ft-ft) [WFB] | 22. Foramen Magnum L. (ba-o) [FOL] |
| | 23. Foramen Magnum Breadth [FOB] |
| | 24. Mastoid Height [MDH] |

Chapter 4

Skulls

Study Skulls #1, 2, 3 and 4

Study skulls #1, 2, 3 and 4 are anatomical teaching specimens purchased from Osta International. The intact cranium was scanned in accordance with the following procedures. The skull is placed on a wooden dowel wrapped in black cloth that extends roughly 8 inches below the base of the skull. The placement of the fabric is critical in allowing for complete scanning of all areas of the cranium without the interference of non-cranial features being scanned into the data. The cranium is scanned in passes starting from the area near or including the bregma to the area near the maxilla. Scans are continued in this fashion around the cranium until a full scan is achieved. Once all dorsal, ventral and lateral scans are complete the underside of the cranium is scanned to include all maxilla and foramen magnum features to include but not limited to Occipital condyle, Hypoglossal canal and Palatine areas.

Modified Skulls

Modified skull #1

Figure11: Prehistoric Native South American Skull ~ 2000 years old cast from “Bone Clones” Picture by Christopher T. Kowalczyk



Modified Skull #2

Figure 12: Native American Provenience or date unknown. Recovered by GBI from a home in North Georgia (Verbal Communication Dr. Matthew Williamson).

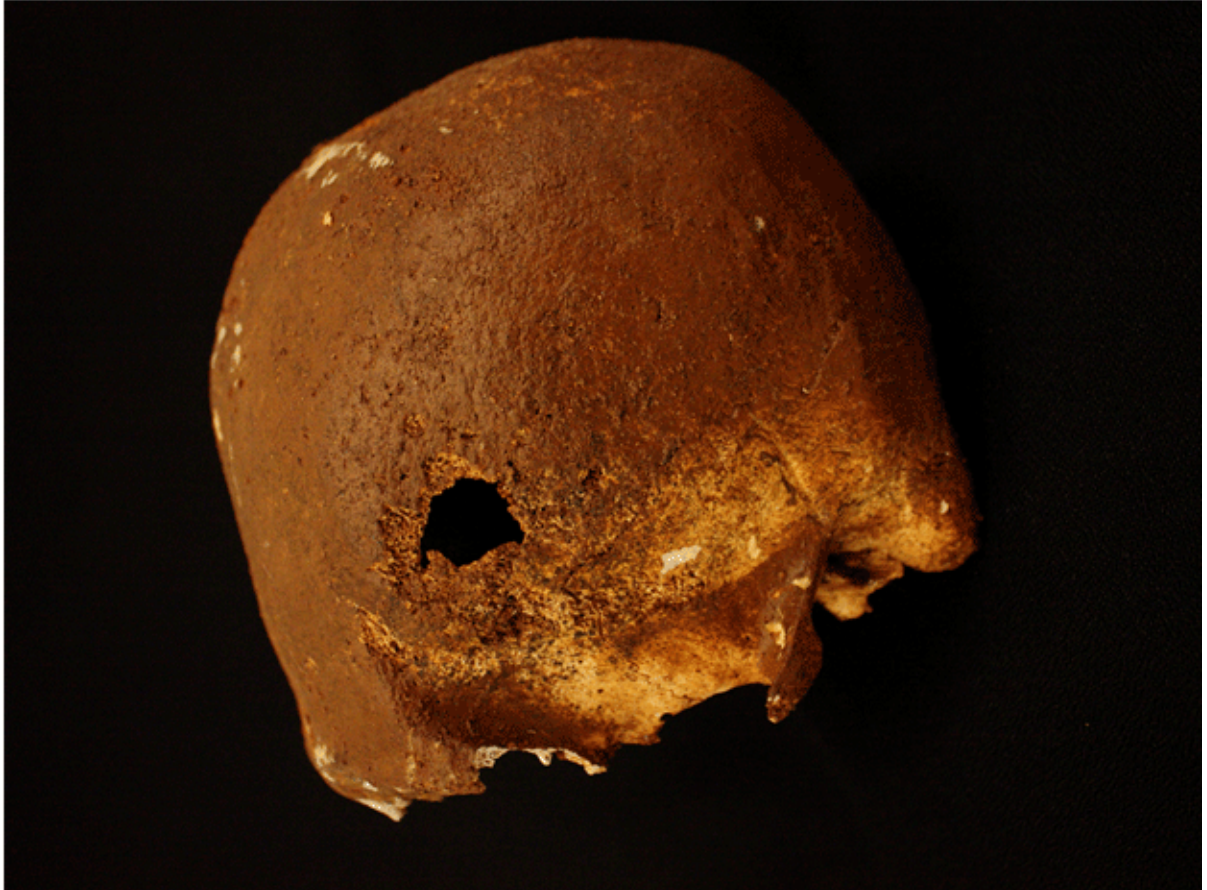
Picture by Christopher T. Kowalczyk



Modified skull #3

Figure 13: Native American from 9TP9 (Burnt Village Site) Georgia probably the 18th Century Lower Creek town of "Okfuskenena" based on Huscher, H.A. (1972).

Picture by Christopher T. Kowalczyk



Modified skull #4

Figure 14: Native American from 9TP9 (Burnt Village Site) Georgia probably the 18th Century Lower Creek town of "Okfuskenena" based on Huscher, H.A. (1972).

Picture by Christopher T. Kowalczyk



Chapter 5

Results

Matched Pairs Summary Unmodified Skulls

Figure 15: Matched Pairs

Difference: Maximum Length (g-op)

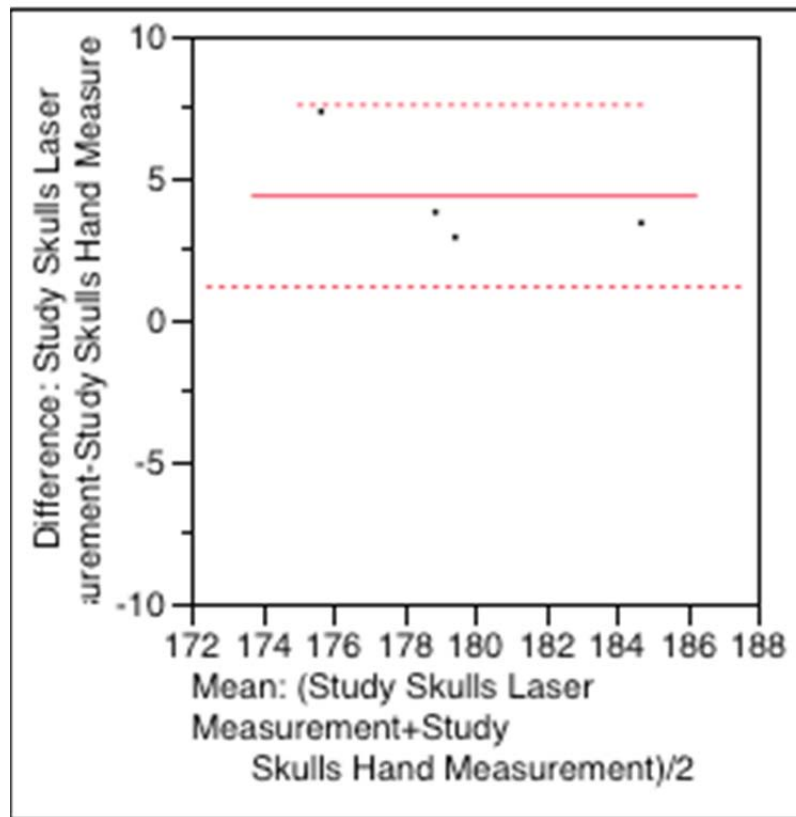


Table 2: Maximum Length

Study Skulls Laser Measurement	181.87	t-Ratio	4.336897
Study Skulls Hand Measurement	177.5	DF	3
Mean Difference	4.36994	Prob > t	0.0226*
Std Error	1.00762	Prob > t	0.0113*
Upper 95%	7.57664	Prob < t	0.9887
Lower 95%	1.16325		
N	4		
Correlation	0.92447		

Figure 16: Matched Pairs
Difference: Maximum Breadth (eu-eu)

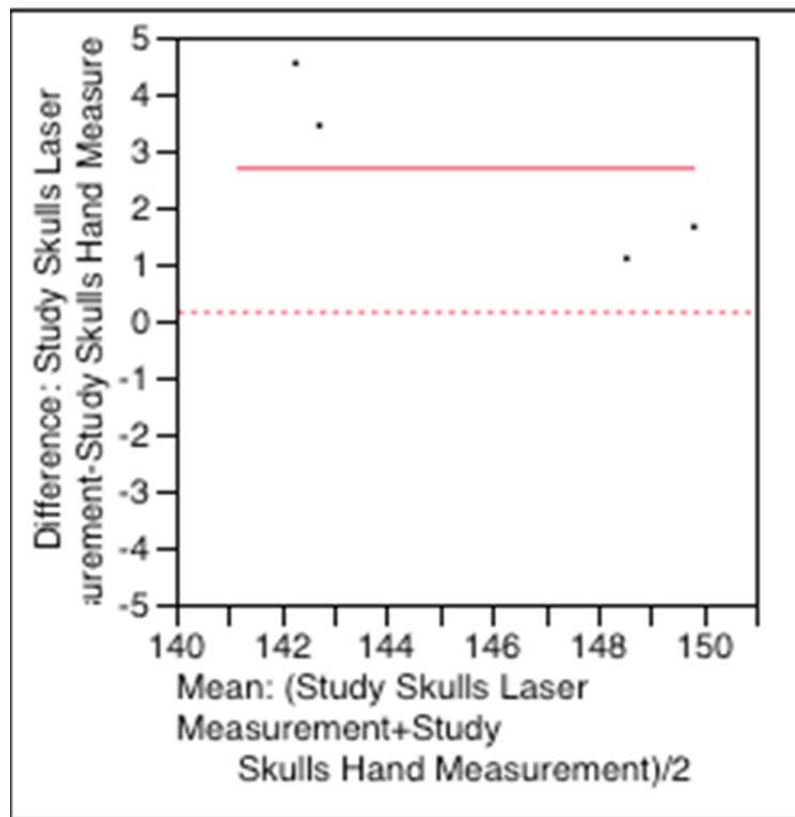


Table 3: Maximum Breadth

Study Skulls Laser Measurement	147.183	t-Ratio	3.373205
Study Skulls Hand Measurement	144.5	DF	3
Mean Difference	2.68312	Prob > t	0.0433*
Std Error	0.79542	Prob > t	0.0217*
Upper 95%	5.21451	Prob < t	0.9783
Lower 95%	0.15173		
N	4		
Correlation	0.98857		

Figure 17: Matched Pairs
Difference: Bizygomatic Breadth (zy-zy)

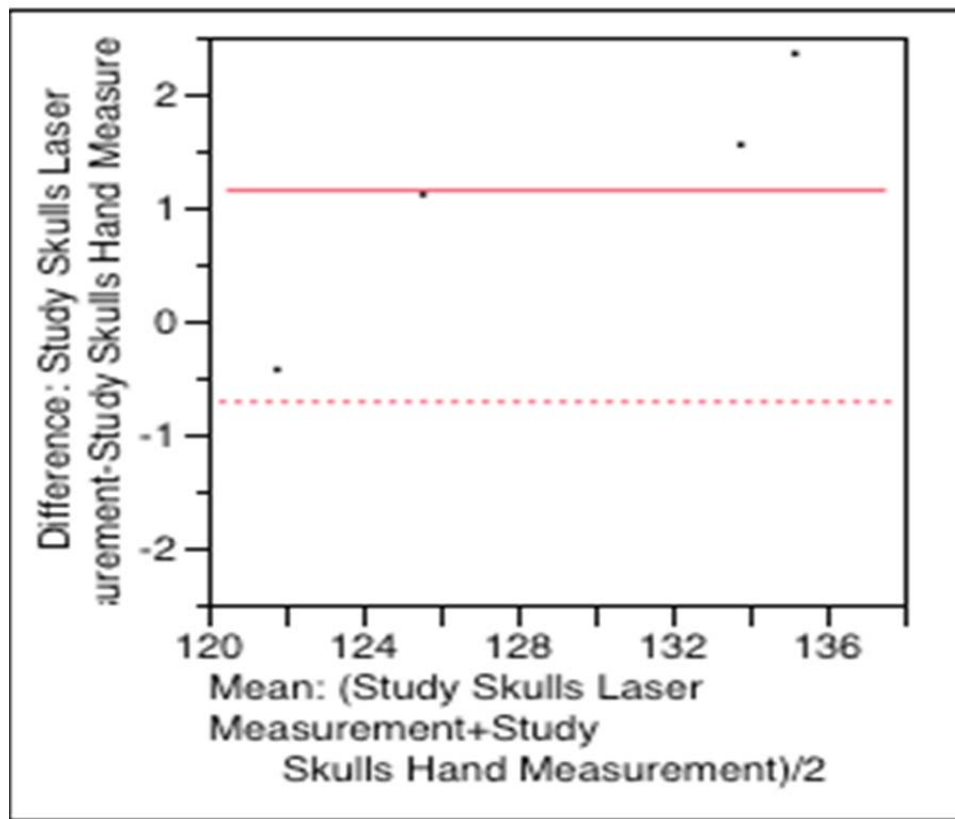


Table 4: Bizygomatic Breadth

Study Skulls Laser Measurement	129.648	t-Ratio	1.961017
Study Skulls Hand Measurement	128.5	DF	3
Mean Difference	1.14771	Prob > t	0.1447
Std Error	0.58526	Prob > t	0.0724
Upper 95%	3.01027	Prob < t	0.9276
Lower 95%	-0.7149		
N	4		
Correlation	0.9975		

Figure 18: Matched Pairs
 Difference: Basion-Bregma (ba-b)

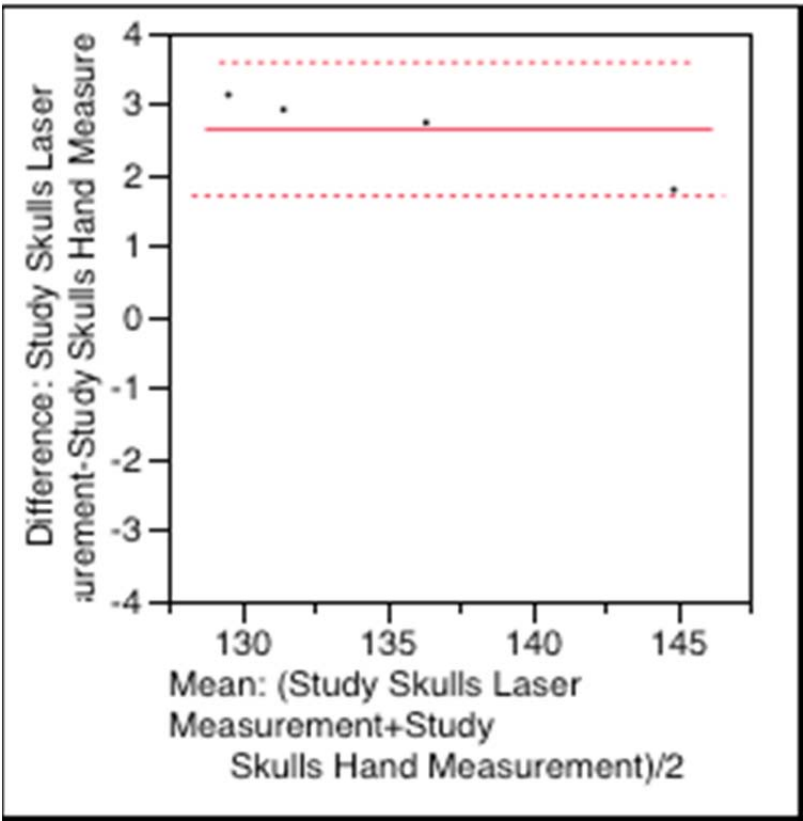


Table 5: Basion-Bregma

Study Skulls Laser Measurement	136.899	t-Ratio	8.967226
Study Skulls Hand Measurement	134.25	DF	3
Mean Difference	2.64891	Prob > t	0.0029*
Std Error	0.2954	Prob > t	0.0015*
Upper 95%	3.589	Prob < t	0.9985
Lower 95%	1.70882		
N	4		
Correlation	0.99987		

Figure 19: Matched Pairs
Difference: Cranial Base Length (ba-n)

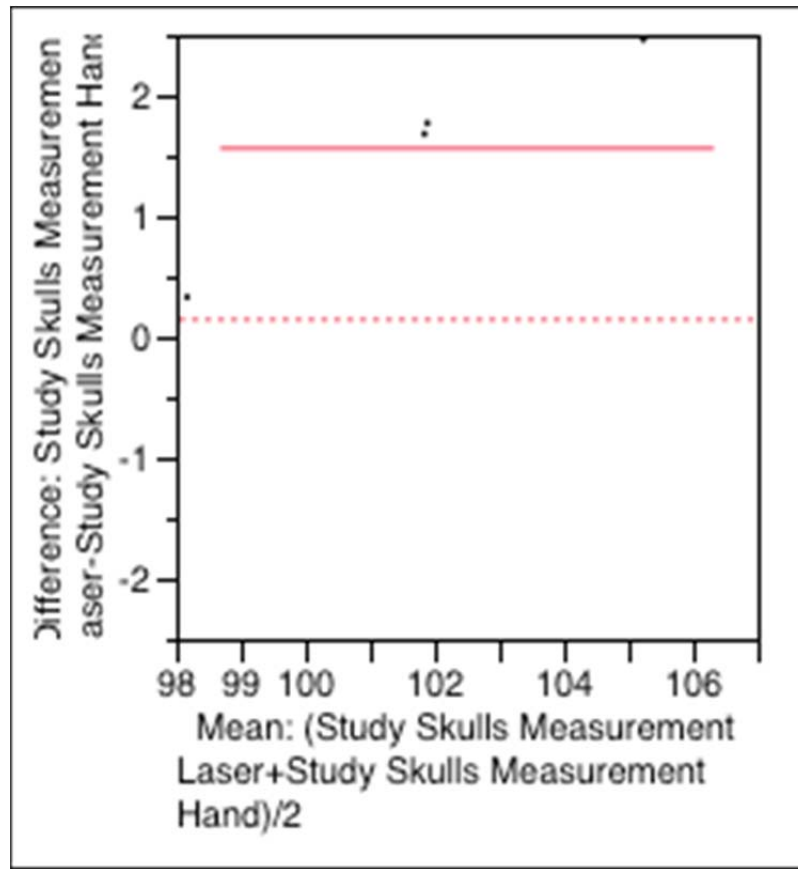


Table 6: Cranial Base Length

Study Skulls Measurement Laser	102.561	t-Ratio	3.504171
Study Skulls Measurement Hand	101	DF	3
Mean Difference	1.56055	Prob > t	0.0394*
Std Error	0.44534	Prob > t	0.0197*
Upper 95%	2.97782	Prob < t	0.9803
Lower 95%	0.14328		
N	4		
Correlation	0.9983		

Figure 20: Matched Pairs
Difference: Basion-Prosthion (ba-pr)

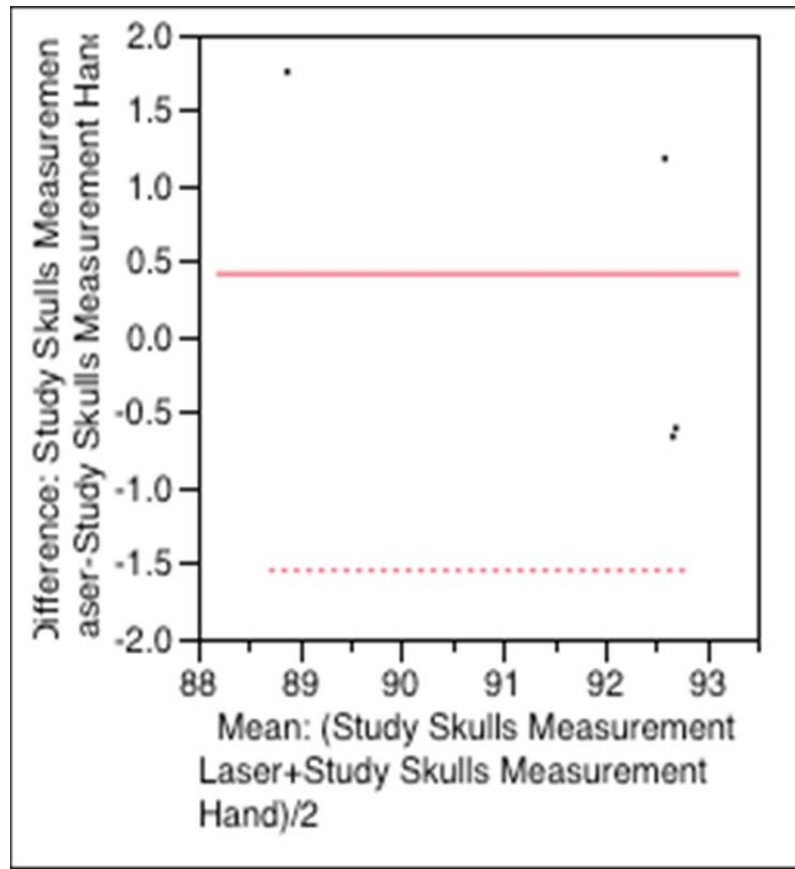


Table 7: Basion-Prosthion

Study Skulls Measurement Laser	91.9182	t-Ratio	0.676868
Study Skulls Measurement Hand	91.5	DF	3
Mean Difference	0.41816	Prob > t	0.5470
Std Error	0.61779	Prob > t	0.2735
Upper 95%	2.38425	Prob < t	0.7265
Lower 95%	-1.5479		
N	4		
Correlation	0.89623		

Figure 21: Matched Pairs
Difference: Maximum Alveolar Breadth (ect-ect)

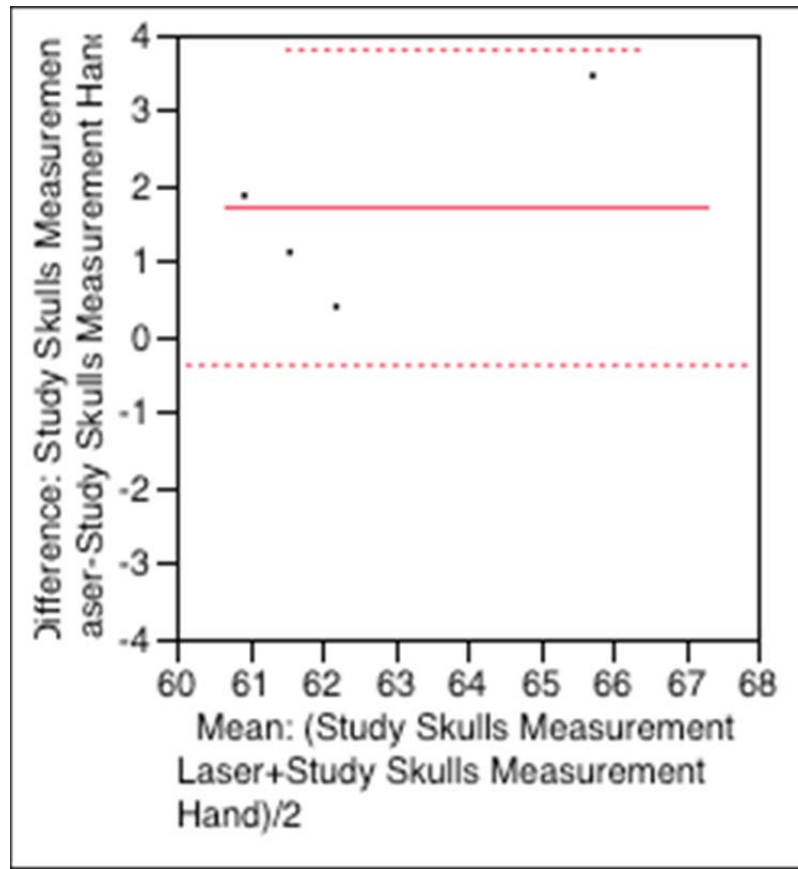


Table 8: Maximum Alveolar Breadth

Study Skulls Measurement Laser	63.4642	t-Ratio	2.616086
Study Skulls Measurement Hand	61.75	DF	3
Mean Difference	1.71424	Prob > t	0.0793
Std Error	0.65527	Prob > t	0.0396*
Upper 95%	3.79961	Prob < t	0.9604
Lower 95%	-0.3711		
N	4		
Correlation	0.91404		

Figure 22: Matched Pairs
Difference: Maximum Alveolar Length (pr-alv)

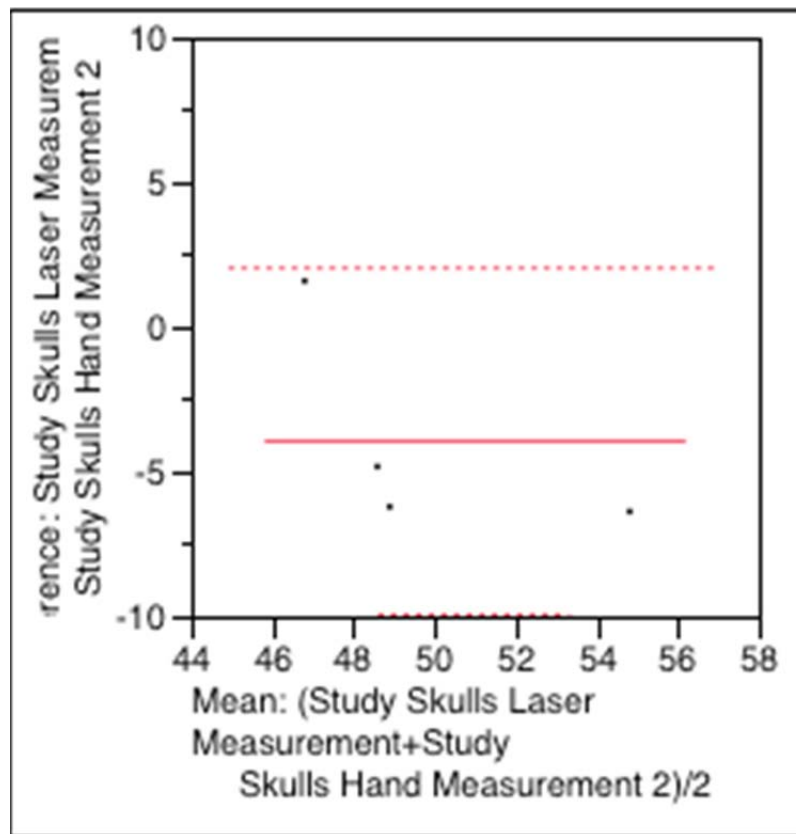


Table 9: Maximum Alveolar Length

Study Skulls Laser Measurement	47.7946	t-Ratio	-2.10251
Study Skulls Hand Measurement 2	51.75	DF	3
Mean Difference	-3.9554	Prob > t	0.1263
Std Error	1.88129	Prob > t	0.9369
Upper 95%	2.03166	Prob < t	0.0631
Lower 95%	-9.9425		
N	4		
Correlation	0.655		

Figure 23: Matched Pairs
Difference: Biauricular Breadth (au-au)

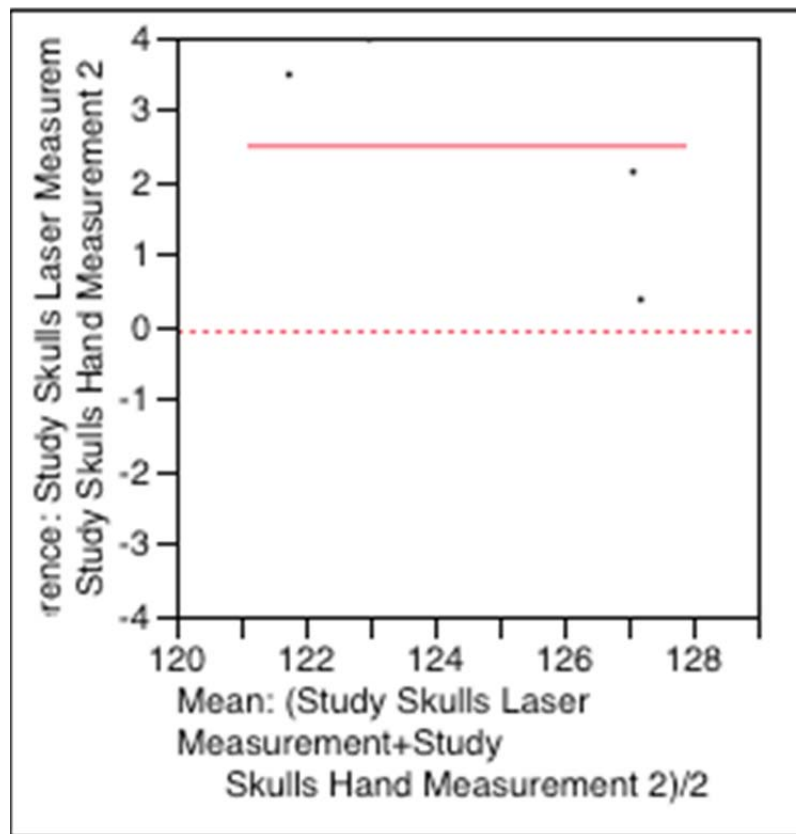


Table 10: Biauricular Breadth

Study Skulls Laser Measurement	125.998	t-Ratio	3.10121
Study Skulls Hand Measurement 2	123.5	DF	3
Mean Difference	2.49844	Prob > t	0.0532
Std Error	0.80563	Prob > t	0.0266*
Upper 95%	5.06233	Prob < t	0.9734
Lower 95%	-0.0654		
N	4		
Correlation	0.95108		

Figure 24: Matched Pairs
Difference: Upper Facial Height (n-pr)

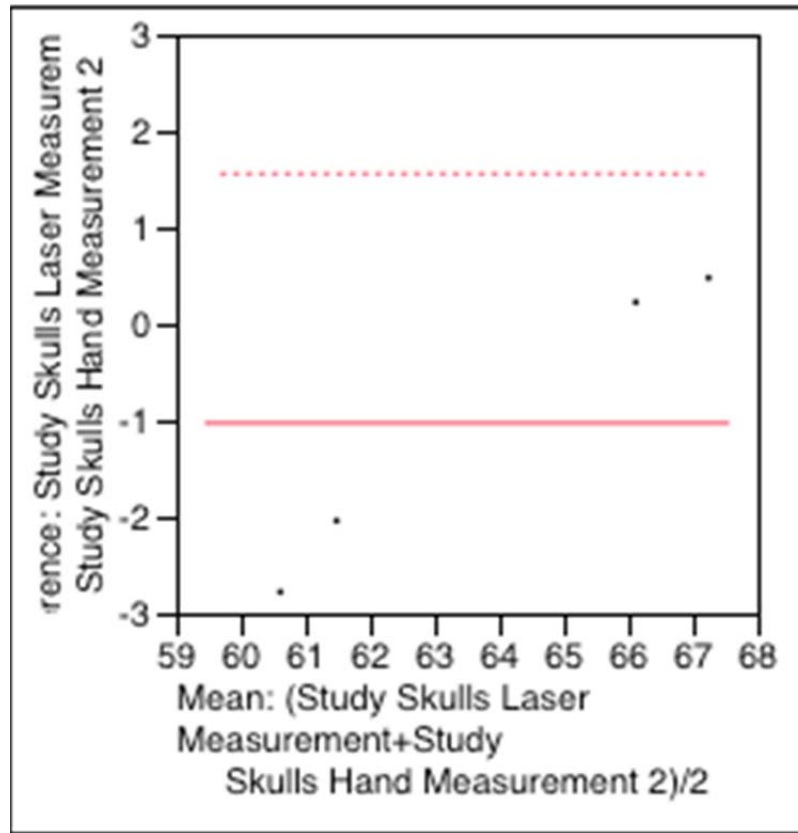


Table 11: Upper Facial Height

Study Skulls Laser Measurement	63.3467	t-Ratio	-1.2648
Study Skulls Hand Measurement 2	64.375	DF	3
Mean Difference	-1.0283	Prob > t	0.2953
Std Error	0.81301	Prob > t	0.8524
Upper 95%	1.55907	Prob < t	0.1476
Lower 95%	-3.6157		
N	4		
Correlation	0.99838		

Figure 25: Matched Pairs
Difference: Minimum Frontal Breadth (ft-ft)

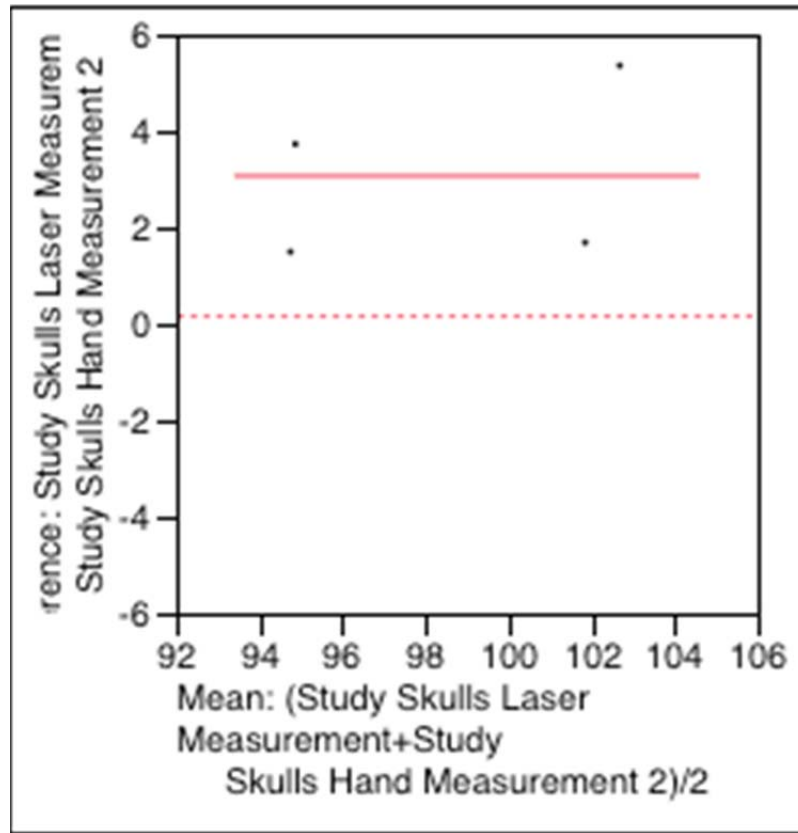


Table 12: Minimum Frontal Breadth

Study Skulls Laser Measurement	100.069	t-Ratio	3.353003
Study Skulls Hand Measurement 2	97	DF	3
Mean Difference	3.06947	Prob > t	0.0440*
Std Error	0.91544	Prob > t	0.0220*
Upper 95%	5.9828	Prob < t	0.9780
Lower 95%	0.15613		
N	4		
Correlation	0.92368		

Figure 26: Matched Pairs
Difference: Upper Facial Breadth (fmt-fmt)

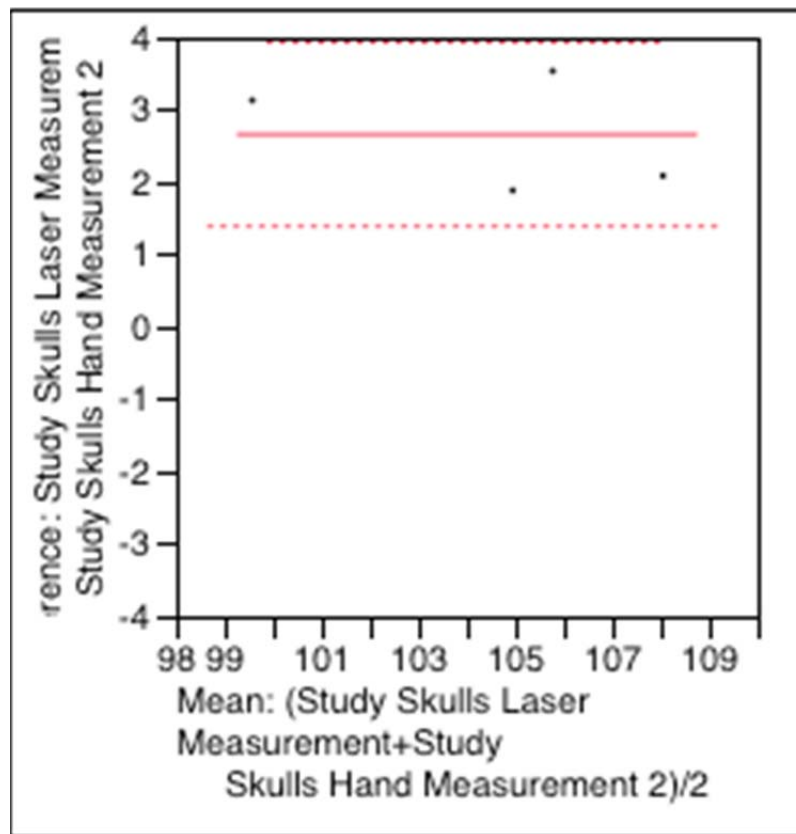


Table 13: Upper Facial Breadth

Study Skulls Laser Measurement	105.912	t-Ratio	6.662873
Study Skulls Hand Measurement 2	103.25	DF	3
Mean Difference	2.6625	Prob > t	0.0069*
Std Error	0.3996	Prob > t	0.0034*
Upper 95%	3.93421	Prob < t	0.9966
Lower 95%	1.39078		
N	4		
Correlation	0.97965		

Figure 27: Matched Pairs
Difference: Nasal Height (n=ns)

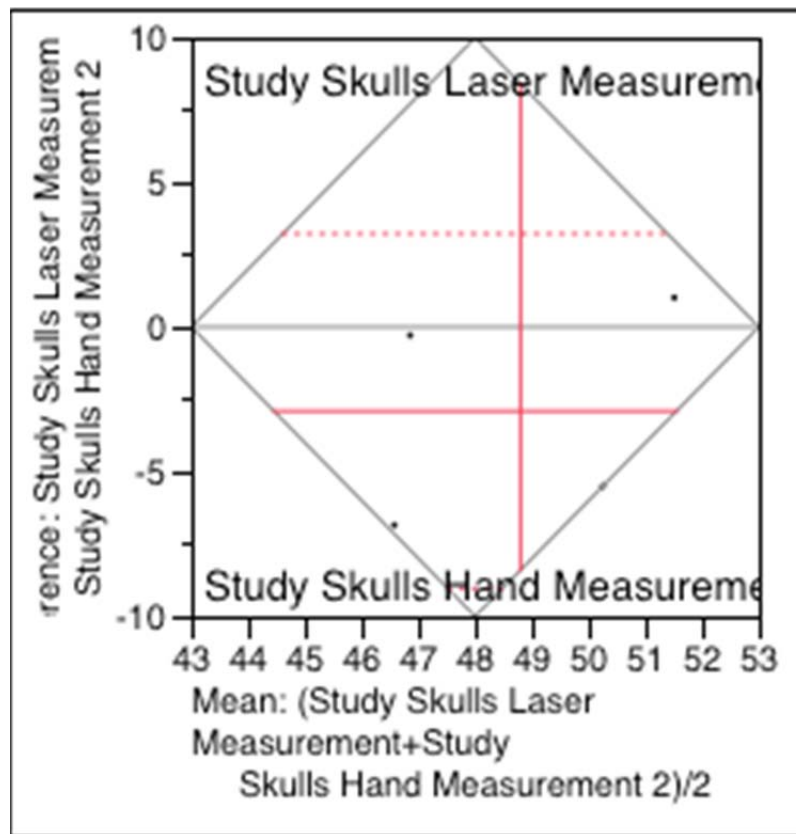


Table 14: Nasal Height

Study Skulls Laser Measurement	47.3441	t-Ratio	-1.50897
Study Skulls Hand Measurement 2	50.25	DF	3
Mean Difference	-2.9059	Prob > t	0.2284
Std Error	1.92578	Prob > t	0.8858
Upper 95%	3.22275	Prob < t	0.1142
Lower 95%	-9.0346		
N	4		
Correlation	0.25715		

Figure 28: Matched Pairs
Difference: Nasal Breadth (al-al)

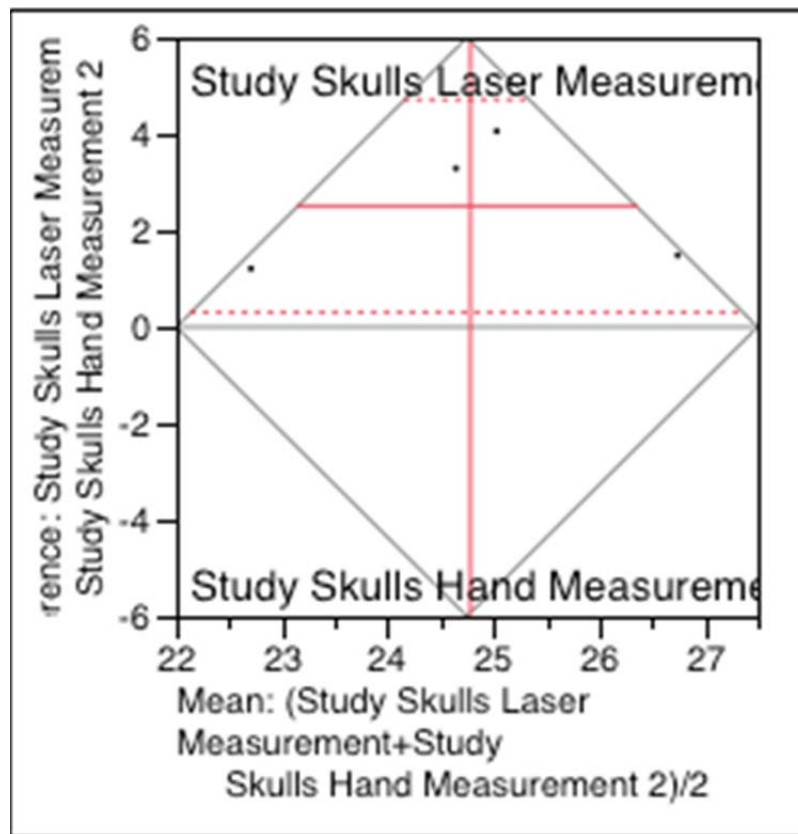


Table 15: Nasal Breadth

Study Skulls Laser Measurement	26.0374	t-Ratio	3.629269
Study Skulls Hand Measurement 2	23.525	DF	3
Mean Difference	2.5124	Prob > t	0.0360*
Std Error	0.69226	Prob > t	0.0180*
Upper 95%	4.71549	Prob < t	0.9820
Lower 95%	0.30932		
N	4		
Correlation	0.70647		

Figure 29: Matched Pairs
Difference: Orbital Breadth (OBB)

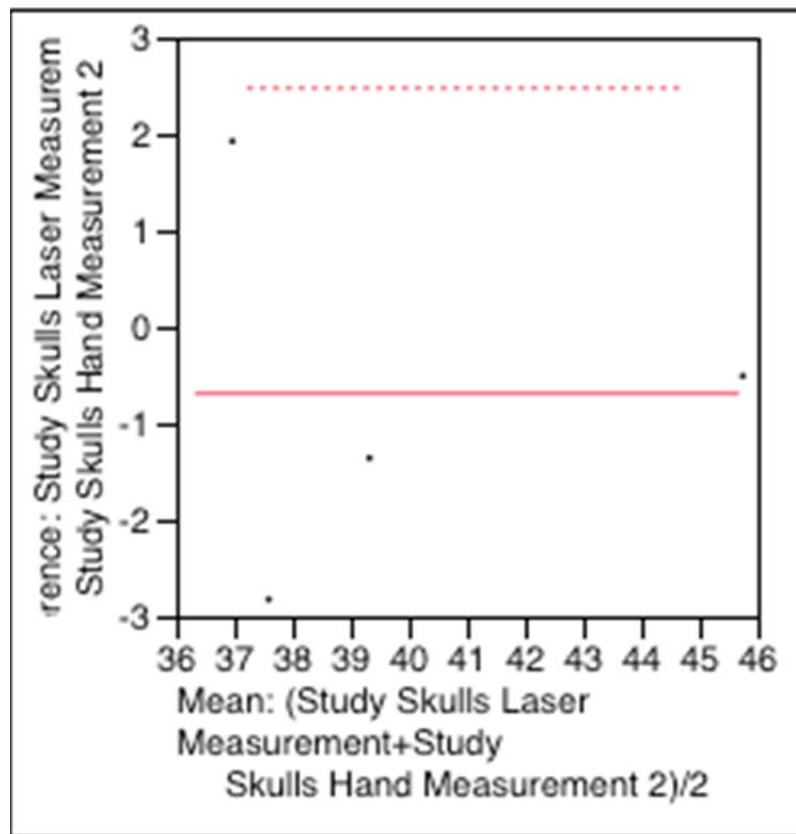


Table 16: Orbital Breadth

Study Skulls Laser Measurement	39.559	t-Ratio	-0.69463
Study Skulls Hand Measurement 2	40.25	DF	3
Mean Difference	-0.691	Prob > t	0.5372
Std Error	0.99482	Prob > t	0.7314
Upper 95%	2.47493	Prob < t	0.2686
Lower 95%	-3.857		
N	4		
Correlation	0.88486		

Figure 30: Matched Pairs
Difference: Orbital Height (OBH)

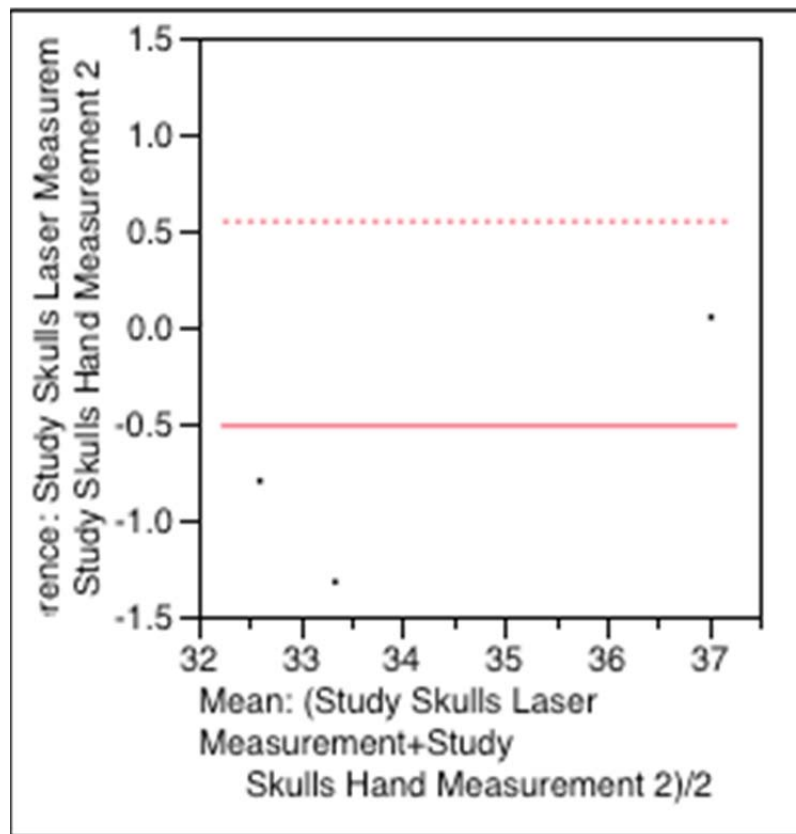


Table 17: Orbital Height

Study Skulls Laser Measurement	33.4868	t-Ratio	-1.54001
Study Skulls Hand Measurement 2	34	DF	3
Mean Difference	-0.5132	Prob > t	0.2212
Std Error	0.33321	Prob > t	0.8894
Upper 95%	0.54728	Prob < t	0.1106
Lower 95%	-1.5736		
N	4		
Correlation	0.96225		

Figure 31: Matched Pairs
Difference: Biorbital Breadth (ec-ec)

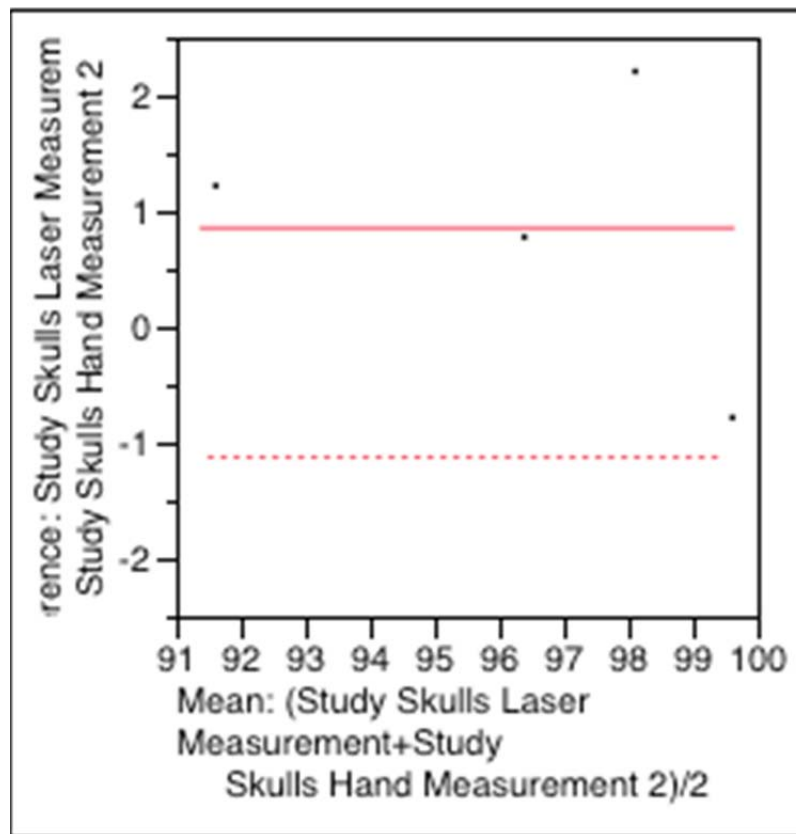


Table 18: Biorbital Breadth

Study Skulls Laser Measurement	96.8558	t-Ratio	1.374594
Study Skulls Hand Measurement 2	96	DF	3
Mean Difference	0.85583	Prob > t	0.2629
Std Error	0.62261	Prob > t	0.1315
Upper 95%	2.83724	Prob < t	0.8685
Lower 95%	-1.1256		
N	4		
Correlation	0.94517		

Figure 32: Matched Pairs
Difference: Interorbital Breadth (DKB)

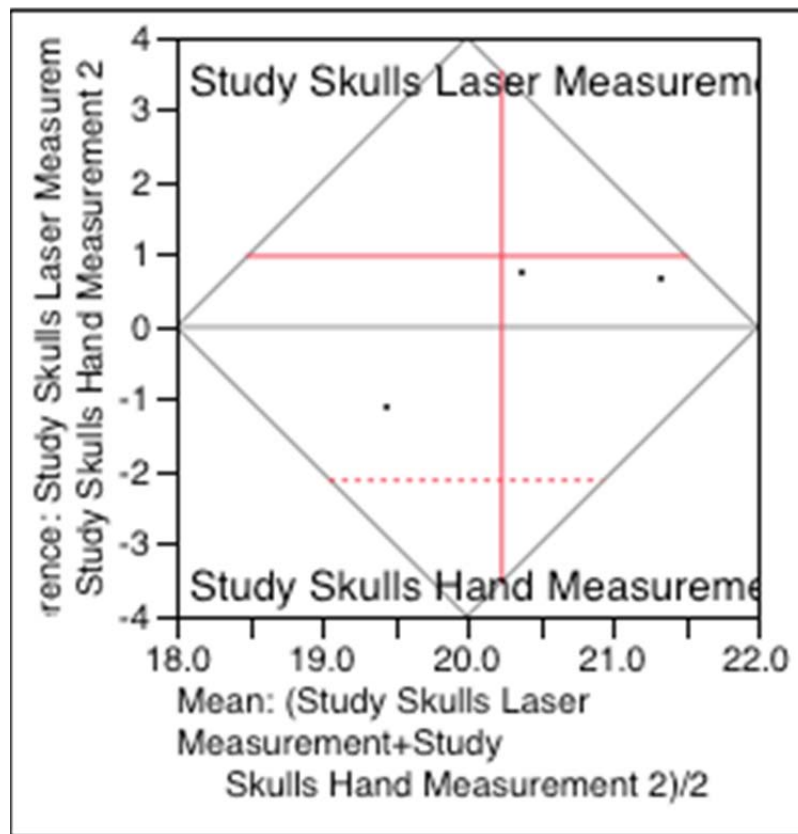


Table 19: Interorbital Breadth

Study Skulls Laser Measurement	20.7304	t-Ratio	1.006277
Study Skulls Hand Measurement 2	19.75	DF	3
Mean Difference	0.98036	Prob > t	0.3884
Std Error	0.97424	Prob > t	0.1942
Upper 95%	4.08083	Prob < t	0.8058
Lower 95%	-2.1201		
N	4		
Correlation	-0.1658		

Figure 33: Matched Pairs
Difference: Frontal Chord (n-b)

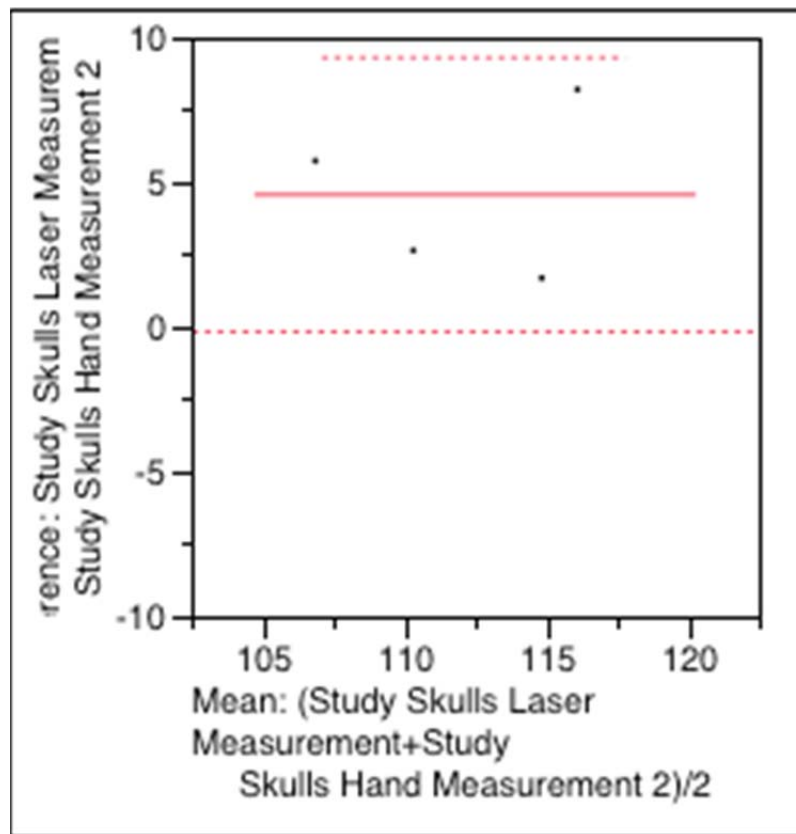


Table 20: Frontal Chord

Study Skulls Laser Measurement	114.322	t-Ratio	3.07048
Study Skulls Hand Measurement 2	109.75	DF	3
Mean Difference	4.5716	Prob > t	0.0545
Std Error	1.48889	Prob > t	0.0273*
Upper 95%	9.30991	Prob < t	0.9727
Lower 95%	-0.1667		
N	4		
Correlation	0.78262		

Figure 34: Matched Pairs
Difference: Parietal Chord (b-l)

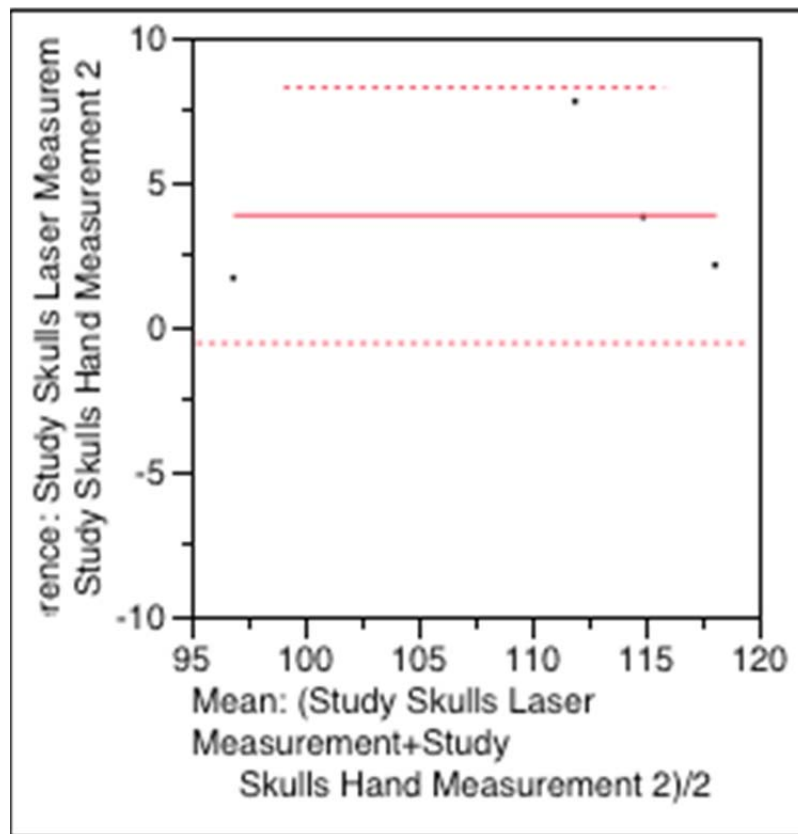


Table 21: Parietal Chord

Study Skulls Laser Measurement	112.36	t-Ratio	2.778983
Study Skulls Hand Measurement 2	108.5	DF	3
Mean Difference	3.8602	Prob > t	0.0690
Std Error	1.38907	Prob > t	0.0345*
Upper 95%	8.28084	Prob < t	0.9655
Lower 95%	-0.5604		
N	4		
Correlation	0.96038		

Figure 35: Matched Pairs
Difference: Occipital Chord (l-o)

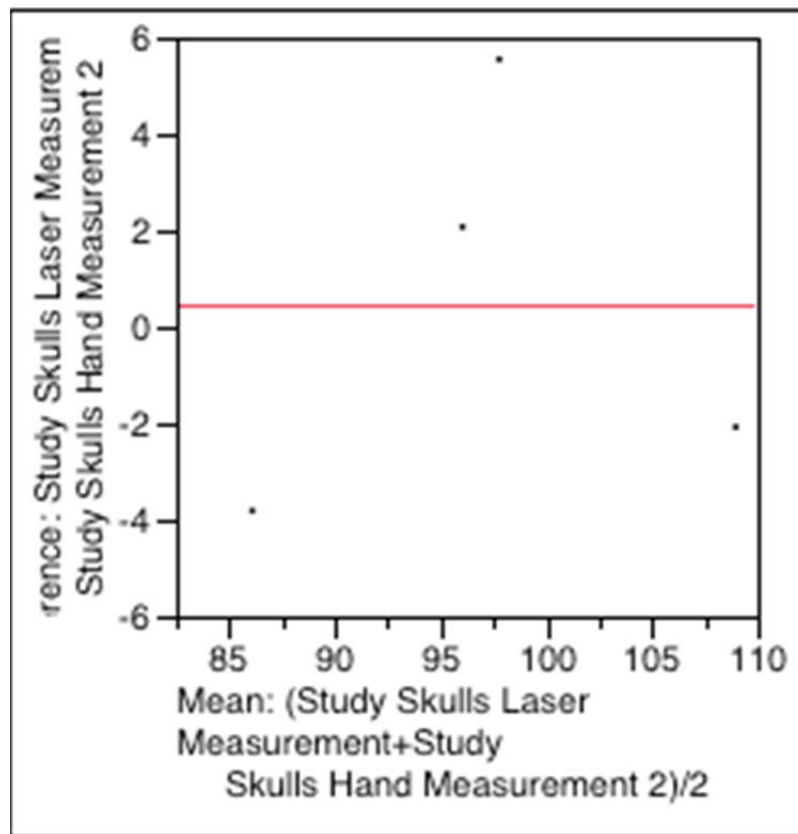


Table 22: Occipital Chord

Study Skulls Laser Measurement	97.4354	t-Ratio	0.206876
Study Skulls Hand Measurement 2	97	DF	3
Mean Difference	0.43541	Prob > t	0.8494
Std Error	2.10468	Prob > t	0.4247
Upper 95%	7.13345	Prob < t	0.5753
Lower 95%	-6.2626		
N	4		
Correlation	0.90601		

Figure36: Matched Pairs
Difference: Foramen Magnum Length (ba-o)

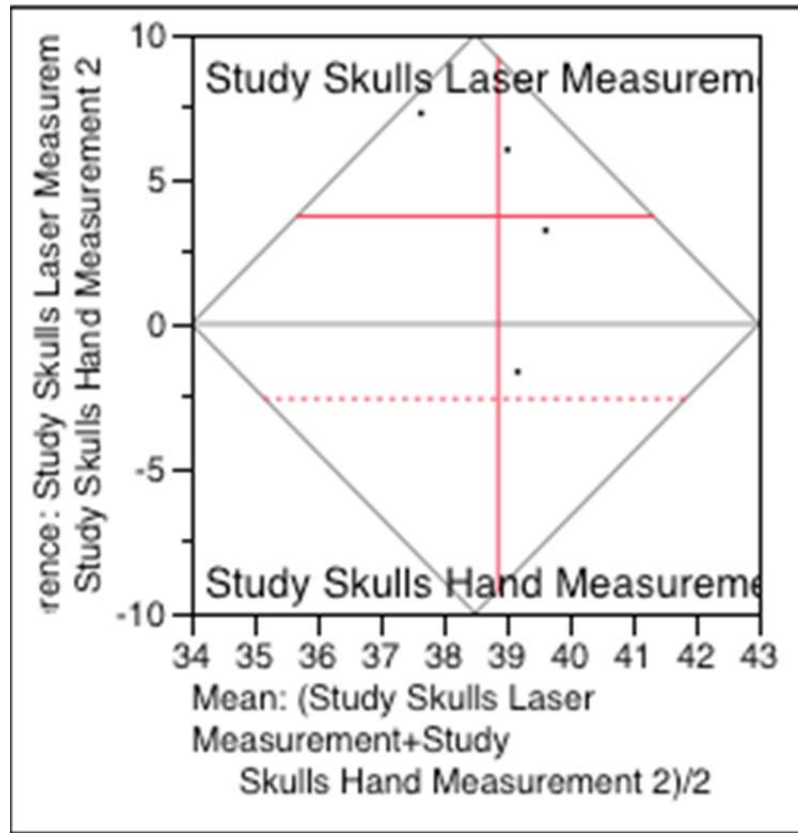


Table 23: Foramen Magnum Length

Study Skulls Laser Measurement	40.7238	t-Ratio	1.879877
Study Skulls Hand Measurement 2	37	DF	3
Mean Difference	3.72375	Prob > t	0.1567
Std Error	1.98085	Prob > t	0.0784
Upper 95%	10.0277	Prob < t	0.9216
Lower 95%	-2.5802		
N	4		
Correlation	-0.7623		

Figure 37: Matched Pairs
Difference: Foramen Magnum Breadth (FOB)

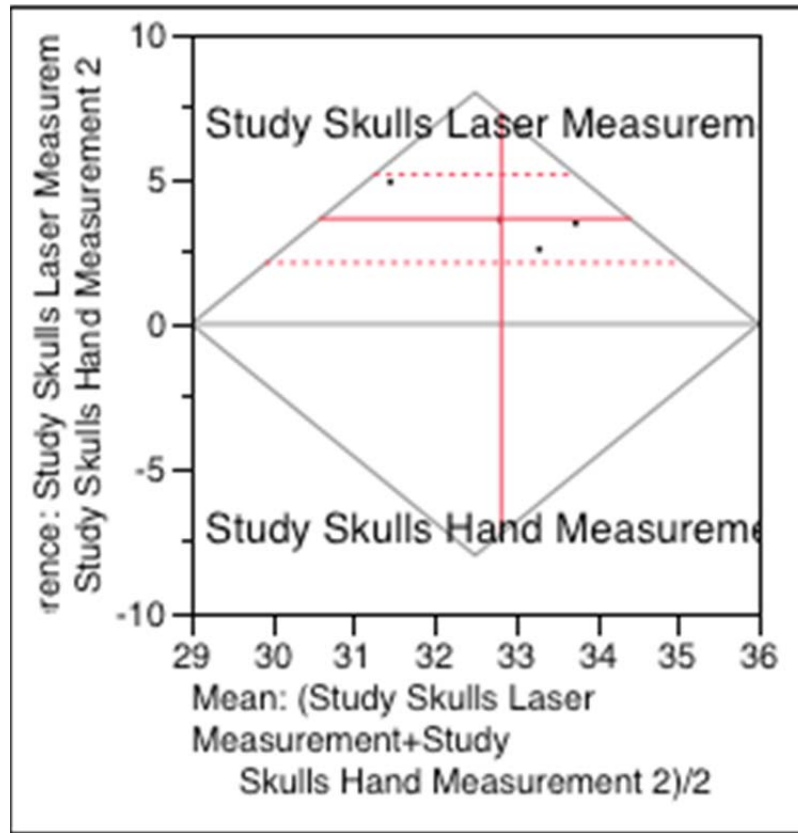


Table 24: Foramen Magnum Breadth

Study Skulls Laser Measurement	34.6434	t-Ratio	7.604687
Study Skulls Hand Measurement 2	31	DF	3
Mean Difference	3.64339	Prob > t	0.0047*
Std Error	0.4791	Prob > t	0.0024*
Upper 95%	5.16809	Prob < t	0.9976
Lower 95%	2.11868		
N	4		
Correlation	0.82132		

Figure 38: Matched Pairs
Difference: Mastoid Height (MDH)

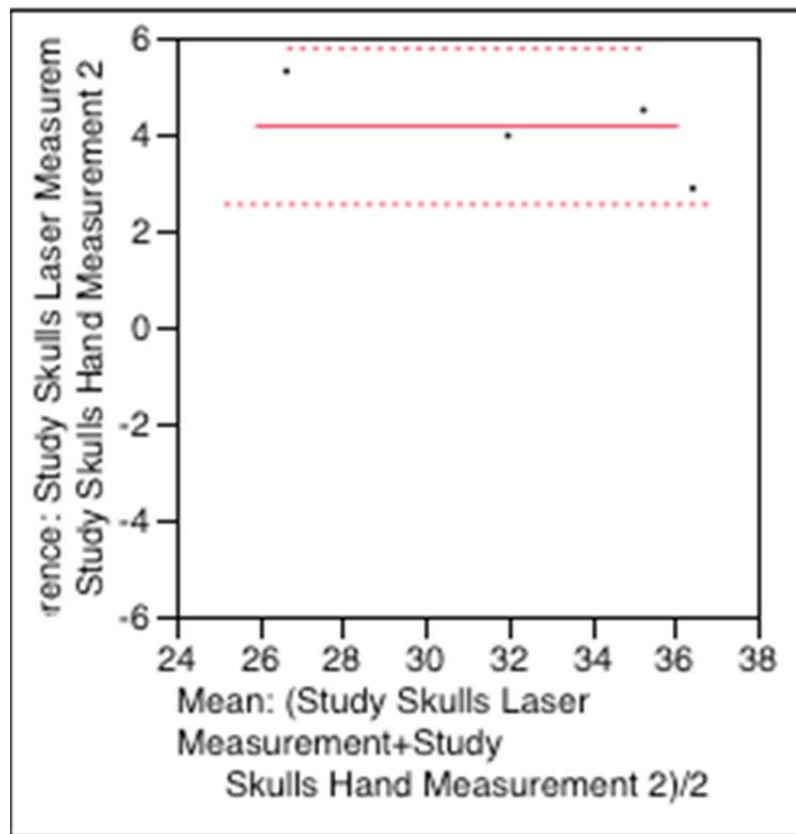


Table 25: Mastoid Height

Study Skulls Laser Measurement	34.6614	t-Ratio	8.175004
Study Skulls Hand Measurement 2	30.5	DF	3
Mean Difference	4.16142	Prob > t	0.0038*
Std Error	0.50904	Prob > t	0.0019*
Upper 95%	5.78142	Prob < t	0.9981
Lower 95%	2.54142		
N	4		
Correlation	0.99021		

Matched Pairs Summary Modified Skulls

Figure 39: Matched Pairs

Difference: Modified Laser-Modified Hand Maximum Length (g-op)

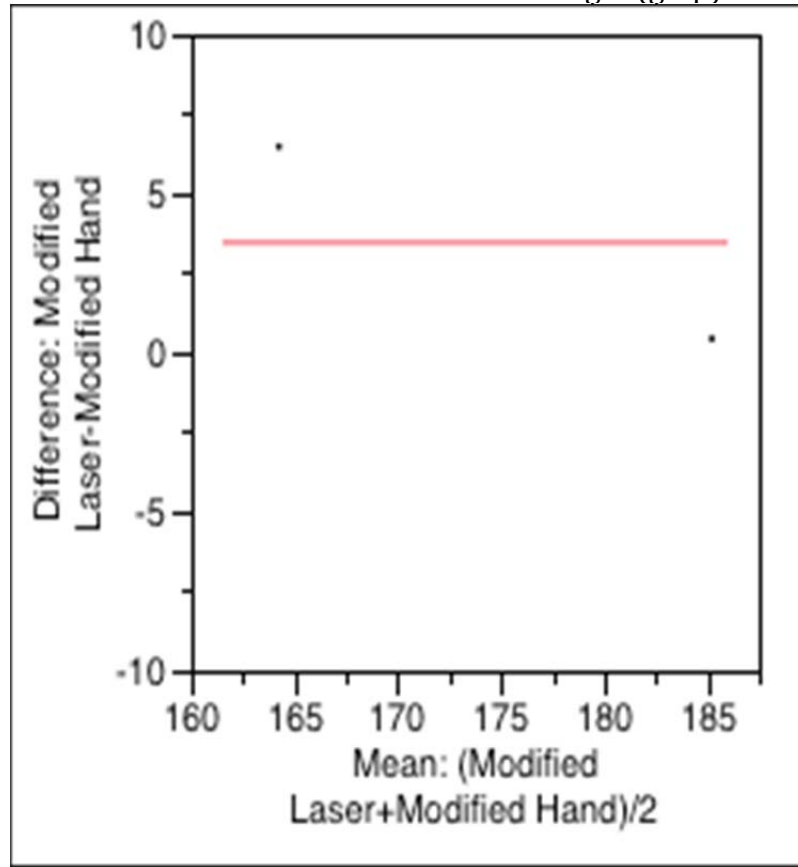


Table 26: Modified Laser-Modified Hand

Maximum Length

Modified Laser	176.458	t-Ratio	1.145657
Modified Hand	173	DF	1
Mean Difference	3.45828	Prob > t	0.4568
Std Error	3.0186	Prob > t	0.2284
Upper 95%	41.8132	Prob < t	0.7716
Lower 95%	-34.897		
N	2		
Correlation	1		

Figure 40: Matched Pairs

Difference: Modified Laser-Modified Hand Maximum Breadth (eu-eu)

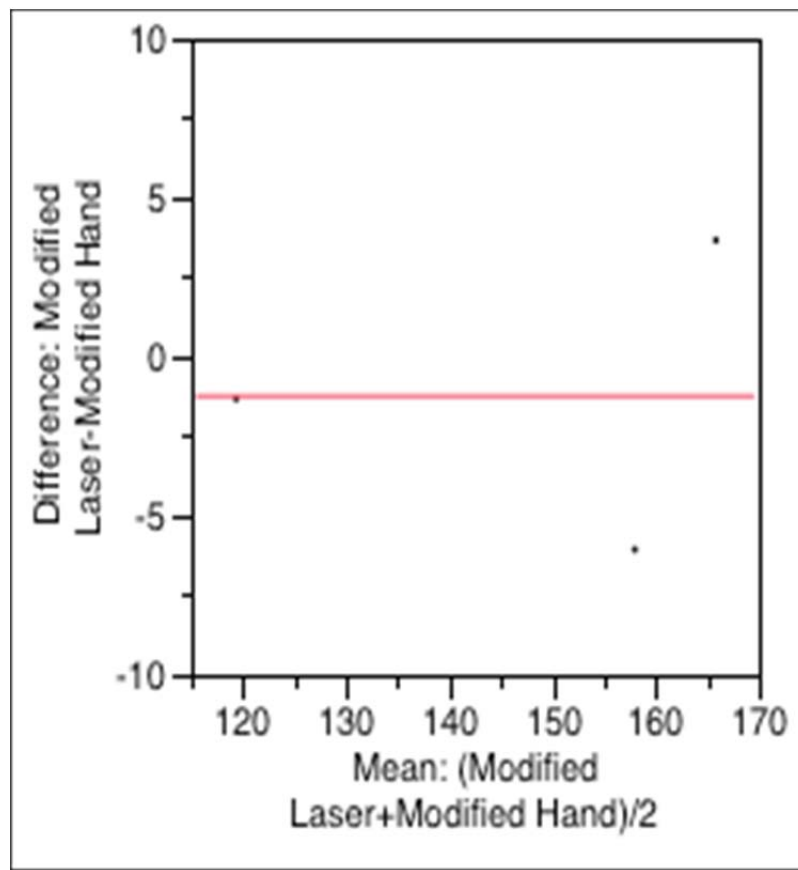


Table 27: Modified Laser-Modified Hand

Maximum Breadth

Modified Laser	147.095	t-Ratio	-0.44114
Modified Hand	148.333	DF	2
Mean Difference	-1.2386	Prob > t	0.7022
Std Error	2.80778	Prob > t	0.6489
Upper 95%	10.8423	Prob < t	0.3511
Lower 95%	-13.32		
N	3		
Correlation	0.98163		

Figure 41: Matched Pairs

Difference: Modified Laser-Modified Hand Bizygomatic Breadth (zy-zy)

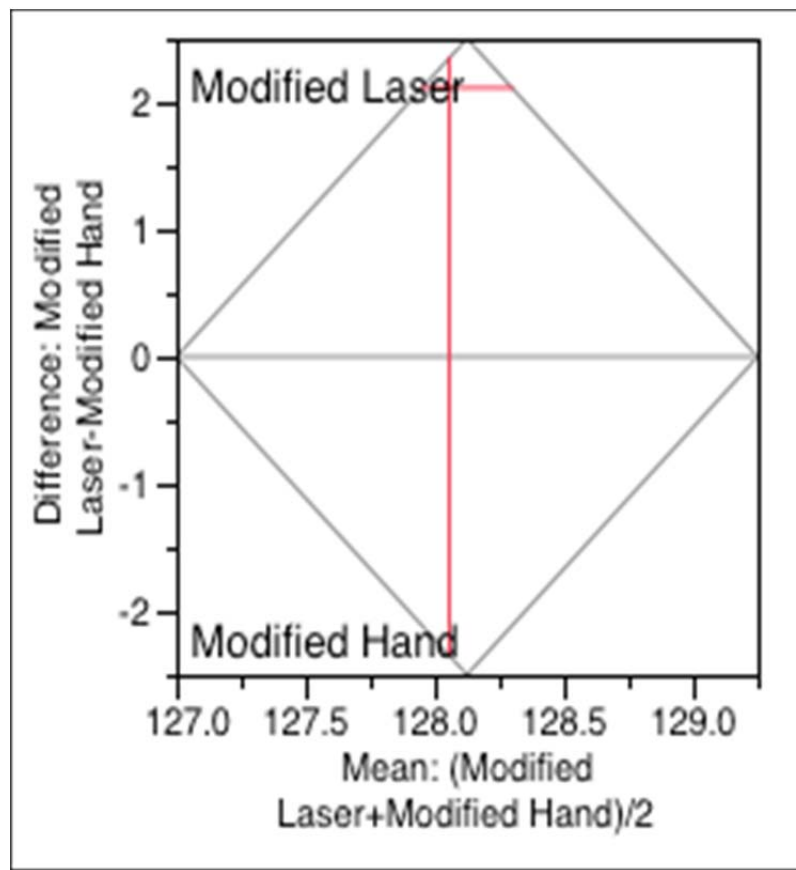


Table 28: Modified Laser-Modified Hand

Bizygomatic Breadth

Modified Laser	.	t-Ratio	.
Modified Hand	.	DF	0
Mean Difference	2.11352	Prob > t	.
Std Error	.	Prob > t	.
Upper 95%	.	Prob < t	.
Lower 95%	.		
N	1		
Correlation	.		

Figure 42: Matched Pairs

Difference: Modified Laser-Modified Hand Basion-Bregma (ba-b)

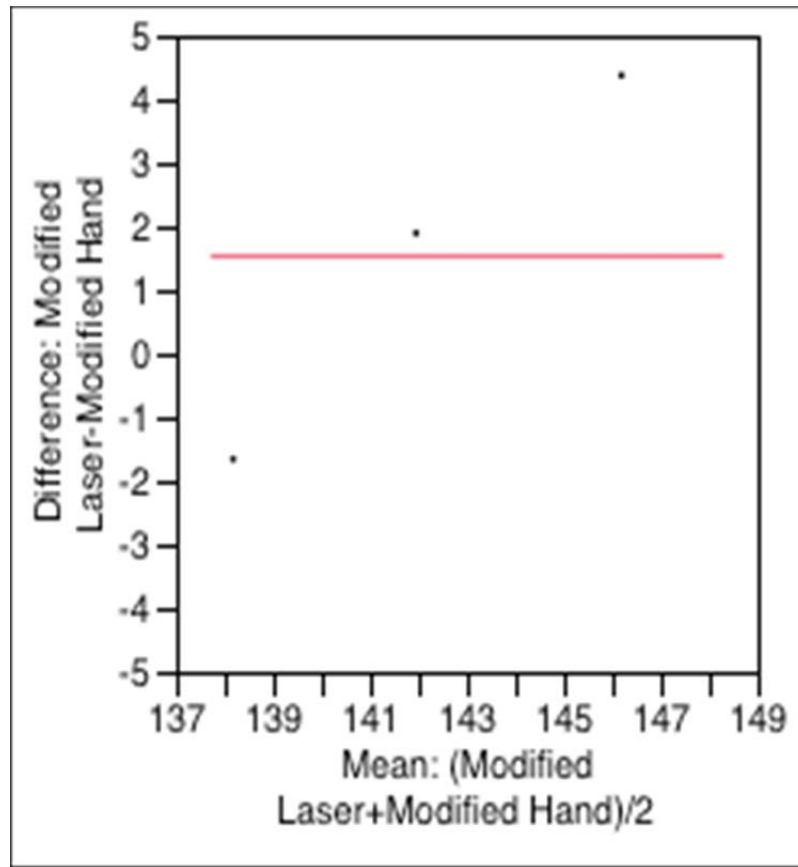


Table 29: Modified Laser-Modified Hand

Basion-Bregma

Modified Laser	142.873	t-Ratio	0.879326
Modified Hand	141.333	DF	2
Mean Difference	1.53922	Prob > t	0.4720
Std Error	1.75046	Prob > t	0.2360
Upper 95%	9.07082	Prob < t	0.7640
Lower 95%	-5.9924		
N	3		
Correlation	0.99296		

Figure 43: Matched Pairs

Difference: Modified Laser-Modified Hand Cranial Base Length (ba-n)

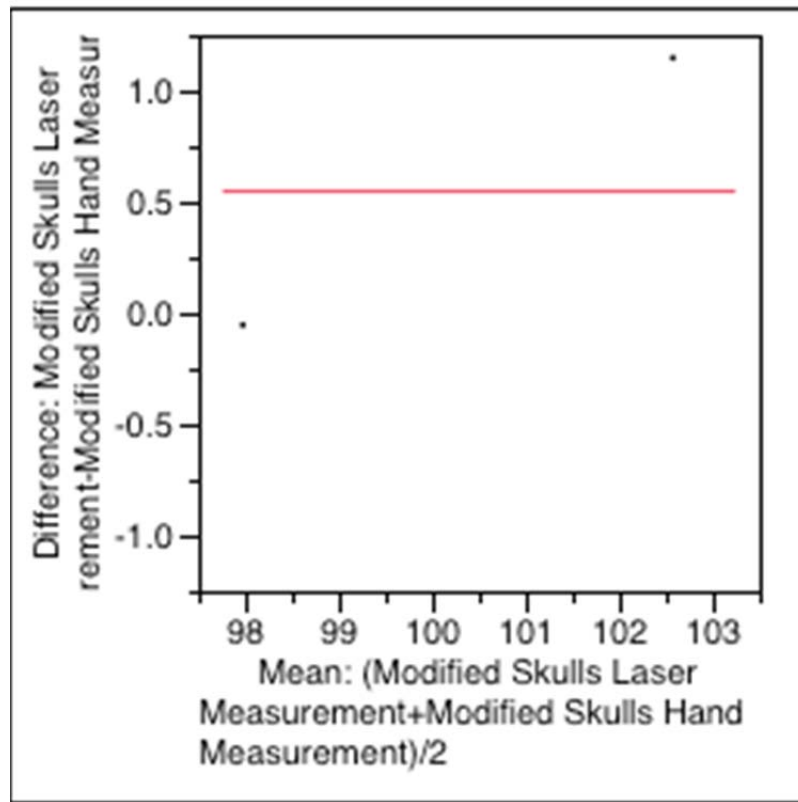


Table 30: Modified Laser-Modified Hand

Cranial Base Length

Modified Skulls Laser Measurement	100.547	t-Ratio	0.91117
Modified Skulls Hand Measurement	100	DF	1
Mean Difference	0.54718	Prob > t	0.5296
Std Error	0.60052	Prob > t	0.2648
Upper 95%	8.17753	Prob < t	0.7352
Lower 95%	-7.0832		
N	2		
Correlation	1		

Figure 44: Matched Pairs

Difference: Modified laser-Modified Hand Basion-Prosthion (ba-pr)

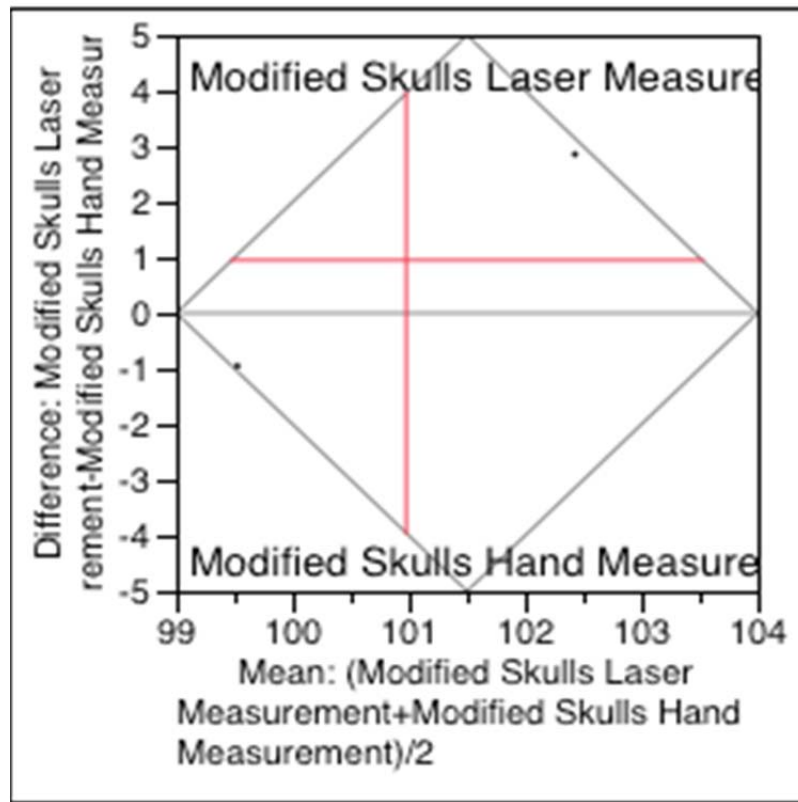


Table 31: Modified laser-Modified Hand

Basion-Prosthion

Modified Skulls Laser Measurement	101.452	t-Ratio	0.50001
Modified Skulls Hand Measurement	100.5	DF	7
Mean Difference	0.95245	Prob > t	0.7048
Std Error	1.90483	Prob > t	0.3524
Upper 95%	25.1557	Prob < t	0.6476
Lower 95%	-23.251		
N	2		
Correlation	1		

Figure 45: Matched Pairs

Difference: Modified Laser-Modified Hand Maximum Alveolar Breadth (ect-ect)

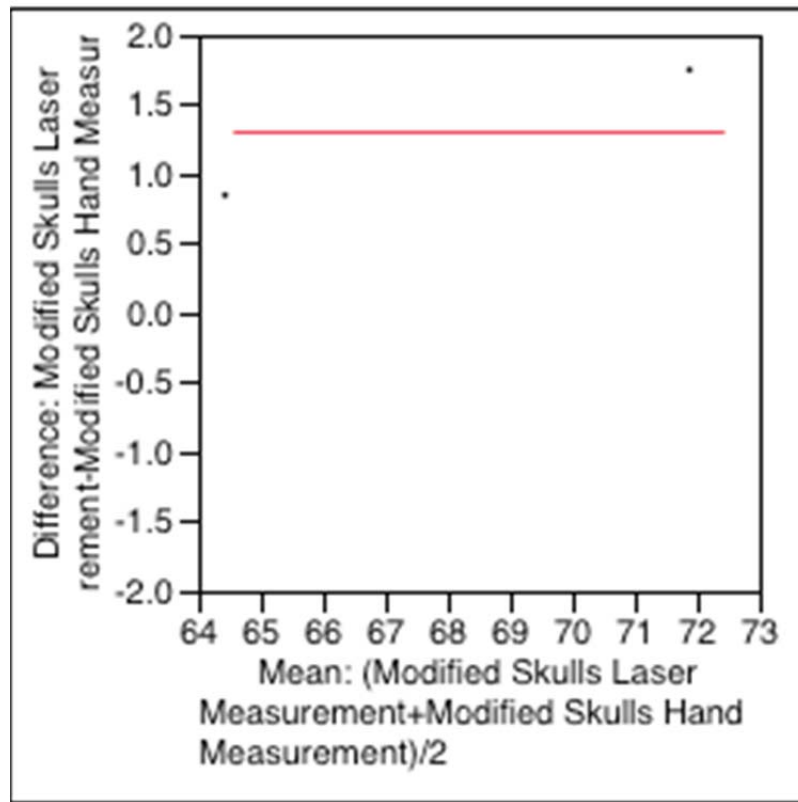


Table 32: *Modified Laser-Modified Hand*

Maximum Alveolar Breadth

Modified Skulls Laser Measurement	68.8	t-Ratio	2.885252
Modified Skulls Hand Measurement	67.5	DF	1
Mean Difference	1.29998	Prob > t	0.2124
Std Error	0.45056	Prob > t	0.1062
Upper 95%	7.0249	Prob < t	0.8938
Lower 95%	-4.4249		
N	2		
Correlation	1		

Figure 46: Matched Pairs
 Difference: Modified Laser-Modified Hand Maximum Alveolar Length (pr-alv)

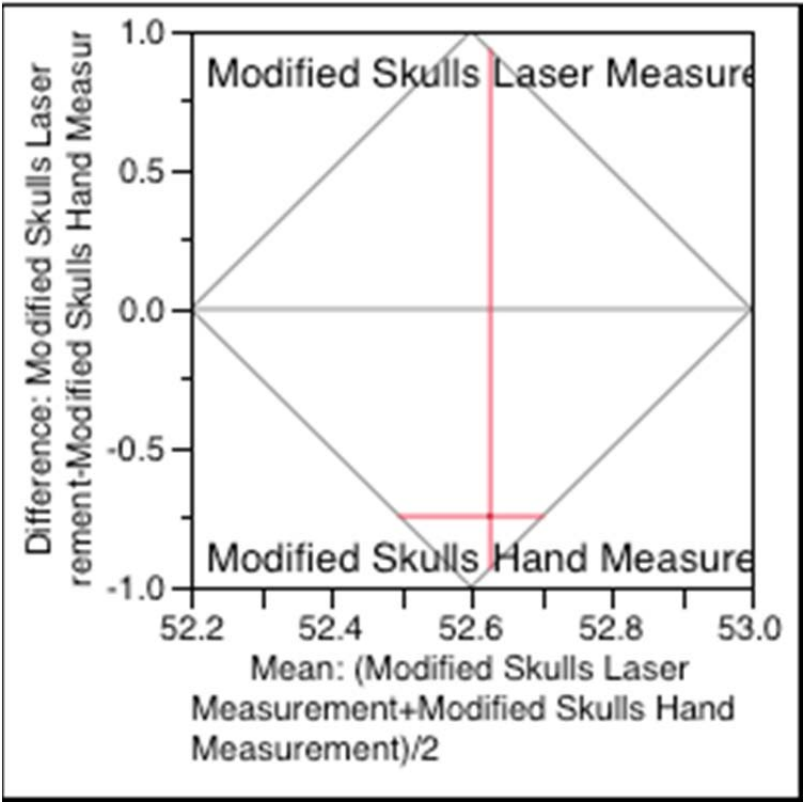


Table 33: Modified Laser-Modified Hand

<i>Maximum Alveolar Length</i>			
Modified Skulls Laser Measurement	.	t-Ratio	.
Modified Skulls Hand Measurement	.	DF	0
Mean Difference	-0.7453	Prob > t	.
Std Error	.	Prob > t	.
Upper 95%	.	Prob < t	.
Lower 95%	.		
N	1		
Correlation	.		

Figure 47: Matched Pairs
 Difference: Modified Laser-Modified Hand Biauricular Breadth (au-au)

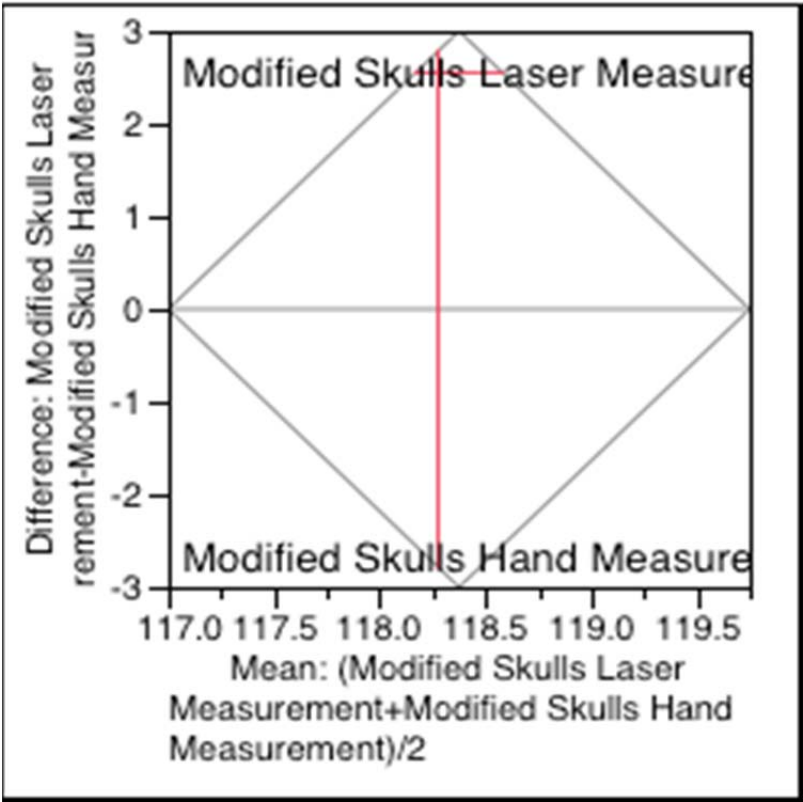


Table 34: *Modified Laser-Modified Hand
 Biauricular Breadth*

Modified Skulls Laser Measurement	.	t-Ratio	.
Modified Skulls Hand Measurement	.	DF	0
Mean Difference	2.55333	Prob > t	.
Std Error	.	Prob > t	.
Upper 95%	.	Prob < t	.
Lower 95%	.		
N	1		
Correlation	.		

Figure 48: Matched Pairs

Difference: Modified Laser-Modified Hand Upper Facial Height (n-pr)

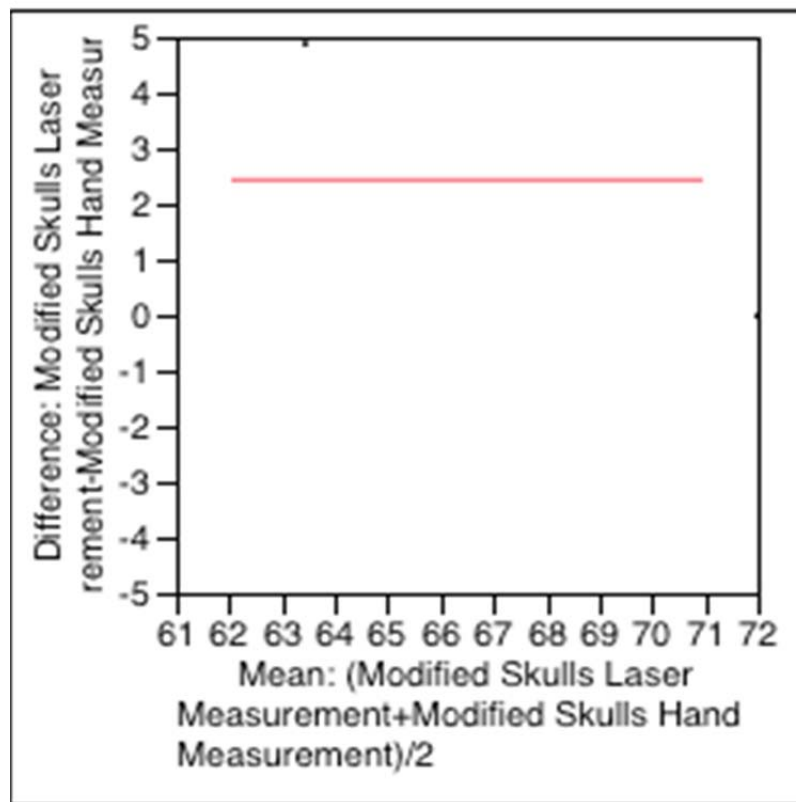


Table 35: Modified Laser-Modified Hand

Upper Facial Height

Modified Skulls Laser Measurement	68.9332	t-Ratio	0.994221
Modified Skulls Hand Measurement	66.5	DF	1
Mean Difference	2.43319	Prob > t	0.5018
Std Error	2.44734	Prob > t	0.2509
Upper 95%	33.5296	Prob < t	0.7491
Lower 95%	-28.663		
N	2		
Correlation	1		

Figure 49: Matched Pairs

Difference: Modified Laser-Modified Hand Minimum Frontal Breadth (ft-ft)

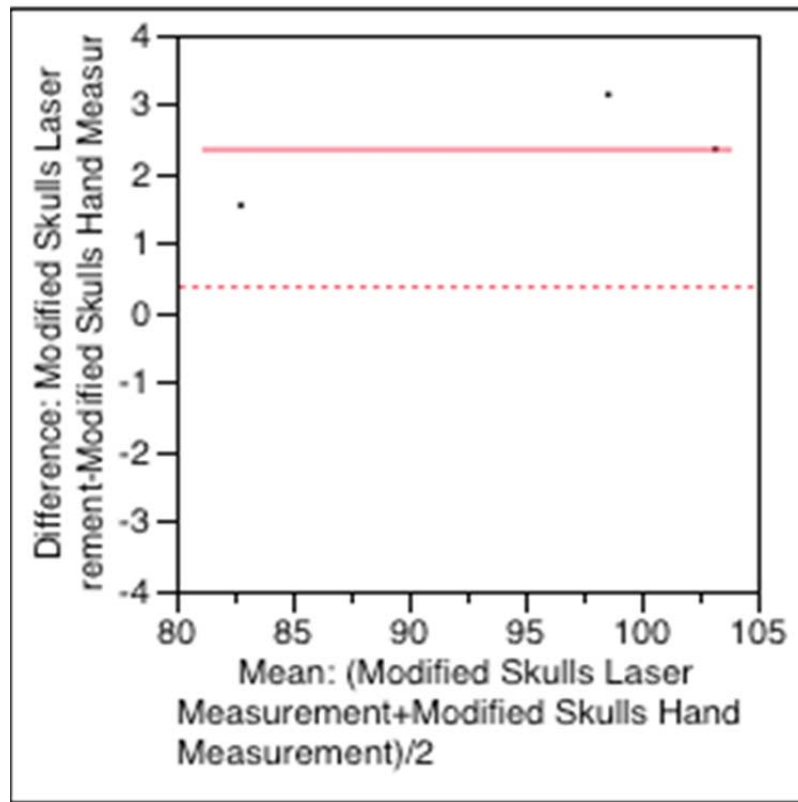


Table 36: Modified Laser-Modified Hand

Minimum Frontal Breadth

Modified Skulls Laser Measurement	96.0193	t-Ratio	5.116078
Modified Skulls Hand Measurement	93.6667	DF	2
Mean Difference	2.35261	Prob > t	0.0361*
Std Error	0.45985	Prob > t	0.0181*
Upper 95%	4.33117	Prob < t	0.9819
Lower 95%	0.37405		
N	3		
Correlation	0.99876		

Figure 50: Matched Pairs
 Difference: Modified Laser-Modified Hand Upper Facial Breadth (UFBR)

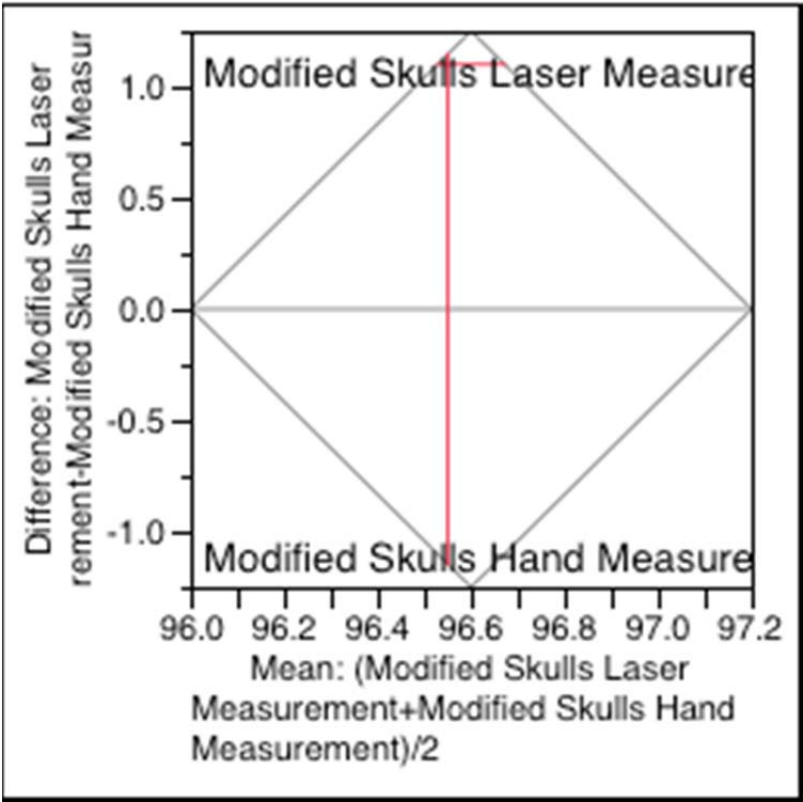


Table 37: Modified Laser-Modified Hand
Upper Facial Breadth

Modified Skulls Laser Measurement	.	t-Ratio	.
Modified Skulls Hand Measurement	.	DF	0
Mean Difference	1.10056	Prob > t	.
Std Error	.	Prob > t	.
Upper 95%	.	Prob < t	.
Lower 95%	.		
N	1		
Correlation	.		

Figure 51: Matched Pairs

Difference: Modified Laser-Modified Hand Nasal Height (n=ns)

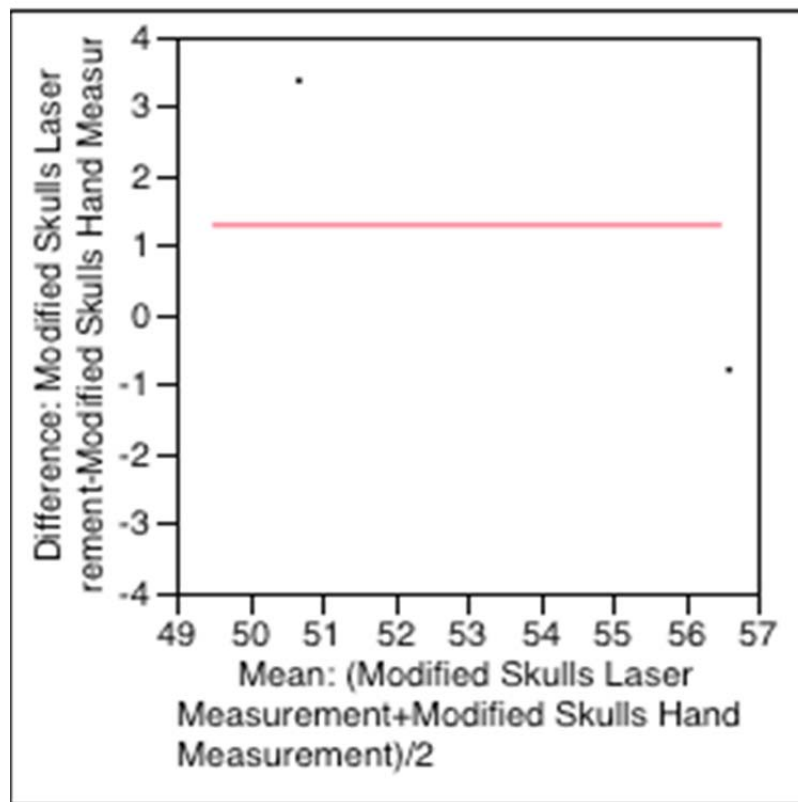


Table 38: Modified Laser-Modified Hand

Nasal Height

Modified Skulls Laser Measurement	54.2943	t-Ratio	0.622108
Modified Skulls Hand Measurement	53	DF	1
Mean Difference	1.29429	Prob > t	0.6457
Std Error	2.0805	Prob > t	0.3229
Upper 95%	27.7295	Prob < t	0.6771
Lower 95%	-25.141		
N	2		
Correlation	1		

Figure 52: Matched Pairs
Difference: Modified Laser-Modified Hand Nasal Breadth (al-al)

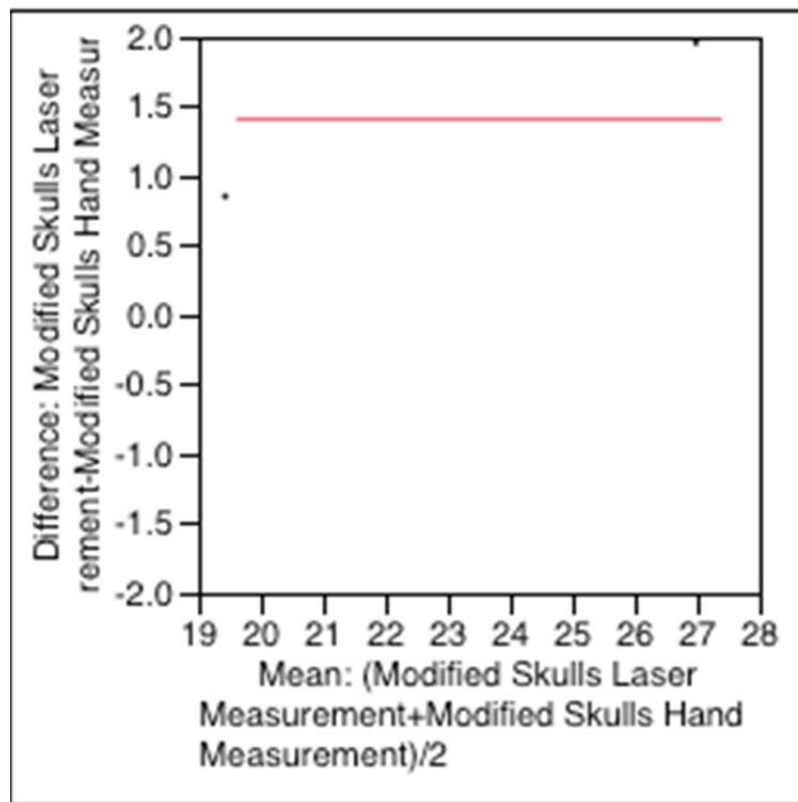


Table 39: Modified Laser-Modified Hand
Nasal Breadth

Modified Skulls Laser Measurement	23.9072	t-Ratio	2.548347
Modified Skulls Hand Measurement	22.5	DF	1
Mean Difference	1.40725	Prob > t	0.2381
Std Error	0.55222	Prob > t	0.1190
Upper 95%	8.42386	Prob < t	0.8810
Lower 95%	-5.6094		
N	2		
Correlation	1		

Figure 53: Matched Pairs
Difference: Modified Laser-Modified Hand Orbital Breadth (al-al)

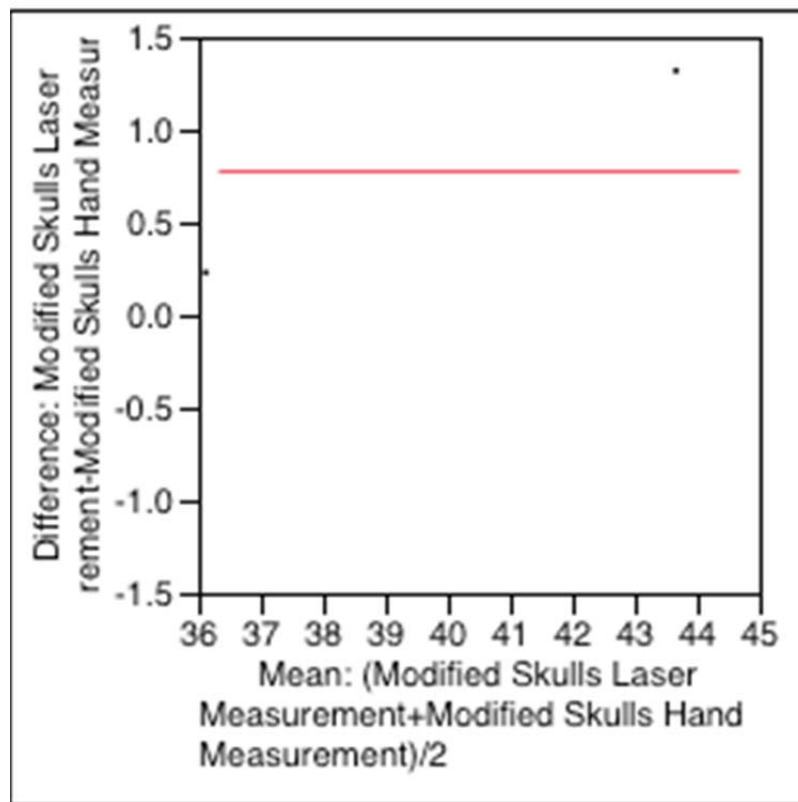


Table 40: Modified Laser-Modified Hand
Orbital Breadth

Modified Skulls Laser Measurement	40.2741	t-Ratio	1.42194
Modified Skulls Hand Measurement	39.5	DF	1
Mean Difference	0.77414	Prob > t	0.3902
Std Error	0.54443	Prob > t	0.1951
Upper 95%	7.69175	Prob < t	0.8049
Lower 95%	-6.1435		
N	2		
Correlation	1		

Figure 54: Matched Pairs
Difference: Modified Laser-Modified Hand Orbital Height (OBH)

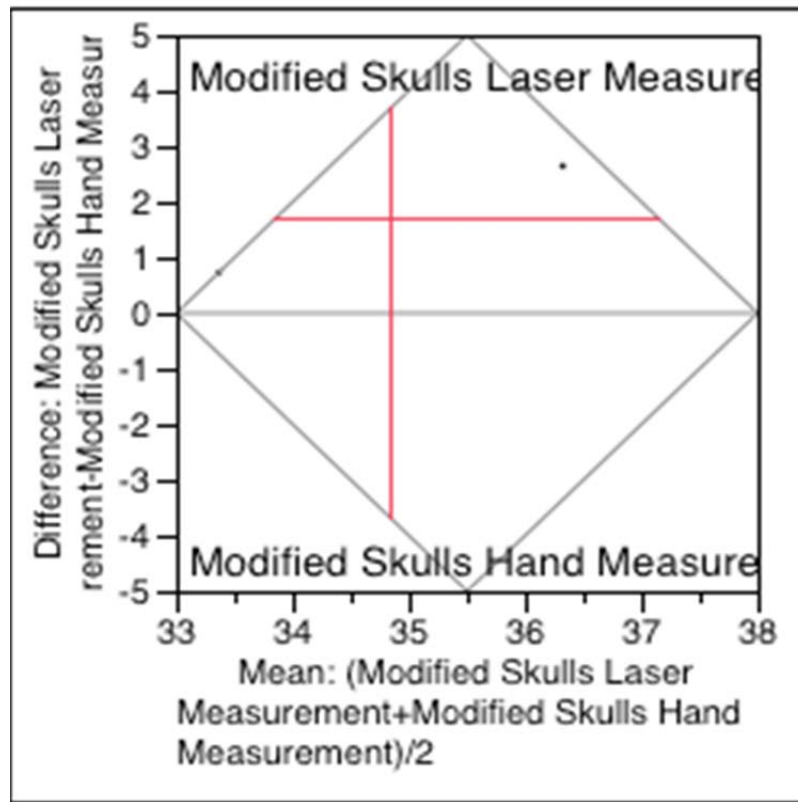


Table 41: Modified Laser-Modified Hand

Orbital Height

Modified Skulls Laser Measurement	35.6908	t-Ratio	1.77041
Modified Skulls Hand Measurement	34	DF	1
Mean Difference	1.69085	Prob > t	0.3273
Std Error	0.95506	Prob > t	0.1637
Upper 95%	13.826	Prob < t	0.8363
Lower 95%	-10.444		
N	2		
Correlation	1		

Figure 55: Matched Pairs
 Difference: Modified Laser-Modified Hand Biorbital Breadth (ec-ec)

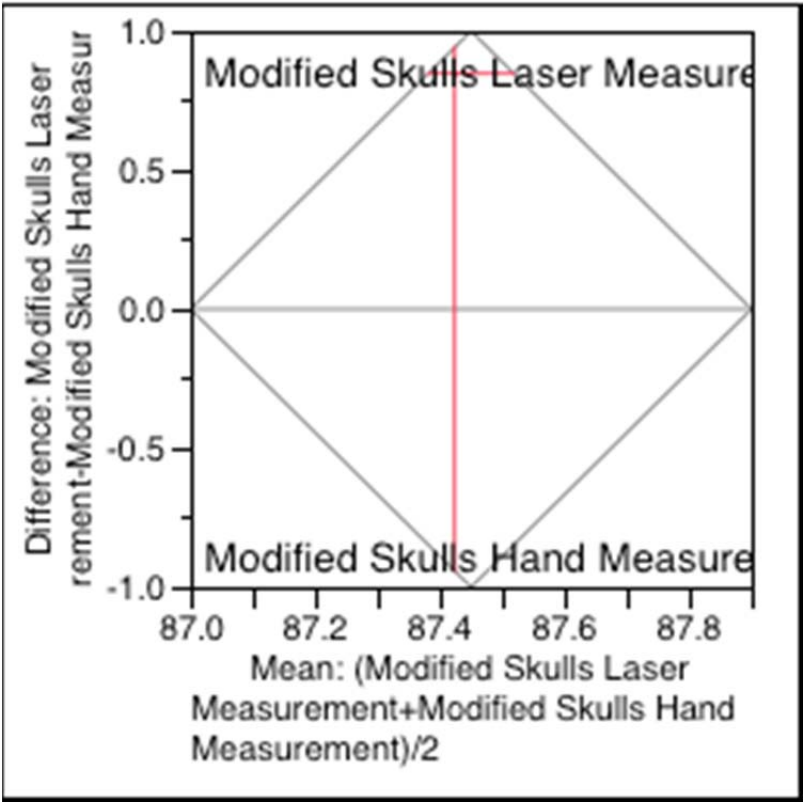


Table 42: *Modified Laser-Modified Hand*
Biorbital Breadth

Modified Skulls Laser Measurement	.	t-Ratio	.
Modified Skulls Hand Measurement	.	DF	0
Mean Difference	0.84742	Prob > t	.
Std Error	.	Prob > t	.
Upper 95%	.	Prob < t	.
Lower 95%	.		
N	1		
Correlation	.		

Figure 56: Matched Pairs
Difference: Modified Laser Modified Hand Interorbital Breadth (DKB)

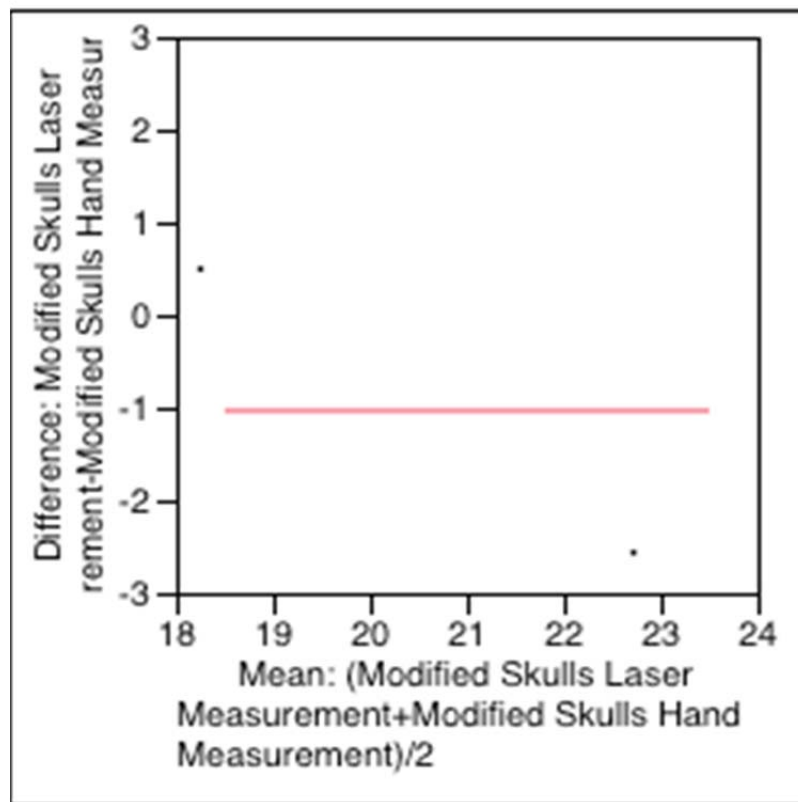


Table 43: Modified Laser Modified Hand
Interorbital Breadth

Modified Skulls Laser Measurement	19.968	t-Ratio	-0.67444
Modified Skulls Hand Measurement	21	DF	1
Mean Difference	-1.032	Prob > t	0.6223
Std Error	1.5302	Prob > t	0.6889
Upper 95%	18.411	Prob < t	0.3111
Lower 95%	-20.475		
N	2		
Correlation	1		

Figure 57: Matched Pairs

Difference: Modified Laser Modified Hand Frontal Chord (n-b)

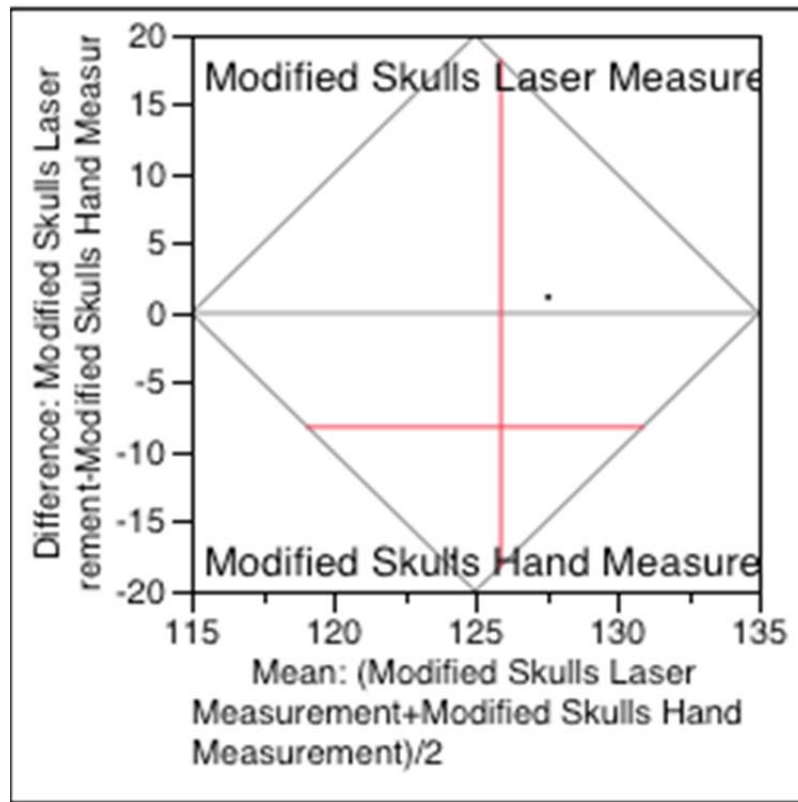


Table 44: Modified Laser Modified Hand

Frontal Chord

Modified Skulls Laser Measurement	121.807	t-Ratio	-0.87688
Modified Skulls Hand Measurement	130	DF	1
Mean Difference	-8.1929	Prob > t	0.5417
Std Error	9.34319	Prob > t	0.7291
Upper 95%	110.524	Prob < t	0.2709
Lower 95%	-126.91		
N	2		
Correlation	-1		

Figure 58: Matched Pairs

Difference: Modified Laser-Modified Hand Parietal Chord (b-l)

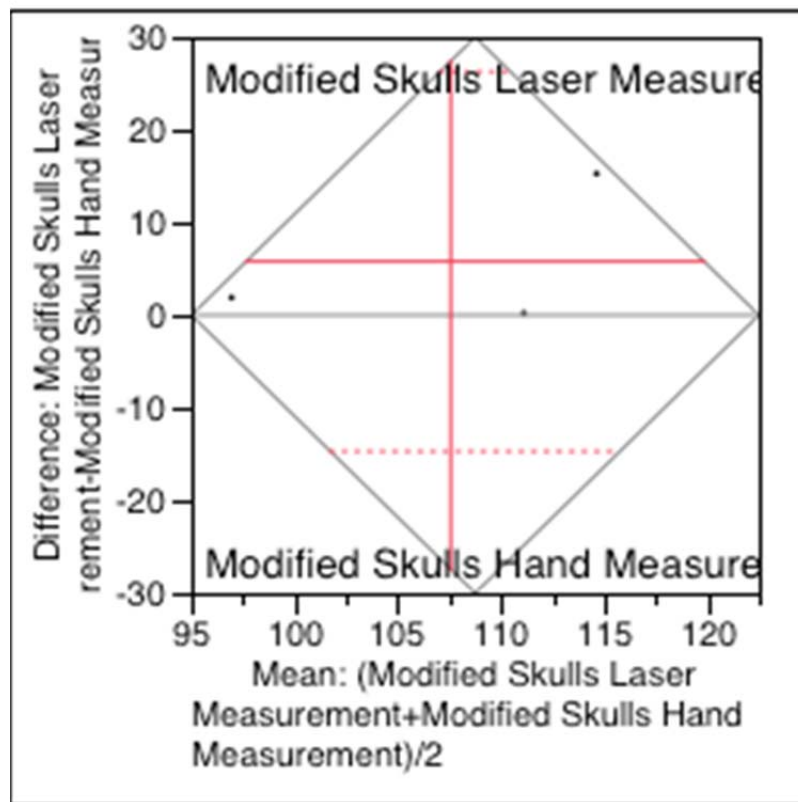


Table 45: Modified Laser-Modified Hand

Parietal Chord

Modified Skulls Laser Measurement	110.456	t-Ratio	1.215966
Modified Skulls Hand Measurement	104.667	DF	2
Mean Difference	5.78971	Prob > t	0.3480
Std Error	4.76141	Prob > t	0.1740
Upper 95%	26.2764	Prob < t	0.8260
Lower 95%	-14.697		
N	3		
Correlation	0.74508		

Figure 59: Matched Pairs

Difference: Modified Laser-Modified Hand Occipital Chord (l-o)

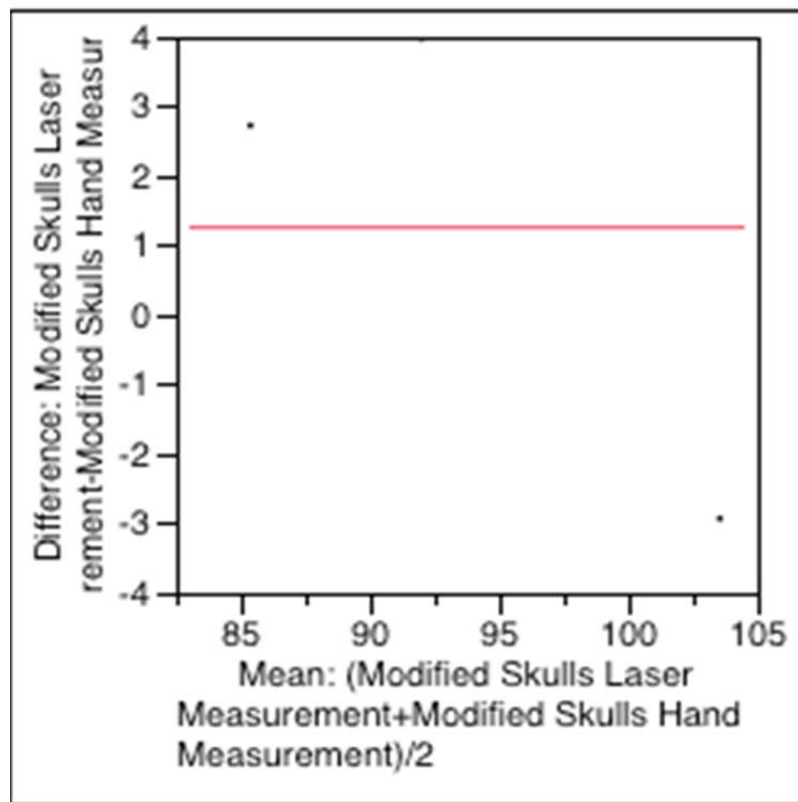


Table 46: Modified Laser-Modified Hand

Occipital Chord

Modified Skulls Laser Measurement	94.26	t-Ratio	0.593329
Modified Skulls Hand Measurement	93	DF	2
Mean Difference	1.25996	Prob > t	0.6131
Std Error	2.12355	Prob > t	0.3066
Upper 95%	10.3968	Prob < t	0.6934
Lower 95%	-7.8769		
N	3		
Correlation	0.97791		

Figure 60: Matched Pairs

Difference: Modified Laser-Modified Hand Foramen Magnum Length (ba-o)

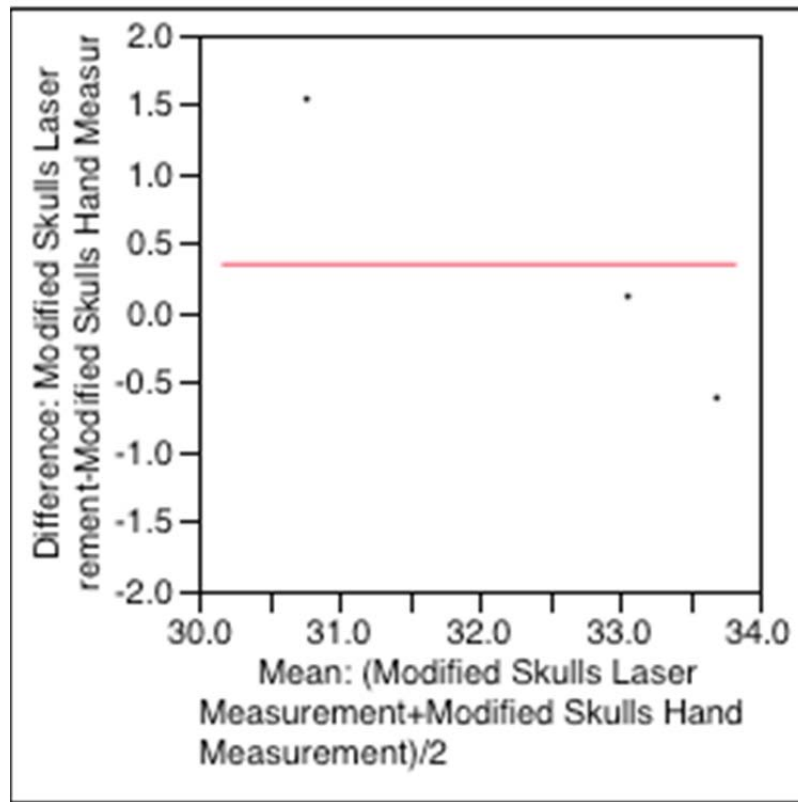


Table 47: Modified Laser-Modified Hand

Foramen Magnum Length

Modified Skulls Laser Measurement	32.6841	t-Ratio	0.55561
Modified Skulls Hand Measurement	32.3333	DF	2
Mean Difference	0.35079	Prob > t	0.6343
Std Error	0.63137	Prob > t	0.3172
Upper 95%	3.06734	Prob < t	0.6828
Lower 95%	-2.3658		
N	3		
Correlation	0.99425		

Figure 61: Matched Pairs

Difference: Modified Laser-Modified Hand Foramen Magnum Breadth (FOB)

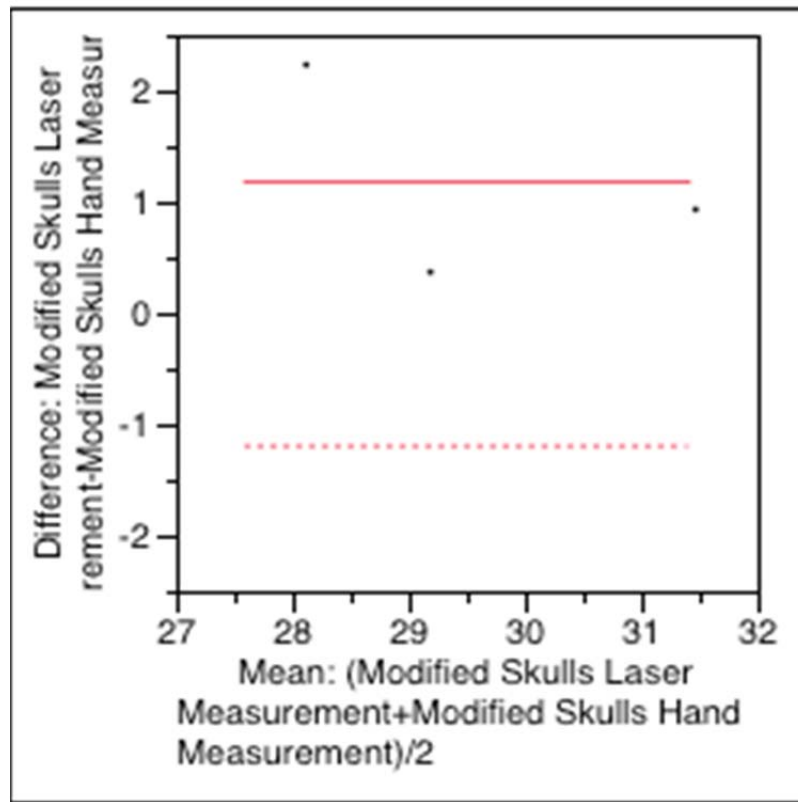


Table 48: Modified Laser-Modified Hand

Foramen Magnum Breadth

Modified Skulls Laser Measurement	30.1785	t-Ratio	2.135239
Modified Skulls Hand Measurement	29	DF	2
Mean Difference	1.17854	Prob > t	0.1663
Std Error	0.55195	Prob > t	0.0831
Upper 95%	3.55337	Prob < t	0.9169
Lower 95%	-1.1963		
N	3		
Correlation	0.88755		

Figure 62: Matched Pairs

Difference: Modified Laser-Modified Hand Mastoid Height (MDH)

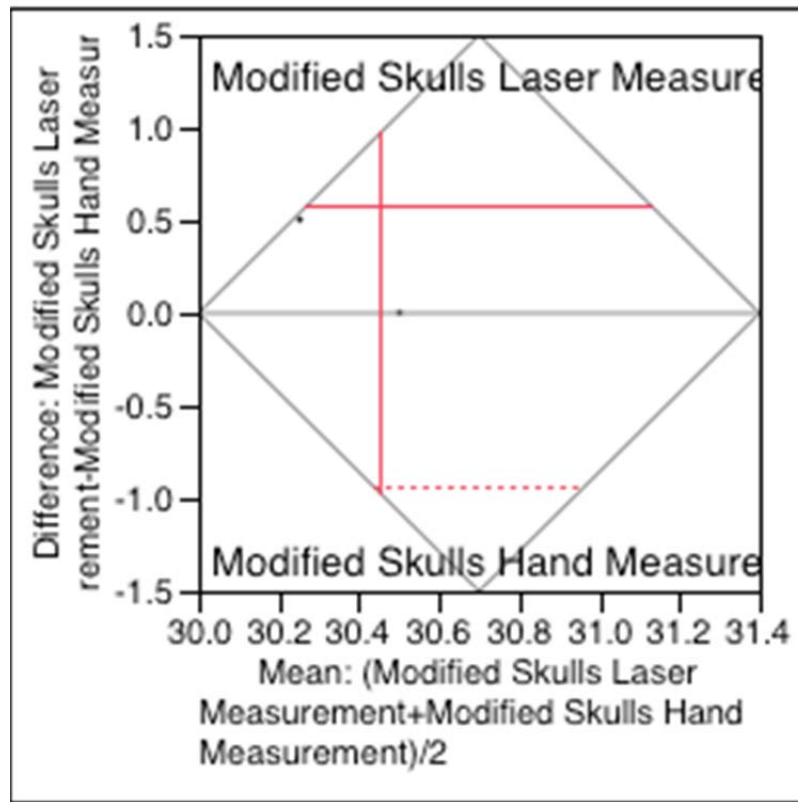


Table 49: Modified Laser-Modified Hand

Mastoid Height

Modified Skulls Laser Measurement	30.7421	t-Ratio	1.632689
Modified Skulls Hand Measurement	30.1667	DF	2
Mean Difference	0.57539	Prob > t	0.2441
Std Error	0.35242	Prob > t	0.1221
Upper 95%	2.09173	Prob < t	0.8779
Lower 95%	-0.9409		
N	3		
Correlation	-0.502		

Matched Pairs Summary All Study Hand-All Study Laser

Figure 63: Matched Pairs

Difference: All Study Hand – All Study Laser

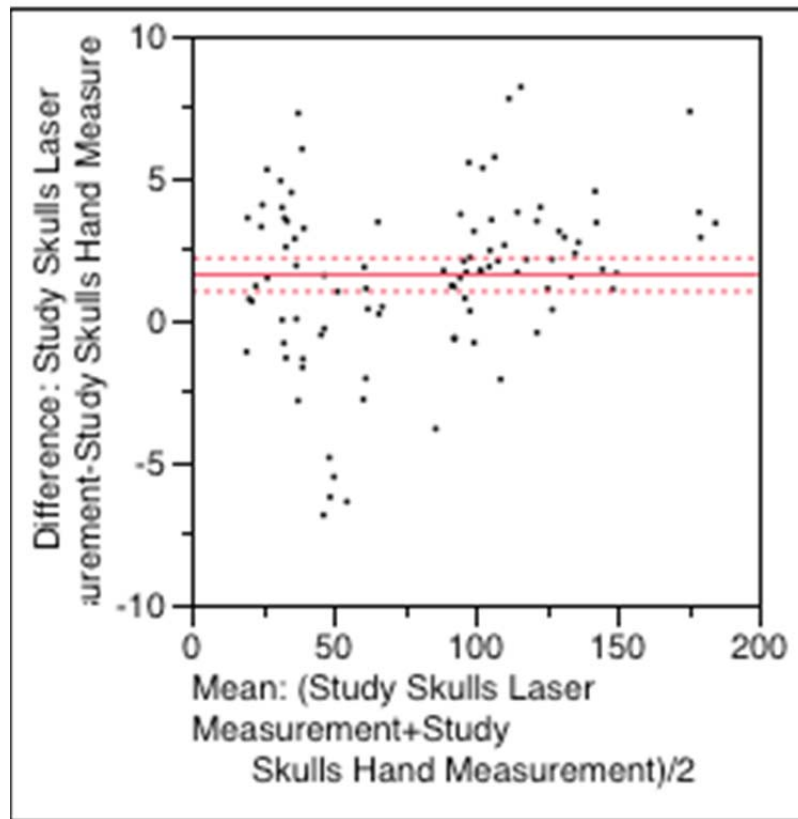


Table 50: All Study Hand – All Study Laser

Study Skulls Laser Measurement	83.1176	t-Ratio	5.386693
Study Skulls Hand Measurement	81.5167	DF	95
Mean Difference	1.60098	Prob > t	<.0001*
Std Error	0.29721	Prob > t	<.0001*
Upper 95%	2.19102	Prob < t	1.0000
Lower 95%	1.01094		
N	96		
Correlation	0.99793		

Matched Pairs Difference: All Modified Hand - All Modified Laser

Figure 64: Matched Pairs

Difference: All Modified Hand – All Modified Laser

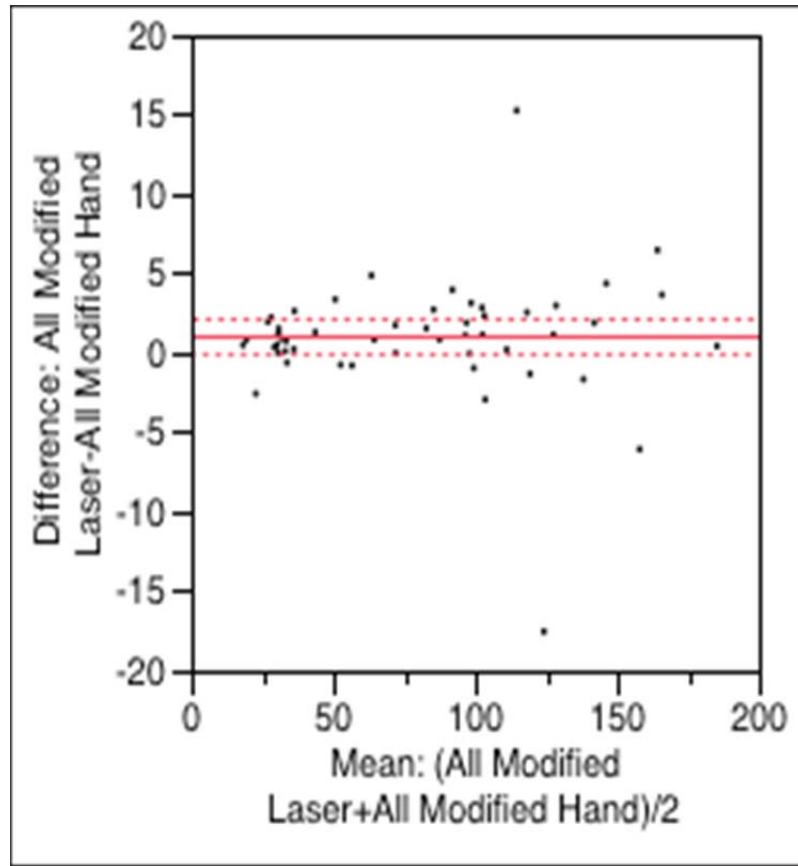


Table 51: All Modified Hand – All Modified Laser

All Modified Laser	81.6457	t-Ratio	1.844817
All Modified Hand	80.6373	DF	50
Mean Difference	1.00842	Prob > t	0.0710
Std Error	0.54662	Prob > t	0.0355*
Upper 95%	2.10634	Prob < t	0.9645
Lower 95%	-0.0895		
N	51		
Correlation	0.99636		

Chapter 6

Discussion

The issue that is central to the scope of this research is to determine if measurements from the scans are significantly different from measurements taken directly from the skulls and to the extent of the variation if any. Secondary interests include the level of operator-associated errors, technique; time required and practical needs assessment.

Time Requirements

The initial aspect of this study was to determine the needs and limitations of both the researchers and the equipment. The time in determining this information for Study skull #1 consisted of hundreds of scans performed over 10 days. During this period changes were made in Max scanning range, max laser angle, best scanning resolution, worst scanning resolution and profile smoothing as well as “noise” in the scans. During this process scans were not saved or imported for anything other than visual comparison. Once an ideal method and image were chosen scans were deleted from the file database and not used. The approximate reported scan time was determined once all parameters were set for ongoing scans and an ideal scan was captured.

Major factors pertaining to the Polhemus FASTSCAN computer assisted method that may potentially affect the accuracy of the scans are:

1. Noise interference from nearby metal objects. This may be a consideration of the suitability of the scanner for the capture of images. For example, if the object is in close quarters to a metal casket or metal artifacts in close relationship to the objects being scanned.
2. Noise interference from a too high of a sensitivity setting. Though this is a major consideration it ranks lesser than metal objects due to the fact it is easily fixable compared to that of outside noise interference.
3. The training and experience of the operator to keep required speed and distance during scan.
4. The efficiency of Delta modeling as a computer program for advanced comparative software. Does the absence of CAD style measuring (Point and

click) make Delta inappropriate for this task? To what extent can the operator's ability serve to compensate for the absence of this ability?

5. The physical condition and material of the skulls; to include the color and reflectivity as well as size.
6. As of this research FASTSCAN and Delta are not available in Mac associated software.

Cost and accessibility are two main barriers that limit the use of 3DLS in the general field of biological anthropology as of this study. I suggest that the expense of 3DLS can easily be justified due to several factors, 1. Total data point acquisition. 2. Maneuverability of parts in 3D space. 3. Specimens kept in electronic storage for unlimited access. 4. Specimen protection. If the researcher can get past the initial price of computerized system and the expense of maintenance and repairs you are still faced with the unavoidable expense of hardware and software upgrading.

General Observations

Operator Error

Subjective Scanning:

The issue of subjectivity first appears in the FASTSCAN scanning process through the adjustments that can be made to settings that alter how data is processed once received by the software. These can be alteration of all or one of the following areas of smoothing; decimation fit accuracy mesh resolution or RBF surface simplification. Adjustments made to one or more of the areas determine the quality the scan in reference to the smoothing or exactness of the scans produced which lead to the subjective of scan quality. Ideally, scanning a known sized surface leads the operator to set all settings as close as possible to the exact measurements which leads to complete and refined scan. This is of highest importance if the most accurate depiction of the object is to be acquired. If the user chooses settings that are less than ideal the representation of the object may be of utmost quality but may not represent the object in its truest form due to smoothing or rounding. In regards to measurements the author was not concerned with the look in regards to smoothness of the scan but more importantly the truest representation of the scan to the original object.

This technique allows for the most detailed form of the original, which in turn allows for landmarks such as sutures and foramen as well as bumps or cracks to be visible in the representative scans.

Wand Operation:

The inevitable issue of wand manipulation in 3D space is a subject of use that must be addressed fully in order to obtain the most accurate scan resolution. The variation of distance between the scorpion wand and object can and will affect the resolution by as much as .5mm per 200mm of distance, and accuracy by as much as 1mm per 200mm of distance from target (Polhemus). It is therefore suggested that a distance of no more than 200mm be used during the scanning process. Potential resolution and accuracy has also been shown to be affected by hesitation and jerky hand movements and unexpected shifts in the object or wand. With these circumstances in mind the operator must exercise extreme caution and care in planning a route that will require the minimum number of sweeps while keeping the smoothest and most accurate hand motions. It is also noted that by sheer necessity the operator will have overlapping sweeps in order to cover the object with complete satisfaction and accuracy. However it must be noted that the more passes over a single area will have a detrimental effect on the processed scan due to point cloud over lap, which there by will not maintain morphological continuity of the object. The subsequent “Register Sweeps” or “Basic Formatting” is designed by Polhemus to correct poorly aligned sweeps through data triangulation which increases the number of alignments and can be seen as potential “noise” and therefore allowing for less than ideal scan resolution.

Using The Scanner

Initial scanning action was achieved through a trial and error method. Polhemus states that scanning should be achieved through a motion similar to that associated with using a spray can. The initial problem associated with this action is not the motion, it is however the speed and angle to which the laser is contacting the object. This is to say that if the motion is correct the speed at which you are passing the wand over the object or the height from the object may be too fast and or far respectively to adequately pick up all features of the object. The user found this difficulty most prevalent with objects that showed initial characteristics of problematic scanning.

The second method of generating images is the use of the ½ inch reference receiver, which can be attached to the object directly and therefore moved in 3D space as it is being scanned. This freedom allows the user to scan objects without the fear of having to rescan because the object has moved; which gives multiple images in the scanning process. Though the receiver can be removed from the point cloud data, the adhesive or banding material cannot be removed from the point cloud data and therefore will be evident in the scans. Lastly the size of the object being scanned must be larger than the receiver itself to ensure a acceptable scan.

The scanner has also shown that in a comparison of direct measuring on skulls using the FASTSCAN Scorpion laser scanner that scans done with exact point localization show very good reliability and were more accurate than conventional methods using osteometric board, hinge calipers and sliding calipers.

Measurements in Delta

Limitations:

In evaluating the role of 3DLS in biological anthropology, it is important to understand the relationships between problems in data acquisition and post-processing. The understanding of this relationship is what is lacking in other case study reports in the use of 3DLS in biological anthropology.

The Delta software is extremely versatile in many ways. Once the image is uploaded into Delta the object is very easy to move and zoom around in 3D space. The limitation arises in the area of measurement of an object. The author discovered that; once the object is uploaded and the measurement section is chosen the outcome is not a given measurement that is readily usable by the operator. For example, if the operator measures the Maximum length (g-op) we first put a point on the Glabella and a second point on the Opisthocranium. The outcome at this point is not a distance that is given between the two points but two distinct sections of X, Y and Z coordinates. These coordinates must then be extrapolated using this formula $[Distance = \sqrt{(X1-X2)^2+(Y1-Y2)^2+(Z1-Z2)^2}]$ to provide a distance between the coordinates in 3D space. Though this method is not difficult it is very time

consuming in comparison to the easier methods of measurement in CAD or computer aided design and others. In these programs the operator chooses the measurement tab, then clicks on the first point and then the second point. Once the second point is chosen the distance between the two points is given directly to the user without extrapolation through the use of equations or manual manipulation.

Chapter 7

Conclusions

Null Hypothesis (H_0)

First let us begin with a basic understanding of what the null hypothesis states; According to “The Little Handbook of Statistical Practice” by Gerard E. Dallal; “Null hypothesis are never accepted. We either reject them or fail to reject them. The distinction between “acceptance” and “failure to reject” is best understood in terms of confidence intervals. Failing to reject a hypothesis means a confidence interval contains a value of “no difference”. However, the data may also be consistent with differences of practical importance. Hence, failing to reject H_0 does not mean that we have shown that there is no difference (accept H_0)” Therefore in this study the null hypothesis is that there will be no statistical difference even though a difference may be present.

Results

The results will be broken down into four categories to include unmodified separate measurements, modified separate measurements and all unmodified and all modified measurements. The 24 measurements used 11 are to be considered arbitrary because they are not associated with sutures or exact points. Of these 11 arbitrary points there is no correlation between these points and a rejection of the null hypothesis. The data does show however that of the original 24 measurements for the unmodified study skulls 15 fail to reject H_0 and 9 measurements reject H_0 . This data tells us that 62.5% of the unmodified scans have given us a non-statistical difference and 37.5% statistical difference and therefore should be considered a viable option. If we look at the modified skull scans we see that of the 24 measurements 18 fail to reject H_0 , 5 are unknown variables due to N being 1, and 1 rejects the H_0 . In this case we are left with 75% of the modified scans giving us a non-statistical difference, 20.8% giving us no data, and 4.2% giving us a statistical difference.

Therefore, we are unable to reject H_0 and are able to assume a high confidence level, as the confidence interval is “no difference”. It must be understood however, that even though the data fails to reject H_0 this by no means suggests in anyway that there is no difference between the data numbers; it just allows us to assume there is no statistical difference between these numbers.

Table 52: Skull measurements / average differences

* Numbers in red are those that show a statistical difference

	Study Skulls		Modified Skulls	
	Laser	Calipers	Laser	Caliper
Maximum Length	181.87	177.5	176.458	173
Maximum Breadth	147.183	144.5	147.095	148.333
Bizygomatic Breadth	129.648	128.5	n=1	n=1
Basion-Bregma	136.899	134.25	142.873	141.333
Cranial Base Length	102.561	101	100.547	100
Basion-Prosthion	91.9182	91.5	101.452	100.5
Max. Alveolar Br.	63.4642	61.75	68.8	67.5
Max. Alveolar L.	47.7946	51.75	n=1	n=1
Biauricular Breadth	125.998	123.5	n=1	n=1
Upper Facial Ht.	63.3467	64.375	68.9332	66.5
Min. Frontal Br.	100.069	97	96.0193	93.6667
Upper Facial Br.	105.912	103.25	n=1	n=1
Nasal Height	47.3441	50.25	54.2943	53
Nasal Breadth	26.0374	23.525	23.9072	22.5
Orbital Breadth	39.559	40.25	40.2741	39.5
Orbital Height	33.4868	34	35.6908	34
Biorbital Breadth	96.8558	96	n=1	n=1
Interorbital Breadth	20.7304	19.75	19.968	21
Frontal Chord	114.322	109.75	121.807	130
Parietal Chord	112.36	108.5	110.456	104.667
Occipital Chord	97.4354	97	94.26	93
Foramen Magnum L.	40.7238	37	32.6841	32.3333
Foramen Magnum Br.	34.6434	31	30.1785	29
Mastoid Height	34.6614	30.5	30.7421	30.1667

The data clearly shows that even though there are differences between measurements of hand vs. laser they are not necessarily significant. One aspect clearly stands out; this is that the laser measurements are much more precise in their exact distances. This precision however has not been shown to be of utmost importance and may be more relevant to future research as technology advances and a better understanding of skeletal differences come to fruition.

Within this study it has been shown that the majority of errors are those associated with the arbitrary points to which there are no set points for measure and are based on visual clues or one point and a feel of length associated with the second point. It is also

suggested that in certain cases the object to be scanned may be coated in a dulling or less reflective white powder to help in scan quality. This simple process could make certain areas of the skull or object more receptive to laser light reflection, which in turn would allow for better post processing and a better ability to mark exact points on the object. The second option for the researcher would be to use the marking tool or the stylus to help mark pre determined points, which will then be associated with the scans permanently as pre marked areas. This process will allow for those arbitrary points to be measured or pre determined by traditional methods and therefore can be picked up by the laser scanner for future purposes.

Limitations

The author acknowledges several factors which potentially hindered both the scanning process and the measuring process and therefore possibly the results due to the fore mentioned areas. These are to include; 1. The data shows a clear difference in the percentages of scans comparing failed to reject and reject data in comparing modified skulls with those of unmodified skulls. The author only knows of one major difference between the two groups. This is to say that the modified skulls have a patina of dirt and other elements layered over the skulls and therefore have less of a sheen which enables a better quality scan then the shiny surface of the unmodified skulls. This patina also allows for a much more apparent suture line in the scanned image and therefore lends to a much easier time finding landmarks and sutures to place measurement markers during the scanning process.

General Observations:

1. Operator ability may affect 3D quality and clarity.
2. Complete subjectivity is impossible to remove in any manual or computer aided measurements due to the fact that some measurements are subjective in nature.
3. Initial training should consist of no less than 50 hours in the use of the laser scanner requirements and abilities, and no less than 75 hours in Delta measurement techniques.
4. Training approximations are based on the initial time to final scan. Due to the low sample size these training hours are based on the authors' ability and initial problems with initial scans.

Summary:

These results demonstrate that computer 3D laser scanning and computer assisted measuring techniques can produce exceptional degrees of accuracy in quality and dimensions. The results are predicated upon the veracity of the images captured by the 3D laser scanner, and the ability of the operator and the efficiency of the analysis program itself.

The maximization of computer aided scans and measurements potential in the context of this research has relied upon the use of appropriate hardware and software programs; which the author acknowledges is not the only means to the results. The full realization can only be copiously realized by continued development of the laser scanner with respect to other 3D computer assisted technologies:

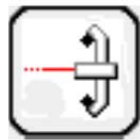
1. Multi-laser, stationary laser or CT (computer tomography).
2. Cranial specific software which has constant distance determination between two or more localized points as offered in other CAD software programs.

APPENDISIES:

APPENDIX A:

POLHEMUS FASTSCAN MANUAL

The following is a direct copy of the Polhemus FASTSCAN Manual authorized by Polhemus for use in this study.



FastSCAN[™]

Cobra[™] and *Scorpion*[™]

Handheld Laser Scanner
User Manual

printed January 2009

Revision 1.0

Copyright © 1998–2009 by Aranz Scanning Ltd

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Before You Begin...



Please read and fully understand **Section 12: Safety Guidelines** before using the *FastSCAN*[™] Scanning equipment. This section contains important safety information.

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1 Introduction

Thank you for purchasing a *FastSCAN*[™] 3D laser scanner. Your scanner will quickly and conveniently digitize the surface of any object into a series of points that fit together in 3D space. The *FastSCAN*[™] software then transforms this data into a detailed 3D object, in a file format that suits your needs.

The *FastSCAN*[™] software combines overlapping sweeps and eliminates redundant data to create a complete surface. This can then be further processed using mathematical functions called RBFs (Radial Basis Functions) to create a smooth watertight surface in the form of your scanned object. The resulting 3D object can be exported in a range of industry standard formats for use in other applications.

Please ensure you have read **Section 12: Safety Guidelines** before using this product.



2 Hardware and Software Setup

2.1 Components

You should have received the following components with your *FastSCAN*TM package:

- Wand (1)
- Processing Unit (PU) (2)
- 2-inch Transmitter (large cube) (3)
- 1/2-inch Reference receiver (small cube) (4)
- Wand cable (color coded) (5)
- PU's power supply and power cable
- Wand pad
- USB cable
- *FastSCAN*TM software install CD
- This manual.



Figure 1: The FastSCANTM Cobra system with numbered components.

Optional Items

- Mechanical Stylus
- Optical Stylus
- Headband.

2.2 Computer Requirements

- Windows 2000 *SP4*, Windows XP *SP2*, Windows Vista.
 - 1 GHz Intel Pentium III or greater
(2 GHz Intel Pentium IV or greater recommended for RBF processing)
 - 512 MB RAM or greater.
 - USB port.
- OpenGL compatible hardware accelerated graphics adapter in 32-bit (true color) mode (minimum resolution 1024 x 768).

2.3 Installing the Software

Important: In order to install *FastSCAN*[™] ensure you have administrator privileges on the computer.

Note to Windows Vista users: Before installing the *FastSCAN*[™] software do the following:

- Go to **Start/Settings/Control Panel/User Accounts**.
- Uncheck the box **Turn user account On/Off**.
- Click **OK**.

The installation procedure is as follows:

1. Insert the *FastSCAN*[™] CD. The set-up program should start automatically. If it doesn't, open the *FastSCAN*[™] CD folder manually and double-click on the **FastSCAN Setup.exe** file to run the wizard.
2. You will be guided through the installation of the *FastSCAN*[™] software. Install the *FastSCAN*[™] files in the default directory. The setup program will also install the USB drivers automatically. During the process you may be alerted that the *FastSCAN*[™] USB software has not passed Windows Logo Testing—if this happens click the **Continue Anyway** button. You will be prompted to restart your computer if necessary.
3. When the software has finished installing open the CD folder, double-click on the license file **FastSCAN.lic.exe** and follow the instructions.
4. After the license file has installed double-click on the **wand(model#)CFG.exe** file to install the calibration data for your particular Wand.

2.4 Connecting It All Together

Note: Ensure that the PU is switched off before any of the front panel leads are connected or disconnected, or the Wand is detached from its cable.

1. Place the PU near the computer and plug it into a power source using the power pack and cable. Connect the USB cable to the front of the PU and to the computer. Allow room for air circulation at the back of the PU.
2. Plug the appropriate color coded plugs of the Wand cable into their respective sockets on the Wand. Plug the two connectors at the other end of the Wand cable into the sockets at the front of the PU, labeled 'Wand'. The two plugs/sockets have different polarization and cannot be connected incorrectly.
3. Plug the Transmitter connector into the socket labeled 'Transmitter'.

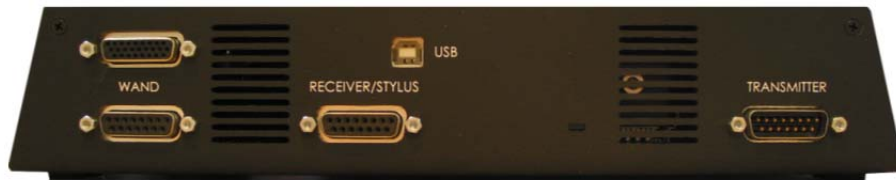


Figure 2: Front view of the Processing Unit.

2.4.1 Installing the Drivers

Ensure you have run **FastSCANsetup.exe**. The *FastSCAN*[™] installation process provides your computer with the necessary drivers. They will become available for loading when the hardware is plugged in and powered on for the first time.

For Windows XP:

1. When the scanner is first plugged in the **Found New Hardware** wizard window will display. If you are requested to allow Windows to connect to the Windows Update Web site select **No, not this time** and click **Next**.
2. Choose **Install from a list or specific location (Advanced)** and click **Next**.
3. Then choose **Don't search. I will choose the driver to install.** and click **Next**.
4. Select **FastSCAN USB Laser Scanner** and click **Next**. If the list contains no item for **FastSCAN USB Laser Scanner** choose **Have Disk** and browse to the location of the driver files located on the install CD, typically:
C:\Program Files\Polhemus\FastSCAN\USB Driver and click **Open**.

5. It is normal for Windows to report that *FastSCAN*TM drivers have not passed Windows Logo testing/are not digitally signed by Microsoft. Click **Continue Anyway** each time when prompted until the drivers are installed.

Note: This procedure needs to be repeated when plugging the scanner into a different USB port.

For Windows Vista:

1. Before powering up the PU connected to your computer click:
Start/Settings/Control Panel to open the **Control Panel** window.
2. Double-click on **System**.
3. In the **System** window click on **Advanced System Settings**.
4. In the **Advanced System Settings** window choose the **Windows Update Driver Settings** button.
5. Select the middle option: **Ask me each time I connect a new device before checking for drivers**.
6. The drivers should now automatically install when you power up the *FastSCAN*TM system connected to your computer.

2.5 Running *FastSCAN*TM

1. Ensure the system is fully connected and the scanning environment set up as desired.
2. Turn on the PU. The green light on the front of the PU should flash for approximately 10 seconds and then stay on. If it doesn't, check that the Wand cable and power supply are correctly connected.
3. Start *FastSCAN*TM by double clicking on its desktop icon. The *FastSCAN*TM startup screen (Figure 3) will appear.

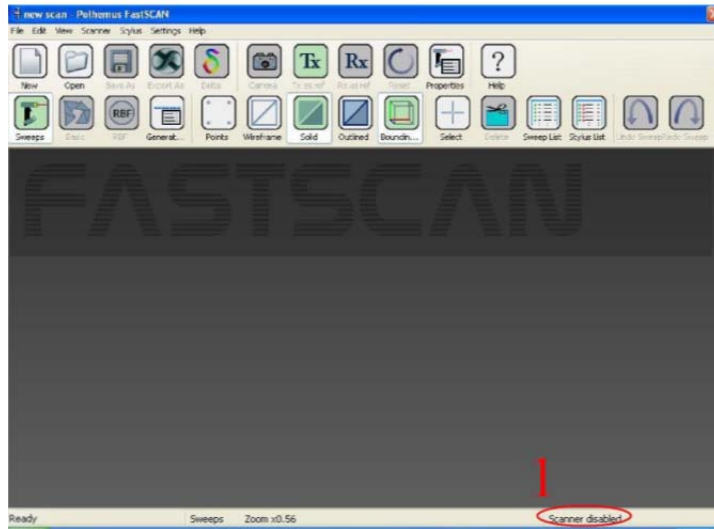


Figure 3: The *FastSCAN* startup screen.

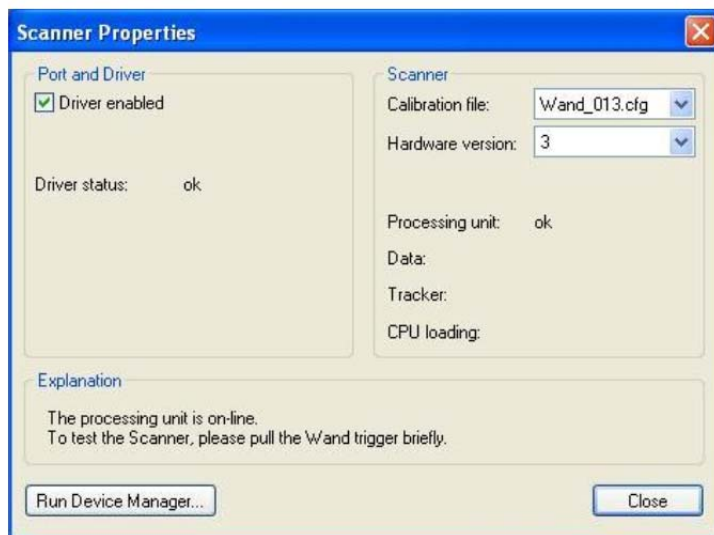


Figure 4: The **Scanner Properties** dialog box.

4. The status indicator at the bottom right of the screen (labeled **1** in Figure 3) should change from **Scanner disabled** to **Scanner initializing...** After approximately 10 seconds this should change to **Scanner on-line**, indicating that the system has initialized.

Note: Do not depress the trigger while the Wand is initializing.

5. When setting up the system for the first time or changing Wands open the **Scanner Properties** box (Figure 4) via **Scanner/Properties...**
6. Confirm that the **Calibration file** corresponds with the Wand you are using (if not you may need to select the appropriate configuration file) and that the **Hardware version** is set correctly. For current systems the correct setting is **3**. If the scanner has not come online ensure that **Driver enabled** is checked. If the Wand has not been used with the system before, you may also have to install the configuration file.



Figure 5: The **Wand Hemisphere Setup** dialog box.

7. When the system has initialized, and the status bar indicates that the scanner is on-line, pull the trigger on the Wand. The **Wand Hemisphere Setup** dialog box (Figure 5) will prompt you to define the hemisphere of operation—follow the instructions in the dialog box.
8. Once the hemisphere has been defined *FastSCAN* is ready for use.

3 Scanning



3.1 The Scanning Environment

An area of subdued lighting is ideal for scanning, with no external light entering from windows. Scanning errors can arise when the scanner's camera views direct sources of strong, bright light, such as the sun or a powerful incandescent light.

Keep the scanning area at least one meter away from the Processing Unit, computer, and any other significant metal objects. A wooden table is an ideal surface on which to place objects for scanning.

For best results always position the Transmitter as close as possible to the object that you are scanning. It is usually most convenient to place it behind or under the object.



Figure 6: An example of scanning a model. Note the wooden table, placement of the Transmitter, and the position of the Wand.

In the default **Transmitter is Reference** mode it is vital that the object remains stationary relative to the Transmitter during the scan. If the object cannot remain stationary, then the Transmitter may be attached to the object, or alternatively the Reference Receiver may be attached and **Receiver is Reference** selected in the **Scanner** menu (refer to Section 3.5.1).

Note - Multiple standard *FastSCAN*[™] systems will not work alongside one another without interference. This can be remedied with a replacement Frequency Module. Contact your vendor if required.

3.2 The Wand

The *FastSCAN*[™] Wand is available in 2 models—the **Cobra**[™] and the **Scorpion**[™]. The **Cobra**[™] is a light and compact single-camera Wand suited to most applications. The double-camera **Scorpion**[™] can enable faster scanning and be more effective where occlusion is potentially a problem.



Figure 7: The **Cobra**[™] Wand.



Figure 8: The **Scorpion**[™] Wand.

Handling the Wand

- The Wand is a sensitive optical instrument—**handle it with care** at all times.
- Place the Wand carefully on the Wand pad when not in use.
- After finishing your scanning session switch off and return the Wand to its protective case.
- If the Wand is mishandled or dropped it will need calibrating.

3.2.1 Wand Controls

The 2-position trigger switch of the Wand controls scanning:

Preview position (trigger pulled in to the first click):

- displays laser profiles on the screen in real-time, but does not store them
- provides feedback to help align successive sweeps in a scan and for filling in gaps.
- reorients the display on the computer screen to a 'Wand's eye' view
- illuminates the **Laser** LED (shown in Figure 9).

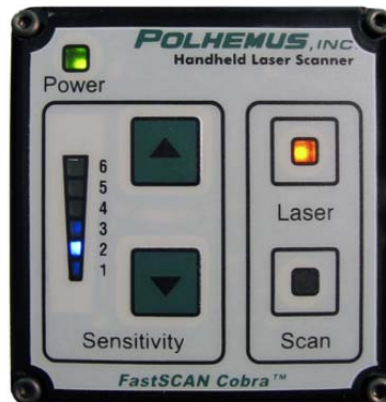


Figure 9: The Wand control panel with the power and Laser lights illuminated.

The secondary function of the Preview position is to reorient the on-screen image without having to return to the keyboard. This is achieved by pointing the Wand at the object, pulling the trigger to the Preview Position so that a profile is displayed on screen and releasing the trigger. The display will then automatically assume a 'Wand's eye' view.

Scanning position (trigger pulled in completely):

- displays laser profiles and surface data on the screen in real-time and stores them in memory
- illuminates both the **Laser** and **Scan** LEDs.

Note: If the scanning equipment is set up incorrectly the Laser and Scan lights may flash alternately when the trigger is depressed into either position.



3.2.2 Wand Sensitivity

The **Sensitivity Control** allows you to compensate for different subject surface types, colors and lighting conditions. Position 1 is the least sensitive and position 6 the most sensitive. For most subjects 2-3 is a good sensitivity setting.

Setting and/or adjusting the sensitivity when scanning any new object can be done using the **Up/Down** buttons on the wand, and the computer. This is best done in **Camera View** mode:

1. Click on the **Camera** icon, or select **View/Camera View**.
2. Set the sensitivity control to position 1.
3. Pull the trigger to the Preview position.
4. Push the sensitivity control **Up** arrow to increase the sensitivity.
 - For the **Cobra™** the red curve of the laser profile should become visible.
 - For the **Scorpion™** red and green curves should become visible; the red curve is the laser profile as viewed by the bottom camera, and the green curve is the laser profile as viewed by the top camera.
5. If no laser profile ever becomes visible, try moving the Wand towards or away from the object.
6. Set the sensitivity control to the lowest value that gives a clean unbroken curve(s).
7. Return to the standard view by deselecting **Camera View** mode.

On powering down the system, the Wand will remember the sensitivity control's last setting.

Note:

A too low sensitivity setting will cause only a small amount of (or no) data to be collected.

A too high sensitivity setting may result in unwanted data or noise being collected due to reflections or extraneous light.



3.3 Scanning With the Wand

The **Transmitter is Reference** option is the default setting for a typical scanning situation (a small–medium size stationary object; the **Tx** icon selected) and normally this button should always be selected.

To scan unstable or large objects you may need to use the **Receiver as Reference (Rx icon)**—see Section 3.5.

3.3.1 Scanning Technique

To scan a complete object you will need to perform a number of sweeps with the Wand. Keep the Wand approximately 10–15 cm away from the subject. Due to the Wand's field of view objects too close (less than 8 cm) or too far away (greater than 22 cm) (for the standard **Cobra™**) will be outside the range of the camera.

Scans are built up from a number of overlapping sweeps, in a manner analogous to spray-painting. A smooth consistent action is required for best results.

To collect a single sweep of data from an object:

1. Prepare the equipment for scanning as outlined in Section 2.5: Running *FastSCAN™*.
2. Depress the Wand's trigger into the Preview position, and ensure you can view the laser profile/sweep start-point on-screen in the *FastSCAN™* viewing window.
3. Press the trigger to the Scan position. The Scan LED on the control panel will illuminate to indicate that scanned data is being collected, and the scanned data will appear on-screen simultaneously.
4. Move the Wand across the surface of the object in a smooth motion.
5. Release the trigger at the end of the sweep.

As you perform the scan data appears in the viewing window on screen. This lets you see any areas that may have been missed or that might need going over again, to enable an accurate complete scan of the whole object.

Pointing the Wand at the region of the object you wish to scan, pressing the trigger to the Preview position and releasing it will reorient the on-screen object to enable viewing of that region.

For best scan results:

- minimize the distance of the Wand from the object to increase the accuracy of the scan. Also keep the Wand as close to the transmitter as conveniently possible
- each sweep of the Wand should be a smooth action, as if spray-painting
- use both hands on the Wand to improve steadiness
- remove any metal objects from the scanning environment before beginning
- sweeps should overlap slightly, and missing patches can be rescanned
- a slow steady scan is typically best, to get the most accurate data and achieve the smoothest final surface
- avoid repeated scanning of the same part of a surface, to reduce file size
- for large objects requiring many sweeps, save your scan at regular intervals to prevent loss of scanned data.

You can erase the last sweep by clicking on **Scanner/Undo Sweep**, or by double clicking the Wand trigger (see Section 3.4: Undoing Scans). The erased sweep can be put back into the scan by clicking on the **Redo Sweep** button.

The speed at which you move the Wand over the surface of the object is the major determinate of the resolution of the sweeps. Selecting **Points** from the **View** menu will allow you to experiment with different scanning speeds and see the difference in results. The closer the points are together, the higher the resolution and quality of the data.

3.3.2 Scanning Resolution - Limits Control

In some situations you may wish to place a limit on the resolution at which data is collected, e.g. to reduce memory and processing requirements. This can be achieved by adjusting the **Best Scanning Resolution** in the **Scanner Limits Control** dialog box (accessed from **Scanner/Limits Control**).

You can control the coarsest scanning resolution at which data is collected via the **Worst Scanning Resolution** in the **Scanner Limits Control** dialog box.

Use this to avoid inadequate resolution when scanning very quickly, in order to maintain a desired accuracy and not miss important detail, or to avoid filling in holes.

Selecting **Wireframe** from the **View** menu will allow you to experiment with different scanning speeds and **Best/Worst Scanning Resolution** values to assess the effect on resolution.



Figure 10: The *Scanner Limits Control* dialog box.

3.3.3 Profile Smoothing

The *FastSCAN*[™] program filters and applies a degree of smoothing to each profile during collection. This filter removes noise and errors in the scanner data, but can also remove surface detail. A high value will remove a larger amount of detail while a low value will preserve detail where it is present but tend to give a rougher surface.

A side effect of the profile smoothing is that some points are lost from the ends of each profile. If the data has a gap in it (as might occur when scanning a hole in a surface) then points are also lost from both sides of the gap. Higher smoothing values increase the number of points lost.

You can control the amount of smoothing using the **Profile Smoothing** option in the **Scanner Limits Control** dialog box (High, Medium, Low (default), or Off—see Figure 10) (Note: Smoothing cannot be turned off when using the **Scorpion™**). Changing this value affects newly captured profiles—it cannot change data that you have already collected. You may need to experiment to find the optimal value before you begin scanning. Figure 11 shows how smoothing can affect a profile.

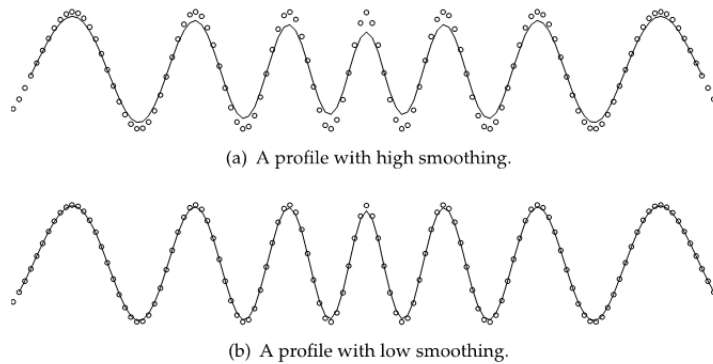


Figure 11: Examples of profile smoothing applied to a single profile when scanning a corrugated surface. The dots are the original scanned points and the black line is the resulting profile. Note that high smoothing drops three points at the end of the profile, while low smoothing only drops one.

The generation of Basic and RBF Surfaces (Section 4) applies a different type of smoothing to profile smoothing. Unlike the profile filter, you can adjust this *without* having to rescan your object.



3.4 Undoing Scans



This Wand function is switched **ON** by default. By clicking on **Settings/Wand** you can choose to switch off/on **Double-click Undoes Sweep** and/or **Triple-click Undoes Scan**. Selecting this option allows you to double or triple click to the Preview position while scanning, to delete the previous sweep or entire scan respectively. **Use with caution!**

Clicking on the **Undo Sweep/Redo Sweep** icons (above) enables you to remove single sweeps (in reverse order to which they were created) and place them back again if desired (in the same order).



3.5 Using the Secondary Receiver - Rx as Reference

By attaching a secondary receiver (Rx) to the subject it becomes possible to move and/or reposition the subject while building up the scan, allowing full 360° coverage. This can also be used to compensate for small movements that may occur in the subject while scanning or to scan large objects.

3.5.1 Moving the Subject During Scanning

Attach the **Receiver** *firmly* to the object you are scanning. From the **Scanner** menu, select **Receiver is Reference**. Note that the Receiver becomes the origin of the Reference Coordinate System. It is also important to note that although the object and Transmitter can be moved—for example, held in the hand—they should not be moved in a rapid or jerky manner.

To achieve the best results, keep the Transmitter as close as practical to the Wand and Receiver. However, you must keep the Receiver at least 100 mm away from the Transmitter to avoid signal overload. The subject can be rolled or rotated as required during scanning to enable full access for the Wand.

It is possible to remove the Receiver if required, allowing you to scan the part of the object where it was attached. Place the object and the Transmitter near to each other, remembering that once you remove the Receiver, the object and the Transmitter must not move. Select **Freeze Receiver** from the **Scanner** menu; the software will then provide instructions.

3.5.2 Scanning Unstable Objects

A live subject being scanned will often move involuntarily, for example, small head movements while scanning a face. This problem can be overcome by attaching the Receiver to the subject's head with a plastic headband **optionally included** with the *FastSCAN*TM system.

Attach the Receiver firmly to the headband with the nylon screws provided and adjust the headband size to give a firm but comfortable fit, as shown in Figure 12.



Figure 12: Using the Receiver attached to the headband.

3.5.3 Scanning Large Objects

You can also use the Reference Receiver to scan extra large objects. Fix the Receiver to the center of the object and place the Transmitter midway between the Receiver and the Wand. As you move around the object also move the Transmitter, keeping it within 100 mm and 750 mm of the Receiver and Wand (Figure 13).

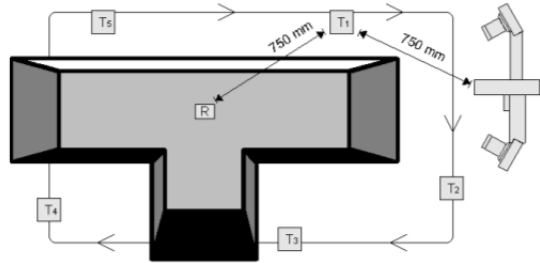


Figure 13: Scanning a large T-shaped object with Receiver as Reference. R is the Receiver (fixed to the object) and T is the Transmitter (moved around the object during scanning, in positions 1 to 5).

3.6 Viewing Options



3.6.1 Data View/On Screen Format

The appearance of the data can be changed by clicking on **View** and choosing from the 3 options: **Points**, **Wireframe** and **Solid**, or their icons in the toolbar. These allow you to view the data in different formats and use this information to get the best possible scan. Many of these functions can be performed via the keyboard **Hotkeys**. See Section 9.1 for a full list.



Points:

Shows the individual data points that make up the scan (Figure 14 (a)).



Wireframe:

Displays the surface triangular mesh, created by linking the points data (Figure 14 (b)).



Solid:

Displays the scanned object as a solid surface (Figure 14 (c)).



Outlined:

Displays the object as a solid surface with the wireframe overlaid upon it (Figure 14 (d)).

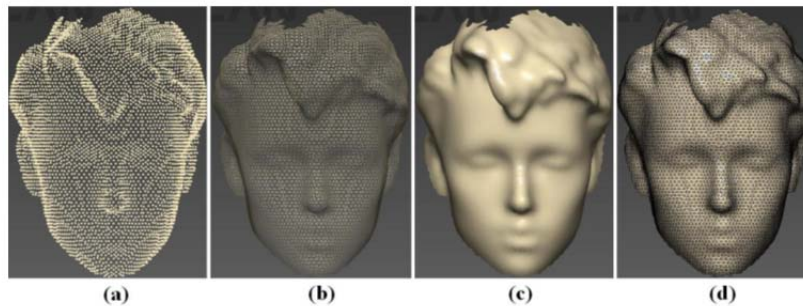


Figure 14: A scan as it appears with the different data viewing options applied.



Bounding Box:

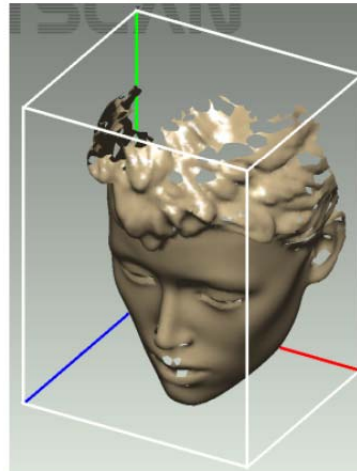
The **Bounding Box** enclosing the perimeter of the data is used in the RBF surfacing process and, in coordination with the **Extents Window**, gives the physical size of the object. It can also be useful for users needing a file for CAD systems or wanting a watertight model or closed object.

Click on **View/Bounding Box** to see the Bounding Box. The **View/Set Bounding Box to View** allows you to reorient the Bounding Box around the data, and the exported data will be exported with the changed coordinate system.

View/View Bounding Box From enables viewing of the Bounding Box from other angles (Front, Back, Top, etc).



(a) Press **F1** to get the view of the front of the Bounding Box.



(b) Use the **movement keys** or **mouse** to get this view.

Figure 15: The Bounding Box as seen from: (a) the front (b) above and to the side.

The Extents Window:

The **Extents Window** displays the exact dimensions of the scan, as enclosed by the Bounding Box. Click on **View/Extents Window** to see it. Click on **Settings/Display Units** to choose between millimeters and inches.

3.6.2 Other Viewing Variables

Viewpoint: The data/object can be moved on-screen by clicking and dragging with the mouse or by clicking on **View/Viewpoint** and selecting the desired direction. **Shortcut keys** to use these functions via the keyboard are also listed here.

Movement: Clicking on **View/Movement** allows you to set the speed at which the data/object changes position when manipulating it using the **View/Viewpoint** options or the keyboard.

	Rotate	Translate	Zoom
Normal	30.0°	25 mm	$\sqrt{2} \times 100\%$
Fine	5.0°	5 mm	1/5 x Normal
Very Fine	1.0°	1 mm	1/5 x Fine
Ultra Fine	0.2°	0.2 mm	1/5 x Very Fine

Table 1: Movement amounts. The zoom increases movement by 5X for each increment.

Normals: Clicking on **View/Normals** will display the normals (90° to the object surface) of all the data points that make up the object.

Scanning Feedback—Color Mapping:

The **View/Color Mapping** options (listed below) display the object's surface in color, highlighting optimum or poor parts of the scan.

- **Pseudo-Grayscale:** displays a texture map based on the surface showing the object in black and white and can enable finer details like text to become visible.
- **Scanning Resolution:** dictated by the speed of the Wand during each sweep. Red is fine resolution/slow speed, blue is coarse resolution/high speed.
- **Tracker Range:** displays the distance between the Receiver (usually the Wand) and the Transmitter during scanning. Green is optimal, red is poor.
- **Wand-Point Range:** displays the distance of the end of the Wand to the object's surface during scanning. Red is good.

4.4 Volumes 21

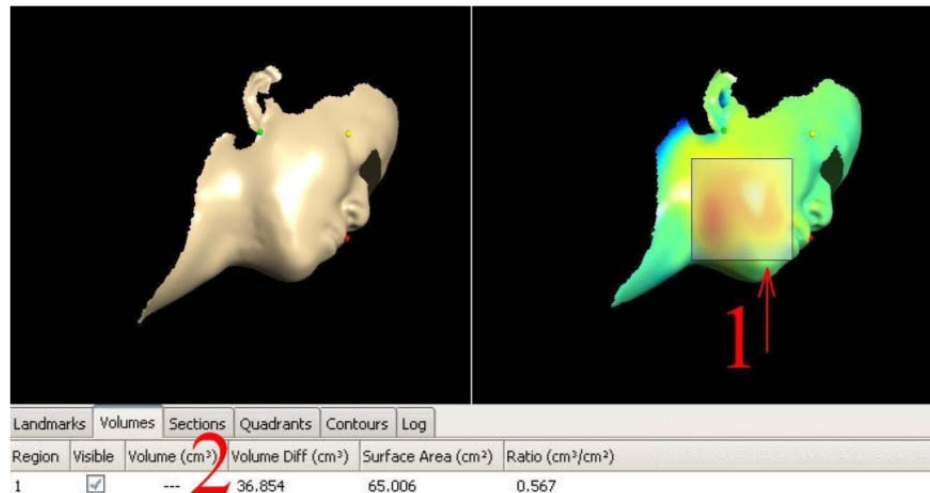
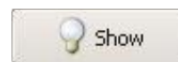


Figure 10: Volume calculation via application of a rectangular bounding box.

3. Press and hold the **Ctrl** key and **left-click the mouse** while dragging a rectangular shape across the region of interest (shown as **1** in Figure 10).
4. The volume difference between the subject and reference (within the volume box), the surface area of the subject within the volume box and the ratio of these two values are displayed in the **Volumes** tab below the display window (labeled **2** in Figure 10).
5. Rotating the objects will give a three-dimensional view of the extent of the region over which the area/volume is calculated.
6. Volume boxes can only be defined in the subject window. Additional volume boxes may be similarly defined on the same object at the same time (Figure 11), or at a point in the future.

Note: Trying to create too small a volume box may result in the volume box not being formed.

4.4.2 Hide/Show Volumes



Click the **Show** button to hide or show all of the volume boxes on an object. Check or uncheck the box next to each volume listed in the **Volumes** tab to hide or show individual volume boxes.

4 Processing Scanned Data

4.1 Surfacing Options



The *FastSCAN*[™] software deals with three surfaces: the **Sweeps Surface**, the **Basic Surface** and the **RBF Surface**. Figure 16 shows the path taken to generate these three surfaces.

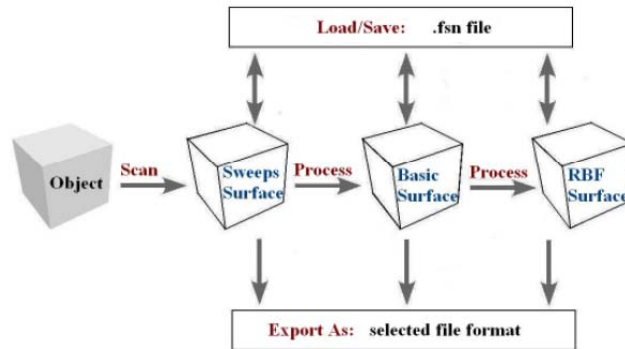


Figure 16: Objects and processes in the *FastSCAN*[™] program.

The display view may be changed between the Sweeps Surface, Basic Surface and RBF Surface. If processing is required to obtain a view it will begin automatically when that display option is selected.



4.1.1 Sweeps Surface

The Sweeps Surface is effectively the raw data gathered by the scanner and is made up of a number of individual sweeps of the object. The (individual) sweeps may overlap and intersect each other, contain holes and may have been scanned with differing resolutions.



4.1.2 Basic Surface

The Basic Surface is generated from the Sweeps by:

- merging overlapping sweeps
- changing and filtering the data
- standardizing the resolution
- simplifying the triangular mesh (optional)
- limiting the number of objects (pieces of data contained in the Sweeps (optional)).



4.1.3 Radial Basis Function (RBF) Surface

The RBF Surface is generated from the Basic Surface by:

- modeling the points of the Basic Surface with a Radial Basis Function (RBF)
- constructing an isosurface (a mesh with evenly spaced points)
- constraining the boundary of the RBF Surface in space
- simplifying the isosurface (optional).

See the FastRBF™ Extensions Manual for more details regarding the RBF Surface.



4.2 Export Format

Surfaces can be exported in a variety of industry-standard formats using the **File/Export As** submenu—this is also accessed by clicking on the **Export As** icon. Supported export file formats include:

.psl	.3ds	.txt	.dxf	.igs	.iv	.lwo	.aop
.op3	.mat	.ply	.stl	.wrl	.vtk	.obj	

For a full description of the various export formats see Section 7.

4.3 Scan Files

4.3.1 Opening and Saving Scans

**New Scan:**

To commence a **New Scan** click on **File/New** or the **New** icon in the toolbar.

**Open:**

To **Open** a scan click on **File/Open** or the **Open** icon in the toolbar. Only **.fsn** and **.hls** file formats can be opened. Saved scans can be processed and exported, but you cannot add more sweeps to them after exporting.

**Save As:**

To **Save** a scan under a new name or format click on **File/Save As** or the **Save As** icon in the toolbar. Scans can only be saved in the **.fsn** and **.hls** file formats. Saved scans can be processed and exported, but you cannot add more sweeps to them once exported.

Note:

If you want to export to a different format, or to change the processing parameters at some time in the future, make sure that you save the scan as an **.fsn** file so that you can reopen it.

4.4 Editing Raw Data



4.4.1 The Sweeps

During scanning your data appears on-screen as the **Sweeps**. You can revert to this view at anytime during the surfacing process by clicking on **View/Sweeps** or on the **Sweeps** icon in the toolbar.



4.4.2 The Sweeps List

You can view a log of all the sweeps in a scan by clicking on **Edit/Sweeps List...** This log allows you to view each sweep individually and to remove single sweeps from your scan if desired.

The **Sweeps List** dialog box (shown in Figure 17) contains a list item for each sweep. The second column gives the number of points in the sweep.

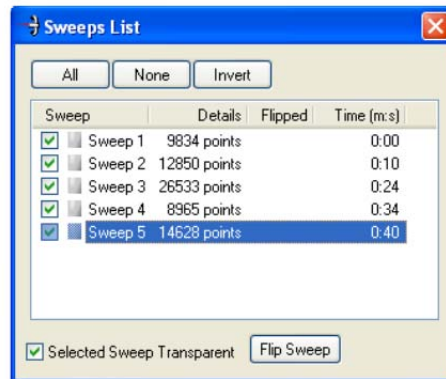


Figure 17: The Sweeps List dialog box.

To highlight a sweep (best viewed with the **Solid** option), click on it in the list. Hold down **Ctrl** or **Shift** while clicking to select multiple sweeps. The color of the highlighted sweep(s) in the main window will be changed to the preview color. The actual display of the highlighted sweep(s) depends on the status of the **Selected Sweep Transparent** check box in the Sweeps List dialog box. If unchecked, only those parts of the sweep not concealed by other sweeps will be colored, as shown in Figure 18(a).



(a) With some sweeps highlighted, and Selected Sweep Transparent box **unchecked**.



(b) With some sweeps highlighted, and Selected Sweep Transparent box **checked**.

Figure 18: Scan with highlighted sweeps, showing color differences. With (a) only visible parts of selected sweeps shown (b) all parts of selected sweeps shown, with different color shades.

If checked, the shading will vary depending on the surrounding sweeps, as shown in Figure 18(b):

Darker sweep color: this sweep is the only one covering this part of the surface.

Medium sweep color: this sweep is on top, but has other sweep(s) behind it.

Light sweep color: this sweep is underneath other sweep(s).

To hide a sweep uncheck the box to the left of the list item. Hidden sweeps will not be displayed in the main window. Hidden sweeps are ignored when processing and exporting, but they are still saved by default when you save in **.fsn** (*FastSCAN*) format. You can hide sweeps at any time, and you can continue scanning after hiding sweeps.

Clicking on **Invert** will reverse the status of all the check boxes in the list and the sweeps visible/invisible on-screen.

Use the **Flip Sweep** button to turn the selected sweep(s) inside out. This reverses the orientation of the sweeps, and can be used to make a mould with further processing.



4.4.3 Selecting and Deleting Data



It is possible to delete unwanted or inaccurate areas of the scan. Change the cursor to a selection tool by either choosing **Edit/Select**, clicking on the **Select** icon in the toolbar or by holding down the **Ctrl** key. Then left-click-and-drag the mouse to enclose the area you wish to delete. To delete either select **Edit/Delete**, click on the **Delete** icon or use the **Backspace** key. Be aware that you may be unwittingly selecting other sweeps behind the one you intended to edit (e.g., the back of a scanned object). To prevent this, you may want to hide all of the sweeps other than the one to be edited by unchecking them in the left hand column in the **Sweeps List** dialog box.



4.4.4 Undo/Redo Sweeps



The **Undo Sweeps** icon enables the removal of single sweeps from the scan (from the most recent to the first created). The **Redo Sweeps** icon places a single sweep back into the scan (from the last removed to first removed).

5 Generating A Basic Surface



5.1 Basic Surface

Creating a Basic Surface removes redundant points in overlapping sweeps. The scanned points can be repositioned and the minimum distance between them fixed to determine the amount of detail present in the final surface.

When you have sufficiently edited your Raw Data click on the **Basic Surface** icon to generate the **Basic Surface**. This uses default parameter settings—you can change these parameters via the **Generate Surface** dialog box—as outlined in the next section.



5.2 Basic Surface Parameters

Clicking on **Edit/Generate** or the **Generate** icon on the toolbar will bring up the **Generate Surface** dialog box (Figure 19). This enables the user to alter the characteristics of the Basic Surface before processing it.

5.2.1 Smoothing

When scanning, you will probably scan some parts of the surface with multiple sweeps. These sweeps may not always align perfectly. Possible causes can include:

- small errors in the scanner measurements
- metal objects interfering with the magnetic locator
- the object or reference moving unintentionally during scanning.

The **Smoothing** parameter controls the degree of smoothing *FastSCAN*[™] uses when aligning sweeps. A low value creates a more detailed surface, but will fail to merge the more widely separated sweeps. A higher value will merge sweeps better, but remove more surface detail. Typically the smallest possible value that merges sweeps correctly is ideal. Figure 20 shows the effect of different values.

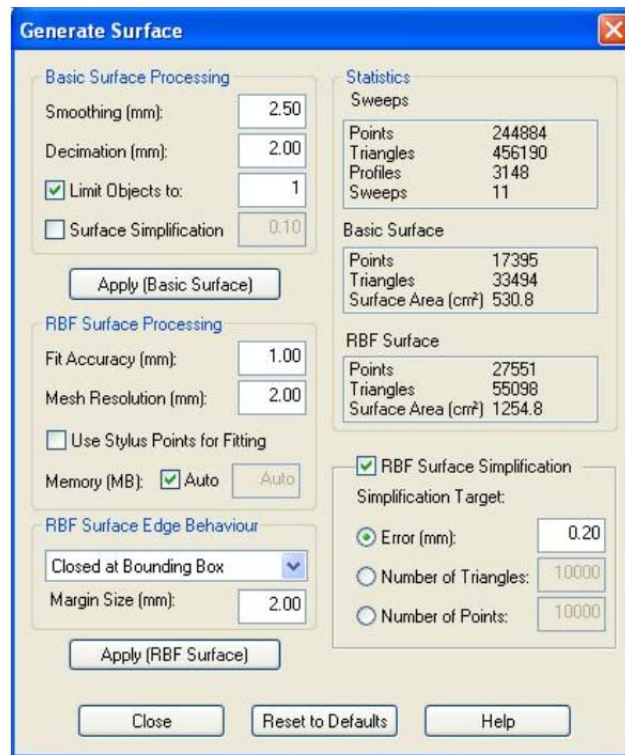


Figure 19: The Generate Surface dialog

If the *FastSCAN*TM program does not merge the overlapping sweeps correctly when it creates the Basic Surface, the surface will appear 'blistered'. Figure 21 shows how the blistering occurs as the Basic Surface jumps between the points in the two sweeps.

5.2.2 Decimation:

Increasing the **Decimation** value in the **Generate Surface** dialog box (Figure 19) reduces the number of points and triangles. This means a smaller export file and subsequently faster rendering of exported scans when loaded into other programs. Decreasing the value produces a more detailed mesh and a larger, slower file. Figure 22 shows the same object exported at two different decimation values.

The amount of blistering that occurs is also dependent on the Decimation param-

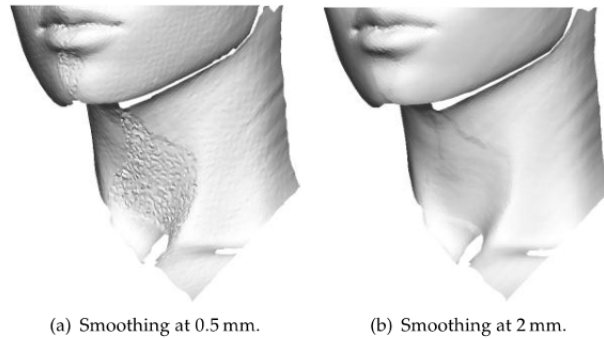


Figure 20: Two Basic Surfaces generated from the same Sweeps using different Smoothing parameters. In (a) the sweeps did not combine correctly, while in (b) they did.



Figure 21: An illustrative example of how a blistered surface (black line) can form between two misaligned sweeps (gray lines).

ter. Smaller Decimation values will have more blistering, while larger values may be completely free of it. If you lower the Decimation value you may also need to raise the **Smoothing** value to compensate.

If you cannot find a suitable value that merges sweeps while also preserving detail, try the following:

- Register the sweeps (see Section 5.3).
- Delete the portion of the sweep(s) which is causing the problem.
- Undo the sweep(s) over the problem area, and re-scan if necessary.
- Re-scan the object after removing metal objects from the scanning area.
- Fix the object and the reference securely so that they cannot move during scanning. Tethering the cables of the transmitter or reference receiver is often important.
- Ensure that the Wand, Transmitter and object are kept as close to each other as is conveniently possible. This also applies to the Reference Receiver if it is the reference device.
- Perform an Alignment Check to ensure that the optics are correctly aligned

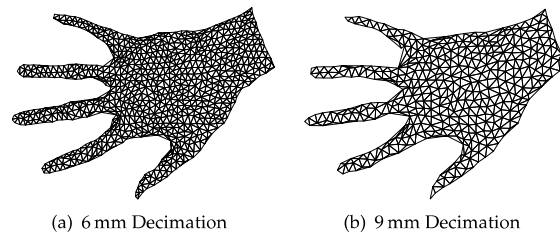


Figure 22: The same object at different decimation values. The 6 mm version (a) has 1378 triangles, while the 9 mm version (b) has only 704 triangles.

(Scorpion models only, refer Section 10.3).

- Perform a User Calibration to ensure the optics are correctly aligned (see Section 10).

5.2.3 Limit Objects to:

You may find that your surface contains parts of background objects (such as the scanning table) that you did not mean to scan—the camera can pick-up partial profiles on objects behind the target object. You can use the **Limit Objects to** control to remove these extra bits of surface, but only if they are disconnected from and smaller than all the pieces of the main object.

Check the **Limit Objects to** box in the **Generate Surface** dialog (Figure 19) and enter the number of objects N that you wish to be preserved. The export process will remove all the smaller objects, leaving only the N largest.

If this method fails, you can:

- delete parts from the Sweeps (see Section 4.4.4)
- edit the Basic Surface afterward using a separate application
- rescan after covering background objects in a black cloth (or similar arrangement) in order to suppress the laser return from them.

5.2.4 Surface Simplification:

Check the **Surface Simplification** box to reduce the complexity of the Basic Surface—this generates fewer triangles for roughly the same accuracy.

5.2.5 Apply Basic Surface:

When you have set the **Basic Surface Processing** values click on the **Apply Basic Surface** button to generate the Basic Surface.

5.3 Registering the Sweeps

The various sweeps of the scan may not always overlap perfectly. This may be due to:

- small errors in the scanner measurements
- metal objects interfering with the magnetic locator
- the object or reference moving unintentionally during scanning.

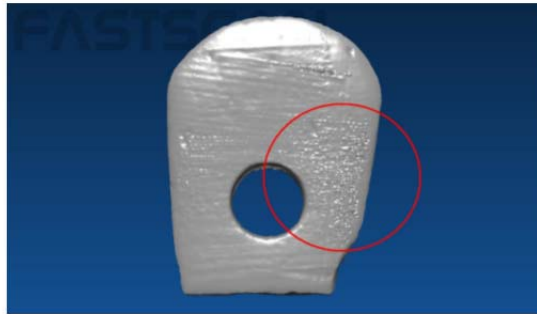
Such errors in sweep alignment are manifested as bumpy patches or blistering on the Basic Surface. You can attempt to correct these by selecting **Register Sweeps** from the **Edit** menu. The process is automatic and takes just a few seconds for a typical scan. Once you have performed sweep registration, regenerate the Basic Surface in the normal way and see if the **RMS error** has improved. Figure 23(a) shows an object with artifacts before **Register Sweeps** has been used and 23(b) the improved result after it has been applied.

Occasionally **Register Sweeps** can cause deterioration in the quality of the Basic Surface. If the RMS error is larger after **Register Sweeps** has been applied, choose **Unregister Sweeps** from the **Edit** menu. The registration algorithm only applies a rapid body transformation to each sweep, i.e. a translation and a rotation. Such transformations cannot correct misalignments due to problems that cause distortion of the data *within* the sweep.



5.4 Surface Information

To view the statistics of your surface, open the **Generate Surface** dialog box (Figure 19). For the raw data this shows the number of points, triangles, sweeps and profiles. For the Basic and RBF Surfaces it shows the number of points and triangles and the surface area.



(a) The object with artifacts visible on the Basic Surface.



(b) The object after **Register Sweeps** has been used.

Figure 23: **Register Sweeps** is used to better align the Sweeps and remove any artifacts.

5.5 Batch Processing

The **Batch Processing** interface allows you to process and export several scan files at once, each with different parameters if required. Figure 24 shows the batch processing dialog.

Select **File/Export As/Batch Process** to open the **Batch Processing** dialog. On the left of the dialog is the list of scans to be processed. If you currently have a scan open it will be placed in this list, otherwise the list will be empty.

On the right of the dialog box are the controls for changing the settings of the selected scan. The upper-most box displays the input scan file name, which cannot be changed.

Choose from **Export Sweeps**, **Export Basic Surface**, or **Export RBF Surface**. The

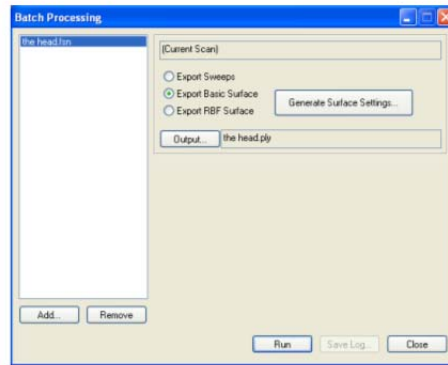


Figure 24: The Batch Processing dialog.

Generate Surface Settings... button opens the **Generate Surface** dialog, where you can specify the surface parameters for the Basic Surface or RBF Surface. The **Output** control displays and allows you to change the output file's format and filename. The default output filename is the scan filename.

Click the **Add** button to add a new scan to the list. The newly added scan's settings (in its **Generate Surface Settings** box) will duplicate those of the preceding scan in the list (if you want to process several scans with the same settings, configure the first scan before adding the rest—if you want different surface settings for each file then be sure to edit them individually via the **Generate Surface Settings** box). To remove a selected scan from the list click the **Remove** button.

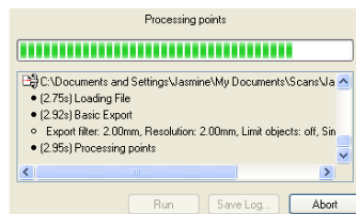


Figure 25: The progress bar and message log displayed during batch processing.

Click the **Run** button to process and export each scan in the list, according to the specified parameters. While running the empty part of the dialog displays a progress bar and message log (Figure 25) displaying which scans and processing steps have been run, the processing parameters and any errors. When processing is complete the **Save Log** button allows you to save this message log to a text file.

6 Generating an RBF Surface



See the FastRBF™ Extensions Manual for instructions on how to generate an RBF surface. While an RBF surface may be generated with the unlicensed *FastSCAN*™ software, a license is required to enable saving of the surface.

7 Exporting a Surface



7.1 Export Options

You can export a surface at any stage of processing—the file formats available are determined by what stage you are at.

FastSCAN[™] can export files in a number of industry standard formats. We have attempted to support the most popular variant(s) for each—if you have difficulties importing one of these files into your 3D application, try exporting another variant or format. If you continue to have difficulties, please go to our website (www.aranz.com) or contact **Aranz Scanning Ltd** (scanning@aranz.com) with the following information:

- the file format used to export from *FastSCAN*[™]
- the importing program's application name and version
- the problem file
- a file that is known to work with your application program.

Scans can be exported with respect to the Screen, Reference or Bounding Box coordinate systems, by selecting the appropriate option in the **Coordinate System** section of the **File/Export As/_____** dialog box. Note: you cannot reload any of these formats back into the *FastSCAN*[™] program.

When saving the Sweeps, some file formats support saving each sweep as a separate object in the file—check the **Separate Sweeps** control. This allows you to manipulate the sweeps easily in another application. Currently only the **Wavefront (.obj)** format supports Separate Sweeps, and only for triangle meshes.

7.1.1 File Types for Export

There are two **Surface Types**, both of which may be available for export with some file types:

Triangle Mesh: Contains points and facet information (created by joining points together).

Cloud of Points: Saves only points and no facet information. This is a smaller file as it contains less data.

7.1.2 Export Formats

FastSCAN[™] lets you export your data in the following formats:

Polyworks Line Scan (.psl) A binary file format for saving the sweeps only. It consists of raw scan data requiring further processing.

3D Studio (.3ds) The file format used by 3D Studio and supported by 3D Studio Max; also supported by other programs. This format supports **cloud of points** or **triangle mesh** data.

Ascii (.txt) ASCII stores a plain-text list of vertex locations. Each line contains the x, y, and z location of a single vertex, separated by spaces.

AutoCAD (.dxf) A file format used by Autodesk, AutoCAD, and other CAD programs. Supports **cloud of points** or **triangle mesh** data, the latter as **3DFACES** or **POLYLINES**, which may be supported differently by various programs.

IGES—Initial Graphics Exchange Format (.igs) IGES is a complex format that can be used to exchange many different types of data. These files tend to be much larger than other export formats. The *FastSCAN*[™] program can save three different types of IGES:

- **NURBS patch—Entity 128:** A **triangle mesh** with each triangle represented as a separate B-spline surface. This format is very inefficient and many programs may run out of memory when trying to load it.
- **Copious data—Entity 106:** A **triangle mesh** with optional normal vectors. This is the preferred mesh format as it is more efficient than Entity 128.
- **Point Cloud—Entity 116:** Automatically used when exporting as **Cloud of Points**.

Inventor (.iv) The native file format of SGI Inventor. Supports **triangle mesh** data only.

Lightwave Object (.lwo) The file format of the Lightwave animation software; also supported by other programs. This format supports **cloud of points** or **triangle mesh** data.

AAOP/OP3(.aop, .op3) These file formats are used by prosthetic and orthotic CAD/CAM vendors (named after the American Academy of Orthotists and Prosthetists (AAOP)). Exportable via the AAOP Export Wizard.

Matlab (.mat) A binary data file format used by The MathWorks MATLAB. Supports **cloud of points** or **triangle mesh** data, both with optional **vertex normal** vectors or **pseudo gray-scale values**. The file will contain five MATLAB variables at most:

- **Points:** A 3-by-N matrix where each column is a vertex location.
- **Normals:** A 3-by-N matrix giving the vertex normal vector for each vertex.
- **Facets:** A 3-by-M matrix where each column defines a triangle as three indexes into the list of Points.
- **Info:** A string containing information about the file.
- **Albedo:** A 1-by-N matrix giving the surface pseudo-grayscale brightness for each point in **Points**.

Note: N = points, M = facets.

Stanford Polygon File Format (.ply) Also known as the Stanford Triangle Format, this format was principally designed to store 3D data from laser scanners. It describes a single object as a series of flat polygons and can be saved as **cloud of points** or **triangle mesh**, in both **binary** or **text** formats. The **.ply** file can also be saved with optional **vertex normal** vectors or **pseudo gray-scale values**.

Stereo Lithography (.stl) A common format that supports **triangle mesh**. The *FastSCAN*TM program supports both **text** and **binary .stl** files (binary is faster and creates a much smaller file).

Virtual Reality Modeling Language (.wrl) VRML is a scene description language common on the Internet. There are different versions of VRML; the *FastSCAN*TM program produces the older 1.0 version, which is still widely supported. Generated files contain a single **triangle mesh** object and a camera object based on the current view.

Visualization Toolkit (.vtk) Supports both **cloud of points** and **triangle mesh**. Only the **ASCII** file format is supported (text files).

Wavefront Object (.obj) The file format used by the Alias|Wavefront software and widely supported by other programs. This is a text file that supports **cloud of points** and **triangle mesh**, the latter with optional **vertex normal** and **pseudo gray-scale values**.

Note: Not all third party software supports color information with .obj files.

7.2 Delta



Click on the **Delta**[™] icon to load the scan data directly into **Delta**[™] software—you must have **Delta**[™] installed.

Delta[™] is a stand alone tool that enables comparison of surface distance and volume variations between two objects. You will need a license to use the **Delta**[™] software. A demonstration copy of **Delta**[™] can be downloaded from:
[http://www.fastscan3d.com /download/](http://www.fastscan3d.com/download/).

8 Help



Clicking on the **Help** icon brings up the reference file for the *FastSCAN*[™] software (also accessible through **Help/Software Reference**. This lists all menu items, with their sub-menus and functions.

Clicking on **Help** in the menu enables the user to view the *FastSCAN*[™] manuals (in PDF format) and software reference/specification files.

9 Hotkeys & Optional Features

9.1 Hotkey List

Menu Item	Shortcut
File/New Scan	Ctrl+N
File/Open	Ctrl+O
File/Save As	Ctrl+S or F4
File/Export Surface	F8
Edit/Undo	Ctrl+Z
Edit/Redo	Ctrl+Y
Edit/Select	Ctrl+left mouse button
Edit/Delete	Backspace
Edit/Sweeps List	Ctrl+W
Edit/Stylus Marks List	Ctrl+T
Edit/Generate Surface	Ctrl+G
View/Sweeps	F5
View/Basic Surface	F6
View/RBF Surface	F7
View/Set Bounding Box to View	Ctrl+B
View/View Bounding Box From / Front	F1
View/View Bounding Box From / Bottom	F2
View/View Bounding Box From / Left	F3
View/Viewpoint/Center	Insert
View/Viewpoint/Reset	Home
View/Viewpoint/Zoom In	Page Up
View/Viewpoint/Zoom Out	Page Down
View/Viewpoint/Rotate Left	←
View/Viewpoint/Rotate Right	→
View/Viewpoint/Rotate Up	↑
View/Viewpoint/Rotate Down	↓
View/Viewpoint/Roll Left	Delete
View/Viewpoint/Roll Right	End
View/Viewpoint/Translate Left	Alt+←
View/Viewpoint/Translate Right	Alt+→
View/Viewpoint/Translate Up	Alt+↑
View/Viewpoint/Translate Down	Alt+↓

continued overleaf...

Hotkey List cont'd...

Menu Item	Shortcut
View/Movement/Normal	Ctrl+1 (object moves by 30.0°)
View/Movement/Fine	Ctrl+2 (object moves by 5.0°)
View/Movement/Very Fine	Ctrl+3 (object moves by 1.0°)
View/Movement/Ultra Fine	Ctrl+4 (object moves by 0.2°)
<i>decrease movement size by 1</i>	Shift+ <i>mvmt key</i> (↑←↓→)
<i>decrease movement size by 2</i>	Ctrl+ <i>mvmt key</i> (↑←↓→)
<i>decrease movement size by 3</i>	Shift+Ctrl+ <i>mvmt key</i> (↑←↓→)
Exit from current edit mode	Esc

9.2 Optional Features



9.2.1 Refraction Correction

Refraction Correction compensates for the surface distortion resulting from scanning through glass and is applied as a “post process” after the scan has been completed. Scanning through glass was primarily developed to enable Orthotics and Prosthetics (O&P) practitioners to obtain high quality scans of the whole foot and lower leg while keeping them stable. This is achieved by placing the feet on a raised pane of glass and scanning from beneath.

Click on **Edit/Refraction Correction...** and a dialog box will appear. Fill in the information boxes and click **Do**.

Normal commercial glass has a Refractive index of approximately 1.52, however this may vary for low lead or tinted glass.

For more information on scanning through glass refer to the Refraction Correction Manual or contact **Aranz Scanning** (scanning@aranz.com, www.aranz.com, www.fastscan3d.com).

(A license is required to enable this function.)

9.2.2 Cast Inversion Mode

The Cast Inversion Mode of *FastSCAN*[™] was developed to enable O&P practitioners to scan the inside surface of plaster casts. The data can then be archived or loaded into applicable O&P CAD software to enable modifications and/or fabrication of a pattern or prosthetic.

For more information on Cast Inversion Mode refer to the Cast Inversion Manual or contact **Aranz Scanning Ltd** (scanning@aranz.com, www.aranz.com, www.fastscan3d.com).

(A license is required to enable this function.)



9.2.3 Laser Pointer/Mark with Mouse/Stylus Mode



The **Laser Pointer**, **Mark with Mouse** and **Stylus** modes enable the user to place reference points and/or lines on the surface of the scanned object.



For more information on Mark with Mouse/Stylus Inversion refer to the Mark with Mouse/Stylus Manual or contact **Aranz Scanning Ltd** (scanning@aranz.com, www.aranz.com, www.fastscan3d.com).

(A license is required to enable these functions.)

Note: Special Functions Available With The Stylus:

When in **Laser Pointer Mode** a double-click of the Wand trigger will remove the last stylus point or line placed. A triple-click will remove all points/lines. As noted above these features can be enabled/disabled under **Settings/Wand** drop down menu.

9.2.4 Export as AAOP/OP3 object

AAOP/OP3 is a 3D file format supported by a number of orthotics and prosthetics CAD packages.

(A license is required to gain access to the AAOP/OP3 Wizard.)

9.3 FastSCAN™ Pipe Interface

The *FastSCAN™* Pipe Interface (FPI) allows another application program to access 3D scan data from the *FastSCAN™* program in real-time during scanning of an object. For further details on how to use the FPI, please refer to the file `FastScanPipeInterface.txt`, usually found at:

`C:\Program Files\Polhemus\FastSCAN\PipeInterface`

10 Calibration

The Wand is fully calibrated before it leaves the factory. However, for optimum performance you may need to check the calibration from time to time. This process is quick and convenient.

You should check the Wand calibration if:

- the Wand has been knocked or dropped
- you notice the visual quality of the scans has deteriorated
- you have not used the *FastSCAN*TM Wand for some time
- you are about to commence a particularly difficult or demanding scan.

The **Calibration Correction** option in the **Scanner** menu allows you to correct the calibration of the Wand. A user correction is not equivalent to a full factory calibration and it may not be possible to restore the scanner to its original condition if it has been badly misaligned. To ensure that your *FastSCAN*TM Wand stays in calibration, always handle it with care.

Windows 2000/XP Note

Under Windows 2000 or XP, you will need Power User or higher privileges if you are going to perform a Calibration Correction.

10.1 Overview

To collect the data required for a Calibration Correction you must scan the Calibration Target with eight separate sweeps. Make the **first four sweeps with a Wand-to-Target distance of 100 mm** and the **last four sweeps with a Wand-to-Target distance of 200 mm**. Make each sweep (in the group of four) **at a 90-degree rotation** to the previous sweep, as shown in Figure 26.



Figure 26: Scanning the Calibration Target at four different angles.



Figure 27: The Transmitter with the Calibration Target attached.

Note: While in Calibration Correction mode, the FastSCAN program monitors the Wand-to-Target distance and will only accept data when the distance is within ± 20 mm of the nominal value.

100 mm data: range is 80 mm to 120 mm.

200 mm data: range is 180 mm to 220 mm.

You may find maintaining the correct distance while scanning the Calibration Target is awkward at first. To assist, the computer “beeps” if the data is within the acceptable range as you scan the Calibration Target.

10.2 Calibration Correction Procedure

Perform the Calibration Correction as follows (please read all the steps before beginning):

1. Set up the scanning environment as described in Section 2.5. It is *imperative* that you keep metal objects (such as computers, monitors and metal furniture) at least one meter away from the scanning area.
2. Attach the Calibration Target to the Transmitter using the two nylon screws provided (Figure 27). The orientation of the target is not important, but you must attach it securely.
3. Place the Transmitter down with the Calibration Target facing upward.

4. Start the *FastSCAN*[™] program (if you are running Windows 2000 or XP then you must have at least Power User privileges).
5. Click on **Scanner/Calibration Correction....** The background color of the *FastSCAN*[™] window will change to black and the **Calibration Correction** dialog box will appear (Figure 28).
6. Set the sensitivity control of the Wand to position 1.
7. Hold the Wand at a range of 100 mm (4") above the Calibration Target.
8. To confirm that you are holding the Wand at the correct distance pull the trigger to the Preview Position (halfway in) and scan over the target. If the range is acceptable your computer will beep as you scan the Calibration Target. Otherwise continue previewing at different Wand-to-Target ranges until you hear beeping. There is a distance gauge on the right hand side of the screen to assist in obtaining the correct Wand-to-Target distance.
9. When at the correct range pull the trigger fully in and *slowly and evenly* scan the target with one sweep before releasing the trigger. You will hear beeping as you scan the Calibration Target.
10. If the range was acceptable a red spot (Cobra) or red and green pair of spots (Scorpion) will appear on the screen.
11. Rotate the Wand by 90 degrees and repeat step 9. Repeat this process two more times until you have scanned the target from all four sides. Four spots (Cobra) or four pairs of spots (Scorpion) are collected at orientations of 0 degrees, 90 degrees, 180 degrees and 270 degrees respectively (Figure 26).
12. Repeat Steps 9 and 11 at a range of 200 mm (8") with the Wand's sensitivity control at position 2.
13. After making all eight measurements there should be two clusters of points in the *FastSCAN*[™] window (Figure 28): one representing the data collected at 100 mm and the other the data collected at 200 mm. In each cluster, there should be four red spots (Cobra) or four pairs of red and green spots (Scorpion).
14. Once the required data is present click the **Compute Correction** button.
15. The variance (RMS) of the collected data will be displayed before and after the calibration parameters have been calculated. A successful Calibration Correction should have an RMS of $< 0.20 - 0.30$ mm. If the RMS is outside of this range you should return your Wand to Polhemus for factory calibration.

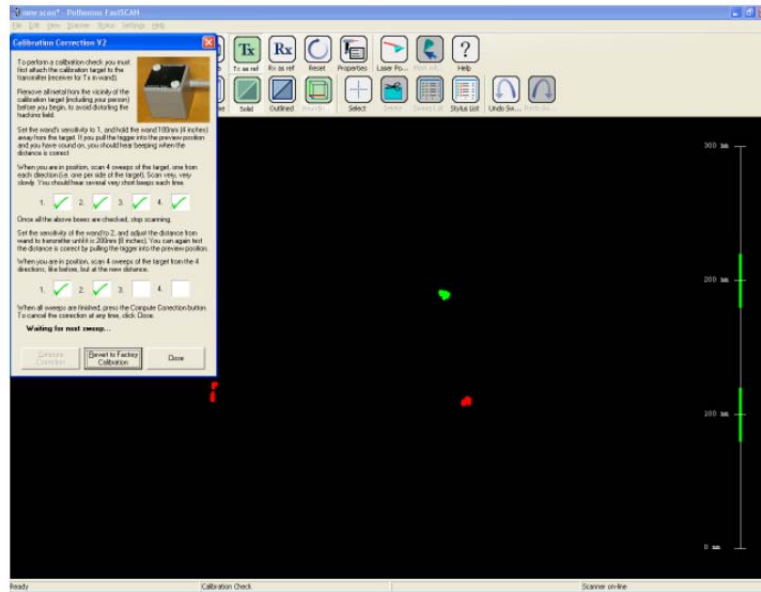


Figure 28: Three of the four calibration spot clusters are visible (for the *Scorpion™*) and the **Calibration Correction** dialog box.

Notes:

- You must collect the 100 mm data first.
- Windows 2000 or XP users must have Power User privileges or greater.
- If desired the most recent sweep (or the point in this case) can be removed with a double click of the trigger, or all data can be removed with a triple click. These functions are switched on by default—see Section ??.
- To help reduce artifacts the data is restricted to points within the vicinity of the Calibration Target; it will not matter if you place the Transmitter and Target on a light-colored surface.
- Should the Transmitter already be bolted to a surface then the Calibration Target may be placed on the opposite face. It is imperative that the target is mounted securely.
- To remove all Calibration Corrections made to date click the **Revert to Factory Calibration** button.

10.3 Alignment Check (Scorpion Users Only)

The Alignment Check is a simple test to assess the alignment of the optics and is independent of the tracking system.

Perform an Alignment Check as follows:

1. From the *FastSCAN*[™] software, select **Scanner/Alignment Check**.
2. Position a sheet of white paper (US-letter or A4) near the Transmitter.
3. Set the sensitivity control to position 1.
4. Gently place the Wand on to the center of the sheet of paper so that the laser aperture faces downwards and the Wand lies across the width of the sheet.
5. With the trigger pulled fully in lift the Wand vertically off the sheet at a constant rate. Note the arrangement of Wand, Transmitter and test paper as shown in Figure 29.
6. Release the trigger once the laser line exceeds the width of the sheet.
7. Press OK.

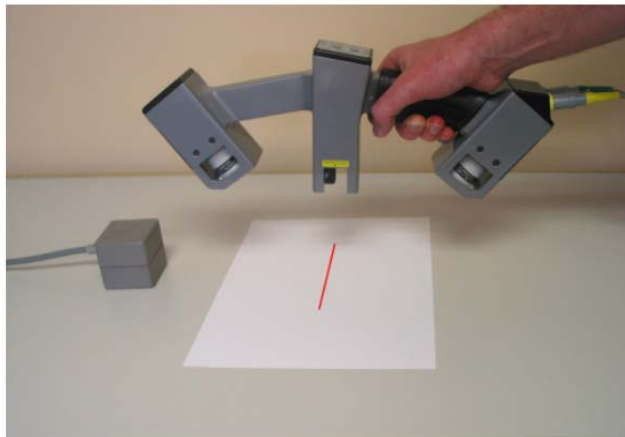


Figure 29: Procedure for performing an Alignment Check.

The result of the Alignment Check is a number greater than zero. A lower number means a better alignment. If the number is greater than 2.0 the Wand requires calibration correction (see Section 10).

11 Troubleshooting/FAQs

Q. The status bar of the *FastSCAN*[™] program continues to show ‘Scanner off-line’—what has gone wrong?

A. Run through the following checklist:

- Ensure you do not have another *FastSCAN*[™] program still running from an earlier session (possibly minimized).
- Ensure that power is getting to the PU. The green ‘Power’ light on the front panel should be on.
- Ensure that power is getting to the Wand. The green ‘Power’ light on the Wand should be on.
- Check connections of all the cables.

Q. I have just performed a scan and there is nothing on the screen. Why?

A. Possibly the scanned surface is out of view. Try centering the scan—select **Center** from the **View/Viewpoint** menu (or point the Wand at the area you wish to view and pull the trigger to the Preview position). If you are new to scanning, check that you are holding the trigger in the Scanning position when scanning so the Scan LED on the Wand is illuminated.

If the object still does not appear then you may be holding the Wand too close or too far away from the object while scanning, preventing the camera from recording the movement of the laser. Keep the Wand about 10-15 cm from the object when scanning.

Q. My scanned image is upside-down on the screen and I can’t get it the right way up. How can I fix this?

A. The **hemisphere of operation** is not defined correctly. Switch off the PU and switch it on again. Then go through the procedure in Section 2.5: Running *FastSCAN*[™].

Q. I have “floating” fragments of surfaces in my scan that are unrelated to the object—what’s happening?

A. The Wand’s camera may occasionally view a bright, broad spectrum light source (e.g., sunlight from a window) that mimics the light of the laser. It is advisable to keep windows shuttered, avoid bright lights above and behind the scanning area, and to set the sensitivity control as low as possible. To check whether extraneous light is being detected, select **View/Camera** (which displays what the camera is seeing), and cover the laser. Anything visible in the display is then due to extraneous light.

Q. How close do I need to keep the components of the *FastSCAN*[™] system?

A. To ensure both high resolution and high accuracy, keep the Wand close to the

object's surface during scanning, but no closer than 80 mm to keep within the camera's field of view. If you are using the Receiver, parts of the surface closer to it will scan more accurately. Try to keep the Transmitter close to the Wand and Receiver, as accuracy deteriorates with distance, but no closer than 100 mm to avoid signal overload. The maximum separation of any two components is about 750 mm, but for best results, keep them as close as possible.

- Q.** When I generate a Basic Surface, it has “bumpy” or “crystalline” patches—what is wrong?
- A.** Successive sweeps over the same part of the surface have not merged properly. Try using **Edit/Register Sweeps** (Section 5.3). If the result is still unsatisfactory you may need to repeat the scan.
- Q.** How far away do I have to keep metal objects from the scanner?
- A.** The presence of metal objects while scanning interferes with the tracking of the Wand and degrades performance. As long as you keep any large metal objects at least 1 m from the Wand, the Transmitter, and the object you are scanning, they should not pose a problem.

12 Safety Guidelines

12.1 FCC Statement

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause interference to radio communications. Operation of this equipment in a residential area is likely to cause interference, in which case the user will be required to correct the interference at his own expense.

12.2 Laser Warning

A laser produces the red light emitted by this product. The laser is a specialized form of light source and although the power of the laser is very low, the laser light is concentrated into a very narrow beam. This property makes it useful in many applications, but also requires that precautions be taken to avoid damage to your eyesight.

Lasers are grouped into different classes according to the degree of potential hazard they present. Class 1 lasers are safe under any circumstances, while the other Classes are not. This laser is **not** a Class 1 laser.

The laser in this device has a Peak Power Output of 3.5 milliwatt at a wavelength of 670 nanometers. It is a **Class 3R** Product in compliance with IEC 60825-1:2001, and a **Class II** Product in Compliance with 21 CFR 1040.10.

Do not stare into the beam as it can damage the retina at the back of the eye. The eye has an aversion to such bright light, and the natural reflex of someone exposed to the beam is to either blink or look away. Usually this happens so quickly that no harmful effects occur. Prolonged staring into a reflection of the beam from a mirror or shiny metal surface may also be harmful, but a more diffuse reflection, off skin for example, is not hazardous.

For safe operation of this device, the following precautions should be taken:

- Never stare into the beam.
- If the device is used to obtain body profiles, warn subjects not to stare into the beam. Young children, or subjects whose natural aversion reflex may be dulled due to medication or a medical condition, may be advised to wear a blindfold or some other form of eye protection.

- Operate the device so that it is pointing away from windows, doors, mirrors and other shiny reflective surfaces, and areas where other people are working.
- There are no controls, adjustments or user serviceable parts that can affect the laser output. In the event of equipment failure, return the Wand to the manufacturer or agent for repair and servicing.

The product includes the following safety features:

- The laser is only activated when the spring-loaded trigger is depressed.
- An indicator light is illuminated when the laser is operating.
- All controls can be operated without direct viewing of the beam.
- Warning labels and a label indicating the laser aperture are attached to the Wand in the positions indicated on the following figures in **Section 12.3: Warning Labels and Locations** (overleaf):

<p>Caution: Use of controls and adjustments, or performance of procedures other than those specified in this manual may result in hazardous laser radiation exposure.</p>
--

12.3 Warning Labels and Locations



(a) The Wand displaying warning labels.



(b) Warning labels.



(c) Close-up of the laser aperture (circled), and two-position trigger switch (bottom).



(d) Wand control panel showing Laser-On indicator light (top-right LED)

13 Distributors

Master Distributor: POLHEMUS
PO Box 560, 40 Hercules Drive, Colchester, VT 05446
United States of America
Ph. 802/655-3519
Fax. 802/6551439
<http://www.polhemus.com>

Austria:
EST, Engineering Systems Technologies
GmbH & Co. KG
www.est-kl.com

Australia:
Aranz Scanning, StormFX Pty Ltd
www.aranz.com
www.fastscan3d.com
www.stormfx.com.au

Belgium:
Immersion SA, IMAQs
www.immersion.fr www.imaqs.com

Brazil:
Absolut Technologies
www.abs-tech.com

Canada:
AD3R Technologies
www.ad3r.com

China:
Beijing 6DOF Technologies Co Ltd
Tech Trend International Ltd
www.6dof.com.cn sales@ttil.com.hk

Croatia:
VR Logic
www.vrlogic.com

Denmark/Finland:
Contact sales@polhemus.com

France:
CADvision S.A.S, Immersion SA
www.cadvision.fr

Germany:
VR Logic, EST Engineering Systems
Technologies GmbH & Co. KG
www.vrlogic.com www.est-kl.com

Greece/Cyprus:
Contact sales@polhemus.com

Hong Kong:
Techtrend International Ltd
sales@ttil.com.hk

India:
CAD Engineering Services
maanavendra@gmail.com

Ireland:
Contact sales@polhemus.com

Italy:

Unocad S.R.L, GEA Media Group S.R.L
www.unocad.it
www.geamedia.com

Japan:

KBK-Kyokuto Boeki Kaisha Ltd
www.kbk.co.jp/cesd/polhemus.htm

South Korea:

Jek Co Ltd
idkwon@jek.co.kr

Luxembourg:

IMAQS
www.imaqs.com

Malaysia:

Interactive Dreams Pte Ltd
www.id-dreams.com/020115/044/
welcome_frame.htm

Netherlands:

IMAQS
www.imaqs.com

New Zealand:

Aranz Scanning
www.aranz.com
www.fastscan3d.com

Portugal:

Aplein Ingenieros S.A
www.apleiningenieros.com/
NORCAM Engenharia E Design
Industrial LDA
www.norcam.pt/norcam/index.html

Singapore:

Interactive Dreams Pte Ltd
www.id-dreams.com/020115/044/
welcome_frame.htm

Spain:

Aplein Ingenieros S.A
www.apleiningenieros.com/

Sweden:

Contact sales@polhemus.com

Switzerland:

EST Engineering Systems Technologies
GmbH & Co. KG
www.est-kl.com

Taiwan:

PC from Expert/Apexsun
www.pcexpert.com.tw

Thailand:

Contact sales@polhemus.com

Turkey:

Contact sales@polhemus.com

United Kingdom:

Virtalis Limited
www.virtalis.com

14 Customer Service

If you encounter any problems with your *FastSCAN*TM system, help is just a telephone call away. Call 802/655-3159 (800/357-4777 U.S. and Canada) and ask for Customer Service. For the most part, our Customer Service engineers can handle your problems over the telephone and get you back into the fast lane right away. If the problem requires repair of your instrument, the Customer Service engineer will issue you a Return Merchandise Authorization (RMA) number. Polhemus strongly suggests retaining the original shipping container for your *FastSCAN*TM system in the event that the instrument may require repair. Please do not return any instrument without an RMA number, as it will not be accepted. If your instrument is still under warranty, Polhemus will repair it free of charge according to the provisions of the warranty as stated in Section 15 of this document. The proper return shipping address is:

Polhemus
40 Hercules Drive
Colchester, Vermont, 05446
United States of America



P.O. BOX 560, 40 HERCULES DRIVE
COLCHESTER, VT 05446

Telephone (voice):	(802) 655-3159
Toll Free (USA & Canada):	(800) 357-4777
Telephone (FAX):	(802) 655-1439
Email:	techsupport@polhemus.com

<http://www.polhemus.com/>

<http://www.fastscan3d.com/>

Software upgrades for licensed users are available from **www.fastscan3d.com**.

15 Limited Warranty and Limitation of Liability

15.1

Polhemus warrants that the Systems shall be free from defects in material and workmanship for a period of one year from the date ownership of the System passed from Polhemus to Buyer. Polhemus shall, upon notification within the warranty period, correct such defects by repair or replacement with a like serviceable item at Polhemus' option. This warranty shall be considered void if the System is operated other than in accordance with the instructions in Polhemus' User Manual or is damaged by accident or mishandling. Parts or material which are clearly expendable or subject to normal wear beyond usefulness within the warranty period such as lamps, fuses, etc., are not covered by this warranty.

15.2

In the event any System or portion thereof is defective, Buyer shall, within the warranty period, notify Polhemus in writing of the nature of the defect, remove the defective parts and, at the direction of Polhemus Customer Service, ship such parts to Polhemus. Upon determination by Polhemus that the parts or Systems are defective and covered by the warranty set forth above, Polhemus, at its option shall repair or replace the same without cost to Buyer. Buyer shall pay all charges for transportation and delivery costs to Polhemus' factory for defective parts where directed to be sent to Polhemus, and Polhemus shall pay for transportation costs to Buyer's facility only for warranty replacement parts and Systems. Removed parts covered by claims under this warranty shall become the property of Polhemus.

15.3

In the event that allegedly defective parts are found not to be defective, or not covered by warranty, Buyer agrees that Polhemus may invoice Buyer for all reasonable expenses incurred in inspecting, testing, repairing and returning the Systems and that Buyer will pay such costs on being invoiced therefor. Buyer shall bear the risk of loss or damage during transit in all cases.

15.4

Any repaired or replaced part or System shall be warranted for the remaining period of the original warranty or thirty (30) days, whichever is longer.

15.5

Warranties shall not apply to any Systems which have been:

- (a) repaired or altered other than by Polhemus, except when so authorized in writing by Polhemus.
- (b) used in an unauthorized or improper manner, or without following normal operating procedures; or
- (c) improperly maintained and where such activities in Polhemus' sole judgement, have adversely affected the Systems. Neither shall warranties apply in the case of damage through accidents or acts of nature such as flood, earthquake, lightning, tornado, typhoon, power surge or failure, environmental extremes or other external causes.

15.6

POLHEMUS DOES NOT WARRANT AND SPECIFICALLY DISCLAIMS THE WARRANTY OF MERCHANTABILITY OF THE PRODUCTS OR THE WARRANTY OF FITNESS OF THE PRODUCTS FOR ANY PARTICULAR PURPOSE. POLHEMUS MAKES NO WARRANTIES, EXPRESS OR IMPLIED, EXCEPT OF TITLE AND AGAINST PATENT INFRINGEMENT, OTHER THAN THOSE SPECIFICALLY SET FORTH HEREIN.

15.7

IN NO EVENT SHALL POLHEMUS BE LIABLE UNDER ANY CIRCUMSTANCES FOR SPECIAL INCIDENTAL OR CONSEQUENTIAL DAMAGES, INCLUDING, BUT NOT LIMITED TO LOSS OF PROFITS OR REVENUE. WITHOUT LIMITING THE FOREGOING POLHEMUS' MAXIMUM LIABILITY FOR DAMAGES FOR ANY CAUSE WHATSOEVER, EXCLUSIVE OF CLAIMS FOR PATENT INFRINGEMENT AND REGARDLESS OF THE FORM OF THE ACTION (INCLUDING BUT NOT LIMITED TO CONTRACT NEGLIGENCE OR STRICT LIABILITY) SHALL BE LIMITED TO BUYER'S ACTUAL DIRECT DAMAGES, NOT TO EXCEED THE PRICE OF THE GOODS UPON WHICH SUCH LIABILITY IS BASED.

16 Indemnity Against Patent Infringement

Polhemus shall have the right at its own expense, to defend or at its option to settle, any claim, suit or proceeding brought against Buyer on the issue of infringement of any United States patent by any product, or any part thereof, supplied by Polhemus to Buyer under this Agreement. Polhemus shall pay, subject to the limitations hereinafter set forth in this paragraph, any final judgement entered against Buyer on such issue in any such suit or proceeding defended by Polhemus. Polhemus at its sole option shall be relieved of the foregoing obligations unless Buyer notified Polhemus promptly in writing of any such claim, suit or proceedings, and at Polhemus' expense, gave Polhemus proper and full information and assistance to settle and/or defend any such claim, suit or proceeding. If the product, or any part thereof, furnished by Polhemus to Buyer becomes, or in the opinion of Polhemus may become, the subject of any claim, suit or proceeding for infringement of any United States patent, or in the event of an adjudication that such product or part infringes any United States patent, or if the use, lease or sale of such product or part is enjoined, Polhemus may, at its option and its expense: (a) procure for Buyer the right under such patent to use, lease or sell, as appropriate, such product or part, or (b) replace such product or part, or (c) modify such product, or part, or (d) remove such product or part and refund the aggregate payments and transportation costs paid therefore by the Buyer less a reasonable sum for use, damage and obsolescence. Polhemus shall have no liability for any infringement arising from: (i) the combination of such product or part with any other product or part whether or not furnished to Buyer by Polhemus, or (ii) the modification of such product or part unless such modification was made by Polhemus, or (iii) the use of such product or part in practicing any process, or (iv) the furnishing to Buyer of any information, data, service or application assistance. Buyer shall hold Polhemus harmless against any expense, judgement or loss for infringement of any United States patents or trademarks which results from Polhemus' compliance with Buyer's designs, specifications or instructions. Polhemus shall not be liable for any costs or expense incurred without Polhemus' written authorization and in no event shall Polhemus' total liability to Buyer under, or as a result of compliance with, the provisions of this paragraph exceed the aggregate sum paid to Polhemus by Buyer for the allegedly infringing product or part, exclusive of any refund under option (4) above. The foregoing states the entire liability of Polhemus, and the exclusive remedy of Buyer, with respect to any actual or alleged patent infringement by such product or part.

APPENDIX B:

DELTA MANUAL

The following is a direct copy of the Delta Manual authorized by Polhemus for use in this study.



Manual for Software Version 1.2.18

Manual for

Delta™ Scan Comparison Utility and

Delta™ for FastSCAN

July 2008

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Delta™ is a registered trademark of ASL.

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1 Introduction

1.1 About Delta™

Delta™ is a stand-alone 3D object analysis software package that enables precise measurements to be made on scanned data. Delta™ takes these measurements and, combined with the creation of a reference object, also gives excellent visual indication of differences between multiple scans. Features include dual object windows for comparisons, object alignment and quantitative analysis tools for measuring volumes, areas, displacements and linear distances. This makes Delta™ an excellent tool for use in temporal studies and for comparisons between scanned objects.

Delta™ supports a number of file formats and works directly with the files generated by the FastSCAN™ family of scanners.

In particular Delta™ can perform the following tasks:

Operations on a single scan:

- Calculate volume of a concave or convex area (by interpolating over the region and calculating the volume in the concavity as delimited by the interpolated surface).
- Calculate absolute volumes.
- Create a reference image for comparison with other scans.
- Point to point measurements.
- Slice the surface in 3D to display contours at any position or orientation.

Operations on two scans:

- Perform landmark based registration on scans using FastSCAN™-defined or Delta™-defined landmarks.
- Perform surface-based registration using an RBF-variant of ICP.
- Display displacements/differences between two surfaces as a color map.
- Calculate volumes and their differences between surfaces in a certain region.
- **.obj** merge—allows merging of two **.obj** files.
- Divide a surface (or pair of surfaces) into quadrants and calculate the absolute volume in each quadrant.

Delta™ loads FastSCAN format **.fsn** files, as well as **.obj**, **.aop**, **.ply** and **.op3**. Legacy Delta™ for FastSCAN loads only **.fsn** format files.

1.2 Customization

At Aranz Scanning Ltd we pride ourselves on listening to your ideas and concerns. If a function or tool is not available within the Delta™ application we will do our best to design and incorporate it into Delta™ for you.

1.3 Getting Help

For help on any aspect of Delta™ please email delta@aranz.com

2 Setting Up / Getting Started

2.1 System Requirements

System Requirements:

- Operating System: Windows 2000, XP or Vista. 1GHz (minimum), 2GHz recommended
- OpenGL compatible hardware accelerated graphics adapter in 32-bit (true color) mode (minimum resolution 1024 x 768).

Not complying with any of the above requirements can result in Delta™ not performing correctly.

2.2 Installing Delta™

To install Delta™ simply run Delta.Install.exe and follow the instructions.

2.3 Licensing

Delta™ has many different functions that may be of value to you as a user. Some of these functions have been licensed separately to ensure the program is streamlined for the individual user. A licensing key—locked to a user's computer—has been implemented to protect the user's personal information and their Delta™ settings.

2.3.1 Delta™ Demonstration Mode

A demonstration version of Delta™ is available from <http://www.fastscan3d.com/download/delta> with all the functionality of the full install of Delta™. The demonstration version is designed to enable a trial of Delta's™ functionality and therefore it is only possible to use Delta™ sample files (provided) with this version.

2.3.2 Licensable Features

This version of Delta™ comes with the following features (these can be turned on and off as required to streamline Delta's™ performance):

- **FastSCAN:** If the user has a license for this feature then the current FastSCAN file is loaded into Delta's™ subject window when Delta™ is launched from FastSCAN.
- **OBJ:** Allows the loading and saving of **OBJ** files. Any file loaded into Delta™ can be saved as an **OBJ** file if this license is present.
- **OP3:** Allows the loading and saving of **OP3** files.
- **AAOP:** Allows the loading and saving of **AAOP** (.aop files) and use of the **AAOP Export Wizard**.
- **Quadrant:** Enables the **Quadrants** tab and associated functionality.
- **Contours:** Enables the the **Contours** tab and associated functionality.

Note: Legacy **Delta™ for FastSCAN™** users can upgrade to the latest release, but will not have access to Quadrants and Contours functionality. If you require any of Delta's™ extra features please contact us at: delta@aranz.com.

2.3.3 Installing a License

The appropriate license file (**Delta.lic**) can be installed by simply transferring it into your Delta™ folder (typically: Program Files\ARANZ Scanning\Delta).

To ensure you have installed the license correctly do the following:

1. Open Delta™. The top left of the screen should read **Delta**. If it reads **Delta - Demonstration Mode** the license installation has failed.
2. Click on **Help/About**. The dialog box should show a list of the installed Delta™ licenses. If the list of licenses does not appear the installation has failed. The **Log** should indicate the license has failed to load and may list a possible cause.

If the license has failed to install correctly please retry the installation. If you are having difficulties please contact us at: **delta@aranz.com**.

2.4 Delta™ Updates

Delta™ is updated frequently and the latest version of the software is available at **www.fastscan3d.com**. Because we are always expanding Delta's™ capabilities we hold user feedback in high regard—please do not hesitate to contact us at **delta@aranz.com** with any queries or problems you may have.

2.5 Trouble Shooting

If at any stage there is an issue with Delta™ we suggest saving any objects you have open (**under a different file name**) and restarting the Delta™ application.

For any further queries please contact us at **delta@aranz.com**.

3 Using Delta™

3.1 The Delta™ Window

The Delta™ window is shown in Figure 1. It consists of seven primary components:

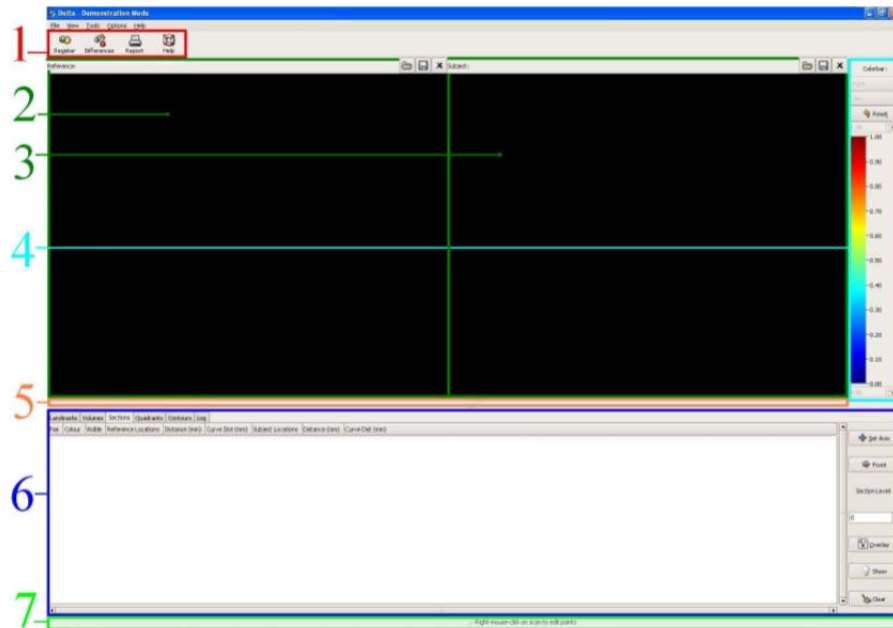


Figure 1: The Delta™ Window.

1. **Delta™ Toolbar:** The toolbar (Figure 2) contains the icons for often used tools in scan comparisons.



Figure 2: The Delta™ Toolbar.

2. **Reference Display Window:** Contains the graphics window for the display

of the Reference Scan and its filename. File **Open**, **Save** and **Close** icons are located at the top right of the window (Section 3.2).

3. **Subject Display Window:** Contains the graphics window for the display of the Subject Scan and its filename. File **Open**, **Save** and **Close** icons are located at the top right of the window (Section 3.2).
4. **Colorbar:** Contains the Colorbar, associated tools and viewing options.
5. **Scan Information Bar:** Displays Anterior-Posterior (AP), Medial-Lateral (ML), and Circumference (C) values when in cross-section mode (if the current cross-section is a closed surface).
6. **Information Tabs/Delta™ Modes:** Selects which Delta™ mode is to be used and displays the measurement information specific to the tab/mode selected. On the right-hand side are control buttons specific to each mode.
7. **Status Bar:** Informs the user of Delta's™ current status, gives feedback, positional information (left-hand side) and instructions (right-hand side).

3.2 Loading and Saving Scan Data in the Display Windows

3.2.1 Loading a scan

To load a scan into the **reference** (left) window, click on the **open scan file** icon (labeled **1** in Figure 3) above the left window, or **File/Open Reference**, and navigate to the folder where your scan file is located. Select the file and click **Open**.

To load a scan into the **subject** (right) window, click on the **open scan file** icon (labeled **1** in Figure 3) above the right window, or **File/Open Subject**, and navigate to the folder where your scan file is located. Select the file and click **Open**.



Figure 3: The Open (1), Save (2) & Close (3) icons found above the reference and subject windows.

3.2.2 Saving a scan

To save a scan in the **reference** (left) window click on the **save scan file** icon (labeled **2** in Figure 3) above the left window, or **File/Save Reference**, and navigate to the folder

where you wish to save the file. Choose a filename and click on **Save**/press **Enter**.

To save a scan in the **subject** (right) window click on the **save scan file** icon (labeled 2 in Figure 3) above the right window, or **File/Save Subject**, and navigate to the folder where you wish to save the file. Choose a filename and click on **Save**/press **Enter**.

3.2.3 Closing a scan

To close a scan in the **reference** (left) window click on the **close scan file** icon (labeled 3 in Figure 3) above the left window, or **File/Close Reference**. You will be prompted to save if you have made any changes.

To close a scan in the **subject** (right) window click on the **close scan file** icon (labeled 3 in Figure 3) above the right window, or **File/Close Subject**. You will be prompted to save if you have made any changes.

3.3 Object Manipulation in the Display Windows

Objects can be viewed and moved within the Display Windows using either the mouse or the keyboard. Movement between the two windows is synchronized (some of these options can be accessed by clicking on **View/Viewpoint**).

3.3.1 Rotation

Left-click and drag the mouse in the viewing window to rotate the object in any direction. Rotation is through the **coordinate system of the object**. To see the coordinate system click on **View/Axes**.

The object can also be rotated using the keyboard arrows, in increments of 30° . Pressing and holding the **Shift** key during keyboard rotation changes the increment to 5° . Pressing and holding the **Ctrl** key during keyboard rotation changes the increment to 1° , while pressing and holding the **Ctrl and Shift** keys during keyboard rotation changes the increment to 0.2° .

Delete rotates the object anti-clockwise with respect to the screen **z-axis** while **End** rotates the object clockwise.

3.3.2 Translation

With the mouse pointer within the viewing window **click and hold both mouse buttons, then drag the mouse** within the window to move the object in any direction, while maintaining its orientation.

For translation using the keyboard hold the **Alt** key while using the arrows to move the object in any direction while maintaining its orientation (coarsest degree of movement). Pressing and holding the **Shift** and **Alt** keys gives medium movement during translation and pressing and holding the **Ctrl** and **Alt** keys gives finer movement during translation. Pressing and holding the **Ctrl, Shift & Alt** keys gives the finest degree of movement.

Insert (View/Viewpoint/Center) will center the object in the viewing window.

3.3.3 Zoom

Use the **mouse roller** to zoom in and out, or **right-click and drag** the mouse.

On the keyboard use **Page Down** to zoom out and **Page Up** to zoom in.

3.3.4 Bounding Box Views

Click on **View/Axes** to bring up the object's bounding box. The measurement points along the edges are automatically set.

Press **Home** or **F1 (View/Viewpoint/Front)** to view from the front of the bounding box (default view when the scan is loaded into the viewing window). In **Sections** mode the object will reorient so that the **cross-section axis is horizontal**.

Press **F2 (View/Viewpoint/Bottom)** to view from the bottom of the bounding box.

Press **F3 (View/Viewpoint/Left)** to view from the left side of the bounding box.

Click on **View/Axes Grid** to place grid lines around the object's bounding box—these are automatically drawn through the measurement points along the edges of the bounding box.

3.4 Delta™ modes and their applications

Delta™ enables the user to take measurements on an object or compare one object with another using five different modes: **Landmarks**, **Volumes**, **Cross-sections**, **Quadrants** and **Contours**. Each of these modes is utilized via an individual tab in the Delta™ window.

3.4.1 Landmarks

Landmarks are markers placed on the object's surface and are used to take measurements and correctly align two scanned objects via the process of **Registration**.

3.4.2 Volumes

Volume boxes enable calculation of the volume on any part of a subject object's surface and the **volume difference** when compared with another object, or with the same object at a different point in time (displayed in the reference window).

3.4.3 Sections

Enables the user to establish cross-section planes through the object and take measurements between points where the plane intersects the object.

3.4.4 Quadrants

Enables the user to divide the object into four regions or quadrants and take individual measurements within each quadrant (this is a licensed feature).

3.4.5 Contours

Multiple contours can be placed around a subject object's surface with customized axis points (this is a licensed feature).

3.5 Units of Measurement

Clicking on **Options/Units** allows the user to select either **Millimeters** or **Inches** for display of measurements.

3.6 Reporting



The **Report** function takes the information currently displayed on screen and turns it into a **.pdf** or **.html** file (two **.jpg** images corresponding to the reference and subject windows are also created with the **.html** file). The report is therefore different for each of the Delta™ modes. Click on the **Report** icon in the Delta™ toolbar, or **Tools/Report** to access this function.

4 Processing data with the Delta™ modes

4.1 Landmarks

The placement of landmarks (markers) on an object's surface enables measurements to be taken and accurate alignment of two objects for comparison.

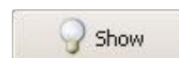
Select **View/Landmarks** or the **Landmarks** tab to view the landmark information. This tab displays the landmark number, color, visibility, the corresponding reference and subject landmark locations and the positional differences between them.

Registration (refer to Section 4.2) uses landmarks placed on both the reference and subjects' surfaces for accurate alignment. For an accurate registration to take place landmark position and order must be consistent between the reference and subject—this may require **Reordering** of some landmarks (Section 4.1.4).

4.1.1 Adding Landmarks

1. **Right-click the mouse** at the point on the object where the landmark is to be placed. This will reveal the landmark options pop-up menu (labeled **1** in Figure 4).
2. Select **New landmark here** and left-click the mouse. A new landmark will appear on the object at the point where the mouse was clicked.

4.1.2 Hide/Show Landmarks



1. **Right-click the mouse** on or near the desired landmark. This will reveal the landmark options pop-up menu (labeled **1** in Figure 4).
2. Select **Hide/Show Landmark** and left-click the mouse to hide or reveal the landmark.

Alternatively, check or uncheck the **Visible** box next to the appropriate landmark color in the Landmark information tab to perform this function.

Clicking on the **Show** icon to the right of the Landmarks tab will show or hide all of the landmarks at once. **Note:** A hidden landmark will have no influence on registration and at least three landmarks are required to be visible for registration.

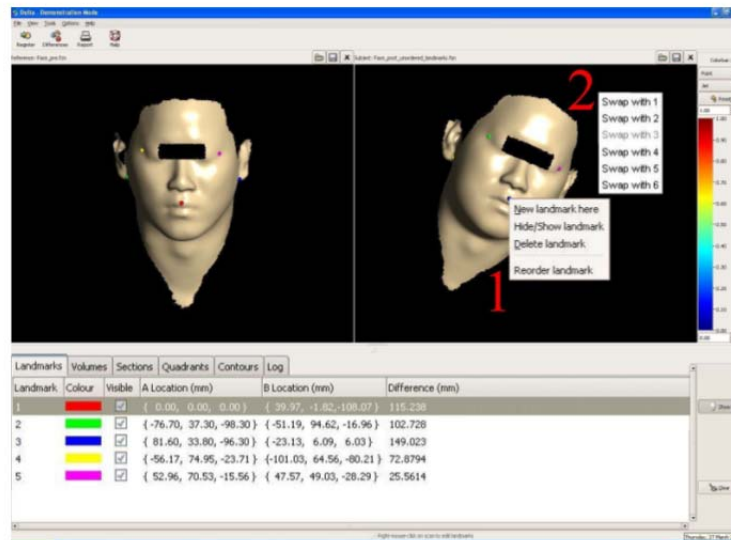


Figure 4: Landmark options (1) and Swap with (2) pop-up menus.

4.1.3 Deleting Landmarks



1. **Right-click the mouse** on or near the landmark to be deleted. This will reveal the landmark options pop-up menu (labeled 1 in Figure 4).
2. Select **Delete landmark** and **left-click the mouse**.

Clicking on the **Clear** icon to the right of the landmarks tab will delete all of the current landmarks, irrespective of their visibility.

4.1.4 Reordering Landmarks

The **Reorder landmark** function applies to the landmarks within the **Subject window** only.

1. **Right-click the mouse** on or near the landmark to be reordered. This will reveal the landmark options pop-up menu (labeled 1 in Figure 4). You can also **left-**

click the mouse on the desired landmark's **details within the Landmark tab** and then **right-click** to show the options.

2. Select **Reorder landmarks** and **left-click the mouse**. This will reveal the **Swap with** pop-up menu (labeled **2** in Figure 4).
3. Choose which landmark you wish to swap the selected landmark with and **left-click the mouse** on it.

To gain further knowledge of using Delta™ with Landmarks try **Tutorials 6.1.1** and **6.2.2**.

4.2 Registration and Data Alignment

In order for accurate comparison between two objects it is first necessary to ensure they are correctly aligned in the same coordinate space in the viewing windows, via the process of **Registration**. This is performed in combination with the **Landmarks** mode.

Registration attempts to accurately align an object in the subject window with another in the reference window and can be a one or two-step process. The first part of the process uses landmarks to produce a coarse registration, then the surface data itself can be used to complete a fine registration.

Note: Surface registration is optional but is on by default.

Landmark-based registration (**translation**, **rotation** and **scaling**) attempts to align the objects in each window using the landmarks, with or without scaling. The **scaling** option is isotropic (the same in each direction) and accounts for differences in the subject object to the reference object such as growth over time.

Surface registration is then performed as a refinement to the landmark-based registration and is achieved via an RBF (Radial Basis Function)-variant of ICP (iterative closest point). The surface registration uses circular surface patches around each landmark on the reference and subject scans to closer align the objects (the patches have a user-defined diameter). The accuracy (registration error) can also be set by the user.

An important feature of the two-step process is that it is less critical to get absolutely accurate landmark placement. Landmark-based registration is only as good as the ability to accurately define the landmarks and this is not always an easy task, especially if performed post original data collection.

4.2.1 Registering Objects



Place corresponding landmarks on the reference and subject objects' surfaces and ensure they are ordered correctly, i.e. are in the same positions (Section 4.1.4). **At least three landmarks are needed** for registration.

1. Click on the **Registration** button (on the Delta™ Toolbar), or **Tools/Register**, to open the Registration dialog box (Figure 5).
2. Select whether the landmark registration is performed with or without scaling (the default is without scaling).



Figure 5: The Registration dialog box.

3. Define the surface registration parameters: the patch diameter associated with each landmark (in millimeters or inches) and the desired accuracy that will halt the process (the default is 0.3 mm or 10 iterations, whatever comes first).
4. Click **Go** to start the registration. If the landmarks have been set appropriately the objects should move into the same alignment within their windows.

Note: Registration is performed using only the landmarks that are visible. Uncheck the **Visible** check boxes in order to hide landmarks that you do not wish to use in registration.

To gain further knowledge of Registering objects using Delta™ try **Tutorial 6.2.1**.

4.3 The Colorbar and Displaying Surface Differences

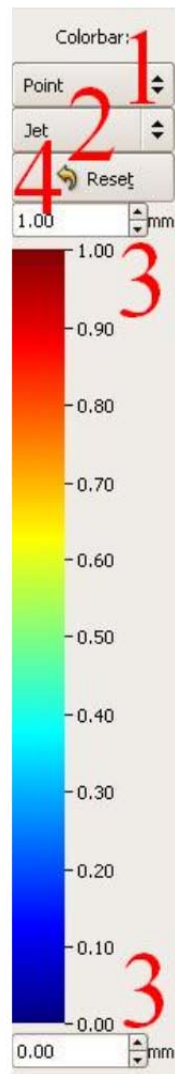


Figure 6: The Colorbar.

4.3.1 Colorbar Options and Displacement Mapping

The **Colorbar options** (1, 2, 3 & 4 in Figure 6) are used in conjunction with the **Differences** function to visually display the surface differences between the reference and subject objects. These options are also accessible by clicking on **View/Colorbar**.

Displacement mapping displays the surface of the object in the subject window as a gradient of color, **according to the displacement (+/- mm/inches) of the subject object's surface from that of the reference object's surface** (Section 4.3.3).

Displacement maps are only visible within the Landmarks, Volumes and Log tabs due to the scan being transparent in the other Delta™ modes.

4.3.2 Calculating the Displacement Map



Clicking on the **Differences** icon in the toolbar (also utilized through **Tools/Differences**) will calculate and display the displacement map on the surface of the on the object in the subject window, giving a visual representation of the surface differences between the reference and subject objects.

4.3.3 Displacement Map Display Type

The displacement map type (labeled **1** in Figure 6) can be defined using **Point-to-Point** or **Point-to-Surface** options. See Figure 7 for a visual example of these displacement map options.

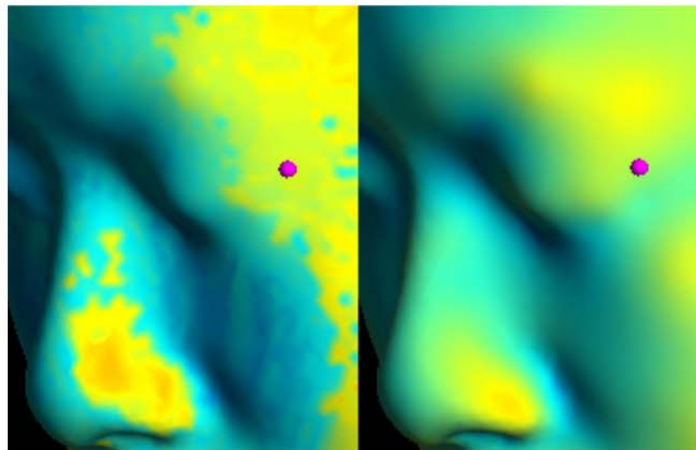


Figure 7: The two types of displacement map display: **Point-to-point** (left) and **Point-to-surface** (right). The Colorbar limits were set to ± 5 mm to accentuate the effect.

Point-to-point (default):

Point-to-point is the default setting. For every point in the subject scan the displacement is calculated as the distance to the nearest point in reference scan. The advantage of this method is that it is quick to calculate. The disadvantage is that even perfectly registered surfaces will give a non-zero displacement by virtue of the fact

that the surface is actually a mesh of discrete points, i.e. the points of the two scans will not in general coincide even if the surface does. Point-to-point mapping is best suited to scans of similar resolutions.

Point-to-surface:

For every point in the subject scan the displacement is calculated as the distance to the nearest part of the surface in the reference scan. This generally results in a more meaningful displacement map; a disadvantage is that depending on the size of the scan it may take a minute or more to calculate the necessary surface representation.

To gain further knowledge of using Delta's™ displacement map try **Tutorials 6.1.1, 6.2.1 and 6.2.4**.

4.3.4 Displacement Map Styles

The displacement map has four styles for the range of colors used: **Jet**, **Cool**, **Hot** and **Blue-Red** (Figure 8). Use the button (labeled **2** in Figure 6) to select the preferred choice.

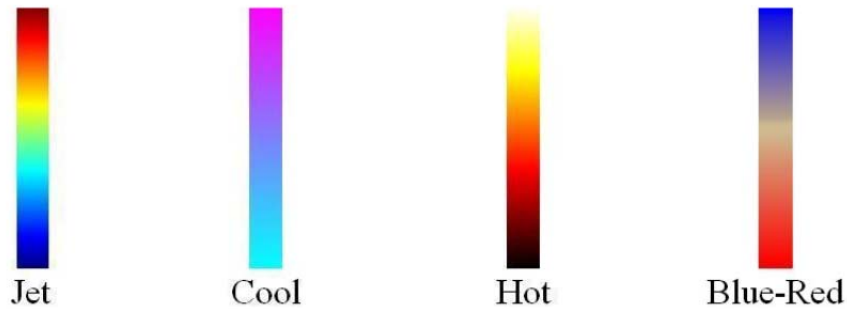


Figure 8: The four displacement map styles

4.3.5 Displacement Map Limits

The displacement map limits (labeled **3** in Figure 6) are automatically determined the first time the displacement map is displayed or whenever the **Reset** button (above the limits settings) is pressed, but can also be set by the user. The initial/reset limits are +/- the absolute value of the **greatest displacement calculated**. This can be artificially large as the extremities of one scan may not be associated with overlying or underlying portions from the other scan.

Note: If the limit is decreased below the maximum displacement then **all displacements within the range of the new limit to the maximum displacement will have the same color**. For example, if the maximum (positive) displacement was automatically calculated to be 16 mm and the positive limit was decreased to 10 mm, then all points in the subject scan with a displacement value between 10 mm and 16 mm will be the same color.

4.3.6 Reset (Displacement Map)

The **Reset** button (labeled **4** in Figure 6) changes the displacement map limits back to their initial settings (automatically determined when the displacement map is first calculated).

4.4 Volumes

Volumes can be calculated within user-defined regions/bounding boxes, giving volume information on areas of interest and changes or differences between objects.

The **Volume** tab displays the volume difference ($\text{cm}^3/\text{inches}^3$) between the reference and subject, as well as the volume box's number (region), visibility status, (absolute) volume ($\text{cm}^3/\text{inches}^3$), surface area ($\text{cm}^2/\text{inches}^2$) of the object within the volume box and the ratio of the volume to the area.

4.4.1 Calculating Volumes using Rectangular Bounding Boxes

Note: Volume boxes can only be defined in the subject (right) display window.

Figure 9 shows side on views of a volume box positioned on a reference object **(a)** and subject object **(b)**. Delta™ calculates the difference between the volumes of the boxes **(c)** (red shading)—this is the **Volume Diff ($\text{cm}^3/\text{inches}^3$)** displayed in the **Volumes** tab.

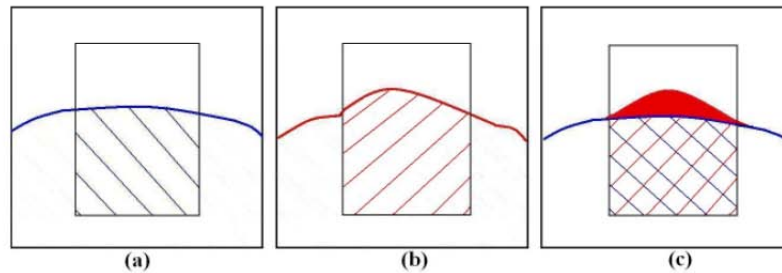


Figure 9: Volume box calculation: **(a)** a volume box applied to the reference scan; **(b)** the same volume box applied to the subject scan; **(c)** the red shaded area is the volume difference **(a)** and **(b)** superimposed)

To calculate the intra-surface volume and volume difference between reference and subject scans, as defined by a rectangular volume bounding box:

1. Ensure your reference scan and subject scan are registered (See Section 4.2)
2. Rotate the object in the **subject window** so that the region of interest is facing towards you.

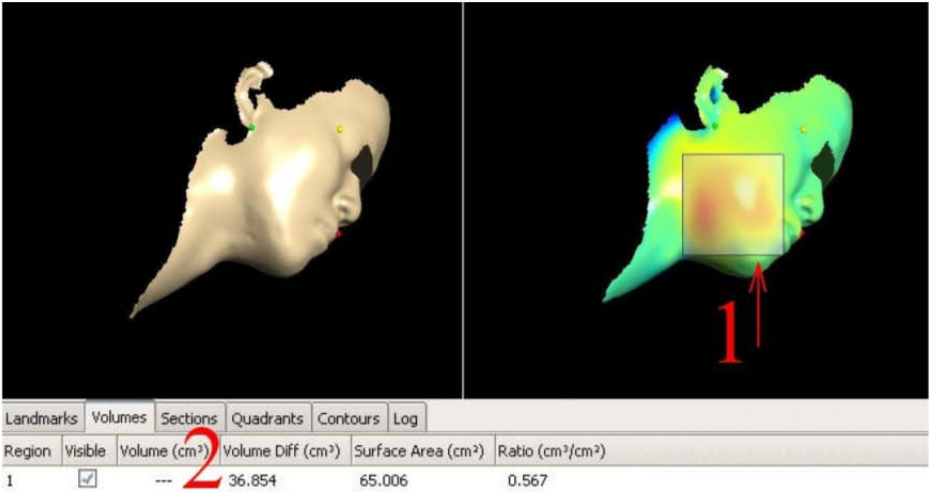
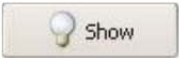


Figure 10: Volume calculation via application of a rectangular bounding box.

- 3. **Press and hold the Ctrl key and left-click the mouse** while dragging a rectangular shape across the region of interest (shown as **1** in Figure 10).
- 4. The volume difference between the subject and reference (within the volume box), the surface area of the subject within the volume box and the ratio of these two values are displayed in the **Volumes** tab below the display window (labeled **2** in Figure 10).
- 5. Rotating the objects will give a three-dimensional view of the extent of the region over which the area/volume is calculated.
- 6. Volume boxes can only be defined in the subject window. Additional volume boxes may be similarly defined on the same object at the same time (Figure 11), or at a point in the future.

Note: Trying to create too small a volume box may result in the volume box not being formed.

4.4.2 Hide/Show Volumes



Click the **Show** button to hide or show all of the volume boxes on an object. Check or uncheck the box next to each volume listed in the Volumes tab to hide or show individual volume boxes.

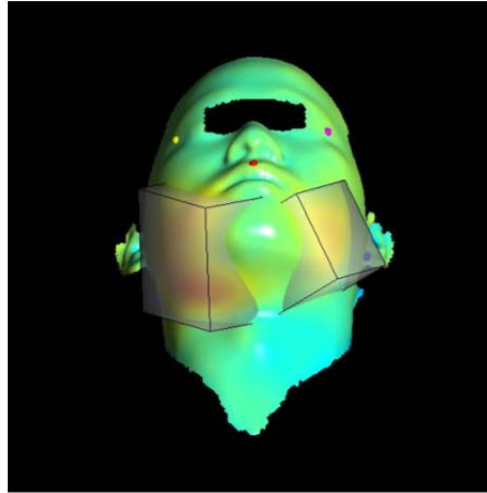


Figure 11: Volume calculation of two regions.

4.4.3 Deleting Volumes



Click the **Clear** button to delete all volume boxes from an object. **Right-click** the mouse on a volume box in the list in the Volumes tab and select **Delete volume** to delete an individual volume box.

4.4.4 Calculating Polygonal Volumes

Note: An RBF surface is required to gain a meaningful result when applying polygonal volume boxes.

To create an irregularly shaped volume box:

- Press **Ctrl** and **left-click the mouse** on each of the positions where you want the corners of the box to be. The individual sides of the box will appear as you do this.
- **Leave the (entire) last side of the polygonal box open** and **right-click the mouse** to bring up the pop-up menu (Figure 12). Click **close shape** to complete the last

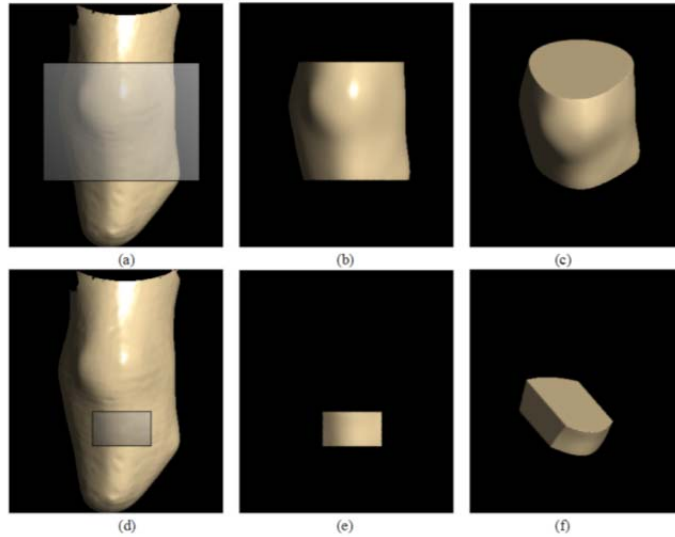


Figure 13: Absolute volume calculation for two different user defined bounding boxes (a and d). The volumes enclosed by the bounding boxes in (a) and (d) are illustrated in (b) and (c) and (at different orientations) in (e) and (f).

Clicking **Show Volume** will display **the part of the object used to calculate the most recent absolute volume** (this shows everything within the volume box and will include the part of the volume box beneath the object surface if the object is open). Clicking **Show Volume** again will revert to the original view, with the other volume boxes visible again.

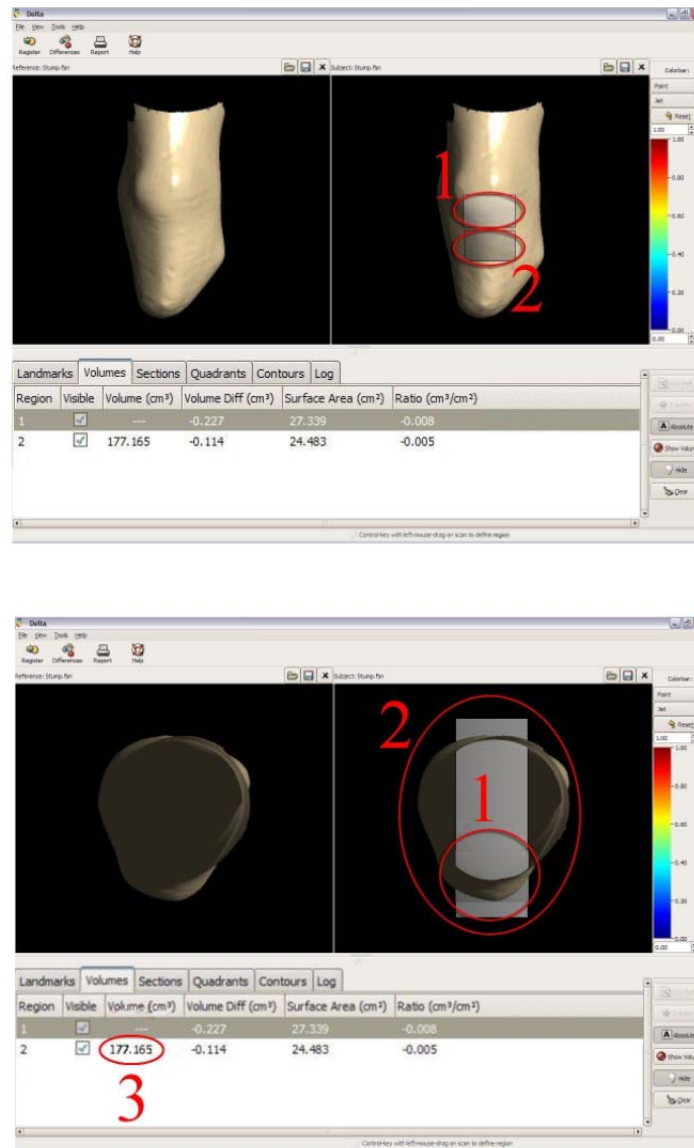


Figure 14: The regions labeled 1 and 2 (both pictures above) were defined in normal and absolute volumes mode respectively. Region 2 extends through the entire object (lower picture). Region 3 displays the absolute volume (cm³) of region 2.

4.4.6 Normal to Surface Volumes

Volume boxes with user defined dimensions can be placed at the point of definition on an object at a **normal to surface orientation** (i.e. perpendicular to the object's surface). This enables placement of multiple volume boxes with exactly the same dimensions.

1. **Right-click the mouse** within the subject window to bring up the **close shape** pop-up menu (Figure 12).
2. Select **volume box settings** to bring up the **Volume Box Settings** dialog box (Figure 15).

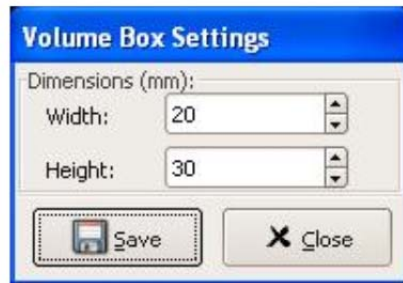


Figure 15: The Volume Box Settings dialog box

3. Enter the dimensions you require for your volume box into the **Width** and **Height** fields and press **Save**.
4. Now **Right-click the mouse** on the surface of the object in the subject window to bring up the **close shape** menu again.
5. Select **add normal volume**. A volume box with the previously defined dimensions will be applied at that point on the object's surface, normal to the surface.

4.5 Reference Surfaces and Scans

4.5.1 Creating a Reference Surface via Interpolation

Delta™ can be used to calculate the volume of a concavity or convexity by loading the object of interest into both the reference and subject windows, then interpolating over the concavity in the reference window and measuring the volume in the region of interest.

1. Load the scan data with the concavity or convexity into both the reference and subject windows.
2. In the **reference window** hold down **Ctrl** and **left-mouse click and drag** a rectangle across the concavity or convexity. Delta™ will interpolate across this area, covering the concavity or convexity and creating a smooth surface across it (labeled **1** in Figure 16).
3. In the **subject window** hold down **Ctrl** and **left-mouse click and drag** a rectangle across the concavity (alternatively click **Transfer** as in Section 4.5.2). This will create a volume box (labeled **2** in Figure 16).
4. The volume difference between the surfaces (the concavity and its interpolated “lid”) will be displayed in the **Volumes** tab (labeled **3** in Figure 16).

To gain further knowledge of using Delta™ for interpolating over and calculating the volume of a concavity try the exercises under **Tutorial 6.3**.

4.5.2 Transfer from Reference



To apply a volume box in the subject window based on the interpolated area in the reference window:

1. Click on the **Transfer** button. This brings up the **Transfer from Reference** dialog (Figure 17). Note that only the **Transfer from Reference** or top part of the dialog is relevant in this case—the **check box for this section should be automatically selected**. Setting the percentage to 100 generates a volume box that is the same size as the interpolation area, while smaller or larger values produce bounding boxes that are smaller or larger than the interpolation area.
2. The volume difference between the surfaces (the concavity and its interpolated “lid”) is displayed in the **Volumes** Tab.

Note: The interpolation and region defining tools are currently limited to rectangles and cuboid(s) respectively.

To gain further knowledge of creating and using a reference surface try **Tutorials 6.3.3 and 6.3.4.**

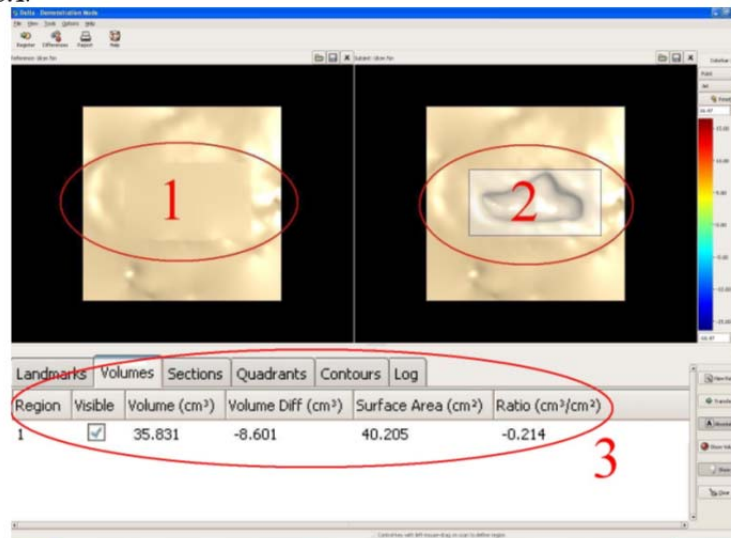


Figure 16: Volume calculation of a concavity.

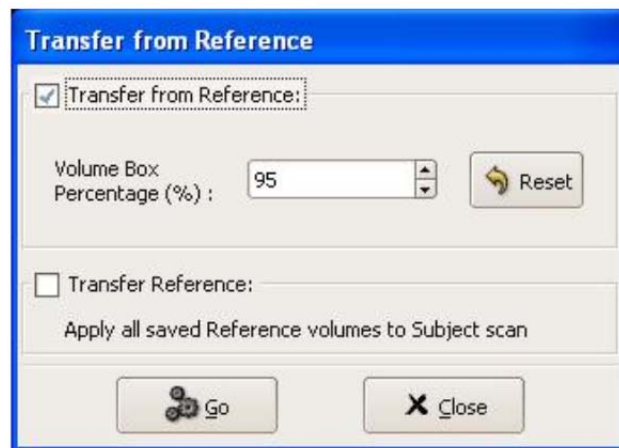


Figure 17: **Transfer (from) Reference** dialog box.

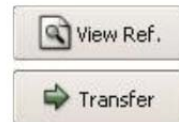
4.5.3 Creating a Reference Scan

Areas on some objects—such as a concavity—may change over time. In these cases it is useful to be able to **apply the same volume box to the original and subsequent surfaces for comparative volumetric measurements**. This is made possible by creating and using a **Reference scan**.

To create a reference scan:

1. Apply the desired volume boxes to the object in the subject window and interpolate over any areas of interest in the reference window.
2. Select **File/Save as Reference** (a tick will become visible to the left of it).
3. Save the object in the left display (reference) window. If the **Save as Reference** option is selected **after** the file is saved it will have **_REF** appended (also displayed above the reference window), e.g. **Ulcer.fsn will become Ulcer_REF.fsn**. The **reference scan** contains the interpolated surface and any volume bounding boxes defined in the subject window. This scan (and associated volume boxes) can now be reapplied at a later time (when loaded into the reference window).

4.5.4 Using a Reference Scan



To use the reference scan and apply the saved volumes:

1. Load the reference scan into the left display (reference) window.
2. Load the scan for comparison into the right display (subject) window.
3. To view the previously defined reference surface volume bounding boxes click the **View Ref.** button. This displays the previously saved volume bounding boxes as outlined in the reference window (Figure 18). This display can be turned off by pressing the **View Ref.** button again.
Note: Volumes applied from a **Reference** image appear as red in the subject window instead of the customary white (Figure 18).
4. To apply these volumes to the surface in the subject window click the **Transfer** button. This brings up the **Transfer from Reference** dialog box (Figure 19). In

this case it is the **Transfer Reference** section or **lower half** that is relevant - **the check box for this section should be automatically selected** and press **Go** to apply the saved volume box(es) to the subject object.

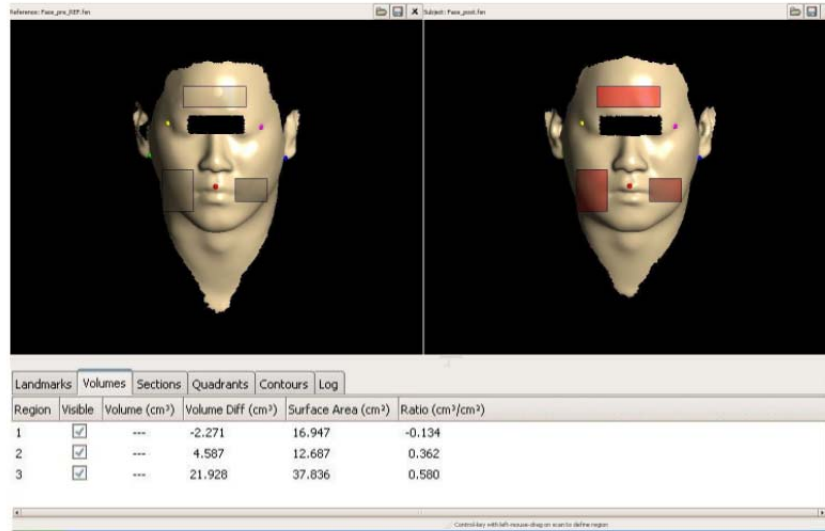


Figure 18: Reference volumes transferred to the object in the subject window.

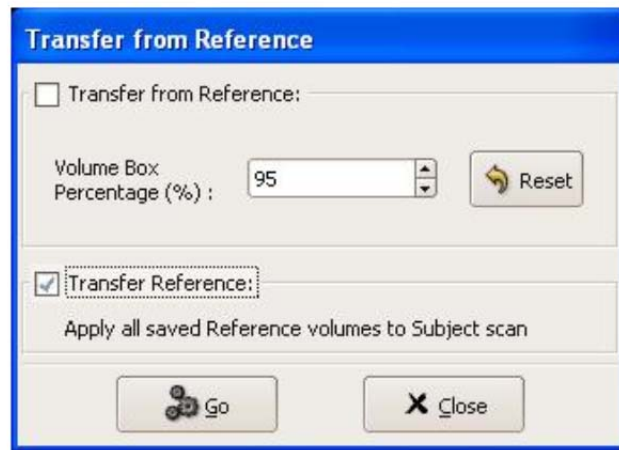


Figure 19: **Transfer Reference** dialog box.

4.6 Sections

In **Sections** mode a scanned surface is intersected by a user-defined cross-section plane. This displays as a contour around the data upon which the user can define point-to-point measurements.

The Sections information tab gives a point pair's number, visibility, reference pair locations, distance between the reference pair, the subject pair locations and the distance between the subject pair.

If the cross-section is closed the Anterior-Posterior (AP), Medial-Lateral (ML) and Circumference (C) values are calculated and displayed directly beneath each scan window (if the cross-section is not closed **Multiple or Open Section** is displayed). These values are calculated assuming that the front of the object is the point closest to the screen (which may not be the case).

Points can be placed by right-clicking the mouse in the reference or subject window and choosing **New point here**. Points can also be deleted and hidden/shown via this menu.

4.6.1 Creating a Cross Section



To create a desired cross-section plane:

1. Select **Sections** mode by clicking the **Sections** tab under the Display Windows (labeled 1 in Figure 20). The objects' surfaces become transparent and a white contour line appears on each, corresponding to the mid range level (with respect to the y-axis—the default cross-section plane). This plane remains fixed even as the surface is rotated, enabling the section to be viewed from all orientations.

Note: This mode can be entered even when the surfaces in each viewer are not registered (as in Figure 20), however the cross-section planes seen on each image will not match. Register the surfaces first (Section 4.2) for accurate comparison between the scan data.

Setting a new cross section also sets a new **Bounding Box**, to which the on screen image can be reoriented to.

2. To set a new cross-section plane **rotate the surface using the mouse and press the Set Axis button** (labeled 2 in Figure 20). This sets the cross-section plane to be perpendicular to the current vertical screen axis, at the mid range level position of the object.

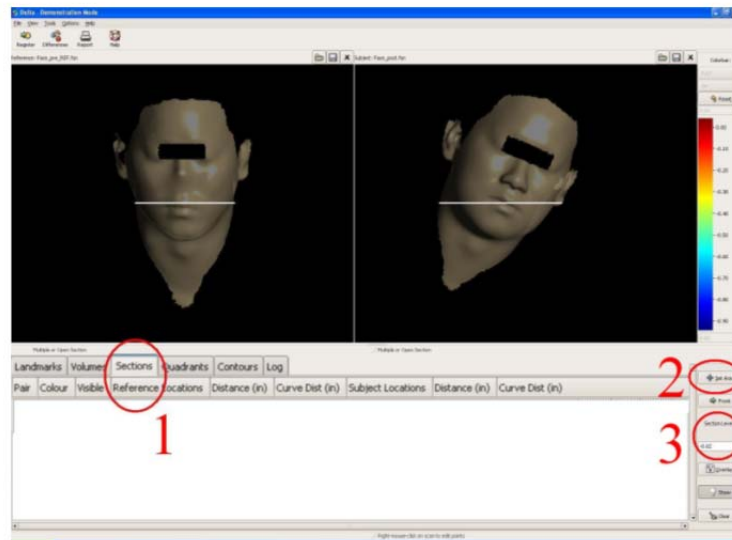


Figure 20: Sections mode for two unregistered surfaces.

3. Repeat this process until the cross section plane slices the surfaces in the desired location and orientation.
4. Once the cross-section plane has been defined it may be moved up and down the set vertical axis by using the **Section Level** control in the Sections panel (labeled 3 in Figure 20).

Note: Many file formats contain orientation information—pressing the **Front** button sets the front of the object's **Bounding Box** to the front of the screen.

4.6.2 Overlay Section



It is possible to overlay the reference cross section onto the subject cross section for direct comparison by pressing **Overlay** or **Ctrl+O**. The **reference cross section** appears as a red line in the subject window (Figure 21). Pressing **Overlay** or **Ctrl+O**

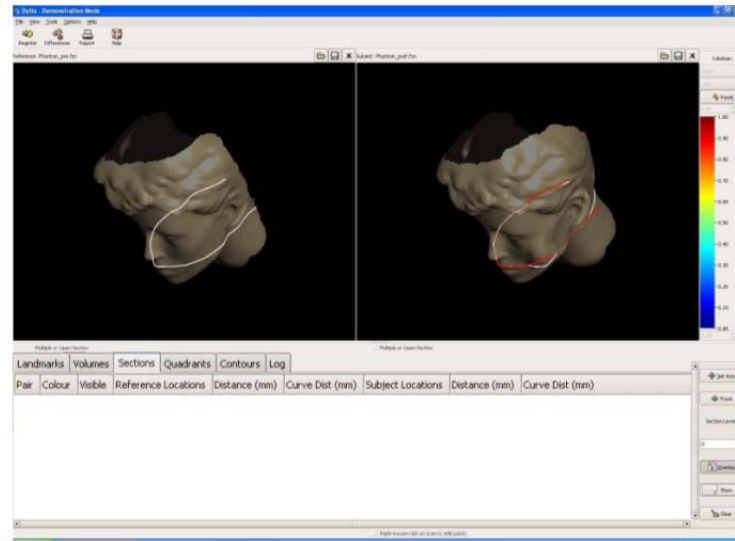


Figure 21: Reference section overlaid on the section in the Subject window.

again removes the reference section from the subject window.

4.6.3 Defining point-pairs on the Section

Right-clicking the mouse on the section through the object's surface opens a popup menu (labeled **1** in Figure 22) allowing the user to **add**, **delete**, **show** and **hide** points. A **line is drawn between each pair of points** and the corresponding (straight line) distance between these points is displayed in the Sections tab under the display window (labeled **2** in Figure 22). The distance between the points along the section curve is also shown (**3**)—note there are two values here—the first is the distance between the points in one direction; the second is the distance in the other direction. If the section is open along where the second measurement is being taken then **open** will be displayed in the information tab.

Select **New point here** to place a point. Repeat to place the corresponding point-pair.

Point-to-point measurements may be defined in either window. Figure 23 shows a second points-pair defined in the reference window and a points-pair that has been defined in the subject window, with the resulting distances shown in the Sections information tab.

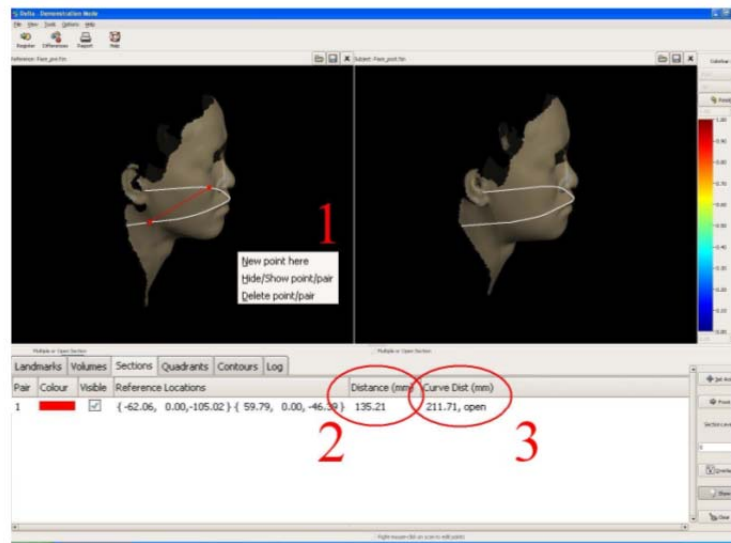


Figure 22: Point to point measurements on the cross section plane and the **point-pair** pop-up menu.

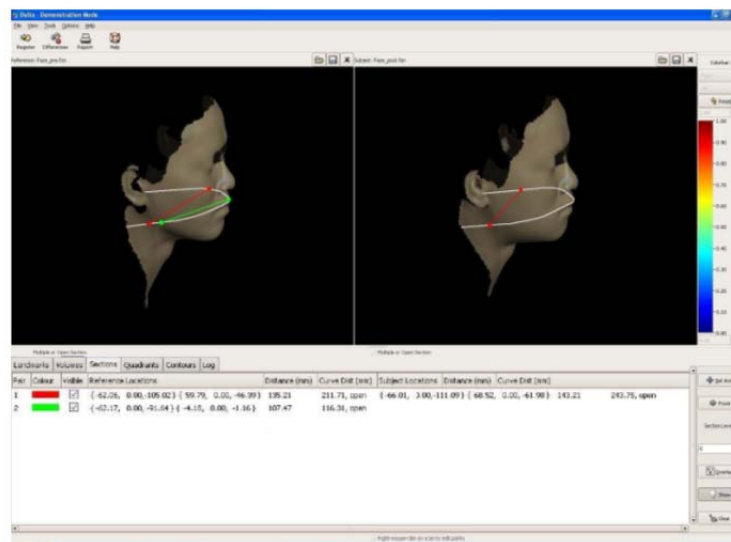


Figure 23: Multiple point to point measurements.

4.6.4 Hide/Show point-pairs



Click the **Show** button to hide or show the point-pairs on the section. Check or uncheck the box next to each point-pair listing in the Sections tab to hide or show individual point-pairs or **right-click** the mouse on one of the points on the object and select **H**ide/**S**how point/pair.

4.6.5 Deleting point-pairs



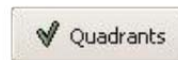
Click the **C**lear button to delete all point-pairs from the section. **Right-click** the mouse on a point-pair in the list in the Sections tab and select **D**elete **p**air to delete a point-pair. Alternatively **right-click** the mouse on one of the points on the object and select **D**elete **p**oint/**p**air. A single point can only be deleted if it is not part of a point-pair.

4.7 Quadrants

In Quadrants mode the surfaces are sliced by two additional cross section planes, perpendicular to the base plane set in Sections mode. These three planes define the quadrants volume boxes used for volume and surface area calculations. When viewed from the front the volume boxes will appear on top of the initial set axis, with only two being visible from this angle.

The total volumes for both the reference and the subject object quadrant boxes are calculated and the Quadrants tab window displays individual quadrant information (color, volume, percentage of total volume for each quadrant, and surface area). The two **Quadrant Levels** allow you to adjust the quadrant axes.

4.7.1 Applying Orthogonal Quadrants



1. In Sections mode set the base plane using the **Set Axis** button (labeled 1 in Figure 24) as in Section 4.6. The base plane can be moved up and down the set vertical axis using the Section Level control (labeled 2 in Figure 24). The quadrant volume boxes will appear above this base plane.

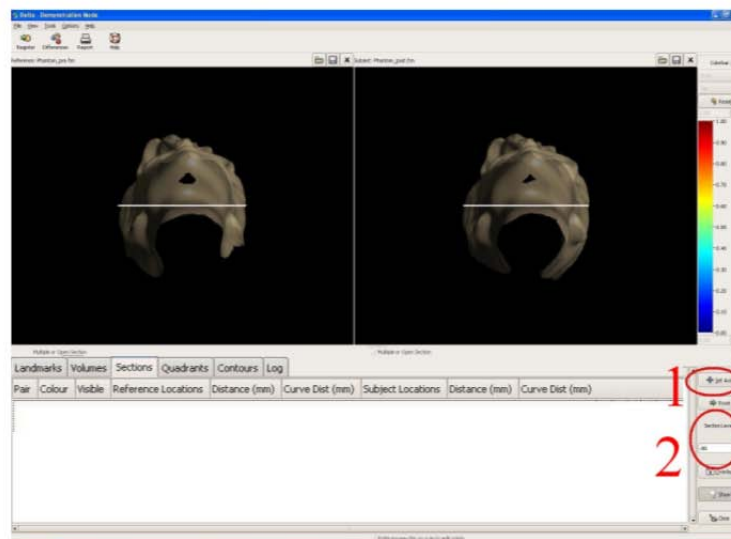


Figure 24: Setting the base plane.

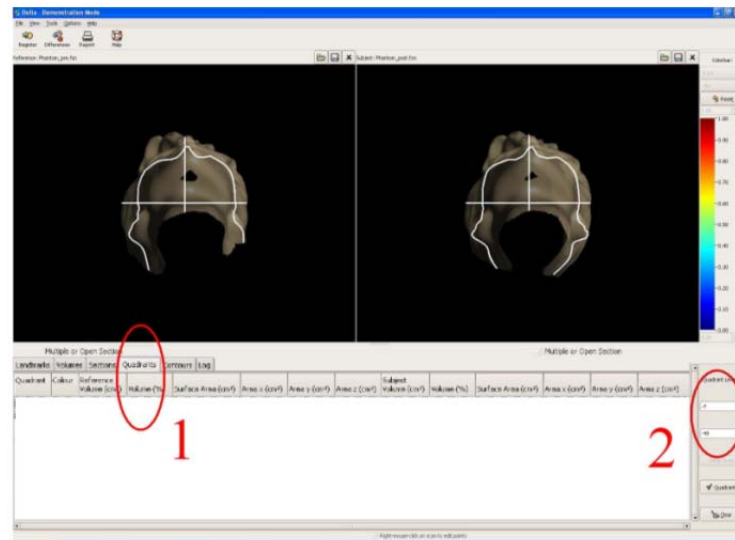


Figure 25: The additional cross section planes.

2. Enter Quadrants mode by selecting the Quadrants Tab under the display windows (labeled **1** in Figure 25). Two more cross section planes will appear, perpendicular to the base plane. These are set to mid range values by default.

3. These new cross section planes can be moved forwards, backwards and left to right to ensure correct positioning, using the controls on the right hand side of the quadrants tab (labeled **2** in Figure 25).

4. When the planes are positioned as desired press the **Quadrants** button (labeled **1** in Figure 26) to generate four quadrant volume boxes. The volume of the surface contained in each quadrant is displayed and each volume is represented as a percentage of the total of the four quadrants. The surface area and area per plane for each quadrant are also calculated and displayed in the Quadrants tab window.

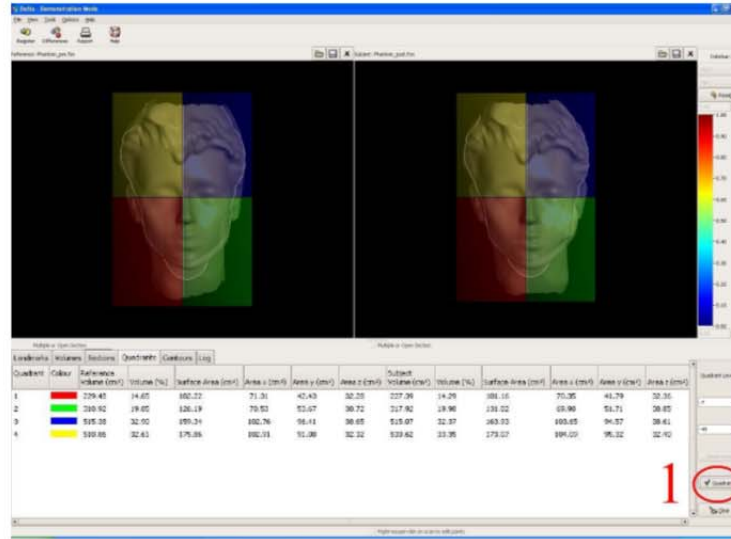


Figure 26: Quadrant boxes.

4.7.2 Quadrants with Variable Axes

Setup Axes

Quadrant axes may be moved away from 90° to each other (in the same plane) to create **Non Orthogonal Quadrants** via the **Use Variable Axes** option, accessed through **Options/Quadrants** in the Delta™ menu.

1. Set the desired base plane via the **Sections** tab (Section 4.6).
2. In the **Quadrants** tab select **Options/Quadrants/Use Variable Axes**.
3. Click the **Setup Axes** icon to the right of the Quadrants tab (labeled **1** in Figure 27). A yellow square will appear around the object with blue and red axes lines within it (Figure 27).
4. Hold the **Shift** key while **left-clicking and dragging** the mouse on the **red** or **blue** axes lines. Each axis line can be moved as a whole or the ends can be moved individually via the white spheres.
5. Press the **Quadrants** icon to the right of the Quadrants tab to view and calculate the quadrants (Figure 28).

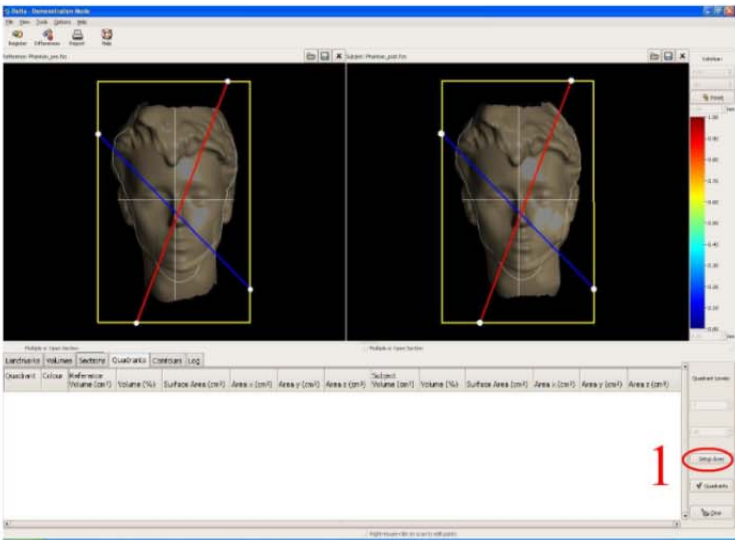


Figure 27: Setting the Variable Axes.

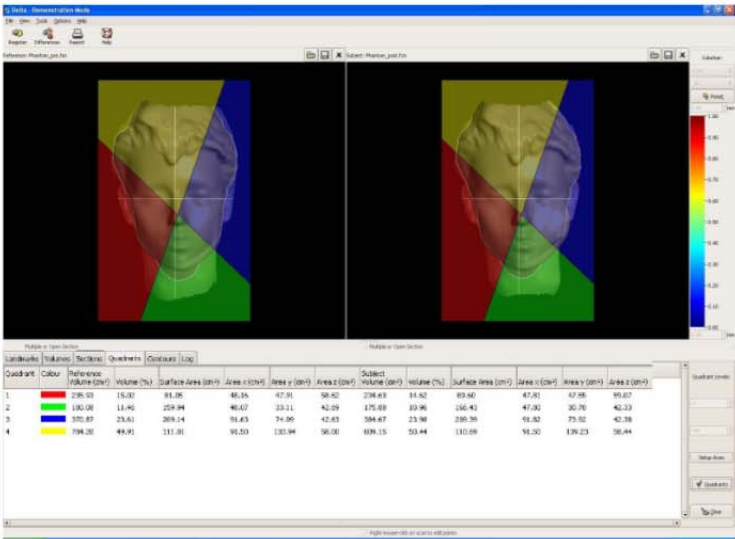


Figure 28: Quadrants using Variable Axes.

4.7.3 Deleting Quadrants



Click the Clear button to delete all quadrants from the object.

4.8 Contours

Contours mode is an extension of the Sections mode (4.6) that enables creation of multiple cross-sections upon an object, as well as calculation of distance measurements between any two points on the scan surface. A total circumference measurement will be given for a **closed** contour.

Contours operations can only be performed on the scan in the subject window.

4.8.1 Layout and controls

Figure 29 displays the components of the Contours mode window.

1. The reference and subject scan windows
2. The **contours information** window.
3. The **contours points information** window.
4. The contours **control panel**.

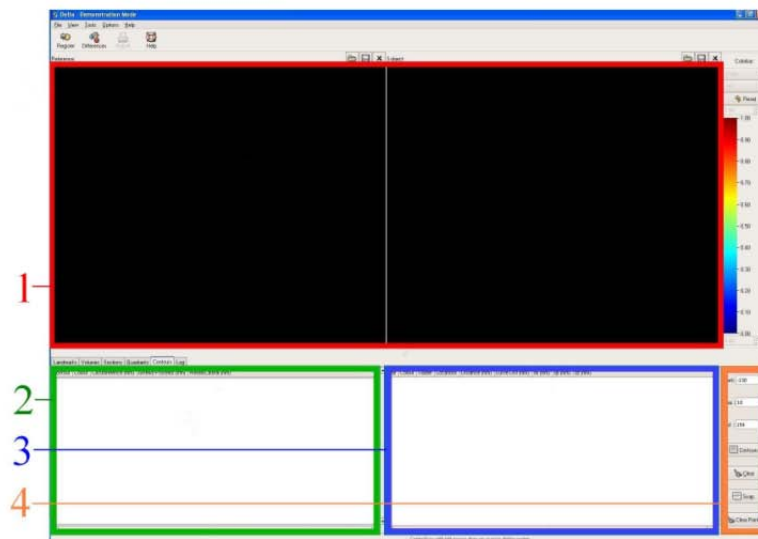


Figure 29: Contours mode layout



Figure 30: Contours pop-up menu

The pop-up content menu (Figure 30) is accessed by **right-clicking** the mouse at any point on the object and enables addition or removal of points and the addition of **individual** and **free** contours to the scan.

There are three methods for placing contours on the subject: **Stepped**, **Individual**, and **Free**.

4.8.2 Stepped Contours



Stepped contours are evenly spaced contours along the length of a vertical axis (the white center line in Figure 31) that runs perpendicular to the cross section plane, previously set in the **Sections** tab (Section 4.6). The **range of the contours** can be modified using the **Start** and **Stop** entries on the control panel and the distance between contours (mm or inches) is set with the **Step** entry.

Figure 31 shows stepped contours applied to a scan.

To place stepped contours:

1. Set the Axis as outlined in **Section 4.6**.
2. Set the contour range using the **Start** and **Stop** boxes on the Contours control panel.
3. Set the distance between adjacent contours using the **Step** box on the control panel.
4. Press the **Contours** button to apply the contours.

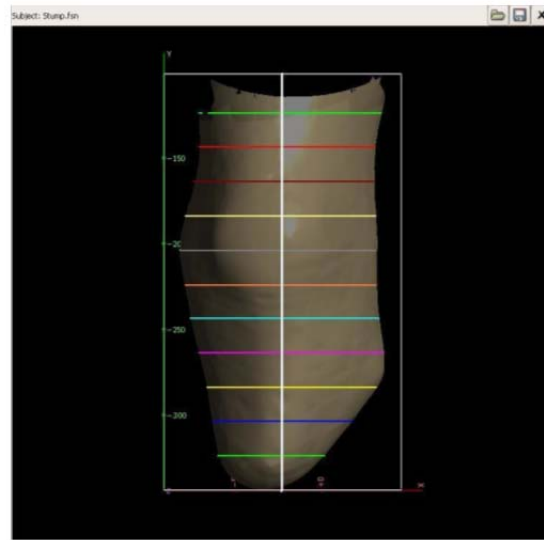


Figure 31: Stepped contours

4.8.3 Individual Free Contours

To place an individual horizontal or vertical free contour on the scan simply **right-click** the mouse on the point where the contour is required and select either **Vertical contour** or **Horizontal contour** from the pop-up menu (Figure 30). The contours are vertical/horizontal **with respect to the set axis** as shown in Figure 32.

4.8.4 Free Contours

Free contours allows the placement of a contour through arbitrarily assigned axis points on the object surface. To apply the **Free contour axis points** right-click the mouse on the object and select **Free contour axis point** from the pop-up menu. When the second axis point is set a contour will be applied through the pair.

Free contours can be applied with fixed or free axes—fixed axes contours will be applied with respect to the set axis while free contours will be applied with respect to the orientation of the object within the viewing window—see **Contour Options** (Section 4.8.5) for more information on free contour settings. Figure 33 has two free axis contours (yellow and blue) at different angles and orientations.

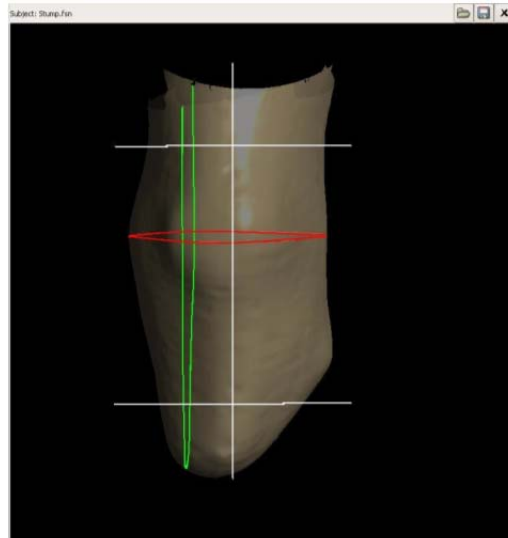


Figure 32: Scan with individual vertical and horizontal contours applied

Note: Clicking the **Contours** button and placing stepped contours onto the object will **automatically delete any individual and free contours** present.

To gain further knowledge of placing contours try **Tutorials 6.4, 6.4.2, 6.4.3, and 6.4.4.**

4.8.5 Contour Options

Under the **Options/Free Contours** menu there are variables for application of free contours.

- **Use Free Contours** enables the free contour options (**Vertical, Horizontal, Free Contour Axis Point**) when **right-clicking** the mouse.
- **Free Contour Axis** applies free contours **with respect to the current screen view** rather than the bounding box view (the previously set axis).
- The outer (white) measurement path of a contour can be enabled or disabled via **Options/**M**easurements/**S**how **C**omplete **C**ircumference.**

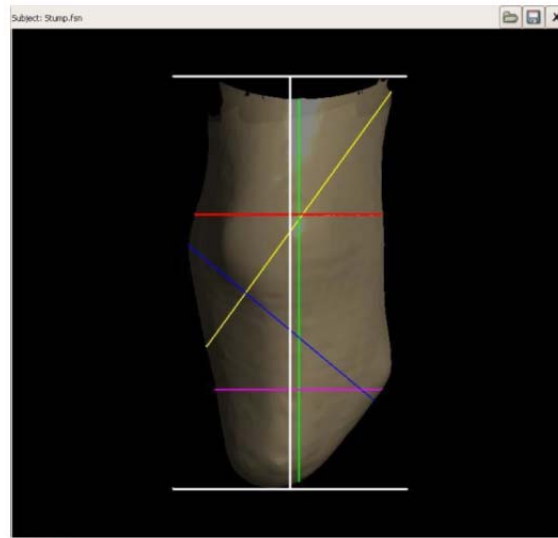


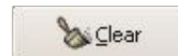
Figure 33: Scan with multiple individual and free contours applied

4.8.6 Contour Information

If a contour is **closed** the following information is displayed in the **Contours** tab.

- **Contour number**
- **Color**
- **Circumference** (or **Open Contour** if the contour is not closed/complete)
- **Anterior-posterior measurement**
- **Medial-lateral measurement**

4.8.7 Deleting Contours



Clicking the **Clear** button on the control panel will remove all contours from the scan.

4.8.8 Point-to-point measurements

Point-to-point measurements can be made using contour point pairs. To apply a point **right-click the mouse** in the desired location and select **New point here** from the pop-up menu. When a second point is positioned a colored line will be drawn between

Pair	Colour	Visible	Locations	Distance (mm)	Curve Dist (mm)	dx (mm)	dy (mm)	dz (mm)
1	■	<input checked="" type="checkbox"/>	{ 8.28,-207.32, 143.33 } { -71.23,-203.51, 127.03 }	81.26	112.04, 267.11	-79.52	3.81	-16.30
2	■	<input checked="" type="checkbox"/>	{ -22.16,-114.64, 154.29 } { -24.87,-206.81, 168.60 }	93.32	95.16, open	-2.72	-92.17	14.32
3	■	<input checked="" type="checkbox"/>	{ -7.08,-251.00, 140.60 } { 26.33,-251.00, 101.18 }	51.67	52.19, 277.23	33.42	0.00	-39.42

Figure 34: Point-to-point measurements

the two points and the associated measurements will appear in the contour point window. Figure 34 shows the point-to-point measurements for the three point pairs in Figure 35:

- **Pair** (number)
- **Colour**
- **Visibility** (hide/show the points)
- **Point locations** (x, y, z)
- **Distance** (Straight line distance between points)
- **Curve Dist** (Distance along the surface between points, in both directions)
- **dx, dy, dz** (Distance change in x, y & z between points in a pair)

The **Curve Dist** or column has two entries. The first is the distance **between the two points along the colored line**; the second is the distance **between the points along the white line**.

If the measurement path crosses over a hole or the scan is open, **Open** will be displayed instead of the second measurement. The outer (white) measurement path can be enabled or disabled via **Options/Measurements/Show Complete Circumference**.

4.8.9 Snap



The **Snap** function will snap any new points to the nearest contour. Select the **Snap** option and **right-click the mouse** near the contour of interest to place a point—the point will jump to the contour. If both points of a point pair are snapped to the same contour, the measurements will then be taken along that contour. To turn Snap on or off click on the **Snap** button in the control panel (alternatively use **View/Contours/Snap to Contours** or **Ctrl+N**).

4.8.10 Deleting Points

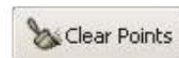




Figure 35: Point-pairs on an object

To delete an individual point/pair **right-click the mouse** on the appropriate row in the contour points information window, or on one of the actual points on the scan, and select **Delete point/pair**. To delete all points from the scan click **Clear Points** on the control panel. Points can also be hidden/shown via the right-click menu.

Figure 35 depicts a close up of the Stump.fsn sample file with three point-pairs and one contour applied to the object.

The first point-pair (red) is an example of a closed measurement, so there are two entries in the **Curve Dist (mm)** column (Figure 34). The first number is the distance measured along the (red) path of the contour inside the points and the second is the distance along the (white) path of the contour outside the points. The display of the outer path can be turned on/off using **Options/Measurement/Show Complete Circumference**.

The second point-pair (green) has been placed so that there is no complete outer path, therefore only the distance measured along the green curve appears in the **Curve Dist (mm)** column and **open** is displayed for the outer measurement.

The third point pair (blue points on the red contour) was applied with the Snap function turned on. The points snapped to the red contour and the curve distance measurements are taken along the contour in this case.

4.9 Log



The **Log** displays details regarding selected events that have taken place since Delta™ has been opened, including any problems that may have occurred.

Save Log:

Saves the log file as a text file for future reference.

Clear:

Deletes all entries from the log.

4.10 Saving objects in .fsn format with Delta™ modifications

Objects that have been modified in Delta™ and saved in **.fsn** format will retain their Delta™ applied changes, i.e. applied volume boxes, landmarks, quadrants etc will reappear the next time they are loaded into Delta™ (except modifications made in **Contours** mode).

4.11 Report



A report will provide a hard copy of the image on screen with all measurements associated with the current mode being used, in either **.pdf** or **.html** format. The report in **.html** format will also provide individual **.jpg** files of the reference and subject window images.

4.11.1 Creating a report

1. Click on the **Report** icon in the toolbar (also accessible through: **T**ools/**R**eport or **Ctrl+P**).

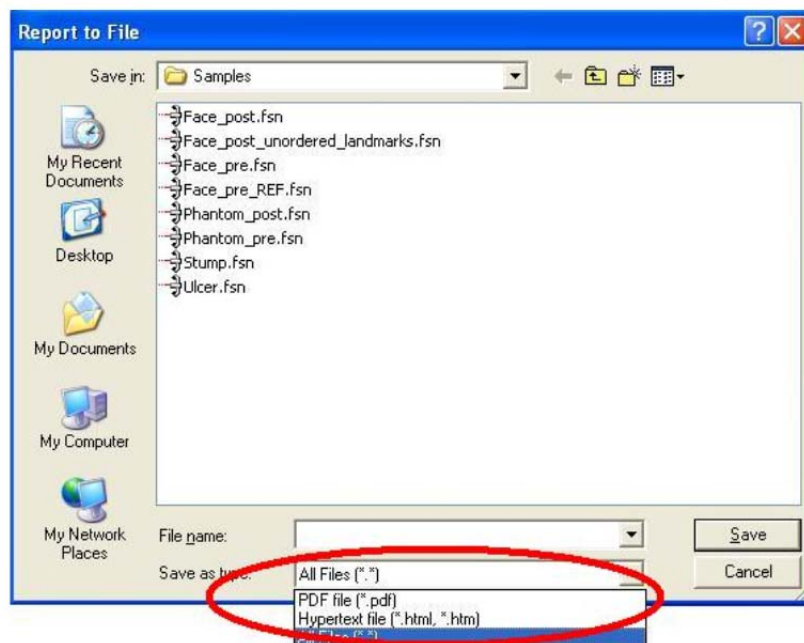


Figure 36: The Report to File dialog box

2. The **Report to File** dialog box will appear (Figure 36).

3. Choose the location where you wish to save the report, the report name and what format to save it in—.pdf or .html (circled in Figure 36).

4.11.2 Printing

Click on **T**ools/**S**ettings/**P**aper **S**ize to choose between the **A4** and **Letter** paper options.

4.12 Help

Help/**M**anual launches the Delta™ Manual in PDF format.

Help/**A**bout displays the version number of the software and license information.

5 Hotkeys & Special Functions

5.1 Hotkey List

Menu Item	Shortcut
<u>V</u> iew/ <u>V</u> iewpoint/ <u>C</u> enter	Insert
<u>V</u> iew/ <u>V</u> iewpoint/ <u>R</u> eset	Home
<u>V</u> iew/ <u>V</u> iewpoint/ <u>F</u> ront	F1
<u>V</u> iew/ <u>V</u> iewpoint/ <u>B</u> ottom	F2
<u>V</u> iew/ <u>V</u> iewpoint/ <u>L</u> eft	F3
<u>V</u> iew/ <u>V</u> olumes/ <u>A</u> bsolute	Ctrl+A
<u>V</u> iew/ <u>S</u> ections/ <u>S</u> et Axis	Ctrl+S
<u>V</u> iew/ <u>S</u> ection/ <u>F</u> ront	F1
<u>V</u> iew/ <u>S</u> ection/ <u>O</u> verlay	Ctrl+O
<u>V</u> iew/ <u>C</u> ontours/ <u>S</u> nap to Contours	Ctrl+N
<u>T</u> ools/ <u>R</u> egister	Ctrl+R
<u>T</u> ools/ <u>D</u> ifferences	Ctrl+D
<u>T</u> ools/ <u>R</u> eport	Ctrl+P

5.2 Special Functions

Function	Result
<u>R</u> otation (using the keyboard arrows)	
Rotation	30 ° rotation
Rotation+Shift	5 ° rotation
Rotation+Ctrl	1 ° rotation
Rotation+Shift+Ctrl	0.2 ° rotation
<u>T</u> ranslation (using the keyboard arrows+Alt)	
Translation	Coarse translation
Translation+Shift	Medium translation
Translation+Ctrl	Fine translation
Translation+Shift+Ctrl	Finest translation
<u>Z</u> oom	
Page Down	Zoom out
Page Up	Zoom in

6 Tutorials

6.1 Opening and Saving Scans Tutorial

Scans are opened and saved via the **Open** (folder) and **Save** (disk) icons directly above each display window (Section 3.2). The sample files can be found in the **Samples** directory below the Delta™ program directory, typically:
 \Program Files\Aranz Scanning\Delta\Samples.

6.1.1 Opening Scans

Click on the **Open** icon above each display window and from the samples directory load: **Face_pre.fsn** into the left display window and **Face_post_unordered_landmarks.fsn** into the right display window (Figure 37).

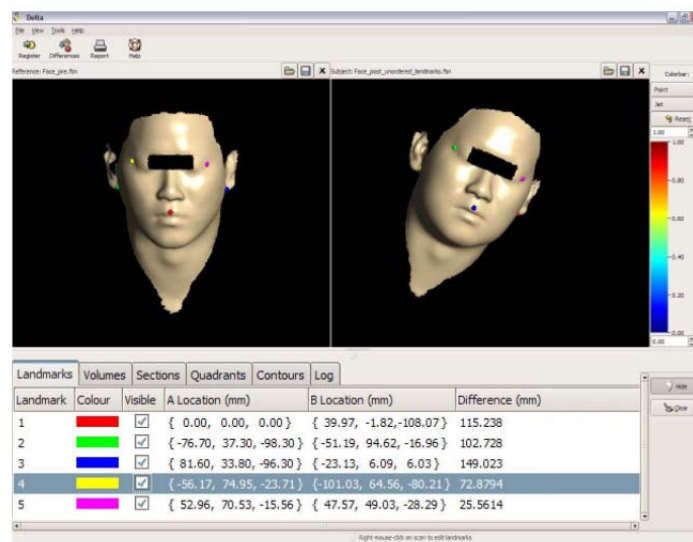


Figure 37: Loading two unregistered scans.

6.1.2 Saving Scans

Click on the **Save** icon above each display window. A dialog box will appear allowing you to choose where to save the scan and in which format to save it.

6.2 Registering Scans Tutorial

6.2.1 Sample scans for Registering

Load sample scans as per Section 6.1.1.

6.2.2 Reordering Landmarks

The landmarks in positions **1**, **2**, **3** and **4** in the Subject window (listed in the Landmarks tab) are different colors to the landmarks in the Reference window and must be reordered before registration. The blue and red landmarks, and the green and yellow landmarks, need to be swapped over.

1. **Right-clicking** the mouse on the blue landmark opens the landmark pop-up menu (labeled **1** in Figure 4). Select the **Reorder landmark** option to open a second pop-up menu listing the positions the blue landmark can be moved to (labeled **2** in Figure 4). Select **Swap with 1** to swap it with the red landmark.
2. Repeat for the yellow landmark and select **Swap with 2** to swap it with the green landmark.

Note: The landmarks can also be reordered by right clicking in the Landmarks tab on the colored row corresponding to the landmark to be moved. This also opens the pop-up menu (labeled **1** in Figure 4); selecting the Reorder landmark option again opens the second pop-up menu (labeled **2** in Figure 4) for swapping the landmarks.

6.2.3 Registration

Click the **Register** icon on the toolbar to open the **Register dialog box**. Click **Go** to start the registration process using the default settings.

6.2.4 Display the Displacement Map

Click on the **Differences** icon to calculate and display the displacement map, as shown in Figure 38.

Note: The distances (**Difference (mm)**) between the corresponding (registered) landmarks are displayed in the Landmarks tab and have decreased significantly post registration (Figures 37 and 38).

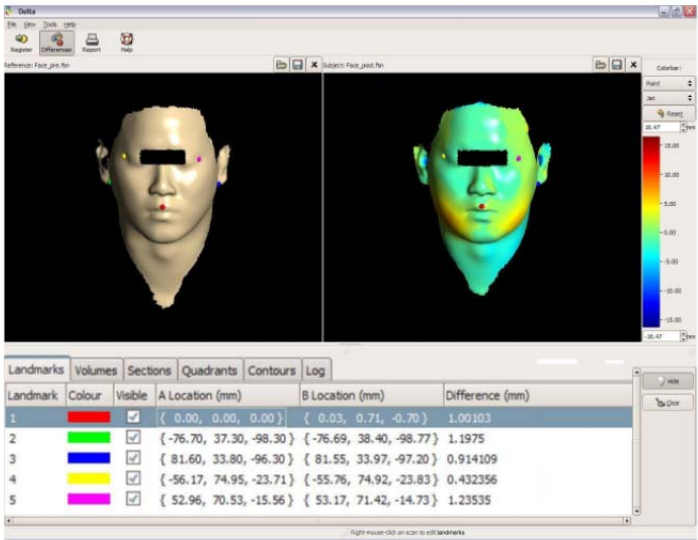


Figure 38: Color map display.

Changing the **color map displacement calculation** from **Point** to **Surface** generates the color map using point-to-surface calculations (Section 4.3.3). The figures in this tutorial were generated using the point-to-surface option.

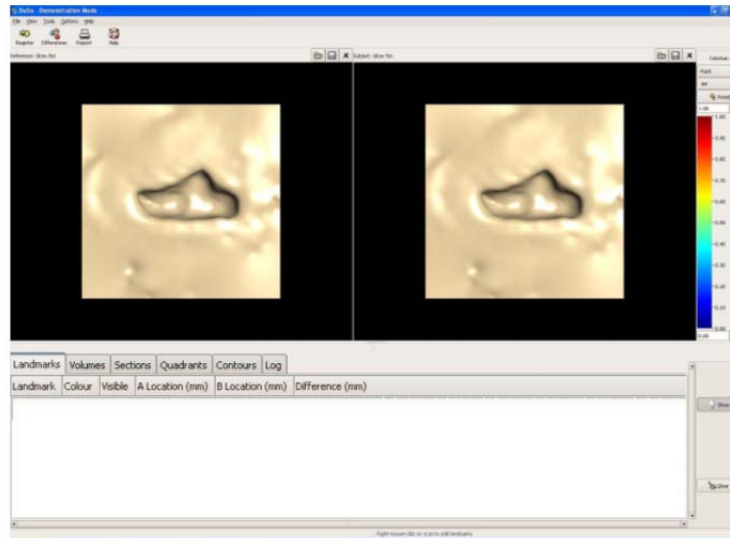


Figure 39: Loading in scans for volume calculation of a concavity.

6.3 Calculating the Volume of a Concavity Tutorial

By loading the same object into both the reference and subject windows Delta™ can be used to:

- Interpolate over a concavity or convexity in the reference window.
- Create a Reference surface.
- Define a region for volume calculation in the subject window.

Load **Ulcer.fsn** into both display windows (Figure 39) and select the **Volumes** tab.

6.3.1 Interpolating Over the Concavity

1. Orient the object so the concavity is towards you as in Figure 39.
2. In the left (reference) window, hold down the **Ctrl** key and **left-mouse-click and drag** to define a region that covers the entire concavity (labeled **1** in Figure 40).
3. Delta™ will interpolate over the concavity, creating a smooth surface.

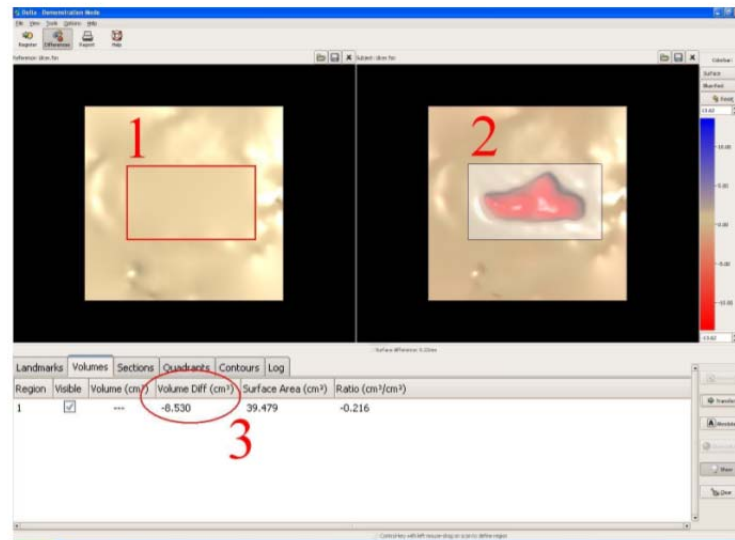


Figure 40: Interpolation (left display window) and region definition (right display window).

6.3.2 Volume Calculation

1. On the right (subject) window, hold down the **Ctrl** key and **left-mouse-click and drag** to define a region that covers the concavity (labeled 2 in Figure 40—alternatively click on **Transfer**: Section 4.5.2 and Figure 41).
2. The volume difference between the surfaces will be displayed in the Volumes tab (labeled 3 in Figure 40).

6.3.3 Creating a Reference Scan

Areas such as a concavity may change over time. In these cases it is useful to be able to **apply the same bounding box for volumetric measurements to the original and subsequent surfaces**. This is made possible by creating a **Reference scan**.

1. Complete the steps in Tutorials 6.3– 6.3.2 and also define any desired volume boxes in the subject window (Section 4.4.1).
2. Select the **Save as Reference** option from the file menu.



Figure 41: Volume boxes created using 95% and 105% of the interpolated area.

3. Save the surface in the left display (reference) window. This **Reference** (saved as **Ulcer.REF.fsn**) contains the interpolated surface and any volume bounding boxes defined in the subject window. The volumes on the reference scan can now be reapplied at a later time.

6.3.4 Using a Reference Scan

1. Load the reference image (**Ulcer.REF.fsn**) into the left display (reference) window.
2. Load the scan for comparison into the right display (subject) window.
3. To view the previously defined reference surface volume bounding boxes click the **View Ref.** button (labeled **1** in Figure 42). This displays the previously saved volume bounding boxes as outlined in the reference window (labeled **2** in Figure 42).
4. To apply these volumes to the surface in the subject window click the **Transfer** Button (labeled **3** in Figure 42). This brings up the **Transfer from Reference** dialog box. In this case it is the **Transfer Reference** section or lower half that is relevant - **ensure the check box is selected for this section** and press **Go** to apply the saved volume box(es) to the subject object (labeled **1** in Figure 43).

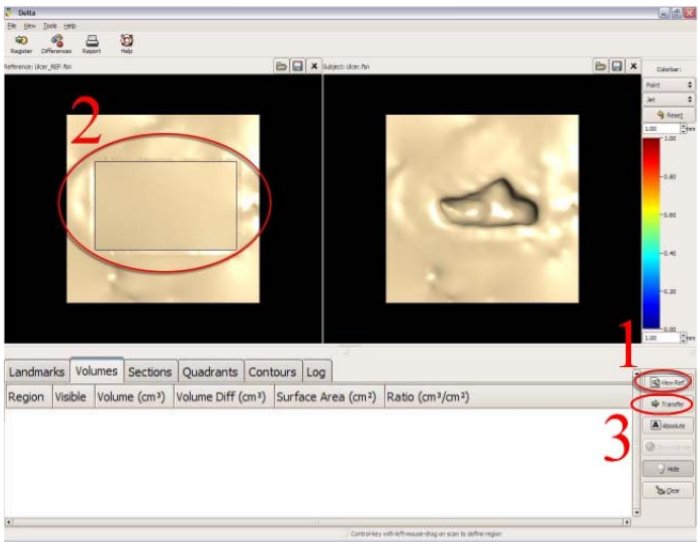


Figure 42: Viewing the reference surface bounding box.

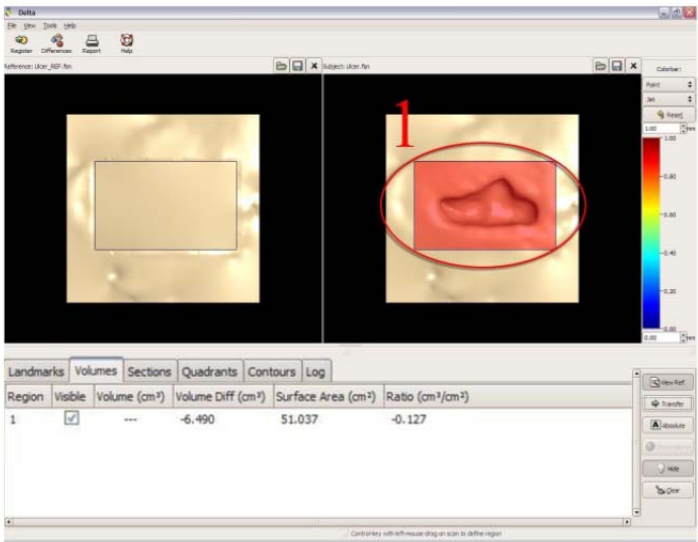


Figure 43: Applying the reference surface bounding boxes.

6.4 Contours and Point-to-Point Measurements Tutorial

This tutorial demonstrates how to use Delta™ to:

- Apply **stepped**, **individual**, and **free** contours to a scan.
- Take **point-to-point** measurements.

6.4.1 Loading a scan

In **Contours** mode all operations are performed **solely on the subject scan**.

For this tutorial open **Stump.fsn** into the subject window and select the **Contours** tab.

6.4.2 Stepped Contours

1. Adjust the range over which contours will be applied using the **Start** and **End** controls below the color bar. In this example Start is set to -300 and End to -150.
2. Set the **Step** size to 15 mm.
3. Press the **Contours** button to apply the contours.

Result: Contours 15 mm apart (11 in total) are applied across the **Start-to-End** range (Figure 44). The circumference, anterior-posterior and medial-lateral measurements for each contour are displayed in the **Contours** tab window.

Retry with a different **Step** size and view the resulting contours.

6.4.3 Individual Contours

1. **Right-click** the mouse on a point on the scan surface.
2. Select **Horizontal Contour** from the drop-down menu. A new horizontal contour will appear, running through the selected point on the surface (as in Figure 45).
3. **Right-click** on another point on the scan surface.
4. Select **Vertical Contour** from the menu. A vertical contour will appear, running through the selected point on the surface (as in Figure 45).

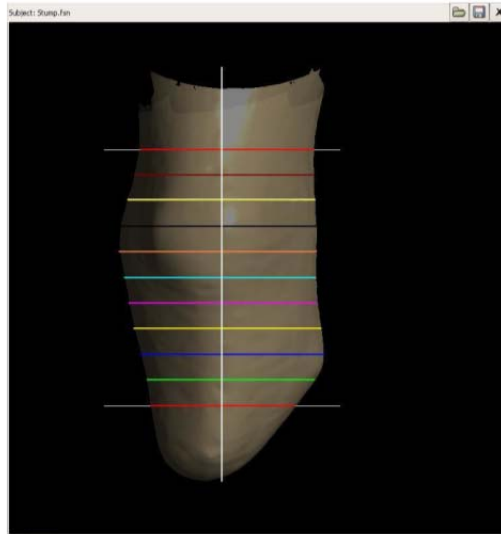


Figure 44: Stepped contours applied to the subject.

5. The various measurements of the individual contours appear in the **Contours** tab window.

6.4.4 Free Contours

1. **Right-click** the mouse on the object surface and select **Free contour axis point** to place the first axis point.
2. **Right-click** at another point and select **Free contour axis point** to place the second axis point. A contour is applied through the two axis points. See the **Contours** tab window for measurements.

Free Contour Axis Option:

Complete the following steps to see the effect this option has when applying free contours.

1. Select the **Options/Free Contours/Free Contour Axis**—it will then have a tick next to it.

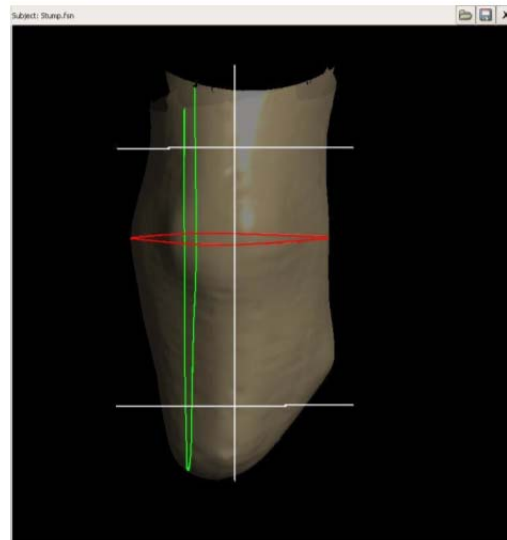


Figure 45: Individual contours applied to the subject.

2. Apply a vertical contour somewhere on the scan (Figure 46—red contour).
3. Rotate the subject in some way (e.g. press the left arrow key three times to rotate 90 degrees).
4. **Right-click** somewhere on the red vertical contour and choose **Free Contour Axis Point**.
5. **Right-click** at another point on the red vertical contour and choose **Free Contour Axis Point**. A free contour will be applied (Figure 47—green contour).
6. **Uncheck Free Contour Axis** in the options menu and repeat steps 4 and 5. A new contour (blue in Figure 48) will be applied with respect to the original bounding box, even though the view it was applied from was different.
7. Return to the original view (press the **Home** keyboard button or select **View/Viewpoint/Reset** (Figure 48)).

Result: Applying a contour with **Free Contour Axis** checked produces a contour oriented to match the current screen view. A contour applied with **Free Contour Axis** unchecked is oriented to match the front view of the subject with respect to its bounding box. Keeping the contour axes fixed is useful if a level contour is desired through two points, where one of the points is inaccessible from the front view of the scan (e.g. one point is on the reverse side of the object).

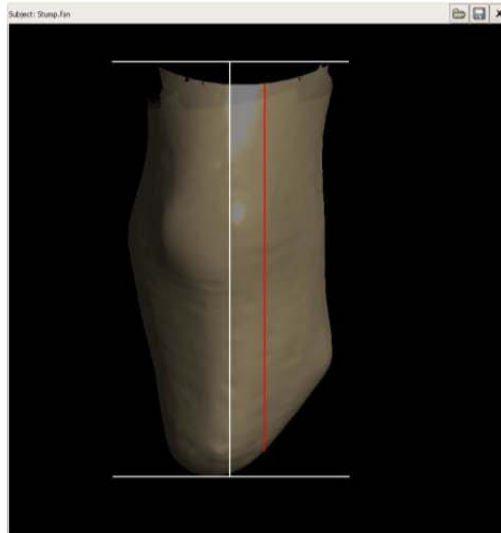


Figure 46: Step 2: Applied vertical contour.

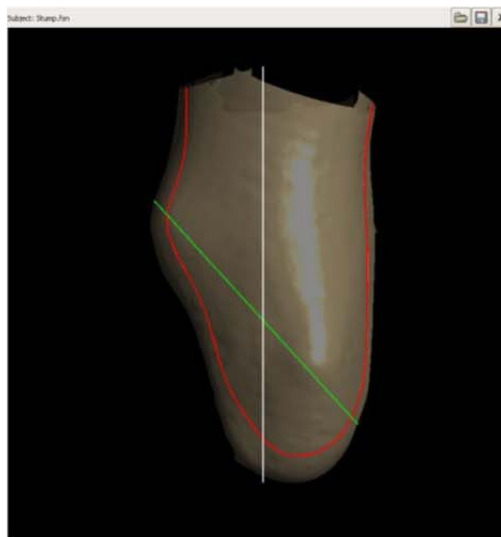


Figure 47: Step 5: Free contour (green) with **Free contour axis** checked, passing through a vertical contour (red).

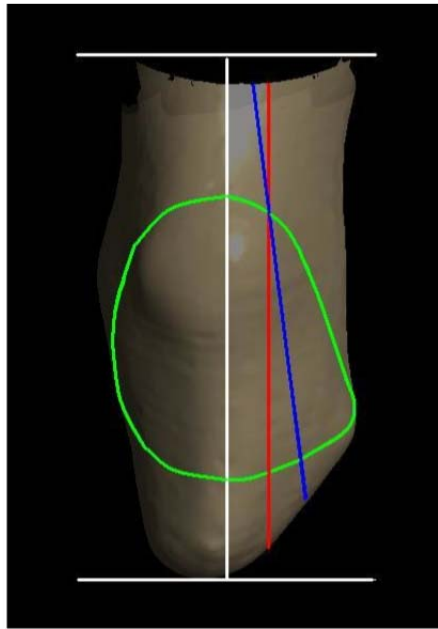


Figure 48: With **Free Axis Contour checked** the free axis contour (green) is aligned to the view it was applied from; with **Free Axis Contour unchecked** the (blue) **free axis contour** is aligned to the axes as set by the front of the bounding box (as is the applied **vertical contour** (red)).

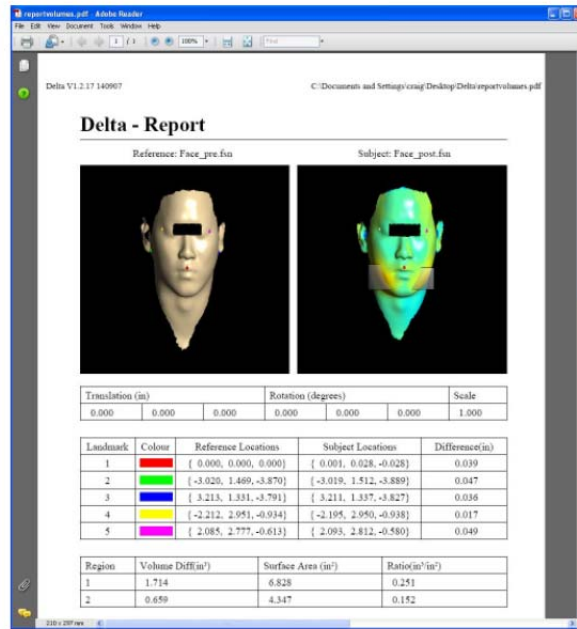


Figure 49: The Volumes tab reported as a PDF document.

6.5 Report Tutorial

6.5.1 Creating a Report (Volumes Tab)

1. Align the objects in the reference and subject windows and create volume boxes on them as outlined in Sections 4.2.1 & 4.4.1.
2. Click on the **Report** icon in the toolbar.
3. In the **Report to File** dialog box choose the location where you wish to save the report and the name for the report.
4. Under **Save as type:** select **PDF file (*.pdf)**.
5. The report will open automatically as a PDF document (Figure 49—you must have a PDF reader installed to view this). This document displays the reference and subject window images and all associated volumes and landmarks tab measurements that have been applied to the subject.
6. Repeat Steps 1–3, then under **Save as type:** select **Hypertext file (*.html, *.htm)**



Figure 50: The Volumes tab reported as an HTML document.

- The report will now display as a page in your web browser (Figure 50) with all relevant information (as in Step 5). Reporting as HTML also creates separate .jpg images of the reference and subject windows.

7 Reference

7.1 Transformation Conventions

Two objects are registered by performing a transformation on the scan in the Subject Display Window (via a translation, rotation and (optional) scale). The transformation is recorded in the Log Tab and three sets of figures are given: the landmark phase, surface registration phase and the two phases combined.

The numbers in each case are:

- A translation vector: $t = (t_x \ t_y \ t_z)^T$, in millimeters.
- A rotation vector: $r = (r_x \ r_y \ r_z)^T$, in degrees.
- A scalar scale factor: s , in millimeters

Such that:

- The coordinate system is right handed.
- The transformation is active, ie moving the object.
- Positive angles cause anticlockwise rotation of vector about the positive axis.

For any point, p , of the object in the subject display window, it is transformed as follows:

$$q = t + s \cdot R \cdot p$$

such that q , t , p are column vectors which are pre-multiplied by the rotation matrix, R , where

$$R = R_z \cdot R_y \cdot R_x$$

and

$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(r_x) & -\sin(r_x) \\ 0 & \sin(r_x) & \cos(r_x) \end{bmatrix}$$

$$R_y = \begin{bmatrix} \cos(r_y) & 0 & \sin(r_y) \\ 0 & 1 & 0 \\ -\sin(r_y) & 0 & \cos(r_y) \end{bmatrix}$$

$$R_z = \begin{bmatrix} \cos(r_z) & -\sin(r_z) & 0 \\ \sin(r_z) & \cos(r_z) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

APPENDIXC:

TERMS AND CONCEPTS

Bias of an estimator: Bias is measured as the average difference between an estimator and the true value of the parameter that it tries to estimate, for finite samples. If this difference is nonzero, the estimator is biased.

Consistency of an estimator: An estimator is considered to be consistent if the estimator converges to the true value of the parameter as the sample size increases. Estimators that do not converge to the true value as the sample size increases are inconsistent estimators of the given parameter. It seems natural that as sample size increases, the estimation of certain population quantities should improve, becoming more and more representative of the true value. When this is not the case, it is due to inconsistency of the estimators. Consistency is generally considered an essential property of any estimator. Also, an estimator cannot be efficient if it is inconsistent.

Effect size and confidence intervals: In most practical situations, simple testing for the presence of an effect is not enough. An estimator of the magnitude of the effect (effect size) and the uncertainty associated with that estimator is necessary. Confidence intervals provide this information. This is one of the reasons why most statisticians prefer reporting confidence intervals for the difference in means, rather than simply testing whether or not the difference in the means is zero (Agresti, 1989).

Efficiency of an estimator: An estimator is considered efficient if it has the smallest (asymptotic) variance among all consistent estimators.

Euclidean space: In geometry, a two – or three – dimensional space in which the axioms and postulates of Euclidean geometry apply, a space in any finite number of dimensions, in which points are designated by coordinates (one for each dimension) and the distance between two points is given by a distance formula (Encyclopedia Britannica).

Maximum likelihood: This is the value of the parameter that makes the observed data most likely (for details, see Casella and Berger, 1990).

Method: A method is any technique used in estimating the parameters of a model (see below) and in further analysis such as hypothesis testing, pattern recognition, or calculation of confidence intervals.

Method of moments: This is the value of the parameter that equates the sample moments to the population moments (for details, see Casella and Berger, 1990).

Model: In the context of this thesis, a model, is a mathematical construct that attempts to characterize certain aspects of the underlying phenomena (e.g., dimensions, dynamics, properties, or interactions). This mathematical construct includes quantities called parameters that are estimated for each sample under consideration.

Nonconvergence: By nonconvergence in this instance, we mean that the optimization algorithm of specific computer routines is unable to find the maximum.

Non-Euclidean space: A space that is not Euclidean. For example, a space defined by the surface of a sphere is a non-Euclidean space.

Nuisance Factors: An unwanted element that gives trouble and vexation; something that is offensive or noxious to the original data.

Power of a statistical test: The power of a statistical test corresponds to the probability of rejecting a null hypothesis when it is false. A uniformly most powerful (UMP) test is a test that has most power among all valid tests.

Shape: Shape is “external form or contour; that quality of material object (or geometrical figure) which depends on constant relations of position and proportionate distance among all the points composing its outline or its external surface.” Shape of a form and the

definition of shape can change when a different size measure is used to standardize the forms under study (Oxford English Dictionary compact edition, 1971).

Size: Size is “the magnitude, bulk, bigness, or dimensions of anything.” Different surrogates can be chosen as measures for size. This choice affects the comparison of size of forms, and the operational definition of shape as the latter definition is dependent on the chosen surrogate for size (Oxford English Dictionary compact edition, 1971).

Validity of a statistical test: A statistical test is considered valid provided the true probability of type I error (the probability of rejecting a hypothesis when it is true) is equal to the specified probability of the type I error. Tests must be valid before one can compare their powers. For example, the usual two-sample t-test that assumes equal variances in the two populations is invalid if the population variances are not equal. It would make little sense to compare powers of two statistical approaches if one of them is invalid.

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