**Which methods of measuring the soft tissue landmarks of the human face are accurate and precise enough for clinical use? A systematic review.**

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1. **Abstract**

**Introduction**

A systematic review of literature to which methods of measuring soft tissue landmarks of the human face are accurate and precise enough for clinical use.

**Aims and Objectives**

A systematic literature review of accuracy and precision of methods to measure soft tissue landmarks of the face with an accuracy and precision under 1mm.

**Methods**

This review searched Embase, Medline and Cochrane Library databases following the PRISMA guidelines. Records were assessed for risk of bias using QUADAS2. Methods included computed tomography, cone beam computed tomography, magnetic resonance imaging, ultrasonography, physical impressions direct anthropometry and optical methods: 2D/Conventional photography, 3D active, 3D passive, 3D confocal and 3D time-of-flight.

**Results**

7609 studies were identified, and 18 final papers included.

Support for computed tomography, magnetic resonance imaging, ultrasonography, physical impressions, direct anthropometry, 3D confocal or 3D time-of-flight methods was absent (n=0).

Optical Methods: 2D photography, 3D active, 3D passive, 3D Confocal and 3D Time-of-Flight were investigated by 18 records. The 2D photography method had support for precision of measurements in the periorbital area (n=1) and poor evidence for accuracy of measurements in lateral areas of the face (n=1). Optical 3D active and passive methods (n=19) had limited support for accuracy with more support for precision.

**Conclusion**

Support for accuracy and precision of computed tomography, cone beam computed tomography, magnetic resonance imaging, ultrasonography, physical impressions, direct anthropometry, optical 3D confocal or optical 3D time-of-flight methods is absent or inconclusive regarding measurements of face features. 2D photography has support for accuracy and precision in the peri-ocular area. There is limited support for 3D optical passive and active method accuracy with increased support for precision.

**Contents Page Number**

1. Abstract Page 2
2. List of figures Page 7
3. List of tables Page 7
4. Research question Page 9
5. Aims and objectives Page 9
6. Null hypothesis Page 9
7. Introduction Page 9
   1. Nomenclature Page 10
   2. Anatomy and perception Page 15
   3. Clinical accuracy and precision Page 17
   4. Statistical analysis Page 20
   5. Methods of measurement Page 25
      1. Computed tomography Page 26
      2. Cone beam computed tomography Page 27
      3. Magnetic resonance imaging Page 28
      4. Ultrasonography Page 29
      5. Physical impressions Page 29
      6. Direct anthropometry Page 30
      7. Optical methods Page 30
8. Methods Page 34

8.1 Information sources and search Page 35

8.2 Inclusion criteria Page 35

8.3 Exclusion criteria Page 39

8.4 Study selection Page 40

8.5 Data extraction Page 40

8.6 Risk of bias assessment Page 40

8.7 Analysis of sub-groups Page 40

1. Results Page 42
   1. Information sources, search,

application of inclusion and exclusion

criteria and study selection Page 42

* 1. Risk of bias assessment Page 44
  2. Data extraction Page 46
  3. Analysis of sub-groups Page 46
  4. Computed tomography Page 47
  5. Cone beam computed tomography Page 47
  6. Magnetic resonance imaging Page 48
  7. Ultrasonography Page 48
  8. Physical impressions Page 48
  9. Direct anthropometry Page 48
  10. Optical methods Page 49

9.11.1 2D photography Page 49

9.11.2 3D active optical method Page 51

* + 1. 3D Passive optical method Page 56

9.11.4 3D Confocal optical method Page 60

* + 1. 3D time-of-flight optical method Page 61

1. Discussion Page 61
   1. Cone beam computed tomography Page 65
   2. Direct anthropometry Page 66
   3. Optical methods Page 66

10.3.1 2D photography Page 67

10.3.2 3D active optical method Page 68

10.3.3 3D passive optical method Page 70

11. Conclusion Page 71

12. Areas for Further Research Page 72

13. Reference List Page 74

14. Appendix One Page 92

15. Appendix Two Page 93

1. **List of Figures**

Figure 1 Anthropometry soft tissue landmarks. Page 14

Figure 2 The mask of Warka. Page 16

Figure 3 Mixed reality Page 17

Figure 4 A computed tomography acquisition machine. Page 27

Figure 5 Vectra XT, Canfield USA, acquisition machine Page 33

Figure 6 Information flow of systematic review Page 43

1. **List of Tables**

Table 1 Anthropometry soft tissue landmarks. Page 14

Table 2 Sources of errors Page 19

Table 3 Statistical analyses techniques and concepts Page 25

Table 4 Methods to measure soft tissue landmarks Page 26

Table 5 PICO identification of criteria Page 35

Table 6 Concepts and related keywords Page 37

Table 7 Concepts mapped to subject headings

and sub-headings Page 39

Table 8 Initial assessment of record structure Page 42

Table 9 QUADAS 2 bias assessment of records Page 45

Table 10 Methods of measuring soft tissue landmarks Page 62

Table 11 Reference methods. Page 64

1. **Research Question**

Which methods of measuring the human face are clinically accurate and precise to a level of 1mm?

1. **Aims and Objectives**

A qualitative systematic literature review of accuracy and precision of methods to measure soft tissue landmarks of the face.

1. **Null Hypothesis**

All methods of measuring the human face are clinically accurate and precise.

1. **Introduction**

Assessment of the surface anatomy of the human face in three dimensions is prevalent in medicine, dentistry, entertainment and fashion, art, security and forensics, anthropology and large-volume data collection and processing industries (De Silveira et al, 2003; Gokberg et al, 2009). Technology is allowing the surface measurements of the human face to be gathered at increasing speed, decreasing cost and with minimum inconvenience to the person being assessed (Heike et al, 2010; Verhoeven et al 2013).

Within the field of dentistry, measurements of the soft tissue landmarks may be used in the fields of orthodontics, dental digital smile design in prosthodontics, prosthetic rehabilitation and in the fields of plastic and aesthetic surgery (Heike et al, 2010).

It would be very convenient for the patient and clinician to be able to measure face dimensions in a quick, accurate, reliable and non-invasive manner. Some argue this is essential (Riphagen et al, 2008).

**7.1 Nomenclature**

The nomenclature in the field is varied when referring to soft tissue landmarks of the face. Soft tissue landmarks may be referred to as surface topology, metrology, profilometry, features, cranio-facial metrics and surface heights to name a few. This systematic review of the literature shall assume the phrase “soft tissue landmarks” to encompass all of the above. Colour assessment and surface texture of the human face is beyond the remit of this review.

Each soft tissue landmark may have different names in the literature. It has been decided to refer to soft tissue landmarks in this review using standardised nomenclature for craniofacial anthropometry soft tissue landmarks (Caple and Stephan, 2016). See Figure 1. Many records referred to landmarks not included in the article by Caple and Stephen. These landmarks and any subsequent calculations were excluded from this review to allow a level of comparison of records. Soft tissue landmarks with gross variability were excluded, for example soft tissue trichion, tr’, and more minor soft tissue landmarks in peri-ocular and nose areas such as soft tissue columella, c’.

|  |  |  |  |
| --- | --- | --- | --- |
| **Soft Tissue Landmark** | **Abbreviation** | **Description** | |
| alar | al’ | Most lateral point on the nasal ala | |
| chelion | ch’ | Outer corners of the mouth where the outer edges of the upper and lower vermilions meet | |
| endocanthion | en’ | Most medial point of the palpebral fissure, at the inner commissure of the eye*; best seen when subject is gazing upward* | |
| exocanthion | ex’ | Most lateral point of the palpebral fissure, at the outer commissure of the eye; *best seen when subject is gazing upward* | |
| glabella | g’ | Most anterior midline point on the forehead, in the region of the superciliary ridges | |
| gnathion | gn’ | Median point halfway between pg′ and me′ | |
| gonion | go’ | Most lateral point on the mandibular angle, adjacent to go, identified by palpation | |
| labiale inferius | li’ | Mid-point of the vermilion border of the lower lip (identical to labrale inferius) | |
| labiale superius | ls’ | Midpoint of the vermilion border of the upper lip *Not to be confused for labrale superius.* | |
| menton | m’ | Most inferior median point of the chin | |
| nasion | n’ | Point directly anterior to the nasofrontal suture, in the midline, overlying n | |
| pogonion | pg’ | Most anterior midpoint of the chin, located on the skin surface anterior to the identical bony landmark of the mandible | |
| pronasale | pn’ | Most anteriorly protruded point of the apex nasi. In the case of a bifid nose, the more protruding tip is chosen | |
| sellion | se’ | Deepest mid-line point of the naso-frontal angle. *Not* *a substitute for n′.* | |
| supra-mentale | sm’ | Deepest mid-line point of the labio-mental sulcus | |
| subnasal | sn’ | Median point at the junction between the lower border of the nasal septum and the philtrum area | |
| stomion | sto’ | Midline point of the labial fissure when the lips are closed naturally, with teeth shut in the natural position; if not in the midline, then below the philtrum | |
| tragion | t’ | Located at the notch above the tragus of the ear (the cartilaginous projection anterior to the external auditory canal), where the upper edge of the cartilage disappears into the skin of the face | |
| zygion, | zy’ | Most lateral point overlying each zygomatic arch, identified as the point of maximum bizygomatic breadth of the face | |
| **Table 1**. Craniofacial and facial anthropometry soft tissue landmarks. (Caple and Stephan, 2016) | | | |
|  | | |
| **Figure 1.** Craniofacial and facial anthropometry soft tissue landmarks. Blue line indicates Frankfurt horizontal plane. | | |

The nomenclature in the relevant fields regarding definitions of accuracy and precision is also varied. Accuracy is defined as the closeness of measurement(s) to the real-life situation. Many records may refer to accuracy as trueness or validity. Precision shall be defined as how close or far apart repeated measurements are to each other (Bureau International des Poids et Mesures, 2020). Precision may also be referred to as reliability, reproducibility, consistency, or repeatability.

**7.2 Anatomy and Perception**

Appreciation of anatomical variation of the human face is important before considering the different measurement methods. A person’s posture, ranging from lying flat to standing, body mass index, movement in the form of voluntary and involuntary muscle activity such as facial expression or pathological muscle activity all affect the face features ([Jakobsone](https://onlinelibrary.wiley.com/action/doSearch?ContribAuthorRaw=Jakobsone%2C+Gundega) et al 2019; Marmulla et al, 2006; Meiyappan et al 2015). Although shade and colour assessment are beyond the remit of this article, the varying optical characteristics of the face may affect measurements of face features, whether ranging from the optically lucent cornea to the optically opaque epidermis (Lui et al, 2021). Reflective or absorbent make-up may equally affect these measurements. The presence of smooth areas such as the frontal region of forehead, which contrasts with sharp, undercut areas such as the commissure of the lips or the ala of the nose are relevant. As is the presence of hair such as a beard or eyebrows. Racial skin tone should also be considered (Cheah et al, 2003; Wesselius et al 2019).

All of the above factors have affected our assessment and representations of soft tissue landmarks since antiquity (See Figure 2) and continue to influence our perceptions today (See Figure 3).

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| **Figure 2.** The mask of Warka. The oldest known three-dimensional model of human face features. Dating from about 3000 BCE. Courtesy of the Iraq Museum. |

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| **Figure 3.** Mixed reality. Super-imposition of augmented reality glasses on to moving image of face. Courtesy of Instagram. (Instagram, 2022) |

**7.3 Clinical Accuracy and Precision**

The level of accuracy and precision deemed clinically acceptable in this

review is 1 unit for linear, surface to surface and angular measurements of face features. For example, one unit would be 1mm for linear distances or 10 for angular measurements which is within working accuracy and precision expected for maxillofacial and cosmetic surgery. This also falls below the level where asymmetries may become visible to an observer (Artopoulos A et al, 2013; De Menezes et al, 2010; Kau et al, 2010; Koban et al, 2020; Metzger et al, 2007; Weinberg et al, 2004; Ye et al, 2016). The accuracy and precision expected for measurements around “fine” soft tissue landmarks such as the periocular area also fall under this level (Guo et al, 2019; Liu et al 2021). It should be noted that some clinical requirements of soft tissue landmark measurements, for example plastic surgery of the ear, may be more lenient, allowing for linear distance accuracy and precision discrepancies of up to 4 mm (Coward et al, 2007). There was little information in literature regarding clinically acceptable levels of accuracy and precision of volumes and angles. It shall be presumed that linear differences resulting from volume and angle discrepancies would fall under same remit as above.

Possible sources of accuracy or precision errors may arise from four sources. Namely; instrument error, underlying variability, respondent and observer errors (Kirkwood and Sterne, 2003). See Table 2.

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| --- | --- |
| **Error Source** | **Example** |
| Instrument error | Resolution/fidelity/voxel size  Instrument faults/calibration |
| Underlying variability | Soft tissues recorded at two different times when physiology may change soft tissue dimensions (posture, body temperature).  Also relevant are the environmental lighting conditions. |
| Respondent error | Person blinking when face illuminated or touched with contact methods (eg direct anthropometry measuring caliper) |
| Observer errors­ | Poor understanding of measuring technique for example subject not positioned |
| Data Processing Errors | Particularly relevant in this field where increasing data processing is being performed by software analysis of digital point clouds. |
| **Table 2.** Sources of errors (Kirkwood and Sterne, 2003; Perini et al, 2005; White et al, 2019) | |

**7.4 Statistical Analysis**

Many statistical analysis techniques and concepts are used by records in this review to infer conclusions about accuracy and precision of measuring soft tissue landmarks. See Table 3.

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| **Statistical Analysis Technique or Concept** | **Comments** |
| Absolute technical error of measurement (TEM) | * An index which is the standard deviation between repeated measures. * Expressed in units |
| Anisotropic | * A volume with geometry with unequal in all directions. Such as the human face * Contrasts with am isotropic such as a sphere. * This characteristic affects statistical analysis. |
| Bland Altman analysis | * May infer strength of agreement between two groups * May be presented as Bland Altman plot * Identical to Tukey mean difference plot |
| Bonferroni correction. | * Used to counteract erroneous statistical deductions when making multiple comparisons. * May not reject false null hypothesis in some instances. |
| Coefficient of variation | * Ratio of standard deviation to the mean. * The higher the coefficient of variation, the greater the level of dispersion around the mean. * Expressed as a percentage. * Without units, it allows for comparison between distributions of values whose scales of measurement are not comparable. * The lower the value of the coefficient of variation, the more precise the estimate. |
| Confidence interval | * Probability that observation will fall within this range |
| Cohen d effect size correlation | * A value which allows affect independent variable has affected the dependent variable in an experimental study. * Effect size in ANOVA: * Less than 0.01 is small affect * Between 0.01 and 0.059 is medium affect. Greater than 0.138 is a large affect |
| Intraclass correlation coefficient (ICC) | * Multiple interpretations possible * For this review:   ICC > 90 indicates “excellent” correlation of observations  ICC >75 indicates “good” correlation of observations |
| Iterative closest point algorithm (ICP) | * Software used to reduce distance between two points in space * Allows translation, mirroring and rotation of digital point clouds but no change in distance between two points in same point cloud. * Falls in the field of “rigid shape modelling” * Contrasts with field of non-rigid, or visco-elastic modelling, which allows scaling and sheer-mapping changes. Therefore, changes between distance of points within same point cloud.   Very fast changing software and statistical field |
| Mean absolute difference (MAD) | * Average absolute value of all deviations from the arithmetic mean. |
| Paired T test also known as student t test | * Compares two groups of observations that are paired to each other * Small group sizes * Equal population standard deviation. This is commonly used in reviewed records as soft tissue landmark observations by a particular method are often compared to, or paired, with soft tissue landmark observations recorded by another method |
| Relative absolute technical error of measurement (rTEM) | * TEM expressed as a percentage relative to other TEM’s of other measurements * Expressed as a percentage * May be used to compare groups of observations of differing magnitudes * 1% is “excellent” agreement * 1% to 3.9% is “very good” agreement * 4% to 6.9% is “good” agreement * 7% to 9.9% is “moderate” agreement * Less than10% is “poor” agreement |
| Shapiro-Wilk test | * Test of the normality of distribution of values of observations within a sample |
| Scheffe test | * Post-hoc test used after analysis of variance (ANOVA) for complex mean comparisons (involving comparing more than one pair of means simultaneously * Only used if the result of ANOVA is significant (null hypothesis is rejected) * Low statistical power (this increases probability of incorrect rejection of null hypothesis) |
| T-Test | * Compares the means of two groups of observations * Small group sizes * Each group has equal population standard deviation |
| Tukey test or Tukey procedure or  Tukey’s honest significant difference test | * Compares means of groups * Post-hoc test based on the studentized range distribution after ANOVA demonstrates significant results. |
| Variance | * Total of squared differences of each observation of from the mean value of same observations. * Units are equal to units of observation squared |
| 1 Standard Deviation (1SD) | * Square root of variance * *If sample or group is normally distributed* possibly indicates 68% probability of an observation falling within sample or group mean |
| 1. Standard Deviation (2SD) | * Square root of variance * *If sample or group is normally distributed* possibly indicates 95% probability of an observation falling within sample or group mean * May be used to derive 95% confidence interval of observations *if observations are normally distributed* |
| **Table 3.** Statistical analysis techniques and concepts.  (Altman and Bland, 1983, Besl and McKay, 1992; Kirkwood and Sterne, 2003; Koo and Li, 2016; Liu et al, 2021; Myronenko and Song, 2010; Perini et al, 2005; Roberts and Richmond, 1997; Shapiro and Wilk, 1965; White et al, 2019) | |

**7.5 Methods of Measuring Face Features**

There are many methods used to measure soft tissue landmarks (Farkas et al 1989; Souccar and Kau, 2012 Keeling et al 2014; Dindaroğlu et al 2016). See Table 4. Further explanation of each of these measurement methods will now be discussed further.

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| **Methods to Measure Surface Face Features** |
| Computed tomography |
| Cone beam computed tomography |
| Magnetic resonance imaging |
| Ultrasonography |
| Physical impressions |
| Direct anthropometry |
| Optical Methods: 2D/Conventional photography, 3D active, 3D passive, 3D confocal and 3D time-of-flight |
| **Table 4.** Methods to measure surface face features |

**7.5.1 Computed Tomography**

Computed tomography uses multiple two-dimensional radiographic images, or “slices”, of the patient because of a radiation source and detector rotating multiple times around the volume of interest. These images may then be amalgamated to form a three-dimensional model. While being non-contact in nature there are risks of ionizing radiation to the subject (Brennar and Hall, 2008). Development of computed tomography over last twenty years may allow accurate measurement of soft tissue landmarks (Cheah et al, 2003; Artopoulos et al, 2013). The high cost of hardware and image artefact generation, possibly due to the presence of metal prosthesis such as dental implants and metal crowns, are disadvantages (Kimoto and Garrett, 2007). Additionally, the narrow bore of the imaging machine may be claustrophobic for some and may not accommodate the obese. The acquisition time is relatively long therefore computed tomography is more susceptible to patient movements when compared to other methods of measuring soft tissue landmarks (Cheah et al, 2003). See Figure 4.

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| A picture containing appliance, iron  Description automatically generated |
| **Figure 4.** A computed tomography acquisition machine. Note supine position of patient and confined space. Courtesy of Canon Medical Systems, USA. |

**7.5.2 Cone Beam Computed Tomography**

Cone beam computed tomography, like computed tomography, uses an amalgamation of two-dimensional radiographic images to form a three-dimensional image. The difference is the radiation “beam” used during cone beam computed tomography which is cone shaped in nature. The detector and radiation source rotating only once around the subject. As with computed tomography there are risks of ionizing radiation to the subject, however radiation doses are lower than that of computed tomography. (Brennar and Hall, 2008). Cone beam computed tomography is lower in cost compared to computed tomography and magnetic resonance imaging. Assessment of the soft tissue landmarks of the human face is possible with cone beam computed tomography (Heiland et al, 2007) although the increased sensitivity to subject movement of cone beam computed tomography should be noted (DeVos G, 2009). Artefact generation, due to the presence of metal prosthesis such as dental implants or metal crowns, is a disadvantage (Kimoto and Garrett, 2007).

**7.5.3 Magnetic Resonance Imaging**

The modality of magnetic resonance imaging measures the signal changes in radiofrequency of hydrogen protons when under influence of a strong electromagnetic field. This difference is used to detect varying water content of tissue. Different body tissues have a unique water content therefore different tissues may be distinguished by interpreting varying water content. Magnetic resonance imaging may be determined in two or three dimensions (Coward et al, 2007). Magnetic resonance imaging modality is not risk-free due to its possible effects on implanted ferromagnetic prosthesis such as cardiac pacemakers. The narrow bore of the magnetic resonance imaging acquisition machine may be claustrophobic for some individuals and may not accommodate the obese (Cheah et al, 2003). The high cost of hardware and artefact generation due to the presence of metal prosthesis such as dental implants and metal crowns are also disadvantages (Kimoto and Garrett, 2007).

**7.5.4 Ultrasonography**

Ultrasonography uses an acoustic signal which is projected into the human body from a transducer at a higher frequency than the range of human hearing (1 to 18 MHz). The reflected acoustic signal which is produced as a result of the acoustic signal passing through different tissue densities is then recorded. As each body tissue has a different density this varies each tissue’s acoustic impedance. By detecting the time taken for the acoustic signal to be reflected and the characteristics of reflected acoustic signal location the type of tissue can be determined, processed and displayed as an image (Aldrich, 2007). Ultrasonography has a relatively long acquisition time and tissues are compressed. Interestingly ultrasonography may be used for assessment of soft tissue landmarks of developing the fetus in-utero (Moos et al, 2017).

**7.5.5 Physical Impressions**

Physical impressions of the face may be recorded in the form of impression plasters, reversible or irreversible hydrocolloids, silicones, other plastics and combinations of these materials. Impression materials may be supported by trays made of boxing wax, metal, visible light cured resins, shellac, and aluminum wire frames. The impressions may be recorded in a variety of methods in one or multiple stages (Coleman, et al, 1985). They have the potential to restrict airway or to cover the eyes, therefore requiring eyes to be closed during the procedure. There are other disadvantages such as inaccuracies due the patient movements and soft tissue deformations due to impression material contact with the face (Runte et al, 2002). Physical impression records are time-consuming, increase cross infection risks and require specialised manufacturing knowledge and materials. The cost of materials may be low (Kimoto and Garret, 2012).

**7.5.6 Direct Anthropometry**

Direct anthropometry is measurement using calipers and/or other measuring tools to gather linear measurements between soft tissue landmarks (Farkas, 1994). Direct methods are time consuming and require an element of co-operation from the subject so may not be suitable for infants, the disabled or those less willing to co-operate. The measurement tool may also cause tissue compression therefore potentially distorting measurements (Farkas, 1994).

**7.5.7 Optical Methods: 2D/Conventional Photography, 3D Active, 3D Passive, 3D Confocal and 3D Time-of-Flight**

Optical methods of assessing soft tissue landmarks, each of which will be discussed in further detail below, are limited by the requirement that area of interest be in the line-of-sight (Cheah et al, 2003). This may result in undercut areas such as around the ala of the nose or areas posterior to the tragus of the ear not being detected. This is particularly relevant for pathological defects. An example being where surgical resection of volumes of the face has created undercuts. Skin shade and presence of hair, whether facial hair or overlapping hair from scalp, may also affect measurements. (Cheah et al, 2003; Lane and Harrel, 2008). The presence of makeup also has potential to mask features by reflecting and deflecting light to reduce accuracy and precision of recording soft tissue landmarks. Although optical methods are considered non-invasive in nature, the health risk of visible laser lights to eyes should not be discounted (Kimoto and Garrett, 2007).

Optical 2D/conventional photography methods are based on 2D images of the face taken with a camera. This may include photographs obtained with a conventional camera or a mobile device. Measurement derived from analysis of those photographs may be known as indirect anthropometry. This may or may not include a fiducial marker (an object of known dimensions) in the image to provide a sense of scale to the observer (Franke-Gromberg et al, 2010; Guo et al, 2020).

Optical 3D passive methods of assessing soft tissue landmarks, which may also be referred to as stereophotogrammetry, use multiple images of a person’s face to construct a three-dimensional model without using projections of lasers or light. However, for the purpose of organisation in this literature review, a flashlight such as one or more LED light source(s) would be classified as a 3D optical passive method.

It is a method commonly used within the medical field due to relative quick acquisition time and being non-invasive in nature. This method is inexpensive and patient comfort is improved when compared to many other methods of measuring soft tissue landmarks (Heike et al, 2010; Sapol et al 2011; Jablonski et al, 2018). Operators using this modality must be careful of excessive ambient light, such as direct sunlight, which may affect images (Heike et al, 2010). Featureless areas of the face, such as the smooth areas of the cheek or forehead, may not be accurately registered (Jablonski et al, 2018).

Optical 3D active methods of assessing soft tissue landmarks are summarised as “the projection of a light (or plane, grid, or more complex shape) at a known angle onto an object. When a light intersects with an object........ light can be seen on the surface of the object. By viewing this......light from an angle, the observed distortions in the line can be translated into height variations” (Flack et al, 2007; Lau et al, 2020). Optical active methods may use multiple images taken at the same time or multiple images taken at different times which are then amalgamated to form three-dimensional model. A disadvantage of this method may include distortion of face features due to orbital reflexes and movement of subject (Runte et al, 2002; Lau et al, 2020). The Apple True Depth® camera technology which is an infrared laser based structured light scan is also considered an optical 3D active method for the purpose of this review. See Figure 5.

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| A picture containing wall, indoor  Description automatically generated |
| **Figure 5.** Vectra XT (Canfield, USA) acquisition machine. An example of an optical 3D active method of acquiring face features by using multiple simultaneous images. Courtesy of Canfield, USA. |

Optical 3D confocal methods use a series of 2D images recorded using laser projections focused on different depths. Each pixel in every image recorded from the scene is assessed for the depth on which the laser is most sharply focused, with other pixels being eliminated from the image. These redacted 2D images are then amalgamated to form a three-dimensional image (Keeling and Holt, 2014). Confocal imaging methods are used for microscopy and some intra-oral dental scanners (Pawley, 2006; Align Technology Inc, 2022). Presently, due to relatively small focal lengths, optical confocal methods are not suitable for surfaces and volumes larger than a few centimeters cubed. However this modality of imaging is evolving at a quick pace towards decreasing the size of image capturing equipment, increasing focal lengths and reducing equipment cost ([Pacheco](https://www.nature.com/articles/s41598-017-13778-2#auth-Shaun-Pacheco) et al, 2017).

Optical 3D time-of-flight methods use a sensor to detect the length of time it takes a short pulse of light to be emitted and reflected from an object’s surface. The measured time is then used to calculate the distances to many points on the object’s surface and therefore calculate object’s profile. This is a rapidly developing field which also encompasses the more specialised use of Lasers in the Light Detection and Ranging (LiDAR) imaging modalities being incorporated on to consumer mobile devices (Cao et al 2020; Willing, 2021). Optical time-of-flight measurement methods may allow for small cameras and sensors to be used.

# **8. Methods**

This systematic review follows guidelines provided by the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) statement (Moher et al, 2009). The PICO identification criteria is defined in Table 5.

|  |  |
| --- | --- |
| **PICO Criteria** | |
| P (Population) | Human |
| I (Intervention) | Measuring face features |
| C (Comparison) | Computerised tomography, cone beam computerised tomography, magnetic resonance imaging, ultrasonography physical impressions, anthropometry and optical methods compared with each other. |
| O (Outcomes) | Accuracy and precision |
| **Table 5.** PICO identification of criteria | |

**8.1 Information Sources and Search**

Literature was gathered from the Embase, Medline and Cochrane Library databases using the Ovid search platform. Keywords and mapping to subject headings and sub-headings searches were carried out. See Tables 6 and 7.

|  |  |
| --- | --- |
| **Concept** | **Keywords Searched** |
| Face | features, profile, visage, craniofacial, cranio-facial, physiognomy, lineaments. |
| Measurement | measurement\*, assessment, assessment\*, size, length, dimension, area volume, height, depth, width, magnitude, scope, thickness, mark deepness, extent, highness, level, degree, proportion, sector, patch, span, longitude, analysis, determination, evaluation, appraisal, estimation, computation |
| Dimension | dimen\*, 3D, 3 dimension, 3 dimensions, 3 dimensional, threeD, three dimension, three dimensions, three dimensional, morph\* , metrology , shape, patterns, pattern\*, angle, aspect, three-dimensional, 3-dimensional,holographic\*, holographically, stereoscopic\*, stereographic\*, profil\* |
| Accuracy | trueness, precision, accurateness, exactness, fidelity, closeness, truth, correctness, truthfulness, exactitude, preciseness, true, correct, valid, exact, correctness, definiteness |
| Comparison | contrast, distinction, differentiation, collation, contrast, disparity, distinctness, divergence, dissimilarity |
| **Table 6.** Concepts and related keywords | |

|  |  |
| --- | --- |
| **Concept** | **Subject Heading and Sub-Headings** |
| Face | exp face/ or exp face asymmetry |
| Measurement | measurement or measurement accuracy or measurement precision or measurement error or measurement repeatability |
| Photogrammetry | photogrammetry or stereophotography or photographic paper or photography |
| Magnetic Resonance Imaging | nuclear magnetic resonance imaging or "imaging and display" or nuclear magnetic resonance or tomography or whole-body MRI or nuclear magnetic resonance scanner or nuclear magnetic resonance scanner software |
| Ultrasound | echography |
| Computerised Tomography | computer assisted tomography or tomography, or x-ray computed tomography |
| Cone Beam Computerised Tomography | cone beam computed tomography or cone beam computed tomography scanner |
| Anthropometry | anthropometric parameters or anthropometry or morphometry or cephalometry or craniometry |
| Optical Methods | light or electromagnetic radiation |
| **Table 7.** Concepts mapped to subject headings and sub-headings | |

The resulting papers were collected and assessed with the following inclusion and exclusion criteria.

**8.2 Inclusion criteria**

All types of study reporting quantitative assessments, encompassing research studies, clinical studies, technical notes, reviews, randomised clinical trials performed on humans of any age, also in-utero, were included. All modalities of measurement of surface face features including computed tomography, cone beam computed tomography, magnetic resonance imaging, ultrasonography, physical impressions, anthropometry, and optical methods (Photography, 3D active, 3D passive, 3D confocal and 3D time-of-flight) were considered.

**8.3 Exclusion Criteria**

Study types: Literature not reporting original data, editorials, opinion letters and case reports. Also excluded were literature older than year 2010, not written in English language, based on three-dimensional assessment, or scanning of intraoral environment, dental restorations or dental prothesis, facial recognition/identification, face detection, software/algorithm abstraction of imaging/measurement modalities.

**8.4 Study Selection**

A single reviewer in non-blinded fashion screened titles and abstracts of literature and applied inclusion and exclusion criteria. If information was not clearly reported in title and abstract of record it was not excluded from full text analysis. Analysis of full text was performed and final decision about inclusion was made.

**8.5 Data Extraction**

Data of interest was extracted from full text articles and recorded onto an electronic spreadsheet (Microsoft Excel).

**8.6 Risk of Bias Assessment**

Each record was assessed for risk of bias using guidelines provided by the Quality Assessment Tool for Diagnostic Accuracy Studies (QUADAS2).

**8.7 Analysis of Subgroups**

Each record was classified according to the method being used to measure face features. Namely; computed tomography, cone beam computed tomography, magnetic resonance imaging, ultrasonography, physical impressions, direct anthropometry, optical Methods: 2D photography, 3D active, 3D passive, 3D confocal.

# While not advisable to rely solely on a numerical system of critical appraisal of record quality (Whiting et al, 2011), and as the author is inexperienced with reviewing literature, an initial assessment of record structure and quality of evidence was used to give an indication of any obvious failings (McGrath et al, 2009). See Table 8. The records were not ranked against each other.

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| **Initial Assessment of Record Structure and Quality of Evidence** |
| Was the aim of the project clear? |
| Was the number of subjects defined? |
| Was it stated how subjects were selected? |
| Were the method of measuring surface face features in three dimensions clearly and fully defined? |
| Did the study have a control group? |
| Were there any subjects that dropped out? |
| Was the method of measuring surface face features in three dimensions compared to another method or “gold standard”? |
| Was the method compared to other studies using any method of measuring surface face features? |
| Was the outcome of the study clearly defined? |
| Was the outcome of the study successful? |
| Were the outcome measures tested for reliability? |
| Was the outcome measure objective? |
| Were the outcome assessors blinded? |
| Were any statistical tests applied? |
| Did the method provide a cost saving / surgical time/ clinical time? |
| Was the accuracy of the method of measuring surface face features in three dimensions achieved? |
| **Table 8.** Initial assessment of record structure. |

**9. Results**

**9.1 Information Sources, Search, Application of Inclusion and Exclusion Criteria and Study Selection.**

The initial search revealed 7603 records composed of 2279 from Embase and 5321 from Medline were relevant to the systematic literature review. No additional records were found through manual searching. 6 additional records were located on searching references of records. After title and abstract screening, 56 records were moved forward for full text review. After full text review it was decided to exclude 38 records. 32 were excluded due to not meeting inclusion criteria (Bakker et al, 2016; Breitbarth et al, 2019 ; Chu et al 2020; Deli et al, 2011; Deng et al, 2020; Fink et al, 2017; Flores et al, 2019; Hallac et al, 2017; Hoogeveen et al, 2013; Hwang et al, 2015; Hwang et al, 2020; Jayaratne et al, 2013; Ji et al, 2021; Jodeh et al, 2017; Jodeh et al, 2019; Kochel et al, 2010; Launonen et al, 2019; Li et al, 2022; Lin et al, 2020; Lübbers et al, 2012; Maal et al, 2011; Meulstee et al, 2020; Nahm et al, 2014; Nogami et al, 2021; Stephan and Munn, 2018; Vallen et al, 2021; Van Der Zeeuw et al, 2015; Wei et al, 2020; Weinberg, 2019; Yang Y and Paton N, 2005; Yilmaz et, 2022; Zhou et al, 2016). 3 records were excluded for not including detailed statistical analysis (Amornvit et al, 2019, Sigaux et al, 2018; Tuin et al, 2019). 3 records were excluded as there was not enough detail over deductions or method (Incrapera et al, 2010; Zhao et al, 2017, Zhao et al, 2020). This allowed 18 records to be included in this qualitative systematic review (Aksu et al, 2010; D'Ettore et al, 2022; De Menezes et al, 2010; Fourie et al, 2011; Franke-Gromberg et al, 2010; Gibelli et al, 2018; Guo et al, 2020; Jablonski et al, 2017; Koban et al, 2022; Kook et al, 2014; Liu et al 2019; Liu et al, 2021; Lim et al, 2022; Othman et al, 2013; Peidra Cascon et al, 2020; Rudy et al, 2020; Staller et al, 2022; White et al, 2020) See Figure 6.

Diagram

Description automatically generated

**9.2 Risk of Bias Assessment**

QUADAS 2 bias assessment for the 18 records included in systematic review was performed (Whiting et al, 2011). See Appendix 1 and Table 9. While some advise not to rely solely on a numerical system of to rank records in order of bias, the QUADAS 2 bias assessment may allow general trends of possible bias to be inferred (Whiting et al, 2011). 13 records had a low risk of bias (De Menezes et al, 2010; Fourie et al, 2011; Franke-Gromberg et al, 2010; Gibelli et al, 2018; Guo et al, 2020; Jablonski et al, 2017; Koban et al, 2022; Kook et al, 2014; Liu et al 2019; Liu et al, 2021; Lim et al, 2022; Peidra Cascon et al, 2020; Staller et al, 2022) 5 records indicate an unclear risk of bias (Aksu et al, 2010; D'Ettore et al, 2022; Othman et al, 2013; Rudy et al, 2020; White et al, 2020).

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| **Table 9.** QUADAS 2 bias assessment of records |

The QUADAS 2 assessment of bias indicates an increased likelihood of bias with regards to the domain ”Conduct or Interpretation of the Index Test”. More specifically the signaling question “Were the index test results interpreted without knowledge of the results of the reference standard?” was unclear or had a high risk of bias in 10 of the records due to data collection not being “blinded” or reference measurements being recorded prior to index measurements (Aksu et al, 2010; D'Ettore et al, 2022; Franke-Gromberg et al, 2010; Gibelli et al, 2018; Guo et al, 2020; Jablonski et al, 2017; Lim et al, 2022; Othman et al, 2013; Staller et al, 2022; White et al, 2020).

**9.3 Data Extraction**

Data of interest was extracted from full text articles and recorded onto an electronic spreadsheet (Microsoft Excel). Data recorded was date, title, authors names, whether accuracy, precision or both are being assessed, modality of measurement, manufacturer name, reference standard for validation participants, age of participants, number of participants, type of measurement (Linear distance, angles, surfaces, volume, surface to surfaces), number of soft tissue landmarks, number of measurements, type of statistical analysis estimation of errors, practical/clinical significance of errors, authors conclusions and disclosure of conflicts of interests. See Appendix 2.

**9.4 Analysis of subgroups**

Each record was classified according to the method being tested for measuring soft tissue landmarks to form subgroups. See Table 7. Some records assess more than one measuring modality. These are listed in more than one subgroup making the total number of categorised records, n= 20, exceed number of included records in this systematic review, n=18. One record assessed precision, so no other reference method was used (Othman et al, 2013).

**9.5 Computed Tomography**

There were no records included in this review that used computed tomography to assess accuracy or precision of measurements of soft tissue landmarks.

**9.6 Cone Beam Computed Tomography**

Two records utilised cone beam computed tomography to assess accuracy of measurements of soft tissue landmarks (Fourie et al, 2011; Kook et al, 2014). No records addressed precision.

**Accuracy**

Ten linear distances on cadavers using the KaVo 3D Exam (KaVo Dental GmbH, Bismarckring, Germany) device have 95% CI's less than 1mm. Namely; g’ to sn’ CI 0.25mm-0.55mm, t’ to gn’ left CI 0.25mm-0.91mm, ex’ to ex’ 0.18mm-0.82mm, al’ to al’ CI 0.43mm-0.85mm, n’ to sn’ CI 0.32mm-0.94mm, n’ to pn’ CI 0.3mm-0.84mm, al’ to pn’ right CI 0.1mm-0.68mm, al’ to pn’ left CI 0.21mm-0.6mm, ch’ to ch’ CI 0.08mm-0.47mm, sn’ to ch’ right and left CI 0.21mm-0.73mm (Fourie et all, 2011).

Ten linear distances on mannequins using the CB MercuRay (Hitachi, Tokyo, Japan) device had TEM less than 1mm for ten linear distances between landmarks. Namely; ex’ to ex’ TEM 0.25mm, en’ to en’ TEM 0.14mm, al’ to al’ TEM 0.3mm, ch’ to ch’ TEM 0.22mm, g’ to pg’ TEM 0.4mm, g’ to sn’ TEM 0.29mm, ls’ to li’ TEM 0.29mm, sn’ to pg’ 0.46mm, n’ to pn’ TEM 0.3mm, al’ to pn’ 0.31mm (Kook et al, 2014).

* 1. **Magnetic Resonance Imaging**

There were no records included in this review used magnetic resonance imaging to assess accuracy or precision of measurements of soft tissue landmarks.

* 1. **Ultrasonography**

There were no records included in this review that used ultrasonography to assess accuracy or precision of measurements of soft tissue landmarks.

* 1. **Physical Impressions**

There were no records included in this review which used physical impressions to assess accuracy or precision of measurements of soft tissue landmarks.

**9.10 Direct Anthropometry**

There were no records in this review that investigated use of direct anthropometry to measure accuracy of measurements of soft tissue landmarks. However, it was used as a reference for many records. See Table 11.

**Precision**

Twenty linear distances between soft tissue landmarks on cadavers had “very reliable” or better intra-observer precision. ICC greater than 0.923. Namely; n’ to gn’, n’ to st’, sn’ to gn’, g’ to sn’, t’ to n’ right and left, t’ to sn’ right and left, t’ to gn’ right and left, en’ to en’, ex’ to ex’, al’ to al’, n’ to sn’, n’ to pn’, al’ to pn’ right and left, ch’ to ch’, sn’ to sto’, sn’ to ch’ right and left) (Fourie, et al, 2011).

One linear distance on living subject in perioral area had acceptable precision. Namely; en’ to ipsilateral ex’ ICC 0.86, MAD 0.77mm, TEM 0.89mm, REM 2.48%, rTEM 2.88% (Guo et al, 2020).

**9.11 Optical Methods**

**9.11.1 2D Photography**

Two records assessed the accuracy of 2D photography when measuring soft tissue landmarks (Franke-Gromberg et al, 2010; Lim et al, 2022).

Three records assessed the precision of 2D photography when measuring soft tissue landmarks (Aksu et al, 2010; Guo et al, 2020; Lim et al, 2022).

**Accuracy**

Eleven of twenty-six linear distances between soft tissue landmarks on living subjects were acceptable to 1SD when compared to direct anthropometry. Namely; en’ to en’ mean difference 0.45mm, SD 0.49mm, ch’ to ch’ mean difference 0.45mm, SD 0.35mm, n’ to sto’ mean difference 0.6mm, SD 0.39mm, se’ to st’ mean difference 0.38mm, SD 0.48mm, g’ to sn’ mean difference 0.28mm, SD 0.41mm, n’ to sn’ mean difference 0.54mm, SD 0.36mm, se’ to sn’ mean difference 0.38mm SD 0.39mm, st’ to gn’ mean difference 0.58mm, SD 0.34mm, ls’ to li’ mean difference 0.05mm, SD 0.33mm, sn’ to st’ mean difference 0.14mm, SD 0.16mm, sm’ to st’ mean difference 0.23mm, SD 0.21mm (Franke-Gromberg et al, 2010).

Three linear distances on living subjects using 2D photographs were found. Namely; sn’ to pn’ mean difference 0.4mm, 95% CI 0.1mm to 0.9mm, p value 0.049, al’ to al’ mean difference 0.1mm 95% CI 0.3mm to 0.1mm, p value 0.343, sn’ to se’ mean difference 0.2mm, 95% CI 0.6mm to 0.2mm, p value 0.411 (Lim et all, 2022).

**Precision**

Nine linear distances between soft tissue landmarks on living subjects deduced from reference distances between two other soft tissue landmarks were considered imprecise for the purpose of this review using 2SD (Aksu et al, 2010).

Three linear distances on living subjects using 2D “photographs” derived from a 3D optical passive device, the Vectra XT 3D Imaging System (Canfield Scientific Inc, NJ, USA) were under 1mm level for intra-operator precision. Namely; en’ to en’ ICC 0.98 MAD 0.84mm TEM 0.81mm, REM 0.93% rTEM 0.9%, ex’ to ex’ ICC 0.99 MAD 0.34mm TEM 0.31mm REM 1.09% rTEM 1% and en’ to ex’ ipsilateral ICC 0.98 MAD 0.28mm TEM 0.27mm, REM 0.95% rTEM 0.93% (Guo et al, 2020).

Five linear distances on living subjects using 2D photographs demonstrated “good” or “excellent” correlation. Namely; sn’ to se’ ICC 0.99, al’ to al’ ICC 0.92, interpupillary distance ICC 0.9, m’ to se’ ICC 0.98, gn’ to gn’ ICC 0.91, zy’ to zy’ ICC 0.84 (Lim et al, 2022).

**9.11.2 3D Active Optical Method**

Six records assessed the accuracy of a 3D active optical method when measuring soft tissue landmarks (Fourie et al, 2011; Jablonski et al, 2017; Koban et al, 2022; Kook et al, 2014; Peidra Cascon et al, 2020; Rudy et al, 2020).

Six records assessed the precision of a 3D active optical method when measuring soft tissue landmarks (D'Ettore et al, 2022; Gibelli et al, 2018; Jablonski et al, 2017; Koban et al, 2022; Rudy et al, 2020; Staller et al, 2022).

**Accuracy**

Five of twenty-one linear measurements between soft tissue landmarks in cadavers using a laser scanning device Minolta Vivid 900 (Osaka, Japan) demonstrated accuracy with 95% CI of mean difference of TEM being less than 1mm. Namely; n’ to sto’ TEM 0.35mm to 0.79mm, sn’ to gn’ TEM 0.37mm to 0.98mm, en’ to en’ TEM 0.18mm to 0.84mm, sn’ to sto’ TEM 0.55mm to 0.99mm and sn’ to ch’ right TEM 0.32mm to 0.97mm (Fourie et al, 2011).

Face surfaces using a combination of a 3D active optical device (a custom-made structured light scanner) and a 3D passive optical methodusing DI4D device (DI4D, Hillington, Glasgow) face masks (Jablonski et al, 2017). This investigation assessed accuracy using the unsigned mean distance between the meshes, which were aligned using a form of the iterative closest point (ICP) algorithm. When considering face as a whole absolute deviation was between 0.14mm to 0.31mm, 1SD 0.13mm to 0.32mm.

(Jablonski et al, 2017).

Eight linear distances of on living subjects between soft tissue landmarks were found to be acceptably accurate when using the 3D optical active device Artec Eva (Artec 3D, Luxembourg). Namely; n' to sn' 0.12mm 1SD 0.3mm p value 0.837, sn' to pn' 0.34mm SD 0.5mm p value 0.33, sto' to sm' 0.32mm 1SD 0.3mm p value 0.341, sn' to gn' 0.44mm 1SD 0.2mm p value 0.438, ls' to st' 0.27mm 1SD 0.2mm p value 0.365, li' to sto' 0.06mm 1SD 0.1mm p value 0.802, li' to sl' 0.14mm 1SD 0.3mm p value 0.627, sl' to gn' 0.76mm 1SD 0.1mm p value 0.122 (Koban et al, 2022).

Eight linear distances on living subjects between soft tissue landmarks were found to be acceptably accurate when using the 3D optical active device Sense 3D scanner device (Sense 3D, 3D Systems, South Carolina, USA). Namely; sn' to pn' 0.07mm SD 0.6mm p value 0.872, st' to sm' 0.02mm 1SD 0.5mm p value 0.957, li' to sto' 0.51mm SD 0.3mm p value 0.117, sm' to gn' 0.17mm SD 0.3mm p value 0.73 (Koban et al, 2022).

Ten linear distances on mannequins using the 3D optical active laser scan COMET VZ device (Steinbichler, Germany) had TEM all greater than 1mm for ten linear distances between landmarks. Namely; ex’ to ex’, en’ to en’, al’ to al’, ch’ to ch’, g’ to pg’, g’ to sn’, ls’ to li’, sn’ to pg’, n’ to pn’, al’ to pn’ (Kook et al, 2014).

One linear distance measurement on living subjects using IPhone X (Apple, CA, USA) had acceptable accuracy. Namely from a reference landmark to gb’ mean difference 0.45mm, 2SD 0.21mm. Three other linear distances fell outside clinical accuracy required. Namely; reference landmarks to sn’ mean difference 1.003mm, 2SD 0.308mm, sn’ to gb’ mean difference 0.846mm, 2SD 0.345mm, sn’ to me’ mean difference 1.247mm, 2SD 0.536mm, ch’ to ch’ mean difference 0.986mm, 2SD 0.563mm (Peidra Cascon et al, 2020).

Surface areas of the face, as a whole, on living subjects were assessed using the IPhone X (Apple, CA, USA) using ScandyPro software (ScandyPro, New Orleans, USA) demonstrating an average 1SD of root mean square difference 0.43mm within a range of -2.43mm to 2.48mm. Further data about soft tissue landmarks and further statistical analysis would have provided greater information about accuracy (Rudy et al, 2020).

**Precision**

Five linear distances between soft tissue landmarks on living subjects using 3D active method on mobile device (iPhone X; Apple, CA, USA) and the Bellus3D Face Application (version 1.6.11; Bellus3D Inc, CA, USA) were tested. Namely; average deviation with 1SD ch’ 1.2mm, 1SD 0.8mm, ex’ 1.1mm, 1SD 5.5mm, en’ 1.1mm, SD 0.6mm, go’ 0.7mm, SD 0.7, st’ 1mm, SD 0.6mm when compared to point clouds generated by a 3D optical passive method. (D'Ettore et al, 2022).

One of sixteen linear distances and angular measurements between soft tissue landmarks on mannequins using a handheld 3D optical active method (Sense®, 3DSystems, Rick Hill, SC, USA) was found to be acceptable. Namely; t’ to go’ TEM 0.7mm. All other distances and angles had TEM over 2mm and 1.8o respectively. The authors report inter-instrument precision of linear distances, angles, facial surface area and volumes rTEM were “very good” in only 4 linear distances or angles Namely; n’ to pg’, zy’ to zy’, n’-sn’-pg’ angle, n’-pn’-pg’. Intra-instrument precision rTEM “very good” in 6 linear distances or angles. Namely; n’ to pg’, ex’ to ex’, go’ to go’, n’-sn’-pg’ angle, n’-pn’- pg’ angle, t’-go’-pg’ angle (Gibelli et al, 2018).

Face surfaces were assessed using a combination of a 3D active optical device (a custom-made structured light scanner) and a 3D passive optical methodusing DI4D device (DI4D, Hillington, Glasgow) face masks (Jablonski et al, 2017). This investigation assessed accuracy using the unsigned mean distance between the meshes, which were aligned using a form of the ICP algorithm. Intra-operator precision was assessed by absolute deviation which varied from 0.14mm to 0.33mm, 1SD 0.002mm to 0.32mm.

(Jablonski et al, 2017).

Twenty-one linear distances measured on living subjects using the 3D optical active device Artec Eva (Artec 3D, Luxembourg) demonstrate high correlation with ICC of 0.889 and 95% CI 0.783mm–0.910mm. A moderate correlation for the Sense® device (3DSystems, Rick Hill, SC, USA) with ICC of 0.486 and 95% CI 0.771mm–0.952mm (Koban et al, 2022).

Five linear distances measured on living subjects using IPhone X (Apple, CA, USA) and BellUS software had precision near or under 1mm. Namely; reference landmark to gb’ mean difference 0.073mm, 2SD 0.0374mm, reference landmark to sn’ mean difference 0.25mm, 2SD 0.144mm, sn’ to gb’ mean difference 0.398mm, 2SD 0.315mm, sn’ to me’ mean difference 0.522mm, 2SD 0.574, ch’ to ch’ mean difference 0.366mm, 2SD 0.346mm (Peidra Cascon et al, 2020).

Surface areas on living subjects of the face, as a whole, were assessed using the IPhone X (Apple, CA, USA) using ScandyPro software (ScandyPro, New Orleans, USA) with an average of root mean square difference of SD 0.35mm with a range of 1.95mm to 2.07mm. Further data about soft tissue landmarks and further statistical analysis would have provided greater information about precision (Rudy et al, 2020).

Fourteen linear and angular measurements on living subjects using 3D optical active device 3dMD Trio (3dMD Ltd, London, UK) Intra and inter-examiner ICC of “good” or “excellent”. Namely; n’ to sn’, n’ to pn’, pn’ to m’, t’ to pn’ right, t’ to pn’ left, t’ to pg’ right, t’ to pg’ left, go’ to pg’ right, go’ to pg’ left, ch’ to ch’, angle n’ to sn’ to pg’, angle n’ to pn’ to pg’, angle g’ to n’ to pn’ with gn' to pg' left being lowest at 0.76.  
(Staller et al, 2022)

Sixteen linear and angular measurements on living subjects using Bellus Face Camera Pro (Bellus 3D Inc, Campbell, Calif),

Intra and inter-examiner precision. ICC “good” or “excellent” (0.86 lowest for interpupillary distance, and gn' to pg' left, 0.76).  
(Staller et al, 2022)

**9.11.3 3D Passive Optical Method**

Four records assessed the accuracy of a 3D passive optical method when measuring soft tissue landmarks (De Menezes et al, 2010; Fourie et al, 2011; Kook et al, 2014; Liu et al, 2019).

Seven records assessed the precision of 3D passive optical methods when measuring soft tissue landmarks (Fourie et al, 2011; Guo et al, 2020; Koban et al, 2022; Liu et al, 2019; Liu et al, 2021; Othman et al, 2013; White et al, 2020).

**Accuracy**

One linear distance on living subjects using 3D optical passive device Vectra 3D Imaging System, unknown model, (Canfield Scientific, Inc. NJ) of ch’ to ch’ MAD is 1.19mm. (De Menezes et al, 2010).

Three of twenty-one linear measurements between soft tissue landmarks in cadavers using the (Di3D Dimensional Imaging Ltd, Glasgow, UK) demonstrated accuracy with 95% CI of mean difference of TEM being less than 1mm. Namely; n’ to gn’ mean difference 0.73mm 95% CI 0.4mm-1.07mm, n’ to sto’ mean difference 0.93mm 95% CI 0.53mm to 1.33mm, sn’ to gn’ mean difference 0.91mm, 95% CI 0.41mm to 1.42mm, t’ to n’ right mean difference 1.11mm, 95% CI 0.63mm to 1.58mm (Fourie et al, 2011).

Six linear distances on mannequins using 3D passive optical method (Di3D Dimensional Imaging Ltd, Glasgow, UK) had TEM less than 1mm. Namely; ex’ to ex’, en’ to en’, al’ to al’ 0.73mm, ch’ to ch’ 0.85mm, n’ to pn’ 0.8mm, al’ to pn’ 0.63mm (Kook et al, 2014).

Surface area of the face, as a whole, on face casts using the 3D optical passive handheld device Vectra H1 (Canfield Scientific, NJ, USA) and discontinued 3D optical passive handheld 3D optical passive Scanify (Fuel 3D Technologies, Chinnor, UK). An ICP algorithm was used to compare digital point clouds in Z axis (forward to back, or “depth” difference) only. Accuracy of less than 1mm of surface area differences was demonstrated in 98-99% with Vectra H1 device (Liu et al, 2019).

**Precision**

Twenty-one of twenty-one linear distances intra-observer and inter-method ICC were greater than 0.923 which is “very reliable” or better (Fourie et al, 2011).

Three linear distances on living subjects between soft tissue landmarks using Vectra M3 3D Imaging System (Canfield Scientific Inc, NJ) landmarks had high level of intra-operator precision. Namely; en’ to en’ ICC 1.0 MAD 0.39mm TEM 0.34mm REM 0.43% rTEM 0.37%, ex’ to ex’ ICC 1 MAD 0.2mm TEM 0.19mm REM 0.63% rTEM 0.61% and en’ to ex’ ipsilateral ICC 0.98 MAD 0.37mm TEM 0.33mm REM 1.23% rTEM 1.07% (Guo et al, 2020). Linear distances on living subjects between soft tissue landmarks using Vectra M3 3D Imaging System (Canfield Scientific Inc, NJ) landmarks had high level of inter-operator precision. Namely; en’ to en’ ICC 0.99 MAD 0.6mm TEM 0.56mm REM 0.66% rTEM 0.62%, ex’ to ex’ ICC 0.99 MAD 0.31mm TEM 0.31mm REM 1.01% rTEM 1.01%, and en’ to ex’ ipsilateral ICC 0.97 MAD 0.54mm TEM 0.48mm REM 1.78% rTEM 1.56% (Guo et al, 2020).

Twenty one linear distances on living subjects between soft tissue landmarks using the 3D optical passive device Vectra XT 3D Surface Imaging System (Canfield Scientific, NJ, USA) demonstrate a high intra-scanner correlation ICC 0.861 95% mean difference CI 0.771mm to 0.952mm (Koban et al, 2022).

Ten unknown linear distances on face casts using the 3D optical passive devices Scanify (Fuel 3D Technologies, Chinnor, UK) and Vetra H1(Canfield Scientific, NJ, USA) had 95% limits of agreement from average difference of -1.06mm to +3.51mm. The Scanify device had coefficient of variation greater that of Vectra H1 device (Canfield Scientific, NJ, USA) and direct anthropometry; 0.0075, 0.0046, 0.0041 respectively.

Variations in capture technique such as using multiple image capture, single image capture and subsequent need to merge images were stated. (Liu et al, 2019).

Two surfaces on living subjects using the 3D optical passive Vectra M3 device (Canfield Scientific, NJ, USA). Endocanthion and middle of lower eyelid areas were within 1mm2 which is an acceptable level of precision for this review. More specifically, intra-rater TEM was between 0.185mm2 and 0.630mm2, inter-rater TEM ranged between 0.255mm2 and 0.978mm2, intra-method TEM for objects one to four was between 0.055mm2 and 0.397mm2. The intra-rater, inter-rater, and intra-method REM was less than 2% for all areas which is “very good” or “excellent”. rTEM for all the objects was less than 2% which is “very good” or “excellent”. Intra-rater, inter-rater, and intra-method ICCs in this study was at least 66.7% which meant all areas measured were either “good” or “excellent”. One exception was the inter-rater ICC for the endocanthion position and the intra-method ICC for object/area one was “poor” (Liu et al, 2021).

Eight linear distances between soft tissue landmarks on living subjects using Vectra 3D (Canfield Scientific, NJ, USA) had an intra-operator ICC greater than 0.75. Namely; g’, al’ right, pg’, li’, ch’ right and left, ex’, en’ which are “good” or “excellent”. Paired t-tests and Wilcoxon Rank tests with p values were between 0.17 and 0.99.

(Othman et al, 2013).

Twelve linear distances on living subjects on digital point clouds generated by 3dMD Face device (3dMD Ltd, London, UK). Namely; al' left , al' right, ch' left, ch' right, en' left, en' right, en' right, ex' left, ex' right, li', ls', n', pn’, sn’. Method precision, assessed on mannequins, was acceptable for 3dMD Face device (average distance difference of 0.13mm, SD 0.07mm, range 0.02-0.37mm and the Vectra H1 device 0.009mm, SD 0.06mm, range 0.01-0.26mm.

Precision of analytical software (Meshmonk Registration Software, 2022) for 3dMD Face device (average distance difference 0.1mm, SD 0.09mm range 0-0.45mm) and the Vectra H1 device 0.02mm, SD 0.04mm, range 0-0.26mm.

Using the mannequin, the TEM for the 3dMD Face device demonstrated average distance difference 0.35mm, SD0.14 mm, range 0.06-1.34 mm. The Vectra H1 device demonstrated an average distance difference 0.34mm, SD 0.13mm, range 0.05-0.87mm.

On living subjects, the “participant error” for the 3dMD Face device was average distance difference of 0.44mm, SD 0.07mm, range 0.31-0.82mm The Vectra H1device had average distance difference 0.40mm, SD 0.06mm, range 0.29-0.92 mm (White et al, 2020).

* + 1. **3D Confocal Optical Method**

There were no records in this review that utilised the 3D confocal optical method to measure accuracy or precision of soft tissue landmarks in this systematic review of literature.

* + 1. **3D Time-of-Flight Optical Method**

There were no records in this review that utilised the 3D time-of-flight method to measure accuracy or precision of soft tissue landmarks in this systematic review of literature.

1. **Discussion**

It is clear in the time-period of this systematic review, 2010 until 2022, that there has been great academic interest in optical methods of soft tissue landmarks (n=18) in contrast to other measurement methods (n=2). See Table 10.

|  |  |
| --- | --- |
| **Method Being Tested to Measure Soft Tissue Landmarks** | **Number of Records** |
| Computed Tomography | n= 0 |
| Cone Beam Computed Tomography | n= 2  Fourie et al, 2011 ; Kook et al, 2014. |
| Magnetic Resonance Imaging | n= 0 |
| Ultrasonography | n= 0 |
| Physical Impressions | n= 0 |
| Direct anthropometry | n= 0 |
| Optical Methods: 2D Photography, 3D Active, 3D Passive, 3D Confocal and 3D Time-of-Flight | n= 18  Aksu et al, 2010; D'Ettore et al, 2022; De Menezes et al, 2010; Fourie et al, 2011; Franke-Gromberg et al, 2010; Gibelli et al, 2018; Guo et al, 2020; Jablonski et al, 2017; Kook et al, 2014; Koban et al, 2022; Lim et al, 2022; Liu et al, 2019; Liu et al, 2021; Othman et al, 2013; Peidra Cascon et al, 2020; Rudy et al, 2020; Staller et al, 2022; White et al, 2020. |
| **Table 10.** Method of measuring surface face features | |

The reference measurement method for many of the records was often direct anthropometry, n=9, or an optical method, n=6. See Table 11.

|  |  |
| --- | --- |
| **Reference Method** | **Number of Records** |
| Direct Anthropometry | n= 9  Aksu et al, 2010;  Fourie et al, 2011;  Franke-Gromberg et al, 2010; Guo et al, 2020;  Kook et al, 2014;  Lim et al, 2022;  Liu et al, 2021;  Peidra Cascon et al, 2020;  Staller et al, 2022. |
| Optical Methods: 2D Photography, 3D Active, 3D Passive, 3D Confocal or 3D Time-of-Flight | n= 6  D'Ettore et al, 2022;  De Menezes et al, 2010;  Gibelli et al, 2018;  Koban et al, 2022;  Rudy et al, 2020;  White et al, 2020; |
| Indirect Anthropometry of Face Masks/Casts using physical impressions | n= 2  Jablonski et al, 2017;  Liu et al, 2019 |
| Radiography: Lateral Cephalogram or CT. | n= 1  Liu et 2019 |
| Co-ordinate Measurement Machine (Contact with probe) | n= 1  Zhao et al, 2020 |
| **Table 11.** Reference methods. | |

Many of the records included in this systematic review of literature did not use a living subject as a reference but instead used a mannequin or cadaver. In particular, all investigations in the cone beam computed tomography method sub-group used non-living subjects. Significant factors are overlooked during investigations on non-living subjects when compared to living subjects. Namely; soft tissue dimensional changes associated with alterations in head and body position, voluntary muscle movements and involuntary muscle movements, tissue compression and errors related to location of unmarked soft tissue landmarks. Brief involuntary muscle micromovements of facial muscles and eyes, lasting 200-500 micro-seconds, even when subject is focused on a fixed point, will occur. These will be registered by many of the methods for assessing soft tissue landmarks. Longer acquisition time results in increased risk these movements will occur (Lin et al, 2014; Maal et al, 2011; Stephan and Munn, 2018, White et al, 2020).

Although not meeting the inclusion criteria for this review, but in a sign of the times by analysing data on a mass scale, Weinberg compared measurements from a large 3D optical database (n = 2454) with a large direct anthropometry database (n = 2326) alluding to differences in accuracy and precision between the two methods. Measurements in the peri-ocular area are more variable, in particular soft tissue exocanthion, and lip areas. However, as the author also acknowledged, caution was urged against using these records as a basis for direct comparison between the two methods as each sample had significant ethnicity and age-related differences Cohen d effect size correlation which indicates low discrepancies (small 0.2-0.49 or very small <0.2 with 95% confidence interval of mean differences within this range) for 11 (st’ to sn’, ex’ to ex’, en’ to en’, al’ to pn’, me’ to pn’, ls’ to sn’, sto’ to sm’, li’ to sm’, al’ to al’, pn’ to se’ and t’ and se’) of 24 linear distances between landmarks (Weinberg, 2019 )

**10.1 Cone Beam Computed Tomography**

**Accuracy**

No investigations have been conducted on living subjects presumably due to danger of exposure of subjects to risks of ionizing radiation.

There is wide support for accuracy of cone beam computed tomography on non-living subjects which supports it use for forensic and post-mortem soft tissue measurements. One record suggests cone beam computed tomography to have accuracy and precision of near equality with optical 3D passive (passive stereophotogrammetry), laser scanning and direct anthropometry for linear distances (Fourie et al, 2011).

**Precision**

No records investigated precision of cone beam computed tomography soft tissue landmark measurements.

**10.2 Direct Anthropometry**

Precision of direct anthropometry on non-living subjects is well supported (Fourie, et al, 2011). However, support for precision on living subjects was limited to one linear distance, en’ to ex’ (Guo et al, 2020).

**10.3 Optical Methods.**

Nineteen records studied the either the accuracy or precision of optical methods to measure soft tissue landmarks which represent the largest area of academic activity in this systematic review of literature.

Significantly 3 records did not specify exact device model used for 3D optical methods (De Menezes et al, 2010; Fourie et al, 2011; Jablonski et al, 2017). Another record provided little technical data about the device (Liu et al, 2019).

3D optical methods are being recognised as more accurate or better than direct anthropometry (De Menezes et al, 2010) and this seems to be evident due to large number of records using 3D optical methods as a reference method, n=6. See Table 11).

**10.3.1 2D Photography**

**Accuracy**

Many soft tissue landmark measurement accuracies under 1mm are not supported but the accuracy of the sn’ to se’ distance is well supported (Guo et al, 2020; Lim et al, 2022)

One record concluded that the inability to palpate skeletal landmarks underlying soft tissue landmarks may lead to reduced accuracy and precision with locating some landmarks. Namely; z’ and gn’. Cultural and religious norms meant several females in this study wore the hijab as a demonstration of their faith which made lateral soft tissue landmark location difficult (Lim et al, 2022).

**Precision**

Generally, precision was poorer than accuracy but good precision for many peri-ocular landmark distances and angles was noted by Guo et al. They propose 2D photography is more accurate than 3D passive optical methods and direct anthropometry (Guo et al, 2020). It should be noted than the 2D photograph used in their investigation was derived from an 3D optical model, in effect taking a “slice” of the 3D model. This technique may have potential to improve accuracy and precision of measurements on other soft tissue landmarks of the face by removing errors derived from errors of depth of focus in conventional 2D photography (Aksu et al, 2010).

The precision of using soft tissue landmarks to “scale” photographs, particularly the precision of using the interpupillary distance, was questioned (Aksu et al, 2010).

**10.3.2 3D Active Optical Method**

**Accuracy**

Four records investigated handheld/mobile 3D optical active devices. (D'Ettore et al, 2022 ; Koban et al, 2022; Peidra-Cascon et al, 2020; Rudy et al, 2020). Accuracy for the mobile 3D optical active device (iPhone X; Apple, CA, USA) using software Bellus3D Face Application (version 1.6.11; Bellus3D Inc, CA, USA) or (ScandyPro, New Orleans, USA) that was clinically acceptable for 1 linear distance (reference to g’, Peidra Cascon et al, 2020)

or demonstrated large discrepancies in measurements of area falling outside level expected for clinical use (D'Ettore et al, 2022; Rudy et al, 2020). However post-mortem and non-clinical use such as patient education or “rough|” treatment plan visualization should not be discounted. Other handheld mobile devices, namely the Sense 3D scanner device (Sense 3D 3D Systems, South Carolina, USA) and Artec Eva (Artec 3D, Luxembourg) demonstrated clinically acceptable accuracy for 8 linear distances which may suggest increased accuracy when compared to other handheld devices (Koban et al, 2022).

Two records investigated static 3D optical active devices indicating potentially the most accurate method of measuring soft tissue landmarks due to the increased statistical robustness of investigations and investigations involving complex face structures such as defects and clefts (Fourie et al, 2011; Jablonski et al, 2017). However, it should it is worth noting that evidence gathered by Fourie et al was based on cadavers.

**Precision**

Evidence for precision of the 3D optical active method is mixed. This is particularly relevant for the 3D optical mobile and handheld devices which demonstrate “good” or “excellent” intra and inter-operator reliability or moderate of high correlation (Koban et al, 2022; Peidra-Cascon et al, 2020; Staller et al, 2022).

However this contrasts with Gibelli et al who demonstrated poor intra and inter instrument precision when using a mannequin to investigate precision of (Sense®, 3DSystems, Rick Hill, SC, USA). Another investigation using (iPhone Xs; Apple, CA, USA) and the Bellus3D Face Application (version 1.6.11; Bellus3D Inc, CA, USA) found limited support for clinically accurate precision (D'Ettore et al, 2022).

Three records acknowledged the importance of the optical device to be able to record colour and texture and therefore pre-indicated landmarks to improve accuracy and precision. Examples of pre-indicated soft tissue landmarks would include a clinician applying eyeliner or adhesive stickers to soft tissue landmarks. This concurs with other records (De Menezes et al, 2010; Gibelli et al, 2018; Koban et al, 2022; Lin et al, 2014).

One record assessed accuracy and precision of combining a 3D optical active method, in this case a custom-made structured light scanner, and a 3D passive optical method using face casts (Jablonski et al, 2017). The hybrid approach to soft tissue landmarks measurements may overcome the shortcomings of each method. Namely the low accuracy and precision of 3D passive methods to with regarding undercut, poorly-lit and featureless areas of the face (Zhao et al, 2020) and the slower acquisition times of 3D active methods which may increase errors associated with soft tissue dimensional changes associated with alterations in head and body posture, voluntary muscle movements and involuntary muscle movements (Lin et al, 2014; Maal et al, 2011; Stephan and Munn, 2018, Weinberg et al, 2004; White et al, 2020).

**10.3.3 3D Passive Optical Method**

**Accuracy**

Generally accuracy was low when considering all landmarks and when compared to 3D optically active methods with only two handheld device Vectra H1 (Canfield Scientific, NJ, USA) and the Scanify (Fuel 3D Technologies, Chinnor, UK) being examined in this category. Liu et al demonstrated 99% accuracy of the face as a whole when comparing surfaces but this was in the z axis only (Liu et al, 2019).

**Precision**

As with the 3D optical active method, precision was increased when compared to accuracy. Precision of measurements of major soft tissue landmarks around the eye, en’ to en’, ex’ to ex’ and en’ to ex’, are supported by many (Fourie et al, 2011; Guo et al, 2020; Koban et al, 2022; Othman et 2013).

White et al investigated sources of precision error on non-living subjects and specifically investigated sources of error from software/data analysis which is relevant in age of increasing investigating using digitally generated models. The number of points in generated point clouds was postulated to be a major factor regarding precision. The Vectra H1 (Canfield Scientific, NJ, USA) producing 90K points compared to 3dMD Face (3dMD Ltd, London, UK) with 35k points (White et al, 2020).

**11 Conclusion**

The null hypothesis that all methods of measuring human soft tissue landmarks of the face are accurate and precise enough for clinical use is not supported by this systematic review.

There is no evidence to support use of computerised tomography, magnetic resonance imaging, ultrasonography, physical impressions, direct anthropometry, 3D confocal or 3D time-of-flight methods with regard to accuracy and precision of measuring soft tissue landmarks of the face for clinical use.

The evidence to support the cone beam computerised tomography method to accurately and precisely measure soft tissue landmarks on living subjects within clinically acceptable boundaries is poor. This is because as all records were completed on cadavers or mannequins. That said, it’s *post-mortem* use, for example in forensic dentistry and anthropology, is fully supported.

2D photography has limited support for accuracy and precision on the face. However, there is good support for precision and accuracy in the peri-ocular area with 2D images derived from 3D models. This technique may have positive implications for use in other parts of the face.

3D optical active and passive methods have limited support for clinically acceptable accuracy but with increased support for increased precision. Its use is probably best suited to grosser assessments of the face where accuracy and precision of less than 1mm is not required.

**12. Areas for Further Research**

Further could begin with improving the quality of this systematic review of literature. Namely by; Including databases Science Direct and Scopus in the search, register with the international Prospective Register of Systematic Reviews (PROSPERO), further knowledge about statistical analysis of complex computer algorithms to compare 3D point clouds, conduct meta-analysis of data, the reviewer could have been blinded, more than one reviewer could participate, the time-period could be extended as there are significant pieces of literature outside time-frame which may have included support for some methods particularly direct anthropometry, further training in application of the QUADAS 2 bias assessment would improve bias assessment and more references in records could have been included.

Further work may also include a more specific literature review regarding optical methods of measuring soft tissue landmarks. Further investigation of living subjects, rather than cadavers, mannequins, or face masks, for accuracy and precision of soft tissue landmark measurements using cone beam computed tomography could be considered.

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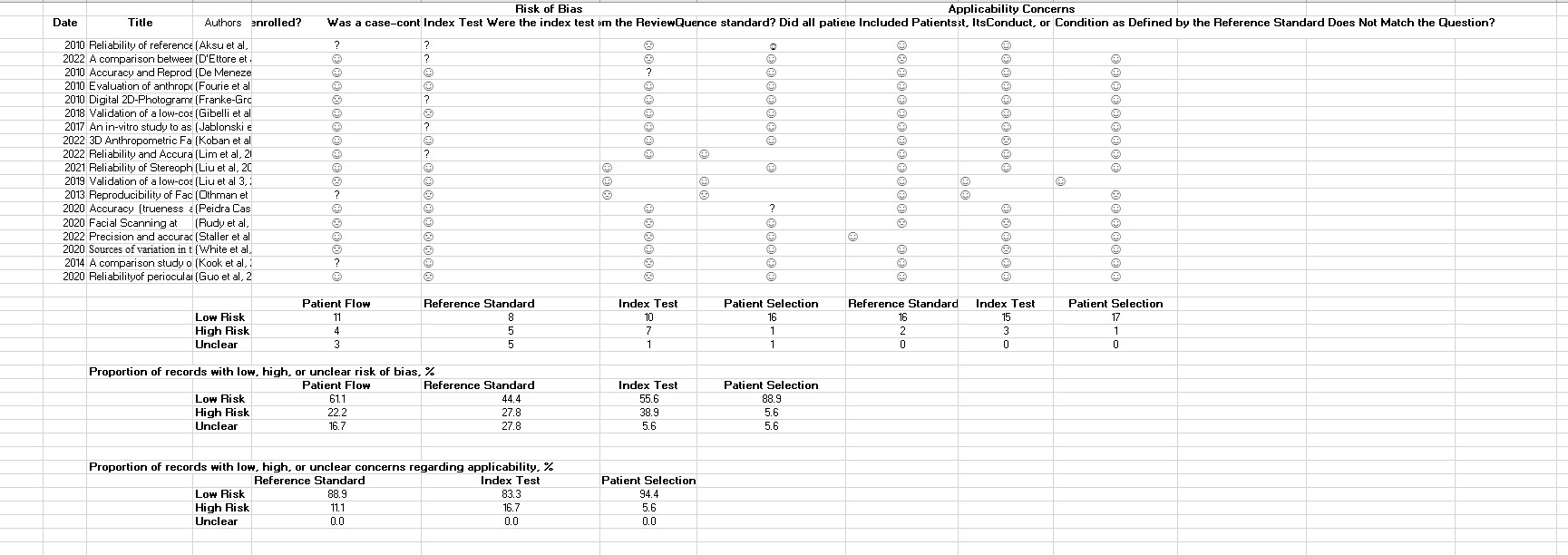
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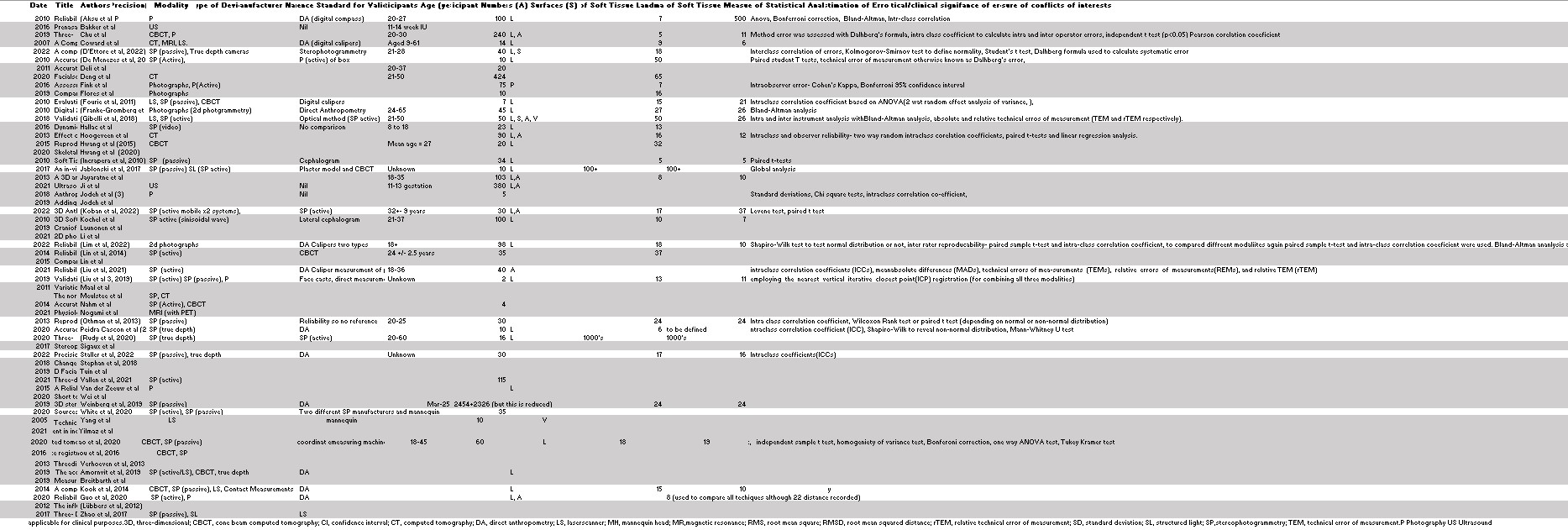
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**13. Appendices**

**Appendix 1 QUADAS 2**

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**Appendix 2 Data Extraction**