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Evaluating the accuracy of soft tissue prediction in patients with mandibular prognathism after orthognathic surgery using handheld scanner versus optical scanner A prospective clinical trial

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Orthognathic surgery; mandibular prognathism; handheld scanner; stereophotogrammetry; soft tissue prediction; three-dimensional imaging; accuracy

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ABSTRACT

Orthognathic surgery for mandibular prognathism aims to restore functional occlusion and optimize facial aesthetics. Accurate three-dimensional (3D) soft tissue prediction is essential for surgical planning and managing patient expectations. While stereophotogrammetry is considered a gold standard for facial soft tissue capture, portable handheld structured light scanners offer potential advantages in cost, flexibility, and accessibility. However, comparative data on their accuracy for soft tissue prediction in patients with mandibular prognathism remains limited. To compare the accuracy of soft tissue prediction following orthognathic surgery in patients with mandibular prognathism using a portable handheld structured light scanner versus a stationary stereophotogrammetry system. This prospective clinical trial included patients with mandibular prognathism requiring orthognathic surgery. Preoperative soft tissue facial scans were obtained using both a Creality Ferret handheld structured light scanner and a stereophotogrammetry system. Virtual surgical planning was performed using ProPlan CMF software, and soft tissue predictions were generated. Six months postoperatively, follow-up scans were acquired using both modalities. Predicted and postoperative scans were superimposed in 3-matic software using iterative closest point algorithms. Linear deviations were measured at eight standardized facial landmarks: pronasale, subnasale, labrale superioris, labrale inferioris, pogonion, right and left oral commissures, and menton. Statistical analysis included paired t-tests and Wilcoxon signed-rank tests with significance set at $p \leq 0.05$. Effect sizes were calculated to determine clinical relevance. Twenty patients (mean age 26.4 ± 5.8 years) completed the study. The handheld scanner demonstrated significantly lower overall mean deviation compared to stereophotogrammetry (2.58 ± 0.82 mm vs. 3.24 ± 1.17 mm; mean difference -0.659 mm; 95% CI: -0.947 to -0.371 mm; $p = 0.0029$), with a very large effect size ($d = -1.58$). Landmark-specific analysis revealed significant advantages for the handheld scanner at pronasale (1.57 ± 0.84 mm vs. 1.89 ± 1.00 mm; $p = 0.023$), labrale inferioris (2.75 ± 1.50 mm vs. 3.17 ± 1.66 mm; p = 0.024), pogonion (1.71 ± 0.38 mm vs. 2.35 ± 1.42 mm; p = 0.028), and both oral commissures (right: 4.80 ± 2.07 mm vs. 5.94 ± 2.19 mm, p < 0.001; left: 2.74 ± 1.30 mm vs. 3.89 ± 1.48 mm, p = 0.009). At the menton landmark, stereophotogrammetry produced consistently non-analyzable surface representations, while the handheld scanner successfully captured all cases (mean deviation 3.00 ± 0.93 mm). No significant difference was observed at labrale superioris (p = 0.520). The portable handheld structured light scanner demonstrated superior accuracy compared to stationary stereophotogrammetry for soft tissue prediction in patients with mandibular prognathism undergoing orthognathic surgery. The handheld scanner showed higher accuracy in the submental area, where stereophotogrammetry exhibited significant limitations. These findings support the clinical applicability of handheld scanning technology as an accurate alternative for 3D facial assessment in orthognathic surgical planning.

Introduction

The primary objective of orthognathic surgery for patients with mandibular prognathism is the restoration of functional occlusion and the optimization of facial aesthetics. Given that underlying skeletal movements do not always result in a direct 1:1 ratio of soft tissue response, accurate pre-surgical simulation is vital for managing patient expectations and surgical outcomes [1]. The aesthetic goal achievement is defined by the harmonious transition of the facial soft tissues, which is based on patient spercific factors such as skin thickness, age, muscular tonicity, and the degree of surgical movement [2]. Historically, two-dimensional (2D) cephalometric planning was the gold standard; however, it often failed to capture complex, three-dimensional (3D) volumetric changes, particularly in some regions like the lips as it’s highly mobile and the submental area [3].

Introducing the 3D imaging has transformed maxillofacial planning by providing detailed volumetric information with high accuracy [4]. Stereophotogrammetry has emerged as a gold standard for soft tissue acquisition due to its rapid capture speed, minimizing motion artifacts and its ability to replicate skin texture without ionizing radiation [5].

The introduction of handheld structured light scanners, alongside traditional stereophotogrammetry represents a shift toward portability in clinical settings. While stationary systems offer high-resolution datasets, handheld structured-light scanners are increasingly favored for their cost-effectiveness and ease of use and being portable [6]. The accuracy of these devices is vey high to sub-millimetre,. For a 3D surface model to be clinically useful, it must has a Root Mean Square (RMS) error that lies within established clinical tolerances margin which is typically less than 0.5 mm [7].

Modern VSP utilizes advanced software like ProPlan CMF (Materialise) to simulate osteotomies and predict post-operative profiles. These softwares utilize specialized algorithms such as the Mass Spring Model (MSM) or Finite Element Model (FEM) to approximately predict how soft tissue will respond to bone movement [7], [8]. Despite these advancements, predicting soft tissue response in mandibular prognathism remains a significant challenge due to the anisotropic nature of facial tissues [9].

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software such as 3-matic is utilized to measure the validity of soft tissue simulation. This software allows for the "Best Fit" alignment of pre-operative predictions and post-operative scans using Iterative Closest Point (ICP) algorithms. By generating color-coded distance maps and surface-to-surface deviations accuracy of soft tissue prediction can be measured [10]. The importance of this type of analysis is to reach patient specific data rather than relying on population average measurements.

Although there are lots of available options in market and existing literature on the accuracy of specific 3D imaging systems, there remains limited research comparing the accuracy of soft tissue prediction in mandibular prognathism patients using contemporary handheld scanners versus stereophotogrammetry.

Most studies have focused on scanning accuracy rather than prediction accuracy in patients undergoing orthognathic surgery. the specific challenges of capturing the submental region and oral commissures haven't been evaluated

The present study aims to compare the accuracy of soft tissue prediction following orthognathic surgery in patients with mandibular prognathism using two different scanning modalities: a portable handheld structured light scanner (Creality Ferret) and a stationary stereophotogrammetry system. The findings of this study will contribute to the evidence base regarding the clinical applicability of handheld scanning technology in orthognathic surgical planning.

Methodology:

Study Design This prospective clinical trial was conducted at the Department of Oral and Maxillofacial Surgery, Cairo university, Ethical approval was obtained from the Institutional Review Board ( ), and all participants provided written informed consent prior to enrollment. The study was conducted in accordance with the Declaration of Helsinki.

A total of 11 patients were included in this study from out patient clinic the Department of Oral and Maxillofacial Surgery, Cairo university

Inclusion criteria:

- Patients with facial mandibular prognathism that requires orthognathic surgery.
- Age (18- 50years).
- Patients are willing for the surgical procedure and follow-up, with informed consent .

Exclusion criteria:

- Dental malocclusion that could be treated with orthodontic treatment only.
- Patients with contraindications for general anesthesia.
- Patient on radiotherapy.
- Patients suffer from bone disease.

Interventions Preoperative Investigations

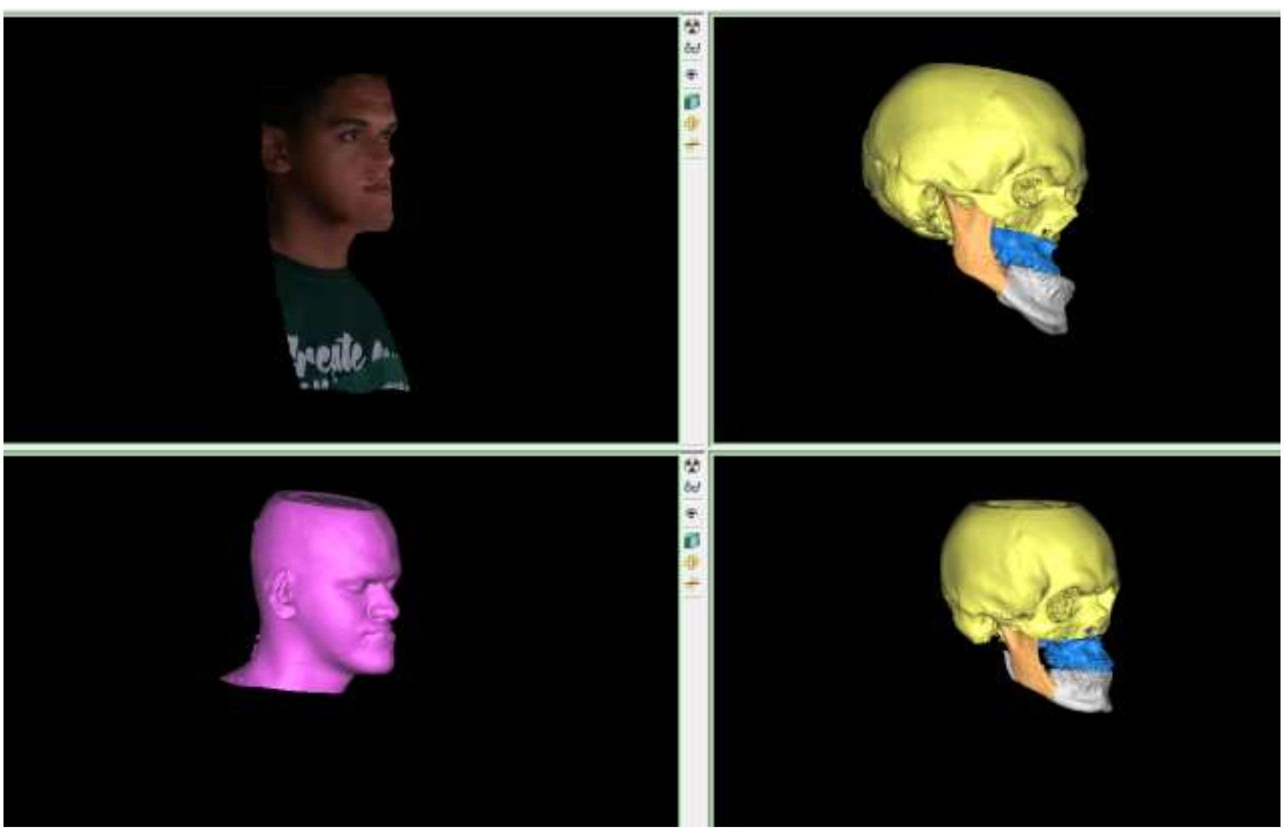
- From the point of eligibility for general anesthesia, complete blood picture, body weight, urine albumin, blood glucose level, kidney and liver function.
- Administration of peri-operative antibiotics.
- A multi-slice CT scan demanded in a form of DICOM files (Digital Imaging and Communications in Medicine) for proper diagnosis and confirmation of patient compatibility to the eligibility criteria and digital planning of the study group.
- For each patient soft tissue scanning was done using cr-scan ferret scanner (Creality,shinzen,china) file will be imported to specialized software PROPLAN CMF™ (Leuven, Belgium)

Setting was set as seen in the figure above
Average number of frames was 900 frame for each patient
It took average of 2 minutes to acquire

- then soft tissue scan was done using optical scanner stereophotogrammetry)

- then the file was imported to a specialized software PROPLAN CMF™ (Leuven, Belgium)
- surgical planning was performed according to each case as it may need mandibular set back only or combined with maxillary advancement (bimaxillary surgery) with or without genioplasty

- soft tissue movement simulation was performed using both scans



- special wafers (intermediate wafer to be used intraoperatively for maxillary fixation in bimaxillary surgery the final wafer for mandibular fixation or final wafer only in cases of mandibular set back

- for segmentation process and superimposition of the soft tissue scan and the CT dicom file and planning the osteotome and fabrication of surgical guide for accurate positioning and fixation of bone segment.
- Sterilization of the patient-specific plates and splints
- For hemostasis an Epinephrine solution in dilution of 1:200.000 with lignocaine 0.5 mg\ml injected along lines of surgical incisions 5 min before the surgery

The surgical technique:
All surgeries will be carried out with endotracheal intubation under general anaesthesia.

1. the planned osteotomies are performed on the upper jaw (maxilla), lower jaw (mandible), or both, depending on the treatment plan.
2. Repositioning of Jaw Bones: into the planned alignment to correct the underlying skeletal discrepancies. This may involve moving the jaws forward, backward, upward, or downward as needed to achieve proper facial harmony and function.
3. Stabilization: using plates and screws to stabilize the bones in their new position. This promotes proper healing and ensures long-term stability of the surgical outcome.

Postoperative Management:

- Postoperative instructions include a sleeping in a supine position semi-up righted, Strict oral hygiene measures.
- Postoperative medications include prophylactic broad-spectrum antibiotics for 5 days' post operatively, nonsteroidal anti-inflammatory drug, diclofenac.

Suture will be removed after 7 days post operative.

Accuracy measurement:
After six months post operative 3d facial scans are obtained and exported to software to perform superimposition of the predicted and post operative results to assess the accuracy of soft tissue prediction
By measuring the difference in millimeter between prespecified points
soft tissue prediction and post operative scans are exported to 3 matic
then both are aligned using (n point registration) while using three different points away from points to be measure
the segmented soft tissue prediction is compared with post operative scan acquired from both scanners points are measured in the sagittal view after using datum plane to draw a true sagittal plane
points to be measured in each scanner

- pronasal
- subnasal
- labrale superioris
- labrale inferioris
- pogonion
- corner of the mouth (left and right)
- menton

Points are placed attached to surface during hiding the comparator and vice vera

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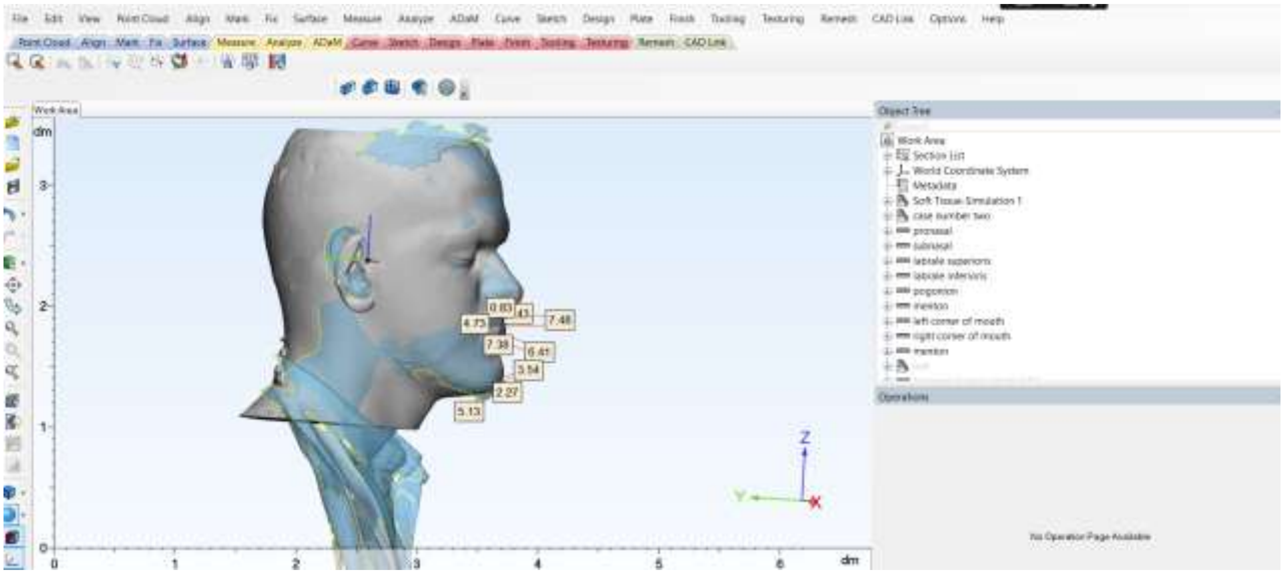

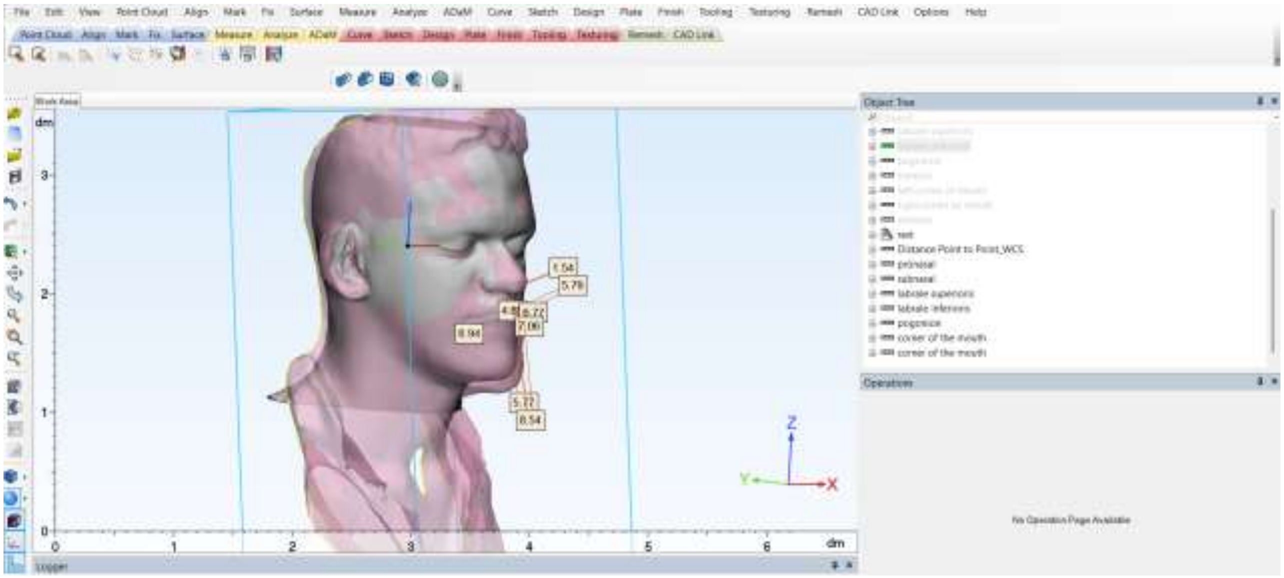

Statistical methods

Statistical analysis was conducted using MedCalc Statistical Software (MedCalc Software Ltd., Ostend, Belgium). The distribution of paired differences for each facial landmark was assessed using the Shapiro–Wilk test ($p \leq 0.05$). All outcomes showed parametric distribution except Subnasal and Pogonion, which demonstrated non parametric distributions. Each variable was summarized using both mean ± standard deviation (SD) and median with interquartile. Intergroup comparisons of parametric data between the handheld scanner and stereophotogrammetry were performed using the paired t test, while outcomes with non normal differences were analyzed using the Wilcoxon signed rank test. Effect sizes were calculated as Cohen’s d for paired t tests and rank biserial correlation for Wilcoxon tests. MedCalc’s paired comparison module was used to compute the mean difference (Handheld – Stereo) along with the corresponding 95% confidence interval (CI). Statistical significance was set at ($p \leq 0.05$), and all tests were two tailed. An overall accuracy metric was also derived by averaging all landmarks to evaluate the global difference between modalities.

Results

1. Pronasale

For the pronasale landmark, the handheld scanner demonstrated lower deviation than stereophotogrammetry. Handheld measurements were 1.57 ± 0.84 mm, with a median of 1.48 mm (IQR: 1.03–2.06 mm), whereas stereophotogrammetry produced 1.89 ± 1.00 mm, with a median of 1.54 mm (IQR: 1.10–2.76 mm). A paired t-test showed a significant mean difference of –0.321 mm (95% CI: –0.539 to –0.103 mm; p = 0.023). The effect size was large (d = –1.02), indicating a meaningful and consistent advantage of the handheld scanner for this landmark. (Table X & Figure X)

Table X: Mean, SD, median and IQR of pronasale among groups

Pronasale	Handheld	Stereo
Mean ± SD	1.57 ± 0.84	1.89 ± 1.00
Median (IQR)	1.48 (1.03–2.06)	1.54 (1.10–2.76)
P value	0.023	
Difference	–0.321 mm	
95% CI	–0.539 to –0.103	
Effect size	–1.02 (large)	

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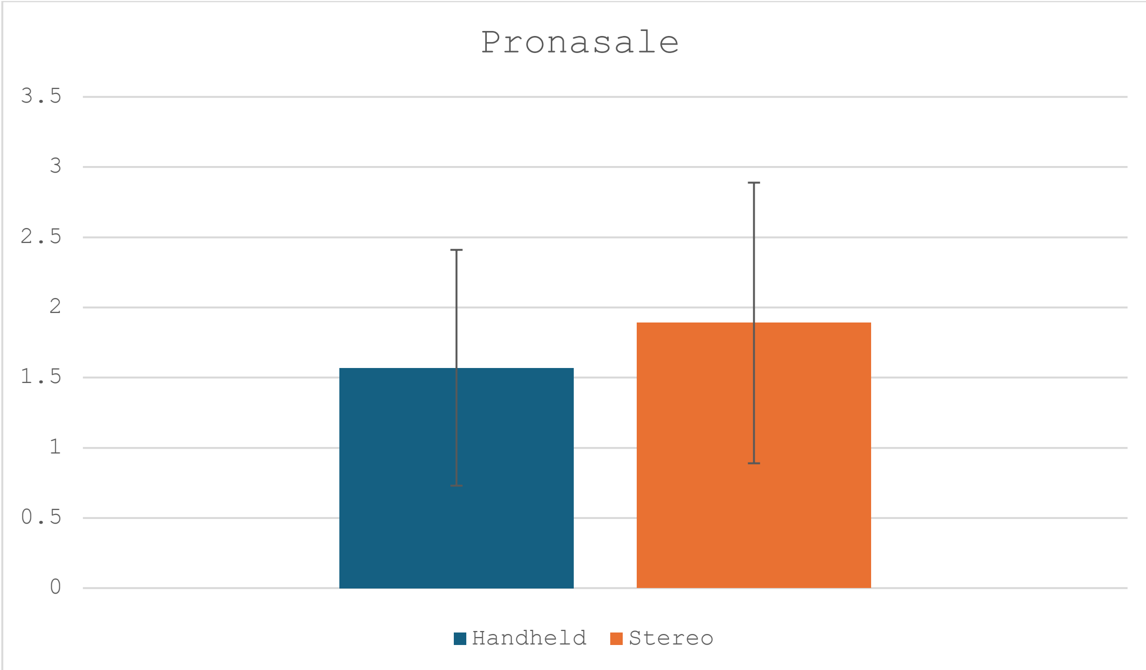

Figure X: Bar chart showing pronasale among groups

2. Subnasale

For the subnasale landmark, the handheld scanner showed lower deviation values (1.69 ± 0.56 mm; median 1.80 mm, IQR: 1.27–2.10 mm) compared with stereophotogrammetry (2.44 ± 1.17 mm; median 2.14 mm, IQR: 1.41–2.76 mm). The Wilcoxon signed rank showed a non-significant mean difference of –0.751 mm (95% CI: –3.474 to 0.605 mm; p = 0.109). Although not statistically significant, the effect size (rank biserial = –0.67) indicated a large directional trend favoring the handheld scanner. (Table X & Figure X)

Table X: Mean, SD, median and IQR of subnasale among groups

Subnasale	Handheld	Stereo
Mean ± SD	1.69 ± 0.56	2.44 ± 1.17
Median (IQR)	1.80 (1.27–2.10)	2.14 (1.41–2.76)
P value	0.109	
Difference	–0.751 mm	
95% CI	–3.474 to 0.605	
Effect size	–0.67 (large)	

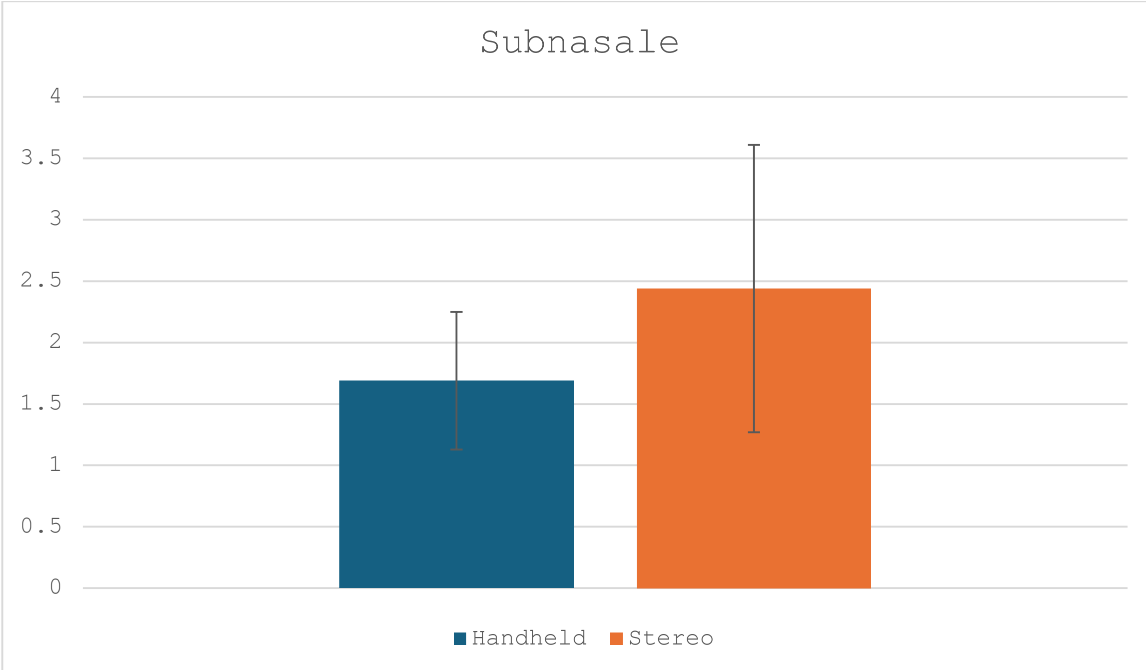

Figure X: Bar chart showing subnasale among groups

3. Labrale Superioris

At the labrale superioris landmark, both imaging systems displayed comparable accuracy. The handheld scanner produced deviation values of 2.81 ± 2.08 mm (median 2.30 mm, IQR: 1.40–3.19 mm), while stereophotogrammetry recorded 3.00 ± 1.71 mm (median 2.40 mm, IQR: 1.80–2.75 mm). A paired t-test showed no significant difference between systems (mean difference –0.189 mm; 95% CI: –0.736 to 0.358 mm; p = 0.520), and the effect size was small (d = –0.24). These findings reflect near-equivalent performance at this landmark. (Table X & Figure X)

Table X: Mean, SD, median and IQR of labrale superioris among groups

Labrale superioris	Handheld	Stereo
Mean ± SD	2.81 ± 2.08	3.00 ± 1.71
Median (IQR)	2.30 (1.40–3.19)	2.40 (1.80–2.75)
P value	0.52	
Difference	–0.189 mm	
95% CI	–0.736 to 0.358	
Effect size	–0.24 (small)	

Figure X: Bar chart showing labrale superioris among groups

4. Labrale Inferioris

The handheld scanner performed significantly better at the labrale inferioris landmark. Its deviation values were 2.75 ± 1.50 mm (median 2.22 mm, IQR: 2.00–2.40 mm), compared with 3.17 ± 1.66 mm for stereophotogrammetry (median 2.69 mm, IQR: 2.30–3.05 mm). A paired t-test indicated a significant difference (mean difference –0.420 mm; 95% CI: –0.707 to –0.133 mm; $p = 0.024$), with a large effect size ($d = –1.02$). This demonstrates a pronounced advantage of the handheld scanner for this landmark. (Table X & Figure X)

Table X: Mean, SD, median and IQR of labrale inferioris among groups

Labrale inferioris	Handheld	Stereo
Mean ± SD	2.75 ± 1.50	3.17 ± 1.66
Median (IQR)	2.22 (2.00–2.40)	2.69 (2.30–3.05)
P value	0.024	
Difference	–0.420 mm	
95% CI	–0.707 to –0.133	
Effect size	–1.02 (large)	

Figure X: Bar chart showing labrale inferioris among groups

5. Pogonion

For the pogonion landmark, the handheld scanner again outperformed stereophotogrammetry. Handheld measurements were 1.71 ± 0.38 mm (median 1.65 mm, IQR: 1.40–1.97 mm), whereas stereophotogrammetry showed 2.35 ± 1.42 mm (median 1.84 mm, IQR: 1.65–1.96 mm). The Wilcoxon test showed a significant difference (mean difference –0.635 mm; 95% CI: –2.970 to 0.165 mm; *p* = 0.028). The effect size was large (rank-biserial = –0.86), indicating substantially higher stereophotogrammetry error at this landmark. (Table X & Figure X)

Table X: Mean, SD, median and IQR of pogonion among groups

Pogonion	Handheld	Stereo
Mean ± SD	1.71 ± 0.38	2.35 ± 1.42
Median (IQR)	1.65 (1.40–1.97)	1.84 (1.65–1.96)
P value	0.028	
Difference	–0.635 mm	
95% CI	–2.970 to 0.165	
Effect size	–0.86 (large)	

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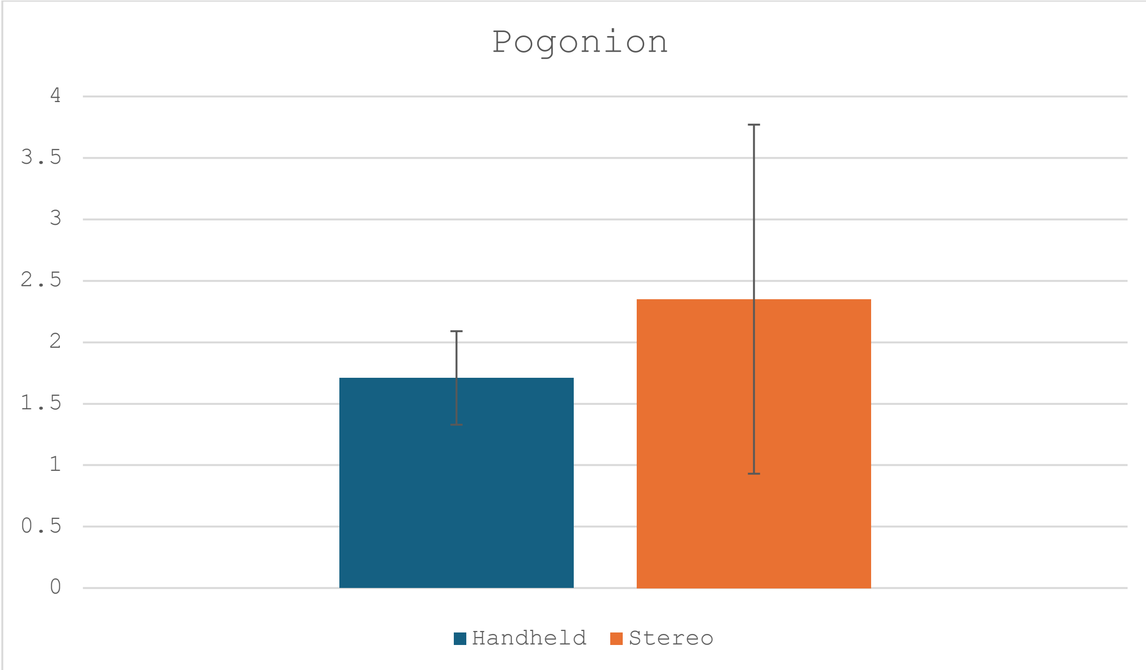

Figure X: Bar chart showing pogonion among groups

6. Corner of the Mouth

6.1. Corner of the Mouth – Right

The right corner of the mouth exhibited the largest discrepancy between the two imaging systems. The handheld scanner recorded deviations of 4.80 ± 2.07 mm (median 4.50 mm, IQR: 3.35–5.65 mm), while stereophotogrammetry produced 5.94 ± 2.19 mm (median 5.68 mm, IQR: 4.54–6.53 mm). A paired t test demonstrated a highly significant mean difference of –1.143 mm (95% CI: –1.447 to –0.838 mm; $p < 0.001$), with a large effect size ($d = –2.60$). (Table X & Figure X)

Table X: Mean, SD, median and IQR of right corner of the mouth among groups

Right corner of the mouth	Handheld	Stereo
Mean ± SD	4.80 ± 2.07	5.94 ± 2.19
Median (IQR)	4.50 (3.35–5.65)	5.68 (4.54–6.53)
P value	0.00016	
Difference	–1.143 mm	
95% CI	–1.447 to –0.838	
Effect size	–2.60 (large)	

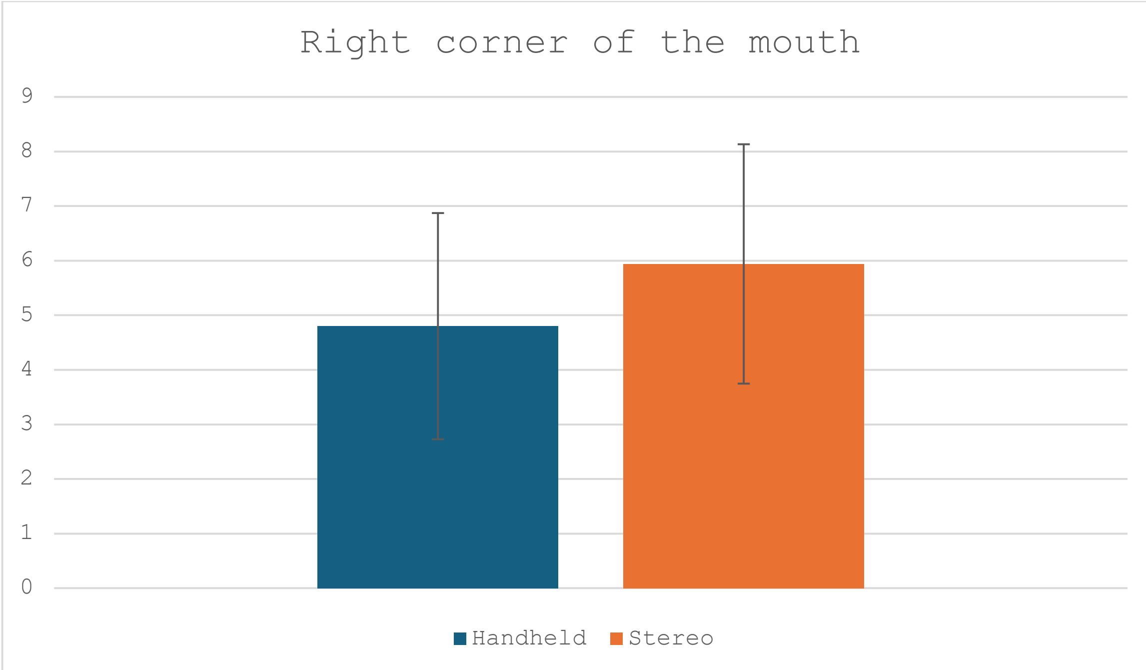

Figure X: Bar chart showing right corner of the mouth among groups

6.2. Corner of the Mouth – Left

The left corner of the mouth displayed a similar pattern. Handheld deviations were 2.74 ± 1.30 mm (median 2.50 mm, IQR: 1.60–3.54 mm), compared with 3.89 ± 1.48 mm for stereophotogrammetry (median 3.59 mm, IQR: 2.78–4.28 mm). A paired t test found a significant difference (mean difference –1.154 mm; 95% CI: –1.788 to –0.520 mm; p = 0.009). The effect size was large (d = –1.26), confirming markedly reduced accuracy of stereophotogrammetry at this landmark. (Table X & Figure X)

Table X: Mean, SD, median and IQR of left corner of the mouth among groups

Left corner of the mouth	Handheld	Stereo
Mean ± SD	2.74 ± 1.30	3.89 ± 1.48
Median (IQR)	2.50 (1.60–3.54)	3.59 (2.78–4.28)
P value	0.009	
Difference	–1.154 mm	
95% CI	–1.788 to –0.520	
Effect size	–1.26 (large)	

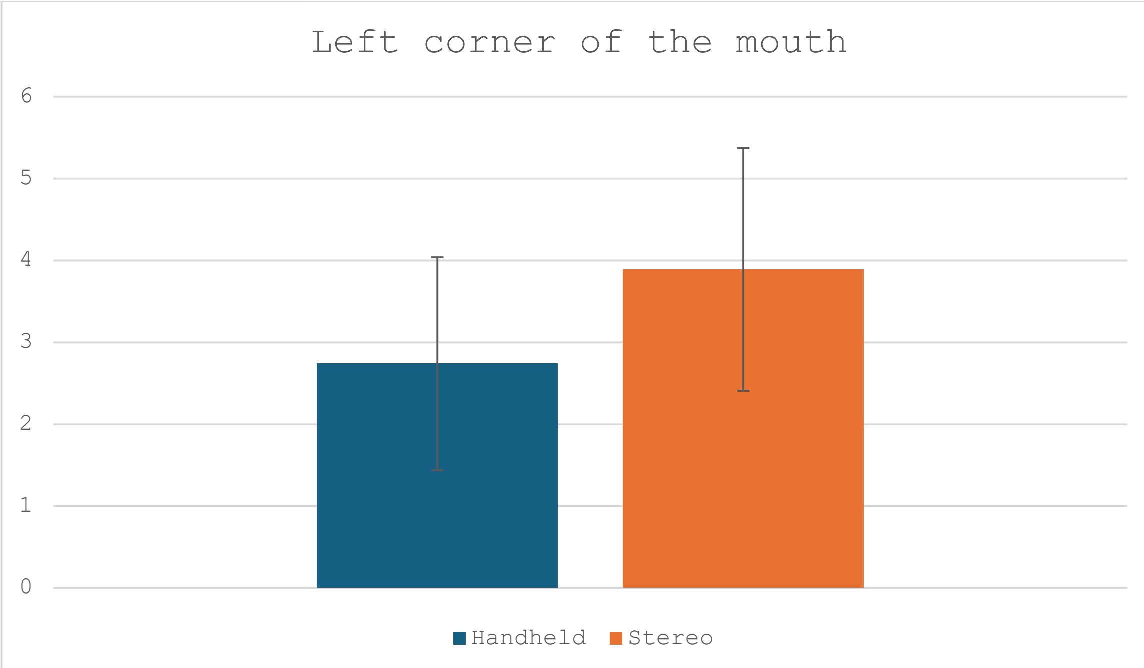

Figure X: Bar chart showing left corner of the mouth among groups

7. Menton

For the Menton landmark, measurable values were obtained only from the handheld scanner because stereophotogrammetry produced badly distorted and non analyzable surface representations in all cases. The handheld scanner recorded a mean deviation of 3.00 ± 0.93 mm, with a median of 3.03 mm and an interquartile range (IQR) of 2.50–3.60 mm. Because the stereophotogrammetry output was consistently unusable, no comparative statistical analysis could be performed for this landmark.

Table X: Mean, SD, median and IQR of menton in handheld scanner

Left corner of the mouth	Handheld	Stereo
Mean ± SD	3.00 ± 0.93	NA
Median (IQR)	3.03 (2.50–3.60)	NA
P value	NA	
Difference	NA	
95% CI	NA	
Effect size	NA	

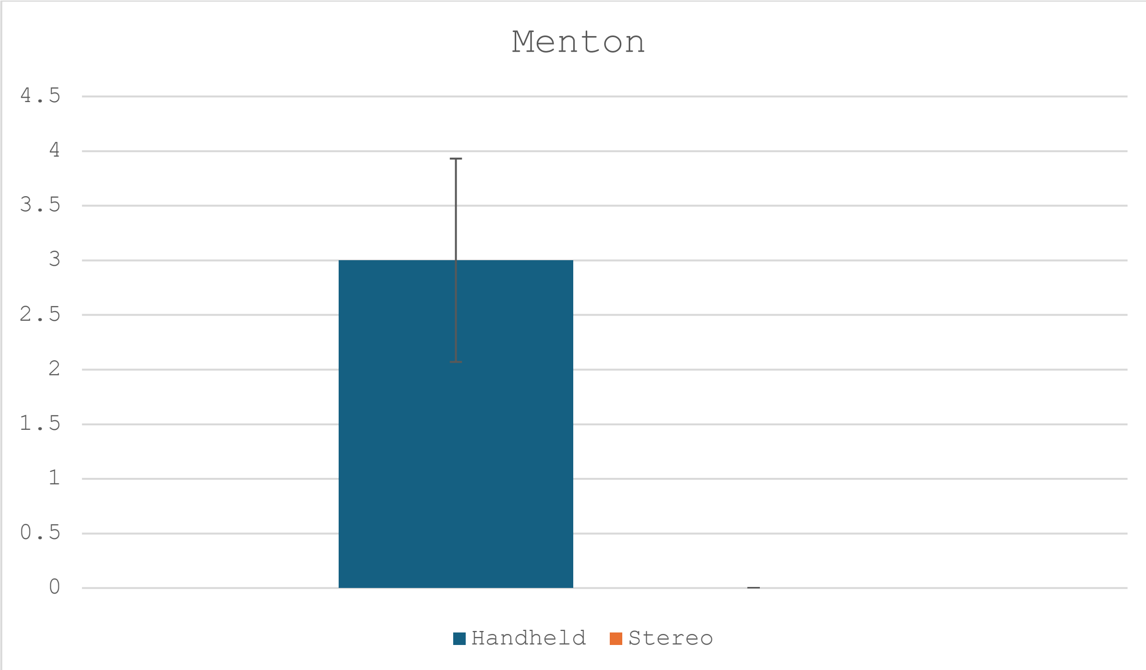

Figure X: Bar chart showing menton in handheld scanner

8. Overall accuracy

Across all facial soft-tissue landmarks, the handheld scanner demonstrated significantly lower deviation compared with stereophotogrammetry. The overall deviation was 2.58 ± 0.82 mm for the handheld scanner (median 2.25 mm, IQR: 1.91–2.58 mm) versus 3.24 ± 1.17 mm for stereophotogrammetry (median 2.73 mm, IQR: 2.32–3.08 mm). A paired t-test confirmed a significant mean difference of –0.659 mm (95% CI: –0.947 to –0.371 mm; p = 0.0029). The overall effect size was very large (Cohen's d = –1.58), demonstrating a strong, consistent superiority of the handheld scanner across all evaluated facial regions. (Table X & Figure X)

Table X: Mean, SD, median and IQR of overall accuracy among groups

Overall	Handheld	Stereo
Mean ± SD	2.58 ± 0.82	3.24 ± 1.17
Median (IQR)	2.25 (1.91–2.58)	2.73 (2.32–3.08)
P value	0.0029	
Difference	–0.659 mm	
95% CI	–0.947 to –0.371	
Effect size	–1.58 (large)	

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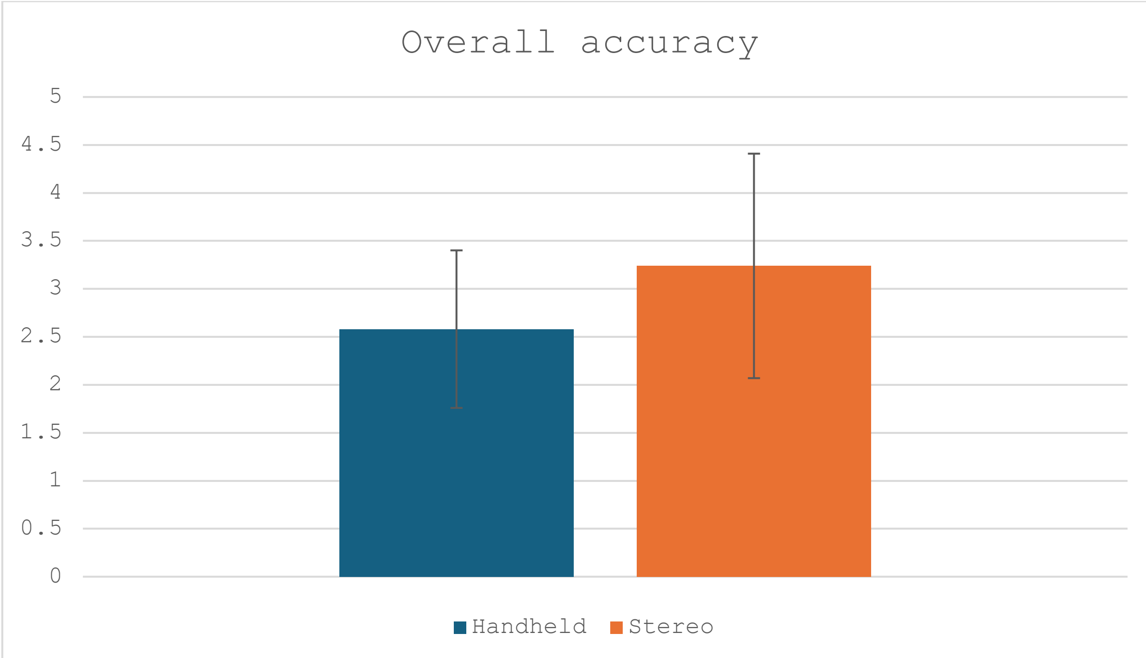

Figure X: Bar chart showing overall accuracy among groups

Descriptive date:
The handheld scanner took around 2 minutes to capture 900 frames that is acceptable for scanning while the sterophotogrammetry around one minute for patient adjustment on the scanner before capturing
During face scanning using handheld scanner the patient had to stay still for the whole two minutes to avoid motion artifacts
The software of the handheld scanner (creality) is user friendly and very easy to use it also offers lots of options regarding the quality of scanning and the object to be scanned specifically face scanning
The cost of cr-scan ferret scanner (Creality,shinzen,china) is 249$ in the official store
a stationary stereophotogrammetry device ranges from approximately $8,000 to over $200,000

Discussion

The main goal of orthognathic surgical planning is to accurately achieve optimal facial aesthetic thus there was a shift from skeletal driven planning into soft tissue based planning, that is why capturing the soft tissue and performing soft tissue registration is an extremely important step in planning for soft tissue prediction, Stereophotogrammetry employs a multi-camera setup that captures two or more images simultaneously from different viewpoints. This method offers distinct advantages, including minimizing motion artifacts and replicating skin texture without ionizing radiation [5]. However, this fixed camera configuration creates inherent limitations: the submental region is often blurred and distorted.
On the other hand, the handheld structured light scanner operates by projecting a light pattern onto the facial surface and measuring the distortions caused by facial contours. The Creality Ferret utilizes near-infrared structured light technology, it also gives feedback during scanning soft tissue to allow operator to adjust the distance between scanner and tissues to be scanned, particularly useful in some regions such as the submental area.
In this study, the handheld scanner required approximately 2 minutes to capture 900 frames per patient, which was acceptable for scanning purposes. Patients had to remain still for the entire 2 minutes to avoid motion artifacts. In comparison, the stereophotogrammetry system required approximately 1 minute for patient adjustment on the scanner before capture

A critical methodological distinction between this study and previous research is the measurement of prediction accuracy rather than scanning accuracy. While prior studies have examined the accuracy of 3D facial scans compared to ground-truth measurements [6], this study assessed the cumulative accuracy of the entire clinical workflow: initial scan acquisition, virtual surgical planning, soft tissue simulation, and six-month postoperative capture. This pproach provides clinically relevant information about the end-to-end performance of each imaging modality in actual orthognathic surgical practice.

The systematic review by Ruggiero and colleagues analyzed the accuracy of soft tissue prediction in orthognathic surgery and reported mean errors ranging from 0.55 mm to 2.9 mm for whole-face simulations [9] but in their study they used postoperative CBCT and MRI and did a retrospective simulation of the LE Fort osteotomy.

overall deviation values for stereophotogrammetry (3.24 ± 1.17 mm) fall slightly above the upper range reported in the systematic review [9]. Several factors may explain this discrepancy. First, our measurement protocol assessed linear deviations at specific landmarks rather than global surface-to-surface RMS values, which typically yield smaller errors. Second, our six-month postoperative follow-up captures not only scanning inaccuracies but also genuine biological variation in soft tissue healing and remodeling.. Third, patients with mandibular prognathism undergo multidirectional mandibular setback movements, which produce soft tissue changes that may be more challenging to predict accurately than the smaller movements typical of other dentofacial deformities.

We found abetter handheld scanner performance at pronasale ($p = 0.023$) and pogonion ($p = 0.028$) aligns with previous observations regarding structured light technology. Cao and colleagues reported that "surface regions closer to the midline were found to have higher accuracy than those on the sides of the face" [6]. This could be due to the direction of scanning as it's easier to maintain accurate distance in scanning medline structures while it's difficult to maintain it during following facial curvature

The labrale inferioris landmark showed a significant advantage for the handheld scanner (mean difference –0.420 mm, $p = 0.024$), while labrale superioris showed equivalent performance ($p = 0.520$). this could be due to The lower lip is more mobile and undergoes greater positional change following mandibular setback surgery,

Oral commissures: The most pronounced discrepancies were observed at the oral commissures, where stereophotogrammetry produced larger errors (right: 5.94 ± 2.19 mm, left: 3.89 ± 1.48 mm) compared to the handheld scanner (right: 4.80 ± 2.07 mm, left: 2.74 ± 1.30 mm). These areas represent significant challenges for optical scanning systems due to their location at the boundary between facial skin and the darker, moist oral mucosa, which can absorb or scatter light differently. Additionally, the depth of the oral commissures creates shadowing effects in multi-camera systems with fixed illumination angles.

Menton landmark: The complete failure of stereophotogrammetry to produce analyzable data at the menton landmark in all cases represents a critical finding with significant clinical implications. This limitation of fixed multi-camera systems has been previously recognized . The submental area is inherently occluded from the perspective of cameras positioned for frontal capture, leading to distorted surface reconstruction or blurring. This limitation has huge significance for surgical planning, as the chin and submental region are primary aesthetic targets in mandibular prognathism correction.

In contrast, the handheld scanner successfully captured this region in all subjects, yielding a mean deviation of 3.00 ± 0.93 mm.), The clinical acceptability of 3 mm prediction errors must be interpreted in context: systematic reviews report whole-face simulation errors ranging from 0.55 to 2.9 mm across various studies and software platforms [10]. Our 3.00 mm menton error falls only slightly above this range and represents a clinically usable prediction for most patients, particularly given that submental contour changes following mandibular setback are typically less dramatic than perioral changes.

The cost difference between the two imaging modalities is remarkable and clinically relevant. The CR-Scan Ferret handheld scanner retails for approximately $249 USD on the official Creality store. In contrast, a stationary stereophotogrammetry device ranges from approximately $8,000 to over $200,000, depending on specifications, brand, and included software. This dramatic cost difference, combined with the comparable or superior accuracy demonstrated in this study, makes handheld scanners a very reasonable option for even limited resourced clinic

The handheld scanner's ability to capture challenging areas like the menton makes it a more versatile instrument for clinical practice.

This study has some limitations: the use of a single stereophotogrammetry system means these results may not be generalizable to all such systems, as performance can vary based on camera configuration, calibration, and software, while the handheld scanner proved more accurate, the process remains operator-dependent.

Future studies should validate these findings across different handheld scanner models and stereophotogrammetry systems to establish generalizability. Additionally, investigation of the optimal scanning protocols for challenging anatomical regions, including the role of patient positioning and operator technique, could further improve handheld scanner accuracy.

Conclusion

This study demonstrates that a portable handheld scanner offers superior accuracy compared to a stationary stereophotogrammetry system for the majority of facial soft tissue landmarks, particularly in the complex midline structures and the challenging submental regions. The overall very large effect size in favor of the handheld scanner confirms its reliability.

While stereophotogrammetry remains a valid and accurate technique, its fixed nature presents inherent limitations for capturing the full facial form.

The difference in cost approximately $249 for the handheld scanner versus $8,000 to over $200,000 for stereophotogrammetry systems combined with the comparable or superior accuracy demonstrated in this study, makes the handheld scanner a reliable and accessible tool for soft tissue scanning in orthognathic surgical planning.

Future research should focus on validating these findings across different scanner models and investigating the technology's impact on clinical workflows and patient outcomes.

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