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Article

# Smartphone-Based Facial Scanning as a Viable Tool for Facially Driven Orthodontics?

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**Abstract:** The current paradigm shift in orthodontic treatment planning is based on facially driven diagnostics. This requires an affordable, convenient, and non-invasive solution for face scanning. Therefore, utilization of smartphones' TrueDepth sensors is very tempting. TrueDepth refers to front-facing cameras with a dot projector in Apple devices that provide real-time depth data in addition to visual information. There are several applications that tout themselves as accurate solutions for 3D scanning of the face in dentistry. Their clinical accuracy has been uncertain. This study focuses on evaluating the accuracy of the Bellus3D Dental Pro app, which uses Apple's TrueDepth sensor. The app reconstructs a virtual, high-resolution version of the face, which is available for download as a 3D object. In this paper, sixty TrueDepth scans of the face were compared to sixty corresponding facial surfaces segmented from CBCT. Difference maps were created for each pair and evaluated in specific facial regions. The results confirmed statistically significant differences in some facial regions in amplitudes greater than 3 mm, suggesting that current technology has limited applicability for clinical use. The clinical utilization of facial scanning for orthodontic evaluation, which does not require accuracy in the lip region below 3 mm, can be considered.

**Keywords:** TrueDepth; CBCT; Orthodontics; Face scan; Smartphone; Facial diagnostics; Smartphone-based sensors; Facially driven orthodontics

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## 1. Introduction

Paradigm shift in orthodontic treatment planning is currently leaning towards soft tissue driven considerations. Although facial 3D diagnosis is undoubtedly a crucial factor in treatment planning, it has been difficult to capture by the traditional means of 2D digital diagnostics. 3D diagnostic workflow shall now be considered a routine procedure, but the affordability of high-end facial scanners is slowing this change. The ability to use the smartphone sensor introduced in 2017 in the iPhone X has given the world a new method of affordable and convenient facial scanning. It captures more than 250,000 3D data points of a face in 10 seconds as the patient slowly turns head in front of the iPhone or iPad. Despite various professional dental applications proclaiming themselves as reliable and accurate solutions, the clinical accuracy has been questionable [1,2].

Dental imaging is a standard clinical procedure that is an important source of information for various purposes. Soft tissue images of the face are important records for evaluating the maxillofacial area in many fields such as orthodontics, orthognathic surgery, and facial plastic surgery, and are used for diagnostic processing, treatment planning, and outcome analysis, among others. The application of 3D scanning methods in healthcare, especially Cone Beam Computerized Tomography (CBCT) imaging in the field of maxillofacial surgery and orthodontics, has expanded significantly over the last decade [3,4].

CBCT is a three-dimensional (3D) diagnostic x-ray imaging technique which provides craniofacial imaging with low distortion and higher image accuracy than

conventional imaging. When the acquired data is processed in the volume, CBCT generates 3D panoramic and cephalometric pictures [5,6]. CBCT has also certain limitations. These devices are being used in dental care mainly to image the hard tissues of the orofacial structure and have a limited capacity to identify soft tissues due to lack of contrast resolution and texture, limiting their usage for soft tissue analysis. Furthermore, the use of stabilizing tools for CBCT scanning such as chin rests or forehead restraints, could deform the surface anatomy of the facial soft tissue and it is also susceptible to a variety of artefacts, including metal and motion artefacts, which can have a negative impact on image quality [7,8]. To address the lack of soft tissue data provided by CBCT scanners, 3D facial scanners have been integrated into digital routines such as stereophotogrammetry, laser and structured-light systems, offering a non-ionizing technique for creating a copy of the facial soft tissue with a precise portrayal of texture and static geometry in three dimensions [9] since the texture and color is significant for treatment planning in orthodontics. These complementary methods could be precise, quick, and easy to use.

Utilization of smartphones in combination with artificial intelligence is a common practice in orthodontics today. Artificial intelligence (AI) in the form of dental monitoring software uses the patient's cell phone for regular scanning. This has advantage in the pandemic era [10] as well as self in self-evaluating coaching tele-health solutions [11] AI is also currently widely used in the diagnosis of 3D facial scans created with smartphones [12].

3D face scanning is a fast-expanding field with an enormous potential in a wide range of uses, but it is still new and quite unexplored. As smartphone availability and capabilities expand, so does the potential for 3D face scanning apps. They have a variety of uses in medicine and dentistry, such as face identification, emotion capturing, face cosmetic planning and surgery, and maxillofacial rehabilitation.

Facial scanners can generate a 3D topography of a patient's facial surface anatomy, which when paired with a digital study model and a CBCT scan creates a 3D "virtual patient" for improved diagnosis, treatment planning, and patient outcomes [13–15].

Recent innovations of devices such as smartphones and tablets have demonstrated that scanning is also possible using LiDAR and TrueDepth technology.

LiDAR, which stands for light detection and ranging, is a radar-like remote sensing technology. The difference is that radar detects its surroundings using radio waves, while LiDAR requires laser energy. The technology refers to a remote sensing technology that generates concentrated light beams and calculates the time taken to detect the reflections by the sensor [16–19].

For the 3D reconstruction depth sensors are used, which have been utilized for a long time in 3D scanners, game systems (Microsoft Kinect for example) and lately in laptops and smartphones. These sensors are resilient in a variety of lighting conditions (day or night, with or without glare and shadows), thereby outperforming other sensor types. Sensors may be positioned at the back and at the front of the device. The depth sensors on the front of the unit have a shorter range and can identify and map hundreds of landmarks in real time and are primarily used to detect the face and produce its 3D image. Their essential use is for biometric smartphone security (e.g., Apple Face ID), to recognize the face of the Apple device owner.

Facial recognition has improved dramatically in only a few years. As of April 2020, the best face identification algorithm has an error rate of just 0.08% compared to 4.1% for the leading algorithm in 2014, according to tests by the National Institute of Standards and Technology (NIST) [20]. To recognize the face in Apple devices (i.e., iPhone X and later), the front-facing cameras with a Dot projector provide depth data in real time along with visual information. The core technology responsible for this process is called TrueDepth. The system uses LEDs to project an irregular grid of over 30,000 infrared dots to record depth within a matter of milliseconds [21,22] and can provide a rapid, reliable, and direct method for producing 3D data [16], [23–25].

The TrueDepth (Bellus3D Dental Pro) scanning performed on an iPhone or iPad with a 3D capture system can use an affordable program for face scanning such as Bellus3D FaceApp, which has simple instructions and was created to be precise and accurate in

recognizing facial landmarks [26–28]. It is also available for Android and iPhone devices, is compatible with the Windows 10 operating system, and it allows simple export of STL files. The first such hardware and software solution using accessory camera for Android smartphones was created in March 2015 at Silicon Valley with aim to generate detailed 3D face scans [29,30]. Later the company presented FaceApp application dedicated for iPhoneX users. The functionality of this app is the same as in Android version, except for using any additional hardware devices, using front facing TrueDepth camera same as in Apple Face ID.

Facial scanning can provide useful correlative data for many studies that would benefit from regular non-invasive evaluation of head and neck soft-tissue morphology as the change of body mass index is not very representative value when the facial morphology is the merit [31,32]. 3D printed extraoral orthodontic appliances in growing patients would benefit from regular noninvasive and reasonably accessible facial scanning [33] Tsolakis et al. 2022, as well can be widely utilized for regular evaluation of growth or therapeutical change of facial morphology [34].

FaceApp captures more than 250,000 3D data points on a face in 10 seconds while the user slowly turns their head in front of the camera. The app then reconstructs a virtual high-resolution version of the face that can be rotated, zoomed, and viewed in three dimensions. Additionally, the face model can be viewed with interactive lighting, using the device's gyro to control viewing angles. Apple just released iOS 15.4 with some improvements for the iPhone 12 and iPhone 13 when it comes to using the Face ID feature while using a mask.

The goal of this work was to assess whether the facial scan created with TrueDepth sensors and compiled with the Bellus Dental Pro app is accurate compared to the surface of the face from the CBCT. And, in the case of inaccuracies, to determine which facial regions are incorrectly imaged and to what extent.

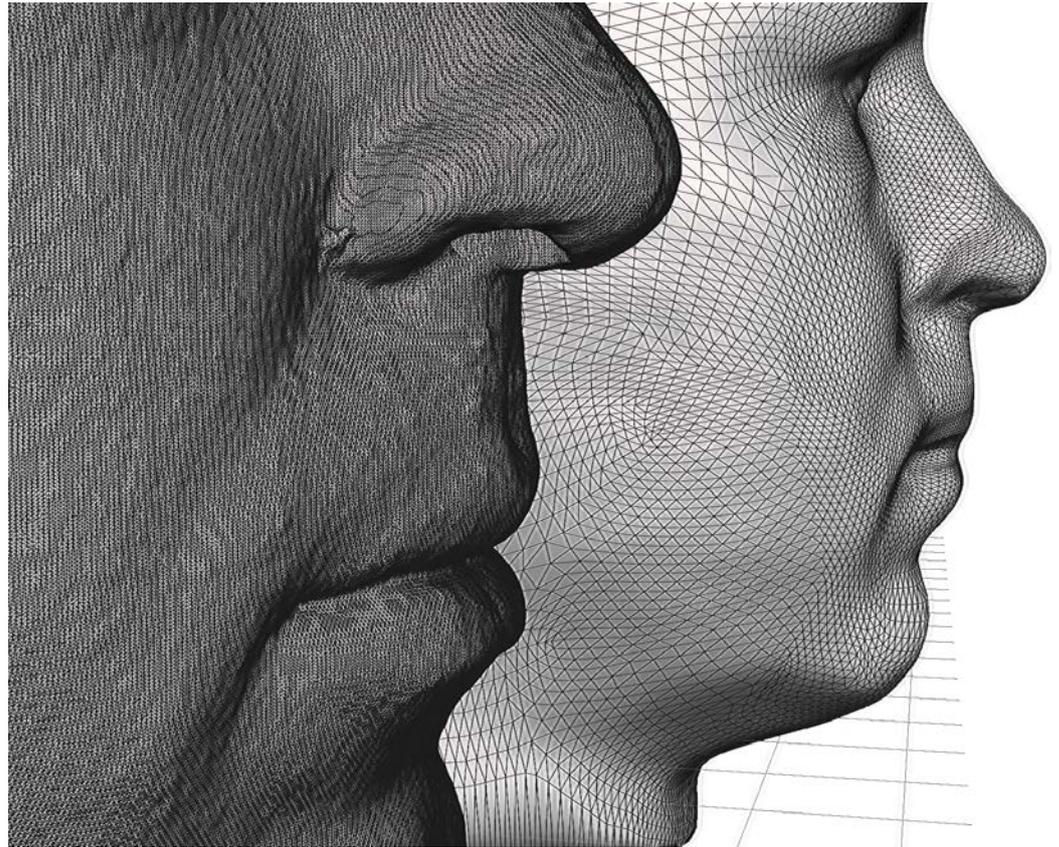
## 2. Materials and Methods

This paper is focused on the analysis and deviations of facial soft tissue scans between CBCT and TrueDepth scanner using Bellus 3D FaceApp application, respectively. Specific facial areas, attributes and points were chosen for evaluation of these scans using programs Invivo 6 (Anatomage Inc., San Jose, California, USA) Dental and in Mesh-mixer™ (Autodesk®, Inc, San Rafael, California, USA).

The assessment of the accuracy of the facial scan was based on the CBCT scan, which accurately reflects the true morphology of the face. From the CBCT of the head, a portion representing the face was segmented and exported as an STL shell. The difference between the polygon resolution of the STL from the CBCT and the STL from the face scan (TrueDepth - Bellus3D Dental Pro) is obvious, as shown in **Figure 1**.

The methods presented can be divided into 3 parts:

- Collecting scans
- Modification, positioning, and analysis of the scans
- Data analysis and comparison.



**Figure 1.** The difference between the polygon resolution of the STL from the CBCT (in the front) and the STL from the face scan (TrueDepth - Bellus3D Dental Pro) in the back is noticeable.

### 2.1 Collecting scans – selection criteria

To achieve an extensive set of CBCT-facial scan pairs, it was necessary to imply strict criteria. To avoid any deliberate differences between CBCT scan and facial scan by:

1. Facial expression, only calm, neutral faces with closed mouth and no facial expression were compared
2. Change in BMI, only pairs of scans separated by less than 7 days were included
3. Extreme artefacts, only CBCTs without extensive artefacts were included

None of the above procedures (CBCT or 3D facial scanning) were performed exclusively for this study but were part of the diagnostic procedures during orthodontic planning. All included patients signed an informed consent form.

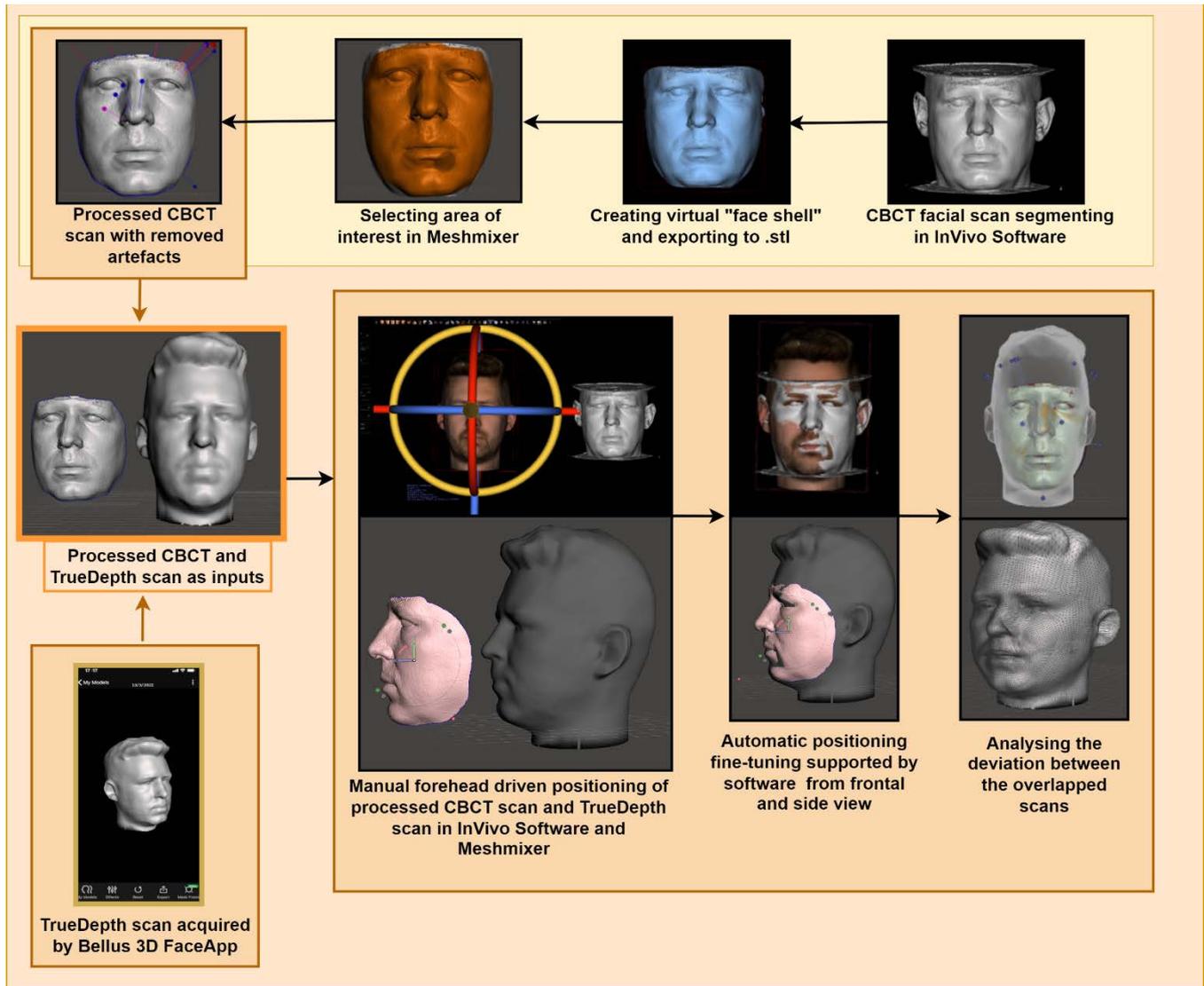
In the first part, we collected sixty CBCT scans of patients (41 women and 19 men) and 60 3D facial scans acquired with the Bellus 3D Dental Pro application using the - scanner. Bellus 3D Dental Pro is an application available for iPads and Apple's iPhone 12 Pro. The patient's face was scanned from every angle using the application's instructions. The instructions were clear and easy to follow.

For each scan, patients had to maintain a neutral facial expression and relax both the jaw and eyes into a comfortable resting position. The measurement and display time is less than 10 seconds while the user rotates the head from left to right, allowing accurate 3D facial models to be created. This application helps capture a person's face and create a high-resolution STL (Standard Tessellation Language) file, which is a 3D model of that object that can then be loaded into three-dimensional analysis software [26,35,36].

Both types of scans were taken at approximately the same time so that there would be no bias in the results due to weight gain or loss or other physical changes in the patient's face that might occur over time.

## 2.2 Modification, positioning and analyzing of the scans

The second part of our research was devoted to modifying and positioning the two scans in the correct positions so that they overlap and can later be used to analyze specific facial areas, points, and attributes. This process consists of several steps (Figure 2).



**Figure 2.** The schematic approach of the proposed method.

In this work, sixty TrueDepth scans of the face were compared with sixty corresponding facial surfaces segmented with CBCT. For the CBCT segmentation, the CBCT scan was segmented into Invivo 6 (Anatomage Inc., San Jose, California, USA), in Medical Design Studio module. Various programs can be used for segmentations of CT/CBCT medical data [37] We used -700 opacity (Isosurface) where we can clearly see all facial soft tissues. We modified each CBCT scan so we could create a virtual "face shell" without unnecessary internal head structures. We used the function Freehand Volume Sculpting and got rid of excessive parts of the face. We also changed in the panel Isosurface the Subsample to 1. The final scan was saved in the stl. file format. This file was opened in the Meshmixer programme (Meshmixer™ (Autodesk®, Inc, San Rafael, California, USA) to process the face scan. We used the Brush function to further modify and select the areas of interest. Then the Optimize and Boundaries functions were used. We used the Invert and Erase functions to get the shape of our final face shell. Then we removed artifacts using the

Analysis Inspector function. We then exported this final CBCT scan and saved it again in stl. binary format. All 50 CBCT face scans were modified in this way.

We used the above modified final CBCT scans and 3D TrueDepth model scans of patients and opened them both in the In Vivo Dental program. We manually positioned them to overlap the most. Then we used the Mesh registrations function so that the scans overlapped even more. In this function, we used points that change less for different facial expressions, such as forehead, temples, and nose. We then exported these positioned TrueDepth model scans in stl. binary format.

In the next step we opened our final CBCT "face shell" model scan and our positioned TrueDepth model scan in the in Meshmixer™ (Autodesk®, Inc, San Rafael, California, USA) program. We used the Analysis – Deviation function with 3mm maximum deviation. This function highlighted specific deviations between these two different scans.

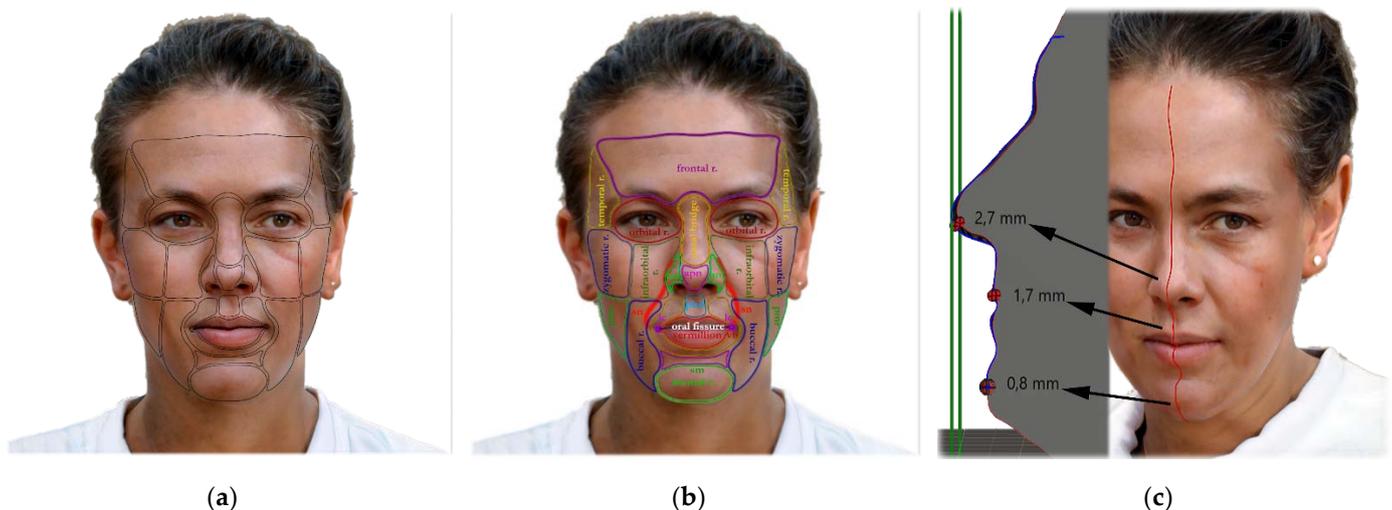
### 2.3 Data analysis and comparison

In the third part of our research, we created a chart with different facial areas, points, and attributes. We have measured 21 facial locations and their deviations of CBCT to TrueDepth scans (**Figure 3**). We recorded if the deviation was present on the specific facial location of each patient. We specifically focused on the deviation of Aesthetic and Harmony line of these scans. We decided the clinical evaluation of the amount of deviation of TrueDepth scans to CBCT scans and afterwards conclude any protentional usage of the TrueDepth scanner in dental medicine (**Table 1**). We suggested that 3 and more millimeters of deviation should be clinically relevant and are questioning suitability of this method.

To compare the results in women and men, we used Fisher's exact test in the contingency tables because the expected frequencies were low in most cases. All tests were performed at a significance level of 0.05.

To compare the scans from the lateral view, we selected seven different sites-the frontal region, nasal tip, philtrum, vermillion border, oral fissure, mentolabial sulcus, and mental region. To compare these seven sites, we used the Friedman test. Since the Friedman test is not parametric, it uses ranks. The higher the value, the higher the rank.

The statistics were analyzed in the statistical software IBM SPSS 21.



**Figure 3.** AI face generator was used to create this hermaphrodite face. It shows: (a) Observed facial locations; (b) Abbreviations of locations used - region(r.), parotid-masseteric region (pmr), labials commissure (lc), ala nasi (an), apex of nose (apn), sulcus nasolabialis (sn), sulcus mentolabialis (sm), vermillion border (vb), philtrum (phil); (c) Example of comparison of sagittal sections of the facial profile of the CBCT surface shell and the Bellus 3D shell. In this way, the differences between the shells were measured and the results of the differential maps were checked in the median plane.

**Table 1.** Clinical evaluation of amount of deviation between CBCT and 3D TrueDepth (Bellus3D Dental Pro) scan.

Intervals of deviation (mm)	Approximation	Clinical explanation
0	0	clinically irrelevant
0-1	0.5	clinically irrelevant
1-3	2	clinically relevant only in extreme detail evaluations for micro-aesthetics
3+	4	clinically relevant, questioning suitability of this method

To compare seven different locations in the middle of the face we used Friedman test. Since the Friedman test is non-parametric, it works with ranks. The higher the value, the higher the rank.

To compare results in women in men we used Fisher's exact test in the contingency tables, because in most cases the expected frequencies were low. All tests were made at alfa significance level equal to 0.05.

### 3. Results

The amount of clinically relevant deviation (differences greater than 3 mm) was measured between the TrueDepth (Bellus3D Dental Pro) scan and the CBCT scan at specific locations on the face (Table 2). The lowest total deviation (less than or equal to 10%) was observed at the tip of the nose, bridge of the nose, nasolabial sulcus, philtrum, mentolabial sulcus, zygomatic bone, infraorbital region, and cheek region. A higher number of deviations (more than 30%) were observed on the right ala nasi, oral fissure, temporal region, and orbital region, with the highest values in the orbital region (65 and 68.3%).

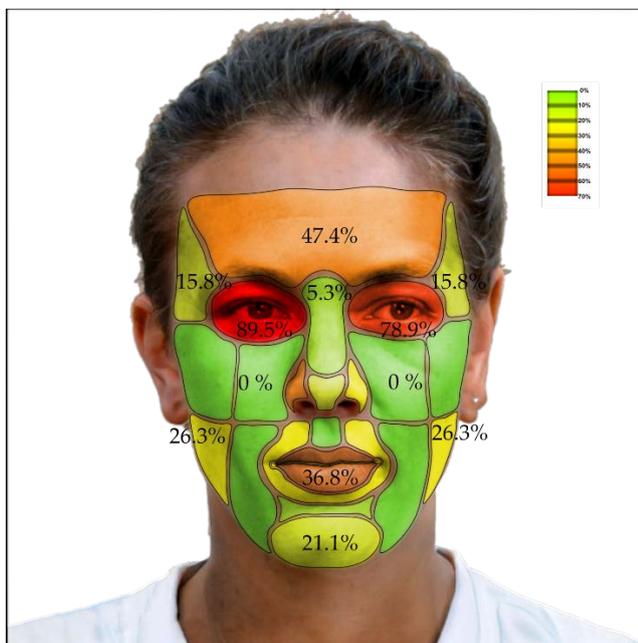
Some differences were found between the right and left parts of some paired regions, such as in the ala nasi and the labial commissure. Significant differences in the amounts of deviations were also observed in males compared with females, statistically confirmed by Fisher's exact 2-sided test in the frontal and right orbital regions. The amounts of clinically relevant deviations of all measured facial regions between the two scans in men, women, and overall are indicated by colored difference maps in **Figure 3a, b**. As can be seen in the figure, the deviations are lowest in the mid and lower facial regions, with higher accuracy in the facial prominences and lower accuracy in the deeper structures.

In addition, and double-check comparison was performed in seven regions visible from the lateral view of both aligned facial shells using Friedmann's test. Since the Friedmann test is non-parametric, it works with rank. The highest average rank was for oral fissure (4.94), the lowest rank for the sulcus mentolabialis (2.8) (**Table 3**).

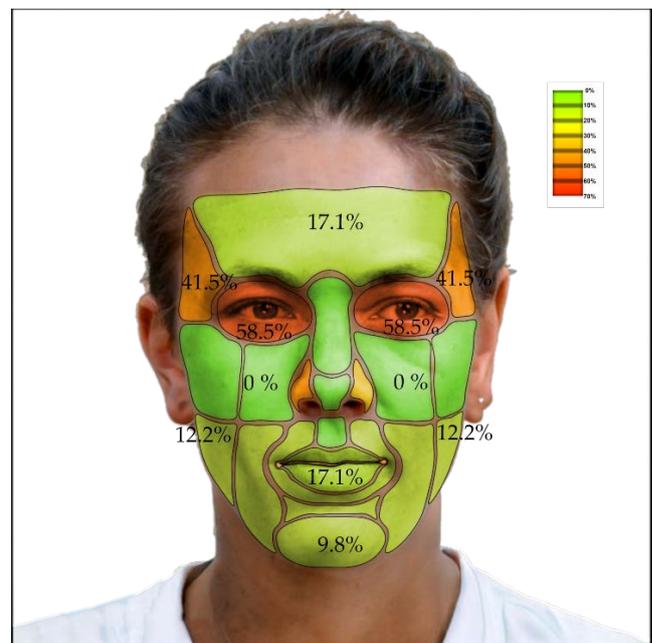
**Figure 4a** shows the amount of deviation in TrueDepth scans from CBCT scans in percent in men and **Figure 4b** in women. **Figure 5** shows complete results for both.

**Table 2.** The amount of deviation of TrueDepth (Bellus3D Dental Pro) scans to CBCT scans. First column represents the facial location, second the percentage of men with deviation more than 3mm between these scans, third column the same as second in women, and the last column represents the difference between men and women evaluated using Fisher's exact test. In the last column bold values represent significant differences.

Facial location	>3mm men	>3mm women	>3mm total	Fisher's exact test (2-sided)
apex of nose	15.8%	2.4%	6.7%	0.116
ala nasi L	26.3%	29.3%	28.3%	1.000
ala nasi R	42.1%	46.3%	45.0%	0.788
nasal bridge L	5.3%	4.9%	5.0%	0.797
nasal bridge R	5.3%	4.9%	5.0%	0.797
sulcus nasolabialis L	0	2.4%	1.7%	0.850
sulcus nasolabialis R	0	4.9%	3.3%	1.000
philtrum	0	0	0	0.365
vermilion border	26.3%	9.8%	15.0%	0.171
vermilion	36.8%	17.1%	23.3%	0.182
oral/labial commissure L	10.5%	19.5%	16.7%	0.453
oral/labial commissure R	10.5%	9.8%	10.0%	0.147
oral fissure	26.3%	36.6%	33.3%	0.342
sulcus mentolabialis	5.3%	7.3%	6.7%	0.908
zygomatic region	0	2.4%	1.7%	0.243
temporal region	15.8%	41.5%	33.3%	0.140
frontal region	47.4%	17.1%	26.7%	<b>0.047</b>
orbital region L	78.9%	58.5%	65.0%	0.154
orbital region R	89.5%	58.5%	68.3%	<b>0.019</b>
infraorbital region	0	4.9%	3.3%	1.000
mental region	21.1%	9.8%	13.3%	0.601
parotid-masseteric region	26.3%	12.2%	16.7%	0.406
buccal region	0	12.2%	8.3%	0.184



(a)



(b)

**Figure 4.** The amount of deviation in TrueDepth scans from CBCT scans in percent: (a) Results in men; (b) Results in women.



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oral fissure	4.94
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#### 4. Discussion

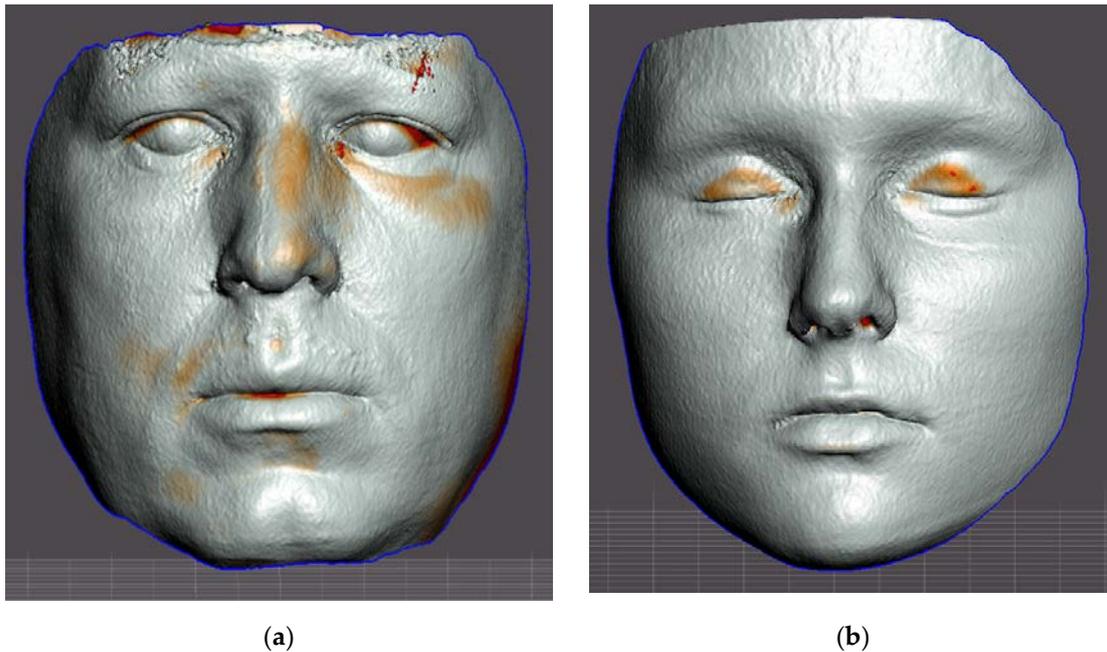
Our results confirm that scans created with TrueDepth sensors (Bellus3D Dental Pro App) are more accurate than one would think at first glance. This study states that the prominences of the face are more accurately imaged, but the accuracy of the concave structures is significantly worse, with higher accuracy in the middle and lower regions of the face. On the other hand, the deviation of 3 mm is still a significant difference from the point of view of orthodontic treatment in terms of microesthetics, but not for a general area of the face. The era of facially driven orthodontics enabled by affordable, non-invasive facial scanning technologies will begin along with increased capability of ubiquitous facial scanners in the form of cell phones and tablets. For macro-proportional facial assessment, the technology is already mature. For micro-esthetic assessment, particularly around the lips, it is not yet.

It can be said that the cell phone scanning approach cannot yet compete with CBCT scans in terms of accuracy, although it clearly dominates in terms of availability and non-invasiveness. Higher accuracy in CBCT scans improves the quality of the data recorded by the scanner, which ultimately improves the outcome. The current accuracy of the TrueDepth sensor used with the Bellus dental pro application is not sufficient to achieve high facial accuracy and therefore cannot be used for detailed orthodontic treatment planning.

A limitation of this study is the initial small total number of participants, where the ratio of women and men was not balanced. This could cause unexpected differences between men and women or between the right and left sides of some paired facial regions.

Another limitation of this study is the comparison of the temporal and frontal regions between CBCT and the TrueDepth scans which were suffering from major artefacts in this region. The upper border of the CBCT was located typically in the middle horizontal level of the frontal bone, representing many artefacts. Despite the crop of these artefacts the data of the upper part of the forehead were often with artefacts or missing in the CBCT scans (**Figure 6**, left). In consideration of why the discrepancy was observed most frequently in the orbital region, probable explanation is difference between closed and opened eyelids. Closed eyes in CBCT scans were typical (**Figure 6b**) compared to open eyes in TrueDepth scans could influence the result (**Figure 6**, right scan).

Sensors are frequently utilized in orthodontics [38,39]. According to recent study of Cho et al. 2022 "From the 3D CT images, 3D models, also called digital impressions, can be computed for CAD/CAM-based fabrication of dental restorations or orthodontic devices. However, the cone-beam angle-dependent artifacts, mostly caused by the incompleteness of the projection data acquired in the circular cone-beam scan geometry, can induce significant errors in the 3D models." [40]. Even research of Pojda et al. 2021 confirms necessity of cheaper and more convenient alternatives to orthodontic facial 3D imaging [41]. Sensors for optical scanning and high-definition CT scanning (microCT) are frequently utilized on the borders of orthodontics and forensic dentistry in identification of dental patterns opening new possibilities of human remains identification [42].



**Figure 6.** Examples of aligned segmented CBCT face surfaces and face TrueDepth-Bellus3D scans of authors of this paper. On the resulting differential maps (heatmaps) Red indicates differences between both scans: (a) Left surface shows frequent disruptive artefacts on the upper border of CBCT scan; (b) The right scan shows frequent differences resulting from eyes closed during the CBCT scanning.

A key context to this discussion is that the TrueDepth scanner available on an Apple smartphone or tablet has an advantage in terms of cost and availability, the scans can be performed in a short time with real-time processing, and of course, the scans can be performed without the patient receiving radiation. In addition, it could open new opportunities for telemedicine applications in dental practices.

However, the TrueDepth scanner, which may be used on certain Apple devices, has tremendous potential, and could potentially be used in a variety of medical settings in the future. Given the pace of development of smartphones and applications, we can predict that the precision and quality of scans will gradually improve.

## 5. Conclusions

The results confirmed statistically significant differences between facial surfaces from CBCT and TrueDepth (Bellus3D Dental Pro cell phone application) in some facial regions with amplitudes greater than 3 mm. This suggests that the current TrueDepth sensor from Apple in orthodontic applications has limited clinical use. However, clinical application of the described approach in orthodontic facial analysis, which does not require accuracy below 3 mm, can be considered.

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**Institutional Review Board Statement:** The analyzed data were anonymized. Because the data collection was part of routine clinical procedures and written informed consent was obtained for each case, IRB approval was waived.

**Informed Consent Statement:** Written informed consent has been obtained from all subjects involved in the study prior undertaking the orthodontic aligner therapy.

**Data Availability Statement:** Anonymized Data supporting the reported results are freely available at: <https://docs.google.com/spreadsheets/d/1wfbPd66RdPE4Eljg6c4jTtp5-kJH5dBWIPBwE-ODouMw/edit?usp=sharing> (accessed on 12 September 2022). Authors ensured that data shared is in accordance with consent provided by participants on the use of confidential data.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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