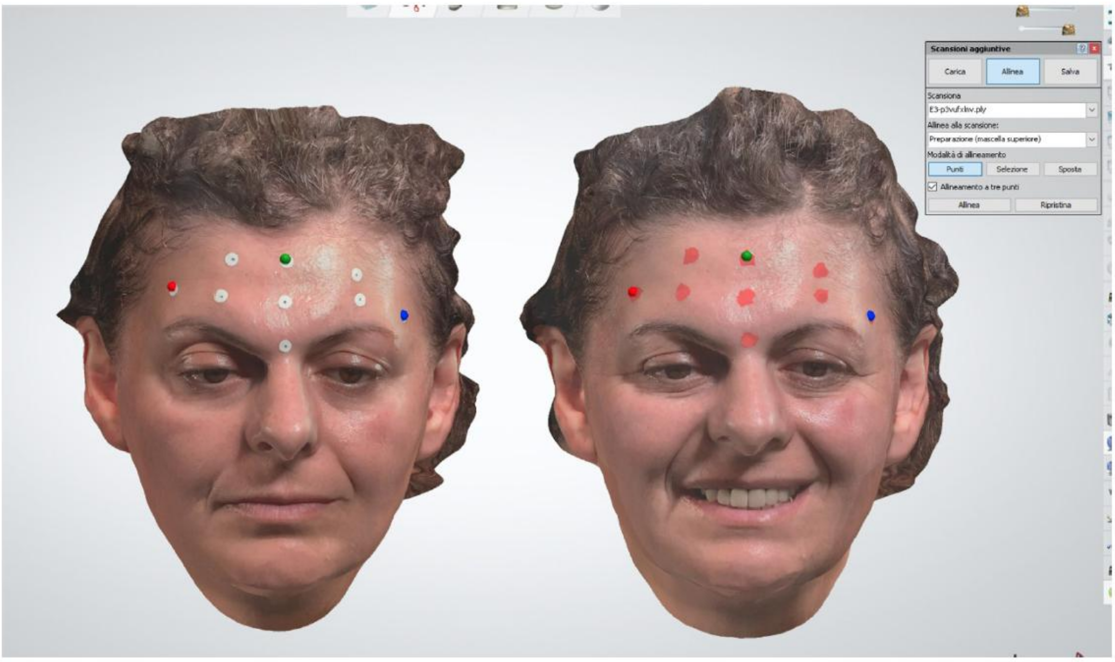

Scansioni aggiuntive
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Allinea alla scansione:
Preparazione (mascella superiore)
Modalità di allineamento
Punti
Selezione
Sposta
Allineamento a tre punti
Allinea
Ripristina

Journal of Dentistry 122 (2022) 104123

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.elsevier.com/locate/jdent

Chairside virtual patient protocol. Part 2: Management of multiple face scans and alignment predictability

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ARTICLE INFO

Keywords:
Digital matching
Full digital workflow
Facescan
Superimposition
Alignment
Virtual patient

ABSTRACT

Objectives: Face scans are currently used in dentistry to obtain a virtual patient. Find stable and repeatable references for their matching is a fundamental step. Aim of this study is to evaluate matching reliability of multiple face scans using frontal adhesives references. Null hypothesis was that no significant discrepancy could be detected between the references position analyzed both with surface analysis and linear analysis.

Materials and methods: Nine patients were enrolled for this study and nine soft tissue adhesives landmarks (APLI Paper S.A.U, 4 mm Ø) placed, equally distributed, on the forehead and glabella. Patients were digitally scanned with a portable scanner (iPad Pro 3rd Gen. Apple Store, Cupertino, CA, USA) using the software Bellus3D (Inc. Campbell, CA, USA) in maximum intercuspation, with a full smile and with a scan reference device. After the scan procedure, a high-definition polygon file format (.ply) was exported, and linear measurements were collected with MeshLab (MeshLab; MeshLab). In order to further evaluate reference accuracy, a surface analysis was performed using a CAD software (GOM inspect, GOM). 3D deviations were calculated as root mean square. Statistical analysis was performed used two repeated-measures ANOVAs.

Results: Results showed non-significant differences both for linear measurements ($p=.22$) and surface analysis ($p=.58$). Frontal references showed to be clinical reliable landmarks for use during face scans alignment, even with different facial expressions.

Conclusion: The proposed technique seems to be suitable for the clinical use when superimposition of several face scans is required.

Clinical significance: This study showed the clinical reliability of face scans matching method using adhesives references. These references are cheap and easy to use, allowing for a rapid registration of the patient anatomy.

1. Introduction

Digital planning of dental rehabilitation has changed the way of approaching complex cases [1]. Advantages of a digital approach are represented by the possibility of considering not only the dental elements but also extra-oral soft tissue landmarks with the aim of harmoniously contextualizing oral rehabilitation to patient's face [2]. Further advantages are represented by the possibility of implementing communication with a higher satisfaction rate and lower risks from the medical-legal standpoint [3]. Complex cases require a multidisciplinary approach and digital set up can implement and enhance teamwork between clinical specialists or with dental laboratories [4]. Several digital techniques were suggested over years in order to plan and visualize treatment's plan. Digital Smile Design (DSD) protocol [3] was born in 2012 with the aim of helping clinicians evaluating dental-facial relationships. In the initial DSD protocol, two-dimensional detections of the facial planes were provided using a series of photos of the patient [3]. The limitations of this technique were represented by two-dimensional assessment that did not allow an adequate evaluation of the spaces in terms of depth. In 2017, Coachman implemented the DSD protocol recommending a dynamic assessment of the smile using videos with the aim of capturing the ideal frame for digital planning [5].

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https://doi.org/10.1016/j.jdent.2022.104123
Received 9 August 2021; Received in revised form 29 March 2022; Accepted 3 April 2022
Available online 9 April 2022
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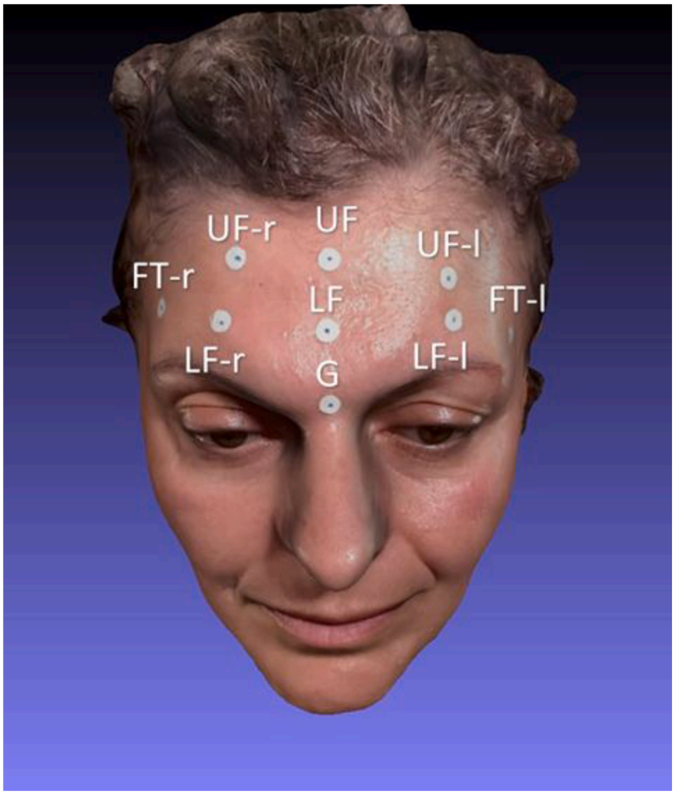

Fig. 1. Nine points were selected for each patients. Landmarks were placed on the forehead.

This protocol showed poor tridimensional analysis and impossibility of correctly evaluate length and thickness of the prostheses, especially in extensive rehabilitations which include a modification of the occlusal planes, overjet, overbite and vertical dimension. Recently, overcoming technical problems due to bidimensional analysis, facial scanners were introduced in dentistry [6]. In literature there are several studies validating the accuracy and reliability of facial scanner devices [7]. On the other hands, there are no clear data regarding precision and repeatability of techniques used to create the virtual patients matching different extra-oral scans (EOS) or extra-oral scans with intraoral scans (IOS) [8]. Regarding EOS/IOS matching, one of the proposed methods is through a CBCT [9]. This method is limited to all the cases where a large-FOV CBCT is required such as orthognathic surgery, multidisciplinary cases needed a CBCT scan or patients already having 3D radiographic exams for other medical issues. As the radiation exposure must be kept as low as reasonably achievable, following the ALARA principle, large-FOV CBCT must be used with caution and is not justify for digital mounting procedures [10]. Some authors [11,12] have proposed a "radiation-free" protocol through the use of a fork with dental support and extraoral landmarks. However in these cases a laboratory scanner is needed for data acquisition and connection meaning the impossibility of carrying out a chair-side digital workflow, higher costs and extended treatments time. Another limitation is the absence of a clear validation of the results obtained, indeed all the articles present in literature are case reports or pilot study [13]. For EOS matching, majority of the protocols use scan references placed on patient's forehead, allowing the superimposition of face scan with different facial expressions [14,15]. When a solid plate is used as face aligner, higher treatments costs are reported. Otherwise, adhesive stickers can be used with the same purpose of the solid plate, reducing costs while maintaining good references for matching. Some authors proposed landmarks marked by pencil as a reference for face scans measurements [16]. Disadvantages of this technique are related with the impossibility of using standard

Table 1
12 measurements were selected for the linear analysis.

Linear Measurements		
1. Frontotemporal right-Upper frontal right (FT-r - UF-r)	2. Upper frontal right - Lower frontal right (UF-r - LF-r)	3. Upper frontal left - Frontotemporal left (UF-l - FT-l)
4. Frontotemporal right - Lower frontal right (FT-r - LF-r)	5. Upper frontal - Upper frontal left (UF - UF-l)	6. Lower frontal left - Frontotemporal left (LF-l - FT-l)
7. Upper frontal right - Upper frontal (UF-r – UF)	8. Lower frontal - Lower frontal left (LF - LF-l)	9. Lower frontal left - Upper frontal (LF-l - UF)
10. Lower frontal right - Lower frontal (LF-r - LF)	11. Upper frontal - Lower frontal (UF – LF)	12. Lower frontal – Glabella (LF - G)

tessellation language (.stl) files when texture defects are detected. Nevertheless, it results to be an efficient and economical protocol for EOS matching. As for the IOS/EOS matching, no clear data are present in literature regarding the accuracy and the reliability of different EOS matching using the protocols previously listed. It is therefore of paramount importance to find stable and reliable landmarks that can be used to match face scans acquired during different facial expressions. The aim of this study is to evaluate matching reliability of multiple face scans using frontal adhesives references. Null hypothesis was that no significant discrepancy could be detected between the references position analyzed both with surface analysis and linear analysis.

2. Materials and methods

2.1. Subject characteristics and reference points

Nine patients were enrolled for this study (5 women, 4 men) and written consent was obtained for each participant. All privacy precautions have been followed (According to Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 (also referred to as GDPR) and of Legislative Decree 196/2003 (called the "New Code of Privacy ") as amended by Legislative Decree 101/2018).

Inclusion criteria were: no craniofacial syndromes, no history of maxillofacial surgery or recent facial trauma, absence of mustache or beard covering the facial landmarks, and presence of a stable occlusion or absence of removable prosthesis.

Nine soft tissue landmarks were placed on the forehead and glabella specifically Frontotemporal left (FT-l), Frontotemporal right (FT-r), Upper frontal (UF), Upper frontal left (UF-l), Upper frontal right (UF-r), Lower frontal (LF), Lower frontal left (LF-f), Lower frontal right (LF-r) and Glabella (G). These points were selected to evaluate their reliability as reference during face scans matching in the digital workflow (Fig. 1). Each landmark was highlighted with a round adhesive sticker (APLI Paper S.A.U), 4 mm in diameter with a 0.5 mm black dot, in order to facilitate length assessment. Twelve linear measurements were selected to evaluate references accuracy (Table 1).

2.2. Data recording, processing and surface analysis

Adhesives were applied and data were recorded by one expert operator (C.R) both clinically and digitally. Clinically linear measurements were recorded using a digital Vernier caliper (Tacklife, Resolution 0.001mm /Accuracy ± 0.03mm). Each measurement was recorded ten times and the mean value was selected. Patient's faces were scanned in maximum intercuspation position (MIP) and natural expression, with a full smile and with a scan reference device as when a virtual facebow is used. During the smile, patients were asked not to corrugate or move the forehead. 5 scans were performed with each facial expression, 15 in total for every patient. All the scans were performed using an Ipad Pro 3rd Gen. (Apple Store, Cupertino, CA, USA) and Bellus3D Dental Pro App (Bellus3D, Inc. Campbell, CA, USA) with a Slider Technique [17]. The

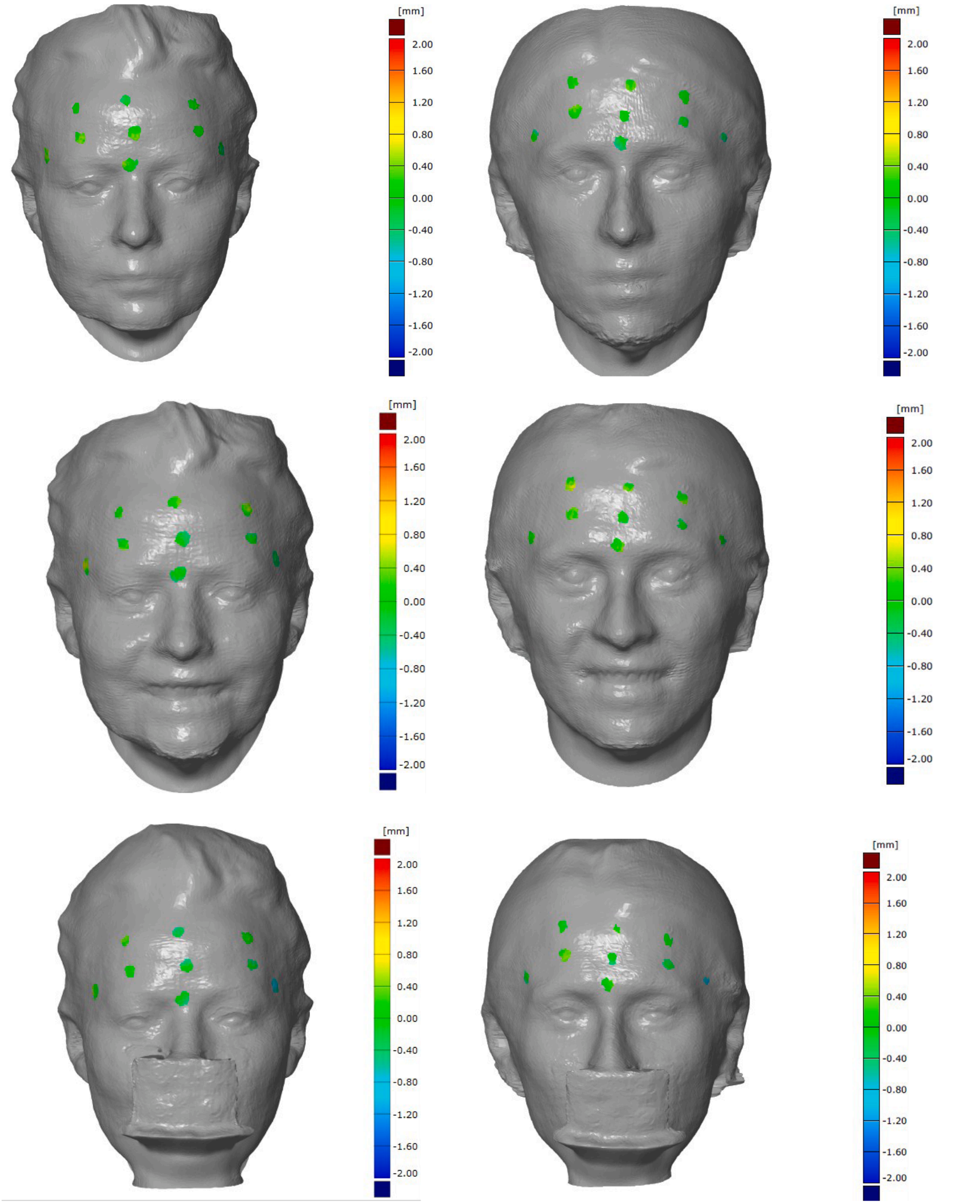

Fig. 2. Surface analysis deviation maps showing mean distance of reference adhesives during the different acquisitions.

scans were carried out using a modified fixed scan support (Neewer Slider 67 Inches Long/180 Degree 1/2 Round Circle Smooth Track, Neewer, Shenzhen Neewer Technology Co. Ltd). Patient heads were motionless and the scanner was moved using the support at a uniform speed. After the scan procedure, a high definition polygon file format (. ply) file was exported if no distortion of the adhesives could be detected. The linear measurements were collected using a 3D mesh-processing open-source software (MeshLab; MeshLab) using the measuring tool. In order to further evaluate references accuracy a surface analysis was performed on every patient's scan using a CAD software (GOM inspect,

Table 2
Descriptive frontal surface measurement and mean distance stickers (mm).

Variable	M (±SD)
Frontal surface analysis	
MIP/smile	0.12 (0.09)
MIP/device	0.20 (0.12)
Device/smile	0.25 (0.17)
Linear distance analysis	
MIP/smile	0.28 (0.17)
MIP/device	0.36 (0.21)
Device/smile	0.29 (0.15)

Legend. M=mean distance; SD=standard deviation; MIP= maximum intercuspation position.

Table 3
Comparison among frontal surface measurements and mean distance stickers (mm).

Sites	*M (±SD)*	*Sites comparison*	*M (±SD)*	*p-value*
Frontal surface analysis				
MIP/smile	*0.12 (0.09)*	*MIP/device*	*0.20 (0.12)*	*0.300*
		Device/smile	*0.25 (0.17)*	*0.145*
MIP/device	*0.20 (0.12)*	*MIP/smile*	*0.12 (0.09)*	*0.300*
		Device/smile	*0.25 (0.17)*	*0.100*
Linear distance analysis				
MIP/smile	*0.28 (0.17)*	*MIP/device*	*0.36 (0.21)*	*0.202*
		Device/smile	*0.29 (0.15)*	*1.000*
MIP/device	*0.36 (0.21)*	*MIP/smile*	*0.28 (0.17)*	*0.202*
		Device/smile	*0.29 (0.15)*	*0.583*

Legend. M=mean distance; SD=standard deviation; MIP= maximum intercuspation position

GOM) at the adhesive references area. Total differences in absolute 3D deviations were calculated as root mean square (Fig. 2).

2.3. Statistical analysis

The statistical analyses were conducted with SPSS Statistical software version 26.0 (IBM SPSS Statistics, USA). Continuous variables, as MIP/smile, MIP/device, and device/smile, were described as mean, and standard deviation (SD). Two repeated-measures ANOVAs, and adjusted for multiple comparisons with Bonferroni post-hoc test was carried out. The first one tested difference among frontals surface measurements with MIP/smile, MIP/device, and device/smile; the second one tested mean distance measurements difference with MIP/smile, MIP/device, and device/smile. Mauchly's sphericity test was used to test whether or not the assumption of sphericity, the condition where the variances of the differences between all combinations of related groups are equal, is satisfied. The Greenhouse-Geisser correction was used when the sphericity was missing (i.e. when the Mauchly sphericity test was significant). A p-value of less than 0.05 was considered significant.

3. Results

Descriptive statistics for sites measurements are reported in Table 2. The mean of frontals surface measurements with MIP/smile, MIP/device and device/smile was 0.12 (±0.09) mm, 0.2 (±0.12) mm, and 0.25 (±0.17) mm, respectively. The mean linear distance measurement with MIP/smile, MIP/device and device/smile was 0.28 (±0.17) mm, 0.36 (±0.21) mm, and 0.29 (±0.15) mm, respectively.

In Table 3 were reported comparisons results among frontal surface measurements and mean distance stickers. The results of ANOVA for frontal surface measurements showed a not significant Sphericity Mauchly test ($\chi 2(2)=1.66$, $p=0.437$) and no significant differences among sites.

ANOVA of mean distance measurements showed a significant Sphericity Mauchly ($\chi 2(2)=7.20$, $p= 0.027$) and no significant differences among sites .

4. Discussion

Enormous strides have been made in the field of dental technology. Thanks to digital technology, clinicians are now able to accurately plan in detail all the phases of the treatments with a predictable outcome [18]. Digital approach can be efficiently used creating a three-dimensional digital patient. Different protocols were proposed during the years in order to have a reliable method to superimpose the different tridimensional files generated by facial scanners, intraoral

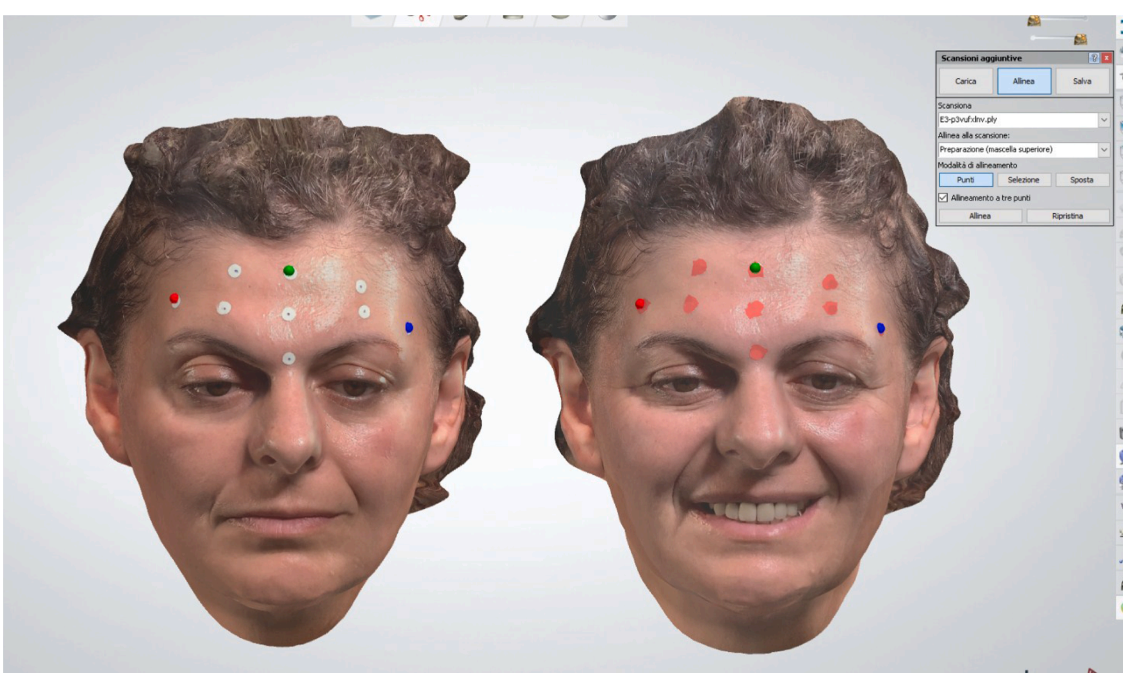

Fig. 3. Frontal adhesives are used as a reference for face scans superimposition.

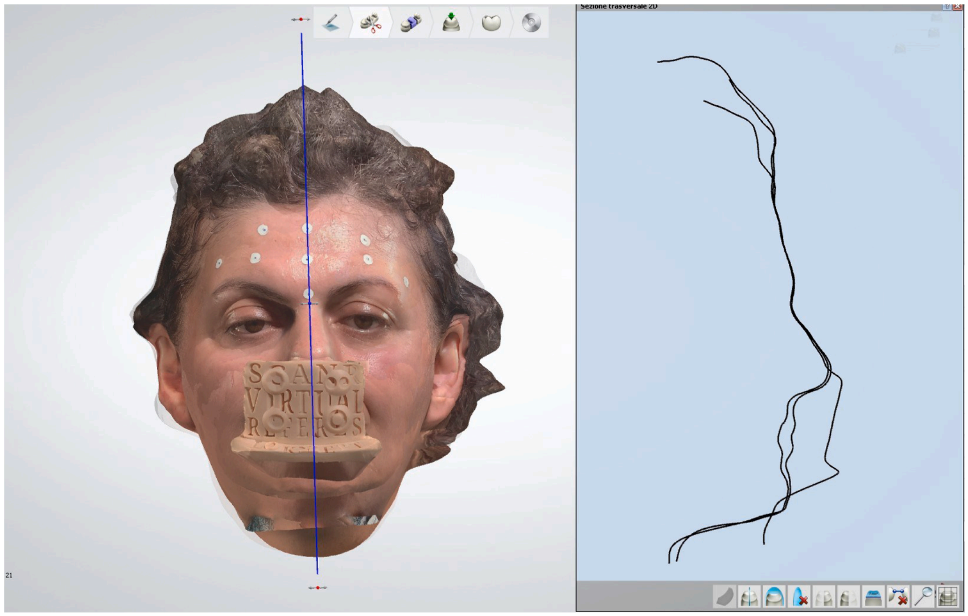

Fig. 4. A section view showing the perfect matching between the three different face scans.

scanner and CBCT [8]. The accuracy of a virtual patient reconstruction is directly related with several source of errors that can affect treatments planning. The factors influencing digital outcome can be due to data acquisition or to the matching processes. The acquisition is closely related to the accuracy of the scanner [19]. While intraoral scanners are extensively studied in literature and accuracy and their limitations are recognized [20], the management of face scans still need to be investigated [21–23]. As described in literature the presence of micro-movements due to facial expressions play a fundamental role in the accuracy of the acquired 3D image [24]. For this reason, patients should be adequately instructed to avoid abrupt movements or uncontrolled expressions [25,26]. In addition, time consuming scan procedure can decrease final accuracy [26]. In a previous network metanalysis [22], a research group has demonstrated that stereophotogrammetry and structured light scanners can reproduce the most accurate scans. A previous study [17] showed that, considering a clinically significant threshold error of 2 mm [27,28], facial scanning software available on smartphones or tablets can produce scans with a mismatch of less than 1 mm from direct anthropometric measurements and therefore clinically suitable for dental applications. The error during the matching processes depends mainly on the reference system or reference points chosen [29]. Initially teeth were proposed as references but, due to phenomena of scattering and overlapping of the perioral area, inaccuracies were reported [30]. In addition, scanning technologies, particularly low-cost ones, are greatly affected by changes in depth [7] resulting in distorted representations of the perioral area and teeth [31]. Other reference systems used are cephalometric landmarks and marker positioned on the forehead [32]. Purpose of the study was to evaluate the reliability of frontal adhesives landmarks as references for different face scans matching. Landmarks were used to increase contrast with the skin, overcoming the lack of texture reported by low-cost scanner [33,34]. Results showed that the mean linear deviation between the groups is always less than 0.36 mm, demonstrating that adhesive landmarks placed on the forehead and glabella are a stable and reproducible reference to use in the superimposition phase of the digital workflow. Surface analysis showed a mean distance up to 0.25 mm with a standard deviation of only 0.17 mm. Consequently, the null hypothesis was accepted. Data confirmed that the proposed protocol can be suitable for the clinical use with excellent clinical outcomes as showed in Figs. 3 and 4. Similar study [35,36] showed that face scans alignment accuracy using best fit technique on bone supported areas (e.g forehead and zygomatic area) results in clinically undetectable discrepancies. Advantages of the proposed technique are in the low cost and in the shallow learning curve needed to the clinicians. Furthermore, the proposed technique seems to be accurate enough for clinical use. Disadvantages can be due to the fact that patients can't move their forehead during smile, and, in some cases, this can be a limit. Unfortunately, it is difficult to make comparisons with other studies due to the lack of literature on the topic.

5. Conclusions

Facial scanners represent an important innovation in the digital workflow. The aim of this study was to evaluate matching reliability of multiple face scans using frontal adhesives references in order to give clinicians protocols guideline during digital workflow. As no significant discrepancy could be detected regarding both surface analysis and linear analysis, null hypothesis was accepted. Limitations of the study are the small number of patients enrolled and the use of just one type of facial scanner. Moreover, inter operator accuracy need to be evaluated. Finally clinical tolerance needs to be investigated to clearly understand if this kind of protocol can be suitable for multidisciplinary complex cases.

CRediT authorship contribution statement

All the authors participated to the article setting, writing and revision process.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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