Original Article

Accuracy of palatal orthodontic mini-implants placed by conventionally or CAD/CAM-based surgical guides: a comparative in vitro study

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ABSTRACT

Objectives: To investigate and compare the transfer accuracy of five different surgical guides (SGs) for the insertion of orthodontic mini-implants (OMIs) in the anterior palate.

Materials and Methods: Stereolithographic files of 10 maxillary patient models and their corresponding lateral cephalograms were virtually matched and used for planning the position of two parallel OMIs in the paramedian region of the anterior palate. For each patient model, three 3-dimensional (3D)–printed and two conventional SGs were manufactured from different materials, and a total of 96 OMIs were transferred to the anterior palates of the respective 50 molded resin models. The planned (T0) and the actual (T1) OMI positions were analyzed and compared after superimposition of the digitized models. The deviations between the OMI positions in T0 and T1 were described as the distance between the head and the tip, respectively, of each OMI in millimeters and the deviating angle between the OMI axes for each patient and SG.

Results: The conventionally manufactured SGs of Pattern Resin LS (GC Europe N.V., Leuven, Belgium) showed the highest linear and angular transfer accuracy for the insertion of OMIs. The highest deviations were found with the SGs made of IMPRIMO LC Splint (3D-printed; Scheu-Dental, Iserlohn, Germany) and Memosil 2 (conventional SG; Kulzer, Hanau, Germany).

Conclusions: The 3D-printed SGs did not reach the accuracy of the conventional SGs made of Pattern Resin but may provide sufficient accuracy for palatal OMI placement. (*Angle Orthod.* 2022;93:79–87.)

KEY WORDS: Orthodontic mini-implant (OMI); Surgical guide (SG); Transfer accuracy; Digital orthodontics

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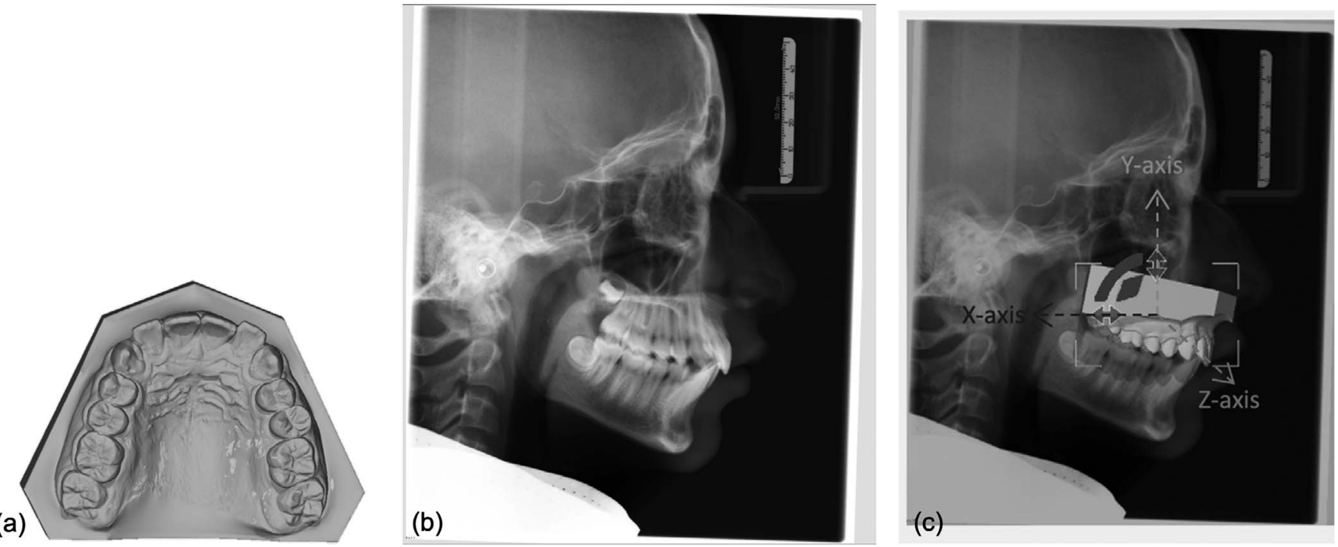
INTRODUCTION

The use of skeletal anchorage offers new solutions for complex problems in clinical orthodontic practice. It has become increasingly important because of its independence from patient cooperation and its possibility of applying continuous forces to the teeth without unwanted adverse effects. Suitable sites for insertion include the interradicular alveolar bone in the upper and lower jaws and the anterior palate in the maxilla.[1,2] The latter has become the preferred region for the placement of orthodontic mini-implants (OMIs), primarily because of the absence of dental roots and because of its sufficient bone supply. This, however, varies significantly depending on the patient's age and sex.[3] Ideally, insertion is performed median or paramedian to the palatal suture and close to the third pair of palatal rugae.[4]

OMIs are indicated in various situations, such as the anteroposterior movement of teeth, space closure, and molar intrusion, and have greatly expanded the orthodontic treatment spectrum.[5,6]



Figures 1. (a) Socketed patient model. (b) Respective lateral cephalogram. (c) Matched 3D model after merging of the socketed STL file with the lateral cephalogram.

However, in patients with ectopic teeth, cleft lip and palate, and reduced palatal bone availability, insertion of OMIs can be challenging. Digital planning of mini-screw insertion reduces unwanted adverse effects such as possible injury to root surfaces or implant loss attributed to poor bone quality.[7] In addition, the use of a surgical guide (SG) to insert the digitally planned OMI has the potential to achieve ideal bone insertion depth and parallelism among multiple mini-screws[8] for a predictable clinical process.

Various authors already described digital workflows for the virtual planning of OMI positions.[8,9] Some of them involved a two-appointment procedure, whereas others inserted the OMIs and the supported appliance in one single visit. Nevertheless, most of them involved an external laboratory or cone-beam computed tomography (CBCT), which results in additional costs or radiation exposure and should be exerted thoughtfully.

Because the position of OMIs can be crucial for their success, SGs are helpful tools. In the literature, little has been described about the transfer accuracy of different SGs, comparing their material eligibility and manufacturing process independent of the chosen design.

Therefore, the purpose of the present study was to investigate the accuracy of OMIs placed by conventionally or CAD/CAM-based SGs made of different materials.

MATERIALS AND METHODS

Simulation Model

Intraoral scans of 10 patients made with an optical scanner (TRIOS 3W, 3Shape, Copenhagen, Denmark) were imported as stereolithography (STL) files in the orthodontic software OnyxCeph (Image Instruments, Chemnitz, Germany), and their corresponding lateral cephalograms were added. The integrated module TADmatch (Image Instruments and Promedia Medizintechnik A. Ahnfeldt, Siegen, Germany) enables the digital planning of OMIs. For this purpose, the STL files were socketed and merged with the respective lateral cephalogram using the incisal edge of the central incisor and the mesiobuccal cusp of the first molar as reference points.

By superimposing the two data sets, the inclination of the anterior teeth and, hence, their root positions were revealed on the virtual model to localize the OMI positions with sufficient safe distance to the surrounding structures and with respect to the available bone supply. The matched three-dimensional (3D) model (Figure 1) was then used for virtual insertion of the OMIs, resulting in a so-called simulation model (Figure 2). Based on the planned position, a “position model” (Figure 3) was created to manufacture the conventional surgical insertion guide later.

Manufacturing Process

3D-printed SGs. The OrthoApps 3D module of OnyxCeph software was employed for designing the CAD/CAM-based SGs (Figure 4) on the underlying simulation model. Two cylindrical guide sockets with a defined length were fittingly arranged around the OMIs and their axes to reproduce the angle of insertion and prevent the screws from penetrating beyond the intended depth into the bone. The design of the SGs was bilaterally extended to the two

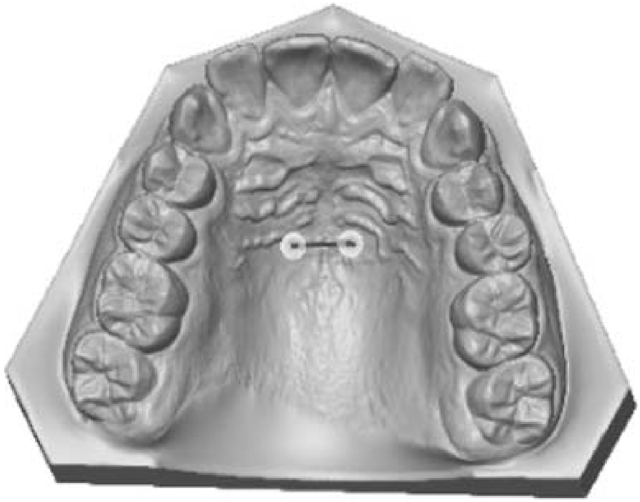


Figure 2. Simulation model.

premolars and the first molar and covered them occlusally and buccally to the anatomical equator for vertical support and stabilization in the transverse plane. The resulting SG was then 3D-printed from three different resin materials for each in vitro patient by the respective company and according to their printing protocol (Figure 5a–c):

- Surgical Guide Resin (Formlabs, Berlin, Germany)
- V-Print SG (VOCO, Cuxhaven, Germany)
- IMPRIMO LC Splint (Scheu-Dental, Iserlohn, Germany).

Conventional SGs. The STL files of the position models were molded by an external laboratory (Rübeling+Klar Dental-Labor, Berlin, Germany). Based on these position models, two conventional SGs were manufactured for each patient in the same design as for the 3D-printed SGs (Figure 5d–e):

- Memosil 2 (Kulzer, Hanau, Germany)
- GC Pattern Resin LS (GC Europe N.V., Leuven, Belgium)

In Vitro Insertion

With the aid of the different SGs, two 2×10-mm self-drilling OrthoLox OMIs (serial no. 20-OLS-010; Promedia Medizintechnik, Siegen, Germany) were inserted in each in vitro patient's molded resin model. All OMIs were inserted by the same investigator. Predrilling into the models was performed with a compatible 1.3×8-mm OrthoLox pilot drill (serial no. OL-PDR-008) with a vertical stop using a battery-powered screwdriver (Orthonia II Safety Insertion System, Jeil Medical Corporation, Seoul, Korea). Screw insertion was manually executed using an OrthoLox ratchet (serial no. OL-RAT-000) and a screw holder with vertical stop to ensure the planned insertion depth.

Accuracy Measurements

To register the actual OMI positions, OrthoLox hexagonal scanbody abutments were placed on the inserted OMIs and captured with an intraoral scan (TRIOS 3W, 3Shape, Copenhagen, Denmark). The planned position (T0) of the OMIs was then compared with the actual insertion position (T1) by superimposition of the simulation and the insertion models using the dental arch and the palate as stable reference structures in a best-fit alignment. The matching of the models and the measurement of the respective OMI positions at the head and tip of each mini-screw and their respective deviating axes were performed in the OnyxCeph software by a subordinate calculation tool in a predefined cartesian coordinate system.

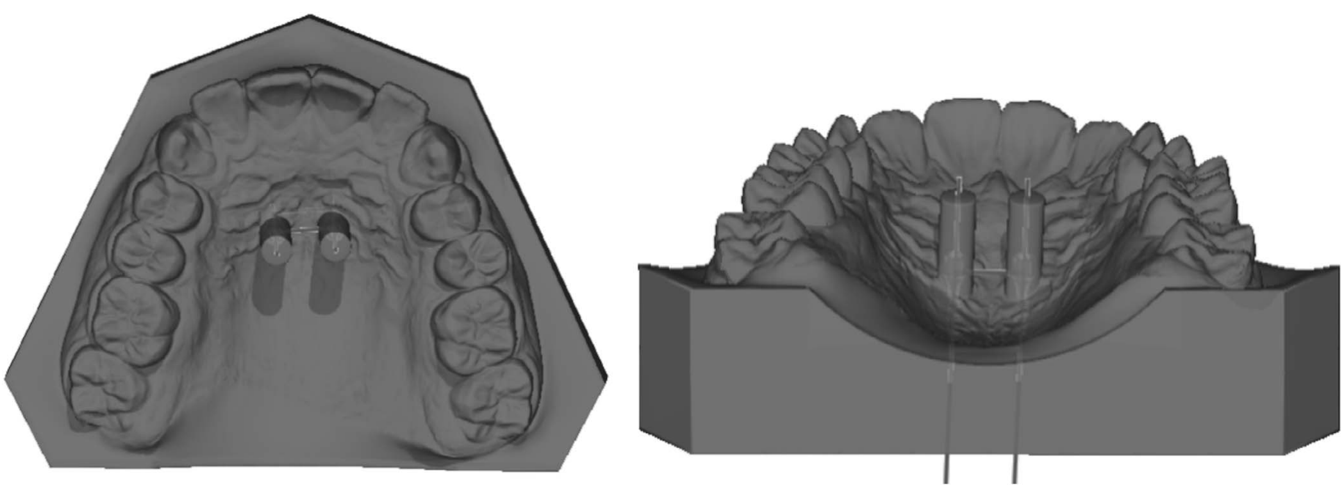


Figure 3. Position model for conventional SG manufacturing in a two-visit protocol.

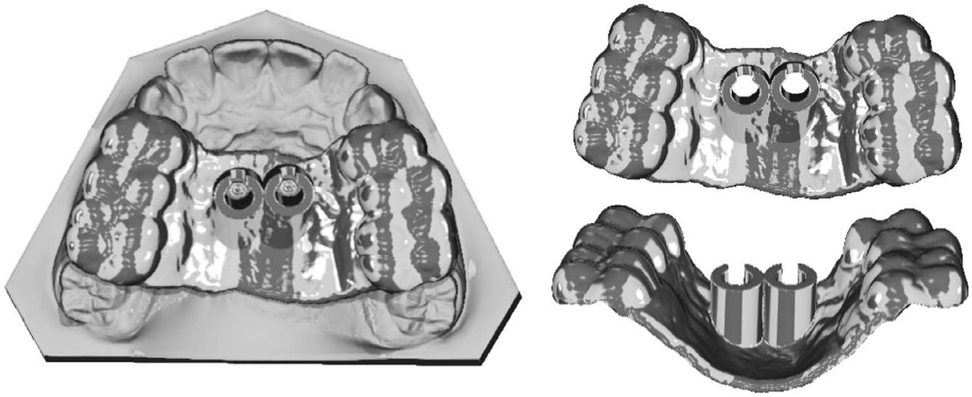


Figure 4. Virtual SGs designed with the OrthoApps 3D module.

The resulting deviations between T0 and T1 were measured in millimeters at the level of the OMI head and tip (and calculated for the x-, y-, and z-axis). In addition, the angular deviations in the longitudinal axes from T0 to T1 were measured in the XY-, XZ-, and YZ-plane. The complete workflow of the study is shown in Figure 6.

Statistical Analysis

Median deviations with interquartile ranges (IQRs) are reported for the OMI head and tip level as well as the angular deviations between T0 to T1, stratified by SGs.

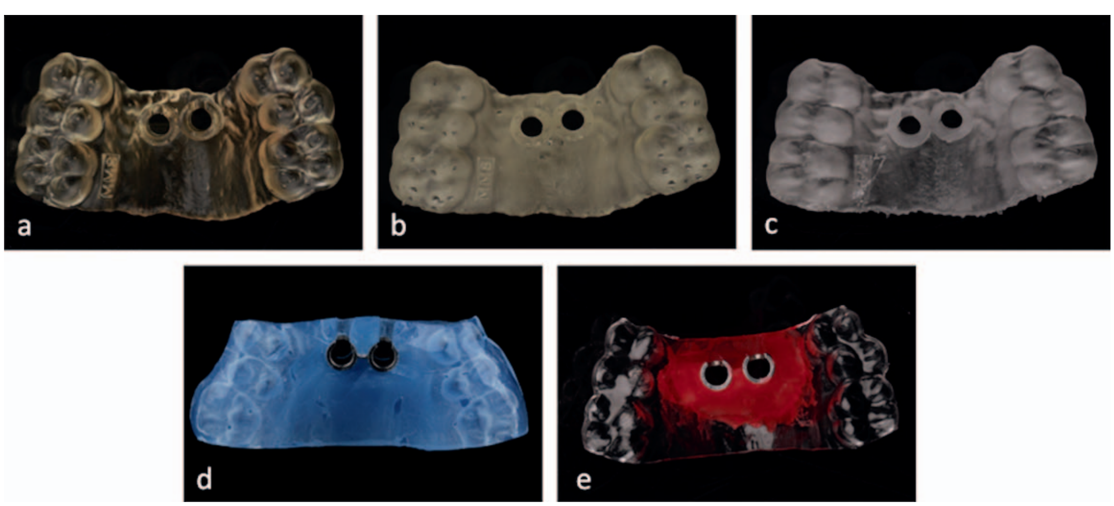
Mixed linear regression models were applied to compare the accuracy of the three 3D-printed and the Memosil 2 SG templates to the Pattern Resin LS material for the SGs, where the latter was used as the reference. The respective outcomes are absolute deviations. The models are specified with a random intercept by patient and a fixed effect for the quadrant. Regression coefficients indicating differences between groups are displayed as estimates along with 95% confidence intervals (CIs). Statistical analyses were performed with R (version 4.1.0).[10–12]

RESULTS

A total of 100 OMIs were planned for insertion in the paramedian region of the anterior palate of 50 insertion models. After the breakage of four implants during insertion, a total of 96 OMIs were transferred using the five different types of SGs on all 10 in vitro patients differing in materials and manufacturing processes.

Metric Deviations at the OMI Head Level From T0 to T1

The median deviation for all materials at the OMI head level from T0 to T1 ranged between +0.73 mm and –0.76 mm for the different axes in the set cartesian coordinate system (Table 1). Overall, the greatest deviations were found for the SGs made of Memosil 2 in the y- and z-axis (Figure 7).



Figures 5. The 3D-printed SGs. (a) Formlabs SG Resin. (b) Voco V-Print SG. (c) Scheu IMPRIMO LC Splint. (d) Memosil 2. (e) GC Pattern Resin LS.

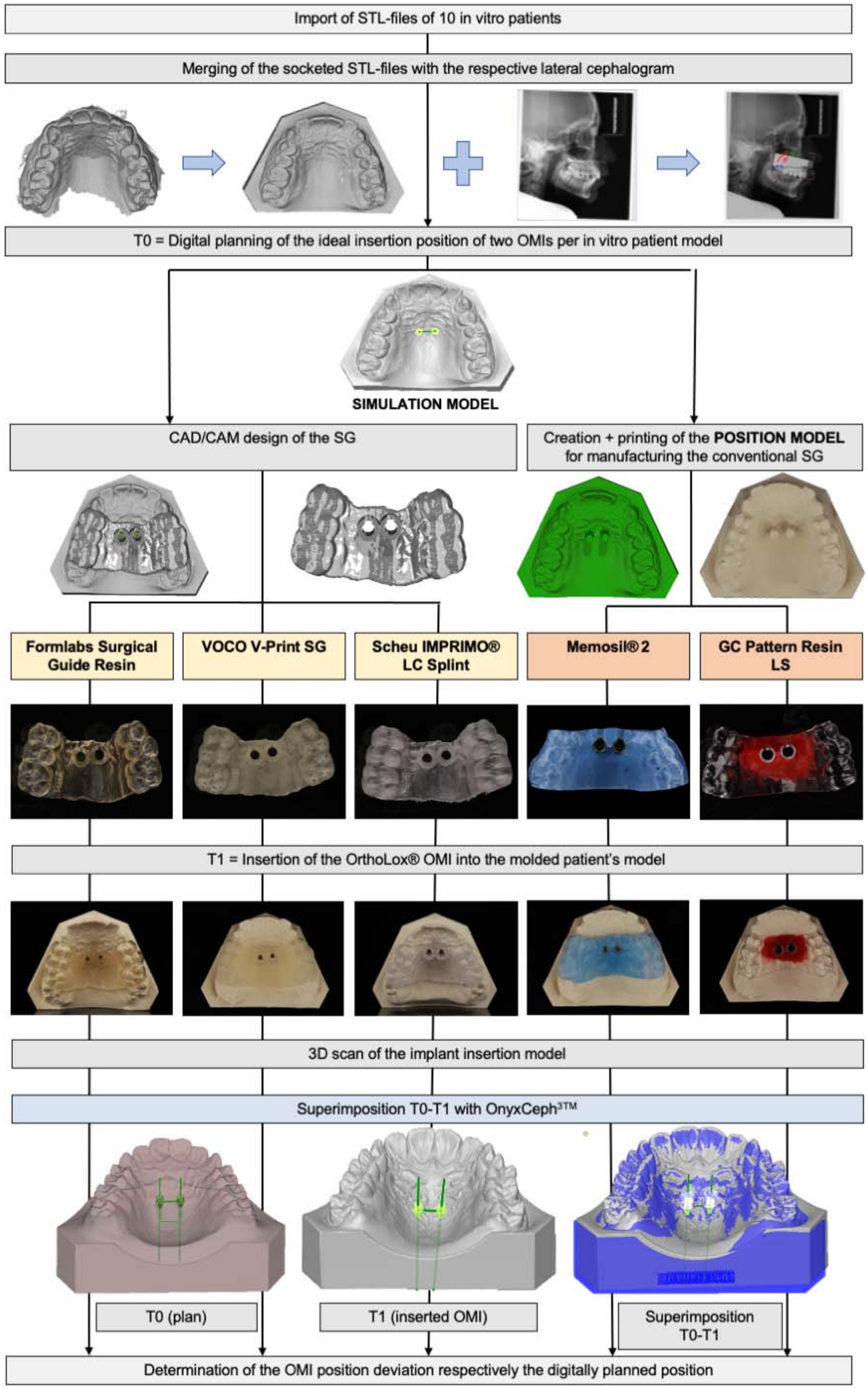


Figure 6. Study workflow.

Table 1. Median (IQR) for Deviation in Metrics (in Milimeters) and Angular Deviations (in Degrees) Between T0 and T1 for the Different SG Templates[a]

Variable	Pattern Resin LS by GC	Surgical Guide Resin by Formlabs	V-Print SG by VOCO	IMPRIMO LC Splint by SCHEU	Memosil 2 by Kulzer
Head deviation x-axis	0.10 (−0.14, 0.31)	0.15 (−0.26, 0.38)	0.25 (−0.12, 0.49)	0.14 (−0.02, 0.43)	−0.05 (−0.31, 0.28)
Head deviation y-axis	−0.64 (−0.97, −0.46)	−0.24 (−0.77, 0.17)	−0.29 (−1.63, 0.08)	−0.15 (−1.80, 0.13)	−0.76 (−0.98, −0.36)
Head deviation z-axis	0.31 (0.17, 0.80)	0.37 (0.08, 0.67)	0.50 (−0.04, 0.97)	0.50 (−0.04, 0.97)	0.73 (0.35, 1.37)
Tip deviation x-axis	0.17 (−0.26, 0.44)	0.36 (−0.27, 0.64)	0.49 (−0.09, 0.78)	0.40 (−0.22, 0.68)	0.17 (−0.34, 0.76)
Tip deviation y-axis	−0.66 (−0.81, 0.35)	−0.04 (−1.12, 0.31)	−0.24 (−1.19, 0.10)	−0.33 (−1.88, −0.06)	−0.57 (−0.89, −0.14)
Tip deviation z-axis	0.25 (0.10, 0.70)	0.32 (−0.45, 1.66)	0.37 (−0.30, 0.80)	0.57 (−0.12, 2.78)	0.34 (−0.07, 1.27)
Deviation XY angle	0.70 (0.30, 1.52)	1.57 (0.46, 2.41)	1.55 (0.52, 2.37)	1.33 (1.03, 2.65)	2.08 (1.13, 3.13)
Deviation XZ angle	1.88 (0.82, 3.88)	3.82 (1.42, 6.44)	4.08 (1.56, 6.59)	6.03 (3.32, 9.01)	5.60 (2.77, 8.12)
Deviation YZ angle	2.39 (0.54, 4.08)	1.64 (0.98, 5.69)	1.35 (0.68, 1.97)	2.47 (0.53, 5.43)	2.62 (0.91, 4.39)

[a] IQR - interquartile range.

The SGs made of IMPRIMO LC and Memosil 2 showed results comparable with Pattern Resin LS in the mixed models. The Surgical Guide Resin (Formlabs) and V-Print SG (VOCO) materials proved to be less accurate, but negligibly.

Metric Deviations at the OMI Tip Level From T0 toT1

The median deviation for all materials at the OMI tip level from T0 to T1 ranged between +0.57 mm and –0.66 mm for the different axes in the set cartesian coordinate system (Table 1). The highest accuracy in the x-axis was observed with the SGs made of Pattern Resin LS. Regarding the insertion depth (y-axis), the best median results were observed with the Surgical Guide Resin by Formlabs.

With respect to the mean absolute differences, the V-Print SG showed accuracy comparable with the reference material in the y-axis (0.01 mm; 95% CI: –0.15, 0.18). The greatest differences were observed in the z-axis, with Pattern Resin LS being the most accurate material (Figure 8).

Angular Deviations Between T0 and T1

The median deviations between the T0 and T1 positions of the OMI ranged between 0.70° and 6.03°. Regarding the anteroposterior direction (XY-plane) and the insertion depth (XZ-plane), the most accurate material was the Pattern Resin LS. Memosil 2 showed the least accuracy for both the mesiodistal and the anteroposterior direction (Table 1, Figure 7a).

Regarding the mean absolute values (Figure 8), the greatest differences were observed in the insertion depth (XZ-plane), where SGs printed with Memosil 2 (6.67°; 95% CI: 4.32, 9.03) and Surgical Guide Resin by Formlabs (3.81°; 95% CI: 1.45, 6.16) presented significantly higher deviation angles than Pattern Resin LC.

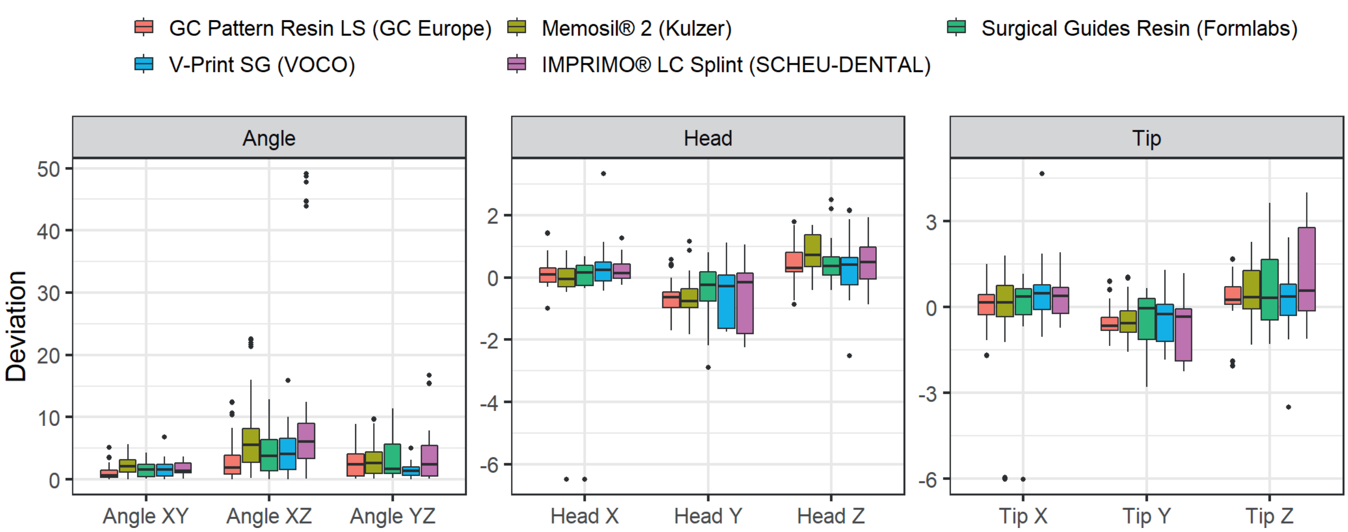


Figure 7. (a) Angular deviation (°) in the OMI position between T0 and T1, measured in the XY-, XZ- and YZ-planes with the different SG templates. (b) Metric deviation (in millimeters) at the OMI head between T0 and T1 measured in the x-, y-, and z-axis with the different SG templates. (c) Metric deviation (in millimeters) at the OMI tip between T0 and T1 measured in the x-, y-, and z-axis with the different SG templates.

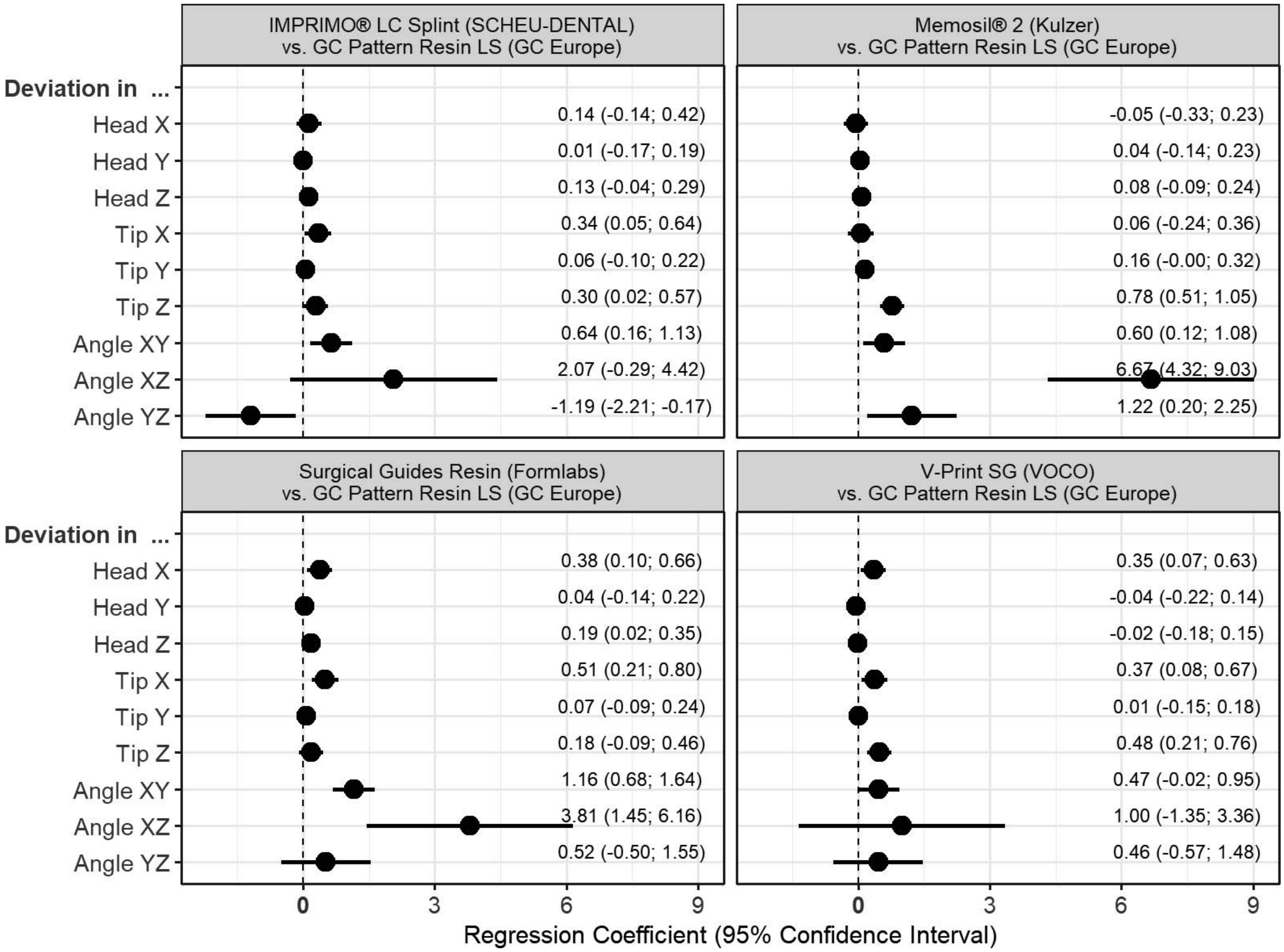


Figure 8. Regression coefficients along with 95% CIs derived from mixed linear regression models.

For angular deviations to the lateral (YZ-plane), only SGs made of IMPRIMO LC Splint were more accurate than the reference material.

DISCUSSION

The aim of this study was to compare the transfer accuracy of SGs made of five materials and in two different manufacturing approaches for the insertion of OMIs. Conventionally manufactured templates made of Pattern Resin LS by GC were found to have the highest transfer accuracy, followed by the 3D-printed templates made of SG V-Print by VOCO. IMPRIMO LC Splint by Scheu-Dental (3D-printed) and Memosil 2 (conventionally manufactured) showed the highest mean deviations.

Möhlhenrich et al. found, in their cadaveric study, that the use of silicone SGs provided sufficient control of OMI placement and concluded that these were comparable with CAD/CAM-based templates.[13] The results of the current study showed that SGs made of silicone were less accurate than the 3D-printed SGs made of resin. It may still be concluded that they were sufficient for this purpose if a very limited bone amount is not suspected in the vertical dimension and, hence, a certain tolerance is acceptable regarding the insertion depth and the angulation. The employed design and exact material differed from the current study, which may explain the observed differences in results. A tooth-borne design covering the premolars and the first molars in both quadrants was employed in the current study, preventing tipping during OMI insertion.

In general, elastic SGs (eg, Memosil 2) can be manipulated by locally applying high finger pressure, causing distortions in the material and, consequently, transfer inaccuracies for the OMI positions. On the contrary, 3D-printed SGs are stiff and do not allow as much tolerance in their fit that in turn is highly dependent on parameters in the 3D-printing process such as the Shore hardness of the material, orientation on the build platform, and postprocessing procedure.[14]

Metallic titanium sleeves were employed for the conventional SGs, allowing precise predrilling with a consistent diameter. However, mobility of the drill sleeves may occur during OMI insertion, contributing to the observed deviations (especially with Memosil 2).[13] Resin drill sleeves were directly incorporated to the 3D-printed SGs.

The 3D-printing process was outsourced to the respective companies, and the exact same data file was sent to all external laboratories for 3D-printing. Differences in the offset selection, the SG orientation on the built platform, or any other settings during the printing process may have contributed in an uncertain degree to the observed different transfer accuracies among materials. All materials were handled according to the manufacturers' instructions.

The observed deviations at the OMI tip level in the mesiodistal direction was higher than at the OMI head level. It was concluded that errors or deviations occurring at the beginning of OMI insertion would result in a higher inaccuracy at the screw tip level. For this reason, it is appropriate to agree with Möhlhenrich et al.[13] and recommend a safety distance when selecting the implant length. Regarding the fitting of the appliance over the screws, the final position of the OMI head is more relevant than the tip position.

OMIs are used only for temporary anchorage, and therefore a certain tolerance regarding their angulation can be allowed. Nevertheless, to ensure fitting of the OMI-based appliance and when a one-appointment workflow is desired, minimum deviation from the planned position is mandatory.

Further error sources that were not assessed in this study were the force and instrument holding position employed by the orthodontist while using the rachet or screwdriver. In this study, all OMIs were inserted by the same investigator, therefore limiting the influence of this aspect.

In the current study, the highest transfer accuracy was achieved with the SG made of Pattern Resin LS, which seemed to compromise between needed stiffness and some elasticity (Shore-D-hardness: 62). Because of the differences in the material properties, different designs according to their degree of elasticity could result in a higher transfer accuracy. Hence, SGs made of an elastic material would need a thicker design, and harder materials would need a thinner profile.

The OMI position was planned after merging of the patient's STL file with the respective lateral cephalogram. TADmatch superimposes both records after the selection of corresponding anatomical structures and merges them in an automated closest-point algorithm. If needed, a manual adjustment is possible afterward. Several studies have already shown the suitability of these radiographs for measuring the palatal thickness and planning of the OMI position.[8,15,16] On this, Jung et al. concluded that vertical palatal bone supply, as measured on the lateral cephalograms, reflects the minimum bone height and provides an accurate and adequate assessment of vertical bone for the paramedian insertion of OMIs.[17] However, superimposing a 3D model on a two-dimensional image can be challenging, especially in the z-axis. For this reason, a safety distance to neighboring structures should be planned. CBCT imaging is not routinely recommended and should be reserved for exceptional cases (eg, impacted teeth, cleft patients) to avoid additional x-ray exposure. A recent study by Iodice et al. proved not only that TADmatch was a suitable planning software but also that a sufficient safety distance could be guarded to the anterior teeth after using a lateral cephalometric radiograph for planning.[18]

Because the insertion of OMIs in the anterior palate represents a challenge in orthodontic practice as surgical interventions are not a routine procedure, the use of SGs is a helpful tool by providing the practitioner with a distinctive OMI position and safety for insertion. Furthermore, it facilitates finding sufficient bone supply and reduces the risk of damaging neighboring structures. The deviations between the planned and actual OMI positions showed some significant differences between the studied materials. Yet, probably all tested materials would satisfy the orthodontic accuracy necessities. However, when aiming at a single-appointment workflow, only the SGs made of Pattern Resin LS, SG Resin by Formlabs, and V-Print by VOCO seem to be suitable for direct placement of the orthodontic appliance after OMI insertion. Further in vivo studies are needed to investigate if a one-session workflow with simultaneous appliance placement is feasible when in-house, 3D-printed SGs are used.

CONCLUSIONS

- Among the investigated materials for SGs, Pattern Resin LS presented the highest transfer accuracy for the insertion of OMIs.
- The highest linear and angular deviations were found with the SGs made of IMPRIMO LC Splint (3D-printed) and Memosil 2 (conventionally manufactured).
- Although some 3D-printed SGs are suitable for clinical practice and can be integrated into a fully digital workflow, they do not reach the gold standard of the conventional SG made of Pattern Resin LS by GC.

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