The osseointegration between bone and dental implants was proven to have a predictable outcome after restoring edentulous areas with dental implants; however, proper planning is required to achieve successful results, and this includes both presurgical anatomical planning and the precise prosthetic position of the implant to achieve the best possible prognosis. In some cases, such as compromised anatomy or where the location of the implant will significantly affect the esthetics, computer-guided implant placement can be important to achieve a better implant position with minimally invasive surgery allowing simultaneous viewing of the bone landmarks with the proposed future prosthesis. Other advantages of guided implant surgery include being simple, safe, and more accurate than the freehand method.

The double-scan protocol was introduced to transfer the prosthetic plan to the 3D imaging software in edentulous patients. In this technique, the first scan function is to allow visualization of bone anatomy, while the second scan is for visualizing the appliance. The DICOM data of both scans can then be superimposed according to the radiopaque radiographic markers, which are considered as a common object appearing in both scans. Many types of radiopaque markers have been introduced for the double-scan protocol. Most of the operators used six to nine spherical gutta-percha markers to 2 mm in diameter distributed on the facial and lingual flanges of the nonradiopaque acrylic denture of the patient or its replica “scan appliance.” Others placed barium sulfate radiopaque markers in the center of the denture teeth or mixed with the acrylic powder to create a completely radiopaque scan appliance. Recently, four miniscrews were inserted into the jaw for registration. All techniques required either duplicating the patient’s denture or modifying it by placing radiopaque markers. Therefore, the marker-free technique might be a viable option for the double-scan protocol.

The aim of this retrospective study was to introduce a novel technique of a double-scan protocol with marker-free registration and compare it to the already-used techniques regarding the accuracy of registration. Materials and Methods: Fifty-nine fully edentulous patients underwent double-scan procedures by three different methods: the barium sulfate method for 11 patients; the gutta-percha method for 26 patients; and the marker-free method for 22 patients. Point-to-point registration of the two scans was followed by a voxel-based surface “best fit” registration. The mean registration error of each case was digitally recorded. Differences in registration error between groups were evaluated using one-way analysis of variance (ANOVA). Results: The accuracy of the registration showed no significant differences according to the method \( P = .719 \). Conclusion: The marker-free procedure was presented as a novel technique for registration of the scans in the double-scan protocol. There was no significant difference in the accuracy of the registration between the three techniques: marker-free, gutta-percha markers, and fully radiopaque barium sulfate scan appliance. Therefore, the marker-free technique might be a viable option for the double-scan protocol. Int J Oral Maxillofac Implants 2022;37:473–478. doi: 10.11607/jomi.9251

Keywords: 3D, CAD, computer-guided surgery, prosthetic procedure, radiology
implant placement as a treatment for restoring their missing teeth through flapless mucosa-supported, computer-generated surgical guides, were selected for this retrospective study. Patients were divided into three groups according to the method of registration of the CBCT images. The study was approved by the internal review board at October University for Modern Sciences and Arts (ETH 27).

The barium sulfate group included 11 patients: 7 maxillary arches and 4 mandibular arches. A scan appliance was fabricated as a duplicate from the patient's denture with the radiopaque barium sulfate mixed thoroughly with acrylic resin (Fig 1).19

The gutta-percha (GP) group consisted of 26 patients: 11 maxillary arches and 15 mandibular arches. In this group, 8 to 12 GP markers (1.5 to 2 mm in diameter) were fixed into small holes drilled into each acrylic denture. These markers were distributed along the denture in the anterior and posterior regions (Fig 2).

The MF group included 22 patients: 11 maxillary arches and 11 mandibular arches. In this group, the scan appliance was the regular nonradiopaque acrylic resin denture of the patient with no radiopaque radiographic markers.

Scanning
The first scan was performed on the patient wearing the denture or scan appliance, while the second scan was performed on the appliance alone. All patients underwent double-scan procedures using CBCT (Scanora 3D, Soredex). Scans were obtained using a setting of 85-kV peak, pulses of 4 to 10 mA, 75 × 100-mm scan dimensions, scan time of 11 seconds of pulsed exposure, exposure time of 2.5 seconds, and reconstruction with spatial resolution of 0.3-mm isotropic voxel size.

The first scan of the double-scan protocol was the same for the barium sulfate and GP groups by having the patient bite firmly on the scan appliance against the opposing arch with bilateral cotton rolls as separators with the mouth closed (Figs 3 and 4). In the MF group, the first scan was performed after placing a suitable-sized cheek retractor and making sure that the soft tissue was as displaced away from the denture as possible. The patient was then instructed to bite firmly on a pair of cotton rolls placed in between the denture and the opposing denture or dentition as the previous groups (Fig 5). All scans were visually examined for a double image to ensure that there were no patient motion artifacts.

The second scan of the appliance for all groups was performed using the same method by placing the scan appliance or denture on a thick piece of cotton or foam separating the scan appliance from the plastic support of the CBCT machine. The scan appliances were positioned in the center of the field of view (FOV).

Registration
Careful thresholding was performed according to the relative linear attenuation coefficient value of reconstruction of the denture/appliance, which defined the transition between the target material and the surrounding background. For each case, this threshold value was individually chosen to obtain an optimum 3D reconstruction approximating the dimensions of the markers or denture/appliance.
Registration was performed between the two scans in two stages, first by using point-to-point registration, and then followed by automatic voxel-based surface registration by RealGUIDE 5.0 software (3DIEMME). At the point-to-point registration stage, the opposing arch was separated by segmentation and removed from the CBCT image. Then, in the barium sulfate and MF groups, eight clear and definite landmarks, such as cusp tips, point angles, and maximum convexities or concavities, were digitized on both scans and superimposed (Figs 3 and 5). In the GP group, the gutta-percha markers were segmented from both CBCT scans and superimposed (Fig 4). This step was performed to achieve the primary registration of both scans based on the common identified landmarks.

The following stage was the automatic voxel-based surface registration. In this stage, the RealGUIDE 5.0 software improved the superimposition between both images of the appliance via a fully automated process using all the available surfaces to achieve the “best fit” (least mean error of alignment) between them.
Measuring the Accuracy of Registration
The registered scans were visually investigated in different cross-sectional cuts along the scans to be sure that the registration was performed successfully. The mean registration error (delta value) was then recorded from the software. Cases with a mean value above 0.35 mm were excluded from this study.20

Statistical Analysis
Statistical analysis was performed using SPSS 20.0 (IBM). Normal distribution was confirmed by the Shapiro-Wilk test. Differences in registration error between groups were evaluated using one-way analysis of variance (ANOVA) and between maxillary and mandibular arches by an independent-samples t test. The significance level was set at .05.

RESULTS
The accuracy of the registration showed no significant differences according to the method (P = .719). The mean registration error was 0.130 ± 0.041 mm in the GP group, 0.122 ± 0.053 in the barium sulfate group, and 0.118 ± 0.056 in the MF group (Table 1).

In addition, there was no significant difference in accuracy according to the dental arch (P = .780). The mean registration error was 0.122 ± 0.048 mm in the maxilla and 0.126 ± 0.050 mm in the mandible (Table 1).

DISCUSSION
To achieve the best esthetic outcome in implant therapy, it is mandatory to transfer the prosthetic information to the 3D anatomical images.21 However, the denture resin material has a relative density similar to the surrounding soft tissues, which makes the process of segmentation not possible from a single CT scan. For the same reason, registration of the denture or scan appliance in the patient’s mouth with another extraoral scan of the denture using a double-scan protocol was also not possible unless radiopaque markers were used.3,22,23

In partially edentulous patients, it was possible to register a 3D model of the patient’s dental arch obtained by a 3D scanner to the CBCT image based on dental landmarks.24,25 Recently, several studies have introduced a protocol for superimposing images of an existing complete denture taken by an intraoral

Table 1 Accuracy of Registration According to Imaging Method and Dental Arch

<table>
<thead>
<tr>
<th>Imaging method</th>
<th>Registration error (mm)</th>
<th>P value</th>
</tr>
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<tbody>
<tr>
<td>BS (n = 11)</td>
<td>0.122 ± 0.053</td>
<td>.719†</td>
</tr>
<tr>
<td>GP (n = 26)</td>
<td>0.130 ± 0.041</td>
<td></td>
</tr>
<tr>
<td>MF (n = 22)</td>
<td>0.118 ± 0.056</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Dental arch</th>
<th>Registration error (mm)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary (n = 29)</td>
<td>0.122 ± 0.048</td>
<td>.780‡</td>
</tr>
<tr>
<td>Mandibular (n = 30)</td>
<td>0.126 ± 0.050</td>
<td></td>
</tr>
</tbody>
</table>

BS = barium sulphate; GP = gutta-percha; MF = marker free. †One-way ANOVA. ‡Independent-samples t test.
scanner and a CBCT machine to fabricate an implant surgical template. This protocol involved injecting radiopaque, flowable composite resin at three different regions on the immobile mucosa. However, this protocol might not achieve accurate intraoral scans in patients with severe alveolar ridge resorption, due to the large amount of movable mucosa.

In this study, a new technique for the double-scan protocol was introduced. This technique was based on separating the soft tissues from the acrylic denture by air, allowing easy identification of the nonradiopaque denture after thresholding. The aim of this study was to clinically assess and compare the accuracy of registration with this new MF technique versus the already-proven-successful and accepted techniques of using radiopaque markers or a completely radiopaque scan appliance. The criteria of technique selection for a specific case were based on the patient decision. In general, the GP markers method was the standard. If it was declined, a barium sulfate duplicate denture was suggested for an extra cost. If both options were dismissed, the MF technique was utilized.

Previous studies assessed the accuracy of the final implant position in relation to the preoperative software plan; however, the final position of the implant is cumulative based on many factors including the thickness of the mucosa, experience of the operator, reproducibility of the position of the scan appliance during radiographing and the guide during implant surgery, mouth opening, tolerance of the drill guide, and use of fixation pins and metal sleeves, among other factors. However, the present study only focused on the registration error, without evaluating the final implant position.

A radiographic index was not used in this study, and cotton rolls were placed instead to ensure separated occlusion; this allowed for more occlusal registration landmarks for the barium sulfate and MF groups, especially in primary point-to-point registration.

According to the literature, the maximum accepted registration error in the double-scan protocol must not exceed 0.35 mm; greater values were considered to be inaccurate registration. No cases exceeding this value were included in the present study.

The results of registration of all three groups were acceptable and comparable to previous studies: Nada et al found that the accuracy of voxel-based registration in different regions of the skull was 0.19 ± 0.12 mm for a voxel size of 0.4 mm. Swennen et al showed that the accuracy of registering two impressions using the voxel-based method from CBCT data was 0.08 ± 0.03 mm. Verhammer et al reported a mean registration accuracy of 0.05 ± 0.01 mm and 0.13 ± 0.01 mm at different threshold values. Meanwhile, Han et al showed that the surface image registration was not statistically as accurate as that using fiducial marker registration, but its accuracy was clinically satisfactory. However, their study was comparing the location of the inserted implant to its planned location, not the registration accuracy per se.

The present results indicated that there were no significant differences between the three techniques of registration; however, the greatest accuracy was obtained with the MF technique, followed by the complete radiopaque appliance technique. Even though the radiopaque scan appliance had more areas for registration, using a radiopaque object produced artifacts in some areas. On the other hand, the MF method had a large area for registration with no image artifacts in all dimensions. However, it has fewer molar landmarks than anterior and premolar areas, which had better retraction compared with the lingual surfaces of the molars that were obscured by the tongue. The GP method had the least accuracy, which might be due to the limited area for registration, in addition to the markers’ artifacts.

The MF double-scan protocol has the advantage over the radiopaque scan appliance of saving time and costs required for fabrication of a new duplicate of the denture to be used as a scan appliance. Moreover, it has several advantages over the GP marker registration technique: it is simpler, quicker, and less technique sensitive; has no artifacts; and does not need drilling in the patient’s denture to place the markers.

CONCLUSIONS

The MF procedure was presented as a novel technique for registration of the scans in the double-scan protocol applied for the treatment planning of implant-supported protheses in fully edentulous patients. There was no significant difference in the accuracy of the registration between the three techniques: MF, GP markers, and fully radiopaque barium sulphate scan appliance. Therefore, the MF technique might be a viable option for the double-scan protocol. However, further studies to assess the overall clinical success rate might be warranted.

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REFERENCES

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