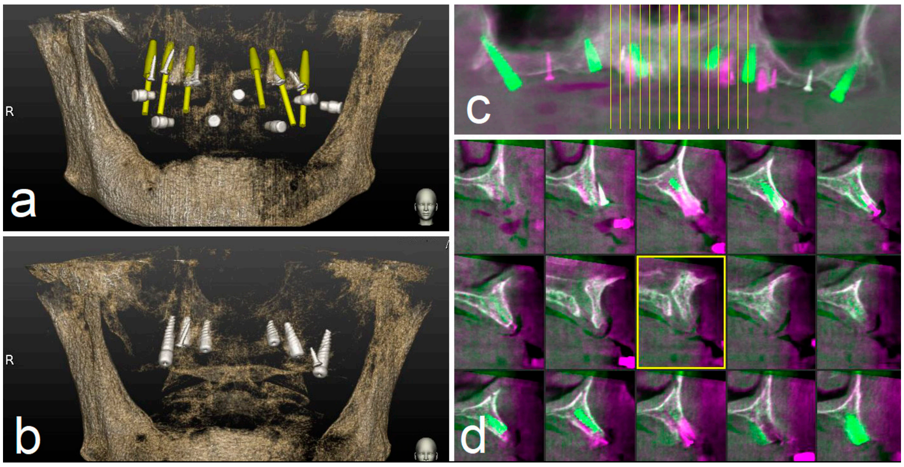

Figure 8. The preoperative surgical plan (**a**) and the postoperative cone beam computerized tomography (CBCT) (**b**) were superimposed using accuracy evaluation software (**c**,**d**). The registration was performed directly between the two volumetric images.

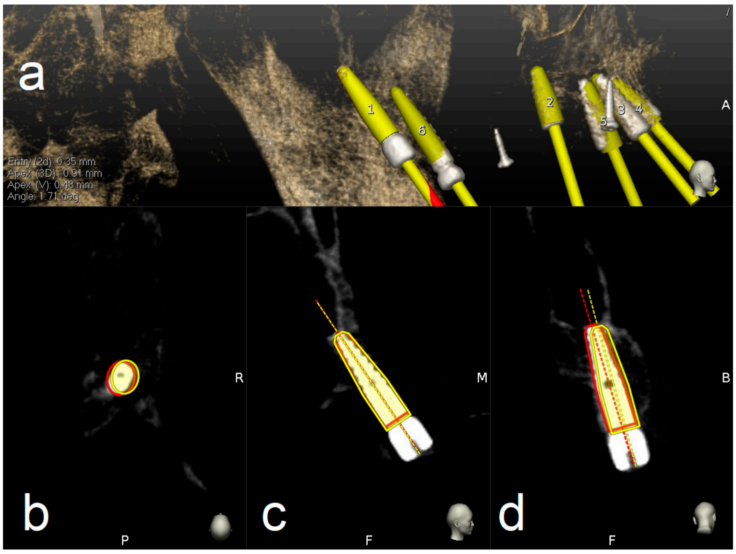

Figure 9. The software automatically fits an implant model to its appearance in the post-operative image (**a**) and computes the angular axis corrected between the planned and actual implant locations (implant inserted with dynamic guidance) (**b**–**d**).

To address the main goal of the study, the accuracy of pterygoid and frontal implants' placement was assessed in terms of deviation at coronal, apical 3D, apical depth, and angular level.

Outcomes were evaluated both clinically and radiographically after three months post-loading.

Implant survival rate, implant length, and mucosa thickness above the planned pterygoid implants were also reported (Figure 10).

The mucosa thickness was calculated as linear measurement above each planned pterygoid implants by means of implant centric CBCT view.

Furthermore, any difference in terms of passivity was evaluated using angled M.U.A. or OT-Equator abutments.

A database was created using Excel (Microsoft, Redmond, WA, USA). Descriptive statistics including mean and standard deviation values were calculated for each variable.

The independent-samples t-test was used to identify statistically significant differences in the coronal position of implants, the apical position of implants, the depth of implants, and the angle of inserted implants between pterygoid and frontal ones compared with planned implants.

Data were evaluated using standard statistical analysis software (IBM SPSS Statistics for Windows, Version 22.0. IBM Corp., Armonk, NY, USA). In each test, the cut-off for statistical significance was $p \leq 0.05$. A power analysis using the G*Power 3.1.9.7 for Windows XP with an alpha level of 0.05 and a medium effect size (f = 0.90) showed that 27 implants for each group would be adequate to obtain 95% power in detecting a statistical difference between two groups in the mean.

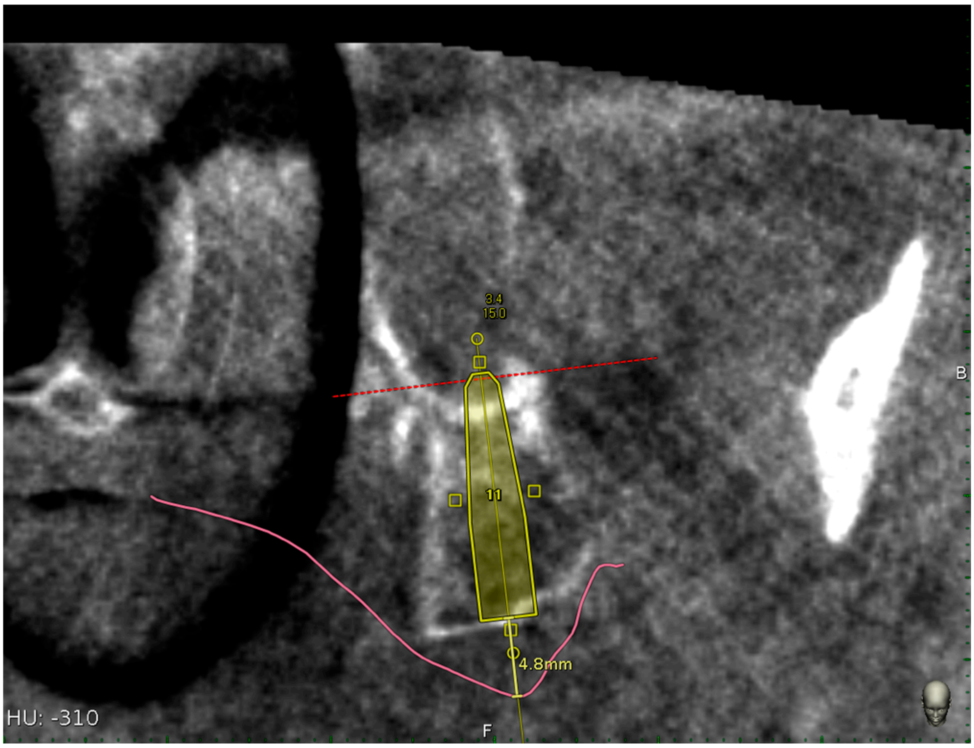

Figure 10. Mucosa thickness linear measurement using the implant centric view of the CBCT.

3. Results

Post-operative complications were not reported by the 14 patients.

In three patients, one frontal implant failed during the first period of the immediate loading (success rate of 92.8%) and final impression was taken on the remaining five implants (two pterygoid and three frontal implants).

In one patient, a pterygoid implant, which did not have a torque useful to be immediately loaded, failed during its first month of insertion (success rate of 96.4%) and was replaced with a new one of the same length, but with a wider diameter. The provisional prosthesis was made using four frontal implants.

The average accuracy in coronal position, apical position, depth, and angle of implants compared with planned implants was reported in Tables 1–3.

Table 1. Mean, maximum, and minimum of the coronal, apical 3D, apical vertical (depth), and angular deviations of the total implants inserted using a dynamic navigation system (n = 74).

Deviation of the Total Implant Inserted (78)	Mean	Minimum	Maximum	Standard Deviation
Coronal (mm)	0.66	0.04	2.19	0.35
Apical 3D (mm)	1.01	0.23	2.52	0.46
Apical (depth) (mm)	0.52	0.02	1.27	0.30
Angular degree (°)	2.61	0.39	7.86	1.29

Table 2. Mean, maximum, and minimum of the coronal, apical 3D, apical vertical (depth), and angular deviations of the pterygoid implants inserted using a dynamic navigation system ($n = 28$).

Deviation of the Pterygoid Implants Inserted (28)	Mean	Minimum	Maximum	Standard Deviation
Coronal (mm)	0.72	0.25	1.42	0.28
Apical 3D (mm)	1.25	0.56	2.52	0.46
Apical (depth) (mm)	0.69	0.06	1.27	0.33
Angular degree (°)	2.86	0.57	7.86	1.56

Table 3. Mean, maximum, and minimum of the coronal, apical 3D, apical vertical (depth), and angular deviations of the frontal implants inserted using a dynamic navigation system ($n = 56$).

Deviation of the Frontal Implant Inserted (56)	Mean	Minimum	Maximum	Standard Deviation
Coronal (mm)	0.64	0.04	2.19	0.37
Apical 3D (mm)	0.89	0.23	2.01	0.42
Apical (depth) (mm)	0.46	0.02	1.22	0.26
Angular degree (°)	2.49	0.39	5.21	1.14

Table 4 reports the average length of pterygoid implants used and Table 5 reports mucosa thickness above pterygoid implants.

Table 4. Number (%) of different implant lengths used.

Implant Length (mm)	Implants Used (%)
13	2 (7%)
15	9 (32%)
16	10 (36%)
18	3 (11%)
20	4 (14%)

Table 5. Mean, maximum, minimum, and standard deviation of the mucosa thickness above the pterygoid implants.

Distances (mm)	Mean	Minimum	Maximum	Standard Deviation
Mucosa thickness	5.08	2.6	8.2	1.77

The independent-samples *t*-test showed that there was a statistically significant mean difference between the frontal implants and pterygoid implants in the apical 3d ($p = 0.001$) and apical depth ($p = 0.01$) of implants; the coronal position of implants ($p = 0.29$) and angle position of implants ($p = 0.27$) showed that there was not a statistically significance between the means (Table 6).

Table 6. *t*-test showing the difference between the means of pterygoid and frontal implants. The difference was considered statistically significant for a value of $p < 0.05$.

t-Test (Frontal Implants vs. Navident)	Difference between Means	Sig. (*p*)
Coronal deviation (mm)	0.07	$p = 0.29$
Apical 3D (mm)	0.36	$p = 0.001$
Apical (depth) (mm)	0.20	$p = 0.01$
Angular deviation (°)	0.37	$p = 0.27$

4. Discussion

In this study, the placement accuracy of both pterygoid and frontal implants for a full maxillary implant supported rehabilitation (Da Vinci Bridge®) was assessed using a digital workflow of a dynamic computer-aided implantology system (DCAI).

DCAI works like a global positioning system by making a triangulation with the two cameras, the contra-angle handpiece, and the patient jaw. In this way, the clinician can follow on the screen in real time both the osteotomy site preparation and the implant placement.

At each step, an accuracy check will enable the clinician to prove system accuracy, and thus provide assurance that everything is set up to proceed with a safe surgery.

It is mandatory to evaluate the accuracy of these systems when an implant as well as the pterygoid one is planned to be inserted in a high risk anatomic area.

The accuracy of all 84 implants inserted using DCAI reported in this study was 0.66 mm at coronal point, 1.01 mm at apical 3D, 0.52 mm at apical depth, and 2.61° as angular deviation.

These deviation values reported in this study were consistent with those reported in the literature by other studies using the same technology or a different one with the use of a radiological stent.

Stefanelli et al., in a recent study, using TaP technology, reported, for 136 implants inserted in 59 patients, the following deviations: 0.67 mm at coronal, 0.99 at apical, 0.55 at depth, and 2.5 as angular error [34].

Block et al., using a second-generation navigation system (X-Guide™, X-Nav Technologies), compared deviations using this system versus free-hand. Three surgeons were involved and treated 100 partially edentulous patients. The results (mean (SD)) with navigation were 0.87 (0.42) mm at entry (lateral/2D), 1.56 (0.69) mm at the apex (3D), and 3.62° (2.73°) angular. The unguided deviations had corresponding means (SD) of 1.15 (0.59) mm, 2.51 (0.86) mm, and 7.69° (4.92°). No statistically significant differences were observed in navigated placement between individual clinicians [31].

Pellegrino et al. treated 10 partially or totally edentolous patients using ImplaNav™ system and reported a mean deviation value of 1.04 mm at entry point, a mean deviation value of 1.35 mm at apex, 0.45 mm as depth deviation, and 6.46° as angular deviation [37].

Stefanelli et al. reported in a retrospective observational study on 231 implants (89 arches) using Navident™ (Claronav, Toronto, YTO, Canada) an error of 0.71 mm at entry point, an error of 1 mm at apex, and a mean angular error of 2.26°. The presence of a learning curve was also evaluated. They reported an error of 0.94 mm at the entry point, 1.19 mm at apical point, and 3.48° as angular deviation in the insertion of the first 50 implants of 231, and an error of 0.59 mm at entry point, 0.85 mm at apical point, and 1.98° as angular deviation in the insertion of the last 50 implants [33].

The reported results of the accuracy using several dynamic navigation systems and several protocols are, in any case, better than the accuracy values of inserted implants by free hand (mental navigation). Vercruyssen et al. [38], analyzed accuracy by inserting dental implants using static guides or the free-hand approach (mental navigation). The deviations reported using the free-hand method were as follows: 2.8 (1.5) mm at entry point, 2.9 (1.5) mm at the apex, and 9.9° (6.0°) for angular deviations.

The deviations reported by Vercruyssen referred to the use of conventional implants (10–13 mm long); if the same angular error (10°) is done by inserting a 20 mm long pterygoid implant, the apical deviations could be 5–6 mm, and these values could be very dangerous in this high risk anatomic area.

Another evaluation of this study was to compare the accuracy between frontal and pterygoid implants to assess if the challenge to approach the pterygoid area could affect the results.

The reported deviations of the pterygoid implants were 0.72 mm at coronal point, 1.25 mm at apex 3D, 0.69 mm as apical depth, and 2.86 degree as angular error, while the deviations of frontal implants were 0.64 mm at coronal point, 0.89 mm at apical 3D, 0.46 mm as apical depth, and 2.49 mm as angular error.

A statistically significant difference was reported between means when accuracy values of the pterygoid implants were compared with frontal ones at apical 3D and apical depth; the reason for this difference was probably owing to the different implant lengths used for pterygoid implants compared with the frontal ones. These results were in accordance with the study published by Van Assche et al. [39], reporting a relationship between the length of the bur and the apical deviation.

Telasne and Tessier in 1989 [24,25] reported that 80% of native bone of the pterygoid area was preserved during the time, and this column of bone was enough to insert a 13–20 mm long implant.

The pterygoid implant lengths reported by Telasne and Tessier are consistent with the results of this study, in which the range of the pterygoid implants used was from 13 to 20 mm. In particular, 15 mm (32%) and 16 mm (36%) implant lengths were the most used in this study.

Bydra et al. analyzed 897 pterygoid implants and reported a 92% index survival rate (70 implants failed before occlusal loading); they also reported failure of nine implants in post-loading phase [28].

Candel et al., in a review of the rehabilitation of the atrophic posterior maxilla with 1053 pterygoid implants in 676 patients, reported that the weighted average success of pterygoid implants was 90.7% [29].

Araujo et al., in a systematic review and meta-analysis of the literature, investigated if the pterygoid implants are predictable for the rehabilitation of atrophic posterior maxillae and which are the mean causes of their failure [30]. They reported that pterygoid implants are predictable as their 10-year survival rate is 94.85% (same rate of the conventional implants). Regarding the causes of implant failures (almost all of them were reported before the loading), the hypothesis indicated is related to the implant mispositioning owing to technique difficulties [40].

Graves et al. described a procedure to insert pterygoid implants free-hand; he suggested to insert them in the center of the pterygoid fossa where the thickness of the pterygomaxillary suture is higher; he suggested completely traversing the pterygoid plate (1–2 mm into the pterygoid fossa). A soft tissue reduction was recommended at the implant insertion stage. He inserted 63 implants and reported 7 implant failures. All the implant failures happened before loading [41].

All these authors reported a high success rate of pterygoid implants and concluded that failures were almost all in the first period before loading. Most likely, this was owing to malpositioning of implants (difficulty in a semi-blinded surgical technique) [40,42].

In this study, a higher success rate (96.4%) was reported and only one pterygoid implant failed owing to a lack of primary stability during its insertion.

This remarkable result is owing, in part, to the use of DCAI that allowed to plan and to insert an implant in an accurate position by engaging cortical plate, as planned in the CBCT with high torque values.

The mean mucosa thickness above the pterygoid implants calculated in this study was 5.08 mm (range: 2.6–8.2 mm). Referable to the amount of measured implant soft tissue, as reported by Graves [41], a soft tissue reduction is suggested at the implant placement stage.

Owing to the different implant angulation, two type of abutments were used: M.U.A. and OT Equator.

Both types of connection in all treated cases did not show any kind of problem in terms of passivity. However, OT Equator could offer several advantages. One of this is that all OT Equator are straight and their prosthetic screw is 1.3 mm, that is, 0.3 mm wider than the traditional M.U.A. screw.

Owing to screw resistance, this increment offers a 70% higher resistance to the stress value.

The limitation of this study is that the results are referred to a single surgeon in a single practice. Caution should be exercised when interpreting these results on a broader context and generalizing such results among surgeons. Additional similar in vivo accuracy studies should be undertaken to validate our results so that more data are available on a broader context in such a challenging, yet important area. Such studies would further improve the guidelines for pterygoid implants surgery protocols and optimize patient safety.

Another limitation of this study is the limited follow up of both the inserted implants and the full arch prosthesis.

5. Conclusions

The high accuracy values reported in this study seem to be related to the use of a dynamic navigation system.

In addition, the insertion of pterygoid implants with the use of a DCAI offers a suitable alternative to traditional reconstructive surgical needs to enable implants to be placed in the atrophic posterior maxilla, which is often deficient of vertical bone height.

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