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ORIGINAL ARTICLE

Effect of full arch two scanning techniques on the accuracy of overdenture conventional and CAD/CAM Co-Cr bars

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KEYWORDS

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Internal gap;
Implant-supported overdenture;
CAD/CAM;
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Abstract *Purpose:* This work evaluates the internal and marginal adaptation of implant-assisted overdenture cobalt–chromium (Co–Cr) bars manufactured using conventional as well as CAD/CAM subtractive and selective laser melting (SLM) utilizing two scanning techniques. Methods: An edentulous study model containing four dental implants placed at teeth sites 36, 33, 43, and 46 was used. The study cast was scanned and compared to the virtual casts developed from two scanning techniques, straight and zigzag motion, using the in silico superimposition process. Then, conventional techniques were used to produce full-arch bars that were compared to the bars fabricated using the two scanning techniques and CAD/CAM subtractive and additive techniques. Results: The conventional impression and casting techniques had the smallest marginal gap among the groups (P-value < 0.05). The CAD/CAM subtractive milling techniques in groups II and III had significantly smaller marginal gaps than SLM technique used in groups IV and V (P-value < 0.05). The analysis of the internal gap within each group showed statistically significant differences between different implant sites in all groups (P-value < 0.001), except when using the conventional impression and casting techniques in group I (P-value $= 0.20$). Conclusion: The conventional impression and fabrication techniques were better than the digital impression and CAD/CAM subtractive and additive techniques for the fabrication of full-arch bars. However, both straight and zigzag scanning techniques and the CAD/CAM subtractive technique had marginal

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and internal gaps that were within clinically accepted ranges, and the SLM was found to be unsuitable for long-span framework fabrication with either scanning technique used.

1. Introduction

The accuracy of optical impressions was found to decrease as the prostheses proceeded from single crowns to full-arch restorations (Mangano et al., 2019). This accuracy was believed to be less than that of conventional impressions, especially when the distance between the intraoral scan bodies (ISB) increased (Fluegge et al., 2017; Giachetti et al., 2020). The transition from one quadrant of the dental arch to the other and the manner in which the operator used the intraoral scanners (IOSs) were also found to affect the accuracy of the optical impressions (Giménez et al., 2015; Gimenez-Gonzalez et al., 2017). Restorations consisting of more than four implants were reported to show limited accuracy on both optical and conventional impressions (Gedrimiene et al., 2019; Rech-Ortega et al., 2019). Some studies have revealed that conventional impressions may be more appropriate for long-span or full-arch restorations (Ahlholm et al., 2018; Anan and Al-Saadi, 2015; Kim et al., 2017a; Mangano et al., 2017).

On the other hand, some studies have found that the overall digital workflow, which includes the impression and fabrication steps, can produce full-arch frameworks that are more accurate than those produced by conventional techniques (Abdel-Azim et al., 2014; Abduo, 2014). However, different scanning protocols were found to affect the accuracy and precision of optical impressions, which could affect the process of data acquisition and interaction between the scanner and scan bodies (14). Although this process is still not well understood, it yielded restorations with a passivity of fit that is similar to conventional techniques (Amin et al., 2017; Cappare et al., 2019; Lin et al., 2013; Mizumoto and Yilmaz, 2018; Moreno et al., 2013; Motel et al., 2020; Pesce et al., 2018; Ribeiro et al., 2018).

There is currently no consensus regarding the best optical impression scanning technology or technique and no specific experience in operating the currently available video-based scanners (Lim et al., 2018; Richert et al., 2017). Several scanners are claimed to have good trueness and precision, irrespective of the resolution or scanning strategy used to capture long-span impressions (25, 26). However, only controlled techniques, such as photogrammetry, were found to have predictable results among the scanning strategies that can capture the details of the dental arch in long, sweeping or in-and-out motions, with detected variations in accuracy among the different IOSs studied (Chiu et al., 2020; Li et al., 2017; Mangano et al., 2020; Mangano et al., 2016; Passos et al., 2019; Peñarrocha-Diago et al., 2017).

The passivity of fit of implant-supported frameworks has been investigated using strain gauges and optical microscopes (Castilio et al., 2006; Guichet et al., 2000; Karl et al., 2012). Some reports have revealed that the passivity of fit can be affected by the alloy type rather than by the casting technique used (Paiva et al., 2009). In addition, the presence of undercuts when tilted implants were used was found to adversely affect the passivity of fit of the frameworks produced from conventional impressions (Sorrentino et al., 2010). In a critical review of several clinical and laboratory evaluation methods of passivity of fit, the microscopic evaluation of marginal adaptation was found to be accurate only in two dimensions (Abduo et al., 2010).

Co–Cr alloy frameworks can be fabricated using several methods, such as laser welding, which was found to provide a better fit than direct SLM when its passivity was tested using light-body silicone (Kim et al., 2013). The Co–Cr alloy was found to show less accuracy than the nickel–chromium alloy (Kim et al., 2017b). However, with optical impressions and the CAD/CAM milling or subtractive technique, the marginal and internal adaptations of the Co–Cr alloy were clinically acceptable, as they did not exceed 120 μm (Al-shalan et al., 2019; Kioleoglou et al., 2018).

This work aims to study the accuracy of digital impressions utilizing IOS two scanning techniques. Further, the passivity of fit of full-arch Co–Cr frameworks fabricated using CAD/CAM milling and direct metal laser melting, as opposed to the conventional impression and casting techniques, was evaluated.

2. Materials and methods

A completely edentulous mandibular stone cast containing four dental implants (NobelActive) placed at the sites of teeth numbers 36, 33, 43, and 46 was used as a study model; these implant sites were named A, B, C, and D, respectively. To make optical impressions with two different scanning strategies, the scan bodies (scan body Elos Accurate 3Shape) were attached to the implants using a screwdriver; an IOS Trios (3Shape Dental Systems, Copenhagen, Denmark) was calibrated, which was used by the same operator in the following two scanning techniques (Lim et al., 2018):

1. Technique I: Straight-motion scanning started at the buccal surfaces of the implant 36 scan body and the edentulous ridge, continued on the buccal surface of the implant 46 scan body, swept over the occlusal surfaces of the scan bodies and the edentulous ridge, and finally, returned to the implant 36 scan body, where a final scanning motion was started on the lingual aspect and was returned to the implant 46 scan body, as seen in Fig. 1a.
2. Technique II: Zigzag-motion scanning started at the buccal sulcus of the implant 36 scan body, proceeded to the lingual sulcus of the same implant while going in a circular motion around the scan body as it passed by its occlusal surface, and finally, returned to the buccal sulcus. This process was repeated and continued on the other side of the arch, as shown in Fig. 1b.

The files obtained from the two different scanning processes were saved in standard tessellation language (STL) format,

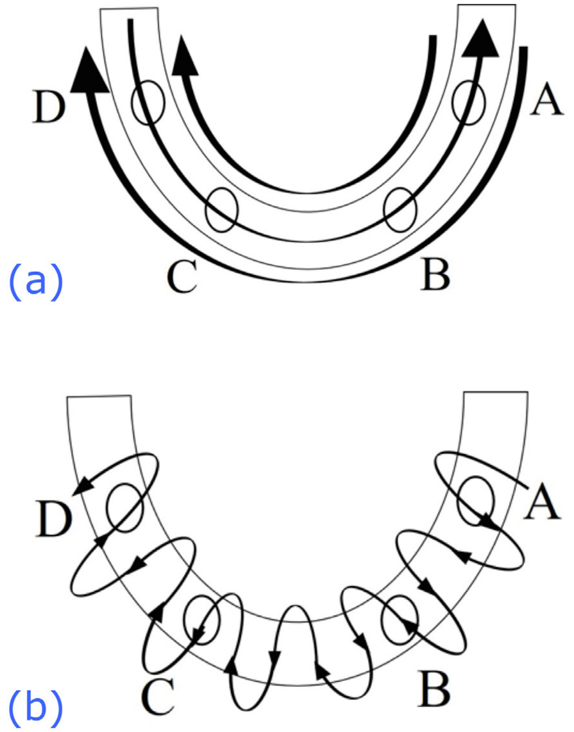

Fig. 1 (a) Technique I: Straight-motion scanning. (b) Technique II: zigzag-motion scanning.

and the 3Shape software (3Shape Dental Systems version 1.4.5.3, Copenhagen, Denmark) was used to allocate the virtual implant fixtures based on the scan bodies' location in the virtual cast developed from the two scanning techniques (Appendix A).

In order to detect the accuracy of the virtual models developed from the scanning techniques, the scan bodies were removed from the stone cast, which was then scanned using a bench-top scanner (KaVo ARCTICA AutoScan, KaVo Everest, CAD/CAM System) that is more accurate than the IOS. Its virtual model was superimposed on the virtual models generated from the straight- and zigzag-motion scans to detect deviations using the Geomagic software (Geomagic Qualify 2013, Geomagic, Morrisville, North Carolina, USA). The best-fit feature of the Geomagic software and its 3D compare feature were used to detect the horizontal deviations of the scans from each other at eight points around the implants (Lim et al., 2018). The detected deviations were presented as surface color maps, with each color representing a 0.1 mm positive or negative deviation (Appendix B). The Geomagic software's "tabular view 3D compare" feature was used to provide values for each of these superimpositions at the eight selected points around each implant. The average reading from each implant position was calculated, and then, the readings from the four implant positions were tabulated for statistical analysis using the Kruskal–Wallis test (SPSS version 23.0, SPSS Inc., Chicago, Illinois, USA), with $P < .05$ indicating statistical significance.

The passivity of fit of implant-assisted overdenture full-arch bars manufactured using conventional and CAD/CAM subtractive and additive techniques was then assessed using the light-body index technique. The full-arch bars fabricated using the conventional impression and casting techniques represented group I; the bars manufactured using the CAD/CAM digital subtractive technique with two different scanning strategies were represented by groups II and III, respectively; and the bars manufactured using the laser-sintering digital additive technique with two different scanning strategies were represented by groups IV and V, respectively.

For group I, a closed-top conventional impression of the study model was made at the implant level, with impression transfer copings (Nobel Biocare, Active 4.3 mm) tightened onto the implants with a 10 Ncm torque ratchet, using heavy- and light-body addition-type polyvinyl siloxane (Aquasil, Dentsply Sirona) in a custom-made tray. The impression with the transfer copings were removed from the study model, and the implant fixture analogues were attached to the transfer copings. Then, the impression was poured on an extra-hard dental stone (Madespa, type IV, Ventura implant stone HG). After a one-hour setting, the resulting model was removed from the impression and was used to fabricate 10 bars with the lost-wax technique (Appendix C).

The virtual model produced from straight-motion scanning was used to produce 10 bars milled with CAD/CAM (Co–Cr milling discs) for group II and 10 more bars using laser sintering for group IV. Furthermore, the virtual model produced from zigzag sweeping-motion scanning, on the other hand, was used to produce 10 metal bars milled with the same CAD/CAM machine for group III and 10 bars using the same laser sintering process for group V (Appendices D and E). In summary, the study groups were as follows:

1. Group I: Co–Cr bars manufactured using the conventional impression and casting techniques
2. Group II: CAD/CAM bars made from the digital impression of the study model with straight-scanning motion
3. Group III: CAD/CAM bars made from the digital impression of the study model with zigzag scanning motion
4. Group IV: SLM bars made from the digital impression of the study model with straight scanning motion
5. Group V: SLM bars made from the digital impression of the study model with zigzag scanning motion

For the characterization of the marginal and internal adaptation of the bars of these study groups, a light-body silicone (Aquasil, Dentsply Sirona) was applied to the abutments and internal surfaces of the holes in the bars. Each bar was carefully seated on the study model and was kept under 50 N pressure for 5 min until the soft silicone hardened. The pressure was set at 50 N to resemble the reported occlusal force of complete denture wearer (Fields et al., 1986). The silicone film was then cut into four parts in the mesial-distal and buccal-lingual directions, and the thickness of the edges of these parts was measured at two points: near the middle to detect the internal gap and at the base of the axial wall to detect the marginal gap. This resulted in eight points of measurement for each implant site conducted using a scanning electron microscope (JSM-6700f, JEOL, Japan) with a low-vacuum non-coating technique (Appendix F). For the statistical analysis of these results, the non-parametrical Kruskal–Wallis test (SPSS Statistics version 22, IBM Corp., USA) was used to evaluate the differences in internal-gap measurements between the five groups in each category. The Mann–Whitney U test was used to detect signif-

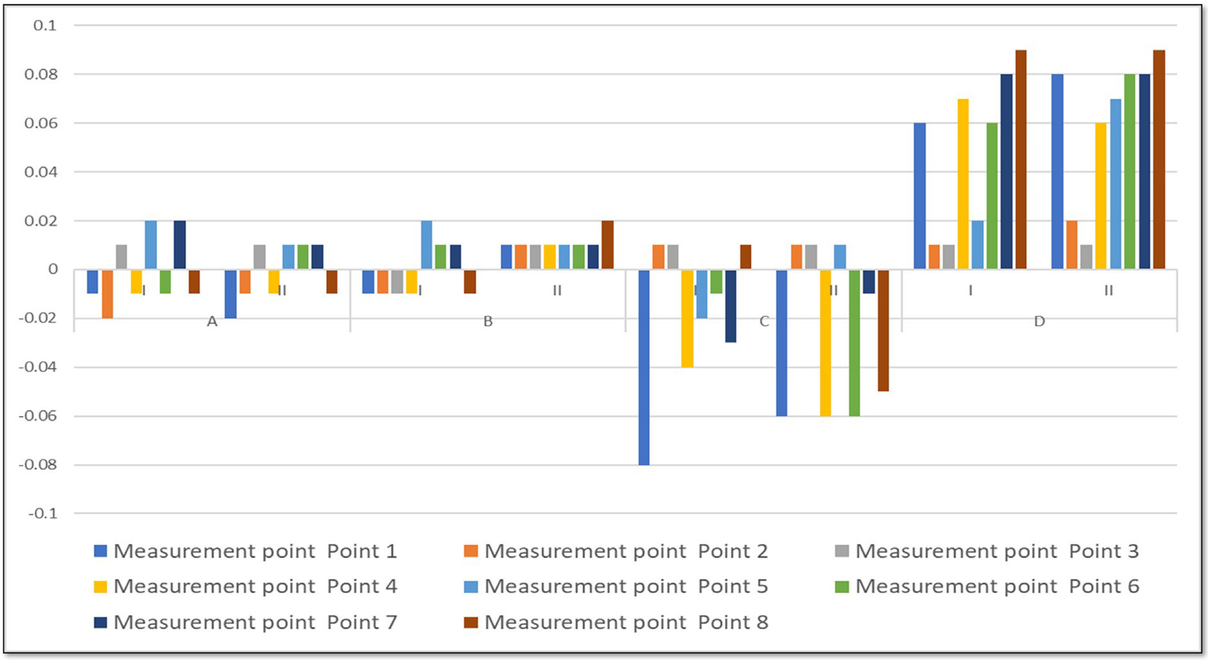

Fig. 2 Distribution of the horizontal deviations at 8 points (arrows) around each implant site in the virtual models developed from the two scanning techniques used, from the virtual model of the study cast developed from the bench top scanner used.

Table 1 Analysis of marginal fit (um).

Groups		Implant site				Overall group measurement	Sig. differences (P value)
		36	33	43	46		
I	Mean	60.75	61.7	63.05	61.9	61.85	0.253908
	SD	3.9	4.13	3.26	3.11	3.6	
II	Mean	115	118.75	121.75	122.6	119.52	0.033592
	SD	8.08	7.76	7.73	9.32	8.22	
III	Mean	134.3	142.65	151.1	158.85	146.72	< 0.001
	SD	7.2	5.4	4.43	5.64	5.66	
IV	Mean	207	215.25	223.7	238.05	221	< 0.001
	SD	4.75	3.83	4.1	2.45	3.78	
V	Mean	244.8	257.9	279.15	302.95	271.2	< 0.001
	SD	3.8	3.4	5.7	7.4	5	

Table 2 Analysis for the significant differences in marginal gaps measurements between each two groups.

The Compared groups	Sig. differences (P value)
group I-group II	0.031
group I-group III	0.025
group I-group IV	< 0.001
group I-group V	< 0.001
group II-group III	0.716
group II-group IV	0.005
group II-group V	0.002
group III-group IV	0.015
group III-group V	0.008
group IV-group V	0.814

icant differences between the two groups in each category. For post hoc test, a Bonferroni test was made with a significance level of 95 %. All data were plotted as mean ± standard deviation.

3. Results

Fig. 2 shows the average horizontal deviations at each implant site as detected from the superimposition of the stone cast scan and the virtual models developed from scanning techniques I and II. Here, there were no statistically significant differences from the stone cast virtual model implant sites except at implant sites C and D in both virtual models developed from scanning techniques I and II, where there were negative deviations at implant site C and then positive deviations at implant site D.

Table 3 Analysis of Internal gap (um).

Group		Implant site				Overall group measurement	Sig. differences (P value)
		36	33	43	46		
I	Mean	72.90	67.30	69.00	71.30	70.13	0.201183
	SD	6.18	8.90	11.89	6.04	8.25	
II	Mean	72.90	71.80	83.50	85.80	78.50	< 0.001
	SD	3.88	4.95	3.69	3.65	4.04	
III	Mean	74.80	74.20	84.30	90.00	80.83	< 0.001
	SD	5.05	4.99	6.30	6.24	5.65	
IV	Mean	38.55	44.50	43.85	59.85	46.69	< 0.001
	SD	6.17	2.44	4.11	8.30	5.25	
V	Mean	63.60	64.75	74.65	74.85	69.46	< 0.001
	SD	2.89	3.16	3.27	3.22	3.13	

Table 4 Analysis for the significant differences in internal gaps measurements between each two groups.

The Compared groups	Sig. differences (P value)
group I-group II	< 0.001
group I-group III	< 0.001
group I-group IV	< 0.001
group I-group V	0.502
group II-group III	0.307
group II-group IV	< 0.001
group II-group V	< 0.001
group III-group IV	< 0.001
group III-group V	< 0.001
group IV-group V	< 0.001

The statistical analysis of the recorded marginal gap values showed that the conventional impression and casting techniques had the smallest marginal gap among the groups in this study, as seen in Tables 1 and 2. However, it was found from the same tables that irrespective of the scanning technique used, the CAD/CAM subtractive milling techniques in groups II and III had significantly smaller marginal gaps than SLM technique used in groups IV and V (P-value < 0.05). The analysis of the marginal gap measurements between the implant sites showed a significant increase between implant positions B and D within each group as well as between each group (Table 1).

The analysis of the internal gap within each group, as found in Table 3, showed statistically significant differences between different implant sites (P-value < 0.001) except when using the conventional impression and casting techniques in group I (P-value $= 0.20$). Meanwhile, the analysis of the internal gap measurements between the implant sites within each group, as found in Table 4, revealed a statistical difference when the two groups were compared (and not when group I was compared with IV [P-value $= 0.50$] and group II was compared with III [P-value $= 0.30$]).

4. Discussion

The current work studied the effect of two digital-impression scanning techniques on the marginal and internal gaps of overdentures' full-arch bars that were manufactured using the conventional techniques, CAD/CAM subtractive and additive SLM.

The comparison of the marginal gaps at each implant site between the groups revealed a significant increase in gap measurement from group II to V. This finding is in agreement with that of the study by Chiu et al. (Chiu et al., 2020), where the digital impression accuracy decreased as the impression moved to the most distal area of the dental arch. These findings indicate the accuracy of the scanning process at its beginning, as confirmed by the virtual superimposition study in which the deviations from the conventional cast started to appear at implant position C.

The marginal and internal gap overall group comparison showed that there were no significant differences in the marginal gap between implants A and D in groups II and III. This indicated that there was no difference between the scanning techniques and that both were within the acceptable clinical range of 120 µm. However, this finding came in contrast to that of Cappare et al., (Cappare et al., 2019) who favored the scanning stitching strategy similar to the long-sweeping motion; it was also in contrast to the findings of Amin et al. (Amin et al., 2017), who claimed that long sweeping-motion scanning is more accurate than conventional impressions. This finding also demonstrated the consistent accuracy of the CAD/CAM subtractive technique compared to the SLM used in groups IV and V, which was found to be unsuitable for long-span framework fabrication with either of the scanning techniques used.

For the adjacent implant sites in each group, no significant increase in the internal gap value was found. This increase may demonstrate the closer accuracy of both scanning techniques in groups II and III and of SLM in groups IV and V compared to the conventional techniques with long-span bar fabrication. This indicates that there is no difference between the two scanning techniques with regard to the internal gap. These findings are in contrast to those reported by others who favored zigzag-motion scanning over long sweeping-motion scanning (DI FIORE et al.; Imburgia et al., 2020).

A possible limitation of the present study was that the bars were not fixed in place with cement or screws. However, based on the findings by Guichet et al. (Guichet et al., 2000), screw fastening decreased the marginal gap of the bars and resulted in an increased stress concentration in the studied bone model. Meanwhile, cementation was reported to increase the marginal gap and reduce the stress concentration. In their study, Castilio et al. (Castilio et al., 2006) found that the slotted and hexagonal screws did not improve the fit of the studied cylinders. In another in vitro study, full-arch bars showed some degree of misfit upon screw tightening (Paiva et al., 2009). Finally, Abduo et al. (Abduo, 2014) found that the accuracy of the bars was not influenced by the retention mechanism. Apart from this possible limitation, another limitation of this study was that only one IOS system was used.

5. Conclusions

1. The conventional impression and fabrication techniques can be better than the digital impression and CAD/CAM subtractive and additive techniques when they are used for the fabrication of full-arch bars.
2. The bars fabricated using both straight and zigzag scanning techniques and the CAD/CAM subtractive technique had marginal and internal gaps that were within the clinically accepted range.
3. The SLM was found to be unsuitable for long-span framework fabrication with either of the scanning techniques used.

Ethical statement

The study does not require ethical approval. It does not involve experiments in humans or animals.

Author Statement

Contributions: A.A. contributed to conception, study design, data collection, analysis and interpretation, and drafted and critically revised the manuscript; M.Y. and M.A. contributed to the conception, design, and interpretation and critically revised the manuscript. All authors participated in the laboratory procedures and gave their final approval and agree to be accountable for all aspects of the work. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare no conflict of interest, financial or otherwise.

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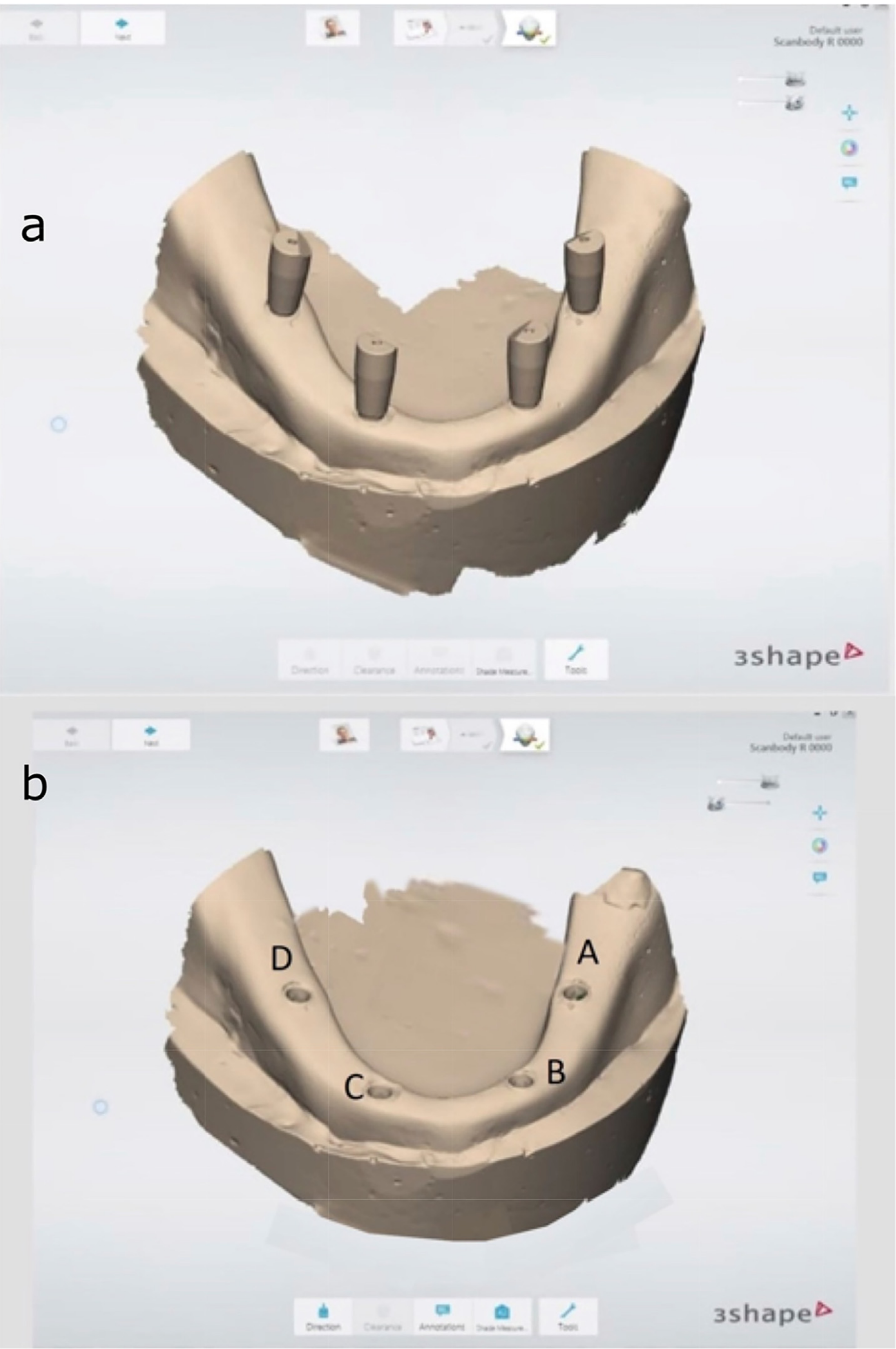
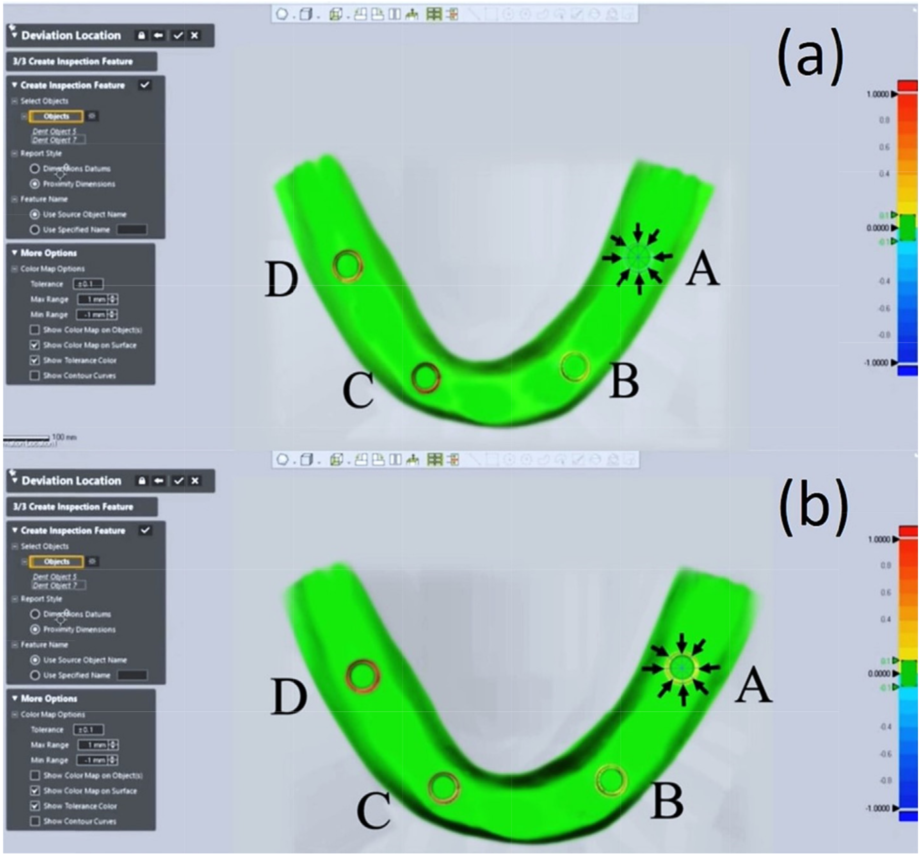
Appendix A. . Virtual model developed from scanning the study cast and intra oral scan bodies with either scanning techniques used I or II. S1. (b) orientation of the virtual implant fixture by the ISB.



Appendix B. . (a) horizontal deviations at each implant site as detected from the superimposition of the stone cast scan and the virtual models developed from the scanning technique I, (b) horizontal deviations at each implant site as detected from the superimposition of the stone cast scan and the virtual models developed from the scanning technique II.



Deviation Location

3/3 Create Inspection Feature

Create Inspection Feature

Select Objects: Objects

Dent Object 5
Dent Object 7

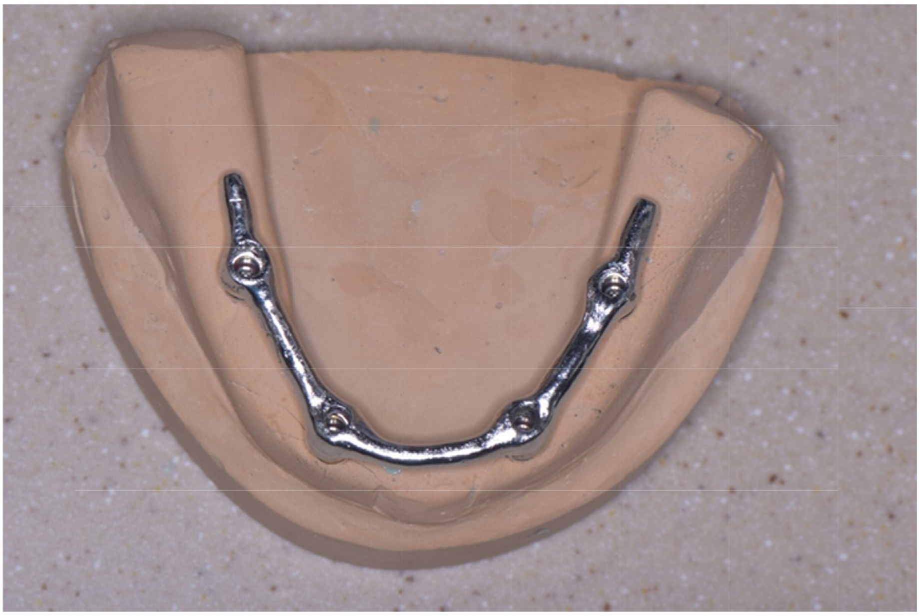
Report Style
○ Dimensions Datums
● Proximity Dimensions

Feature Name
● Use Source Object Name
○ Use Specified Name

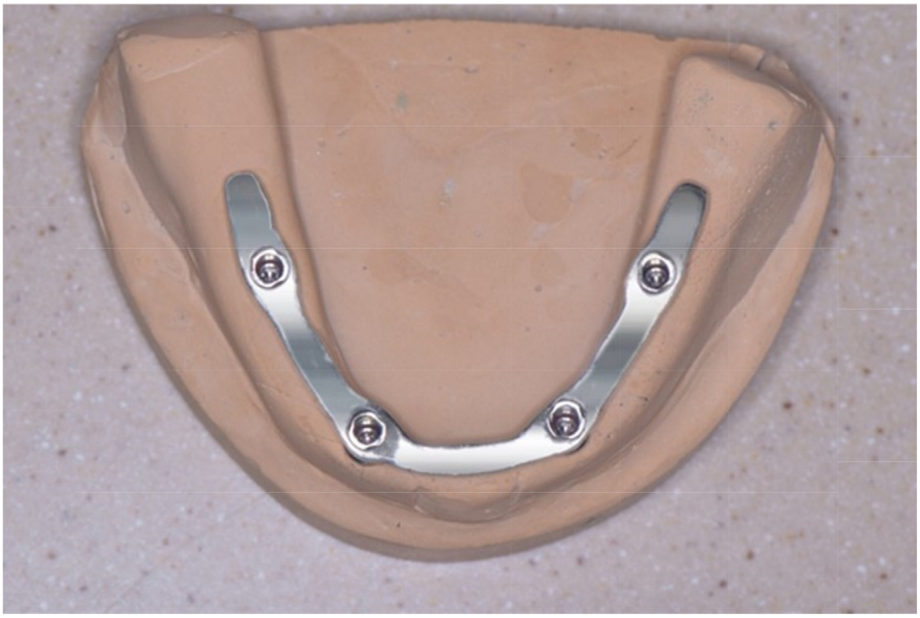
More Options

Color Map Options
Tolerance: ±0.1
Max Range: 1 mm
Min Range: -1 mm
☐ Show Color Map on Object(s)
☑ Show Color Map on Surface
☑ Show Tolerance Color
☐ Show Contour Curves

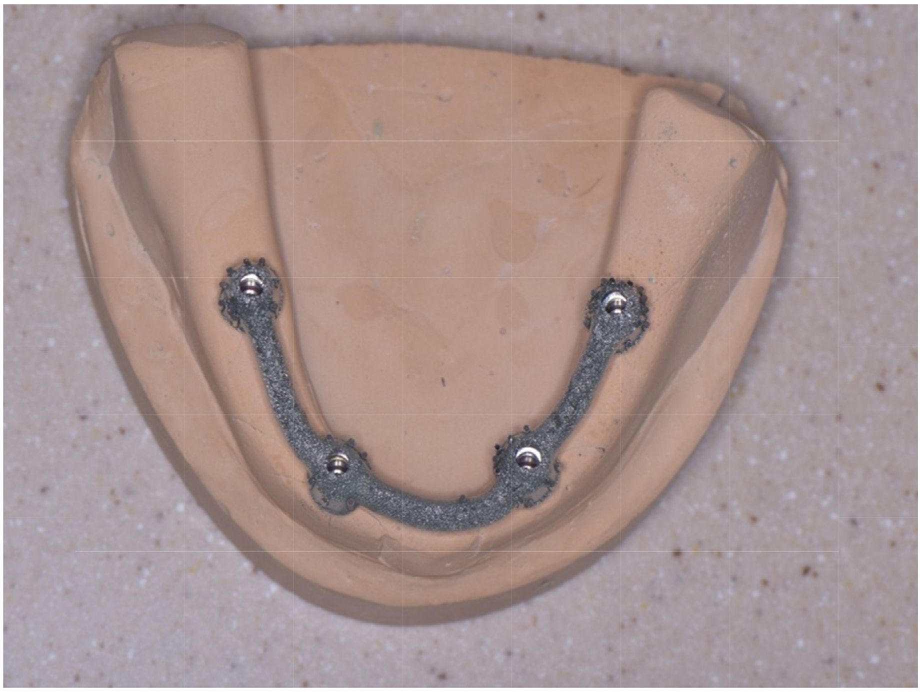
Appendix C. . Full arch bar fabricated with conventional impression and casting technique.



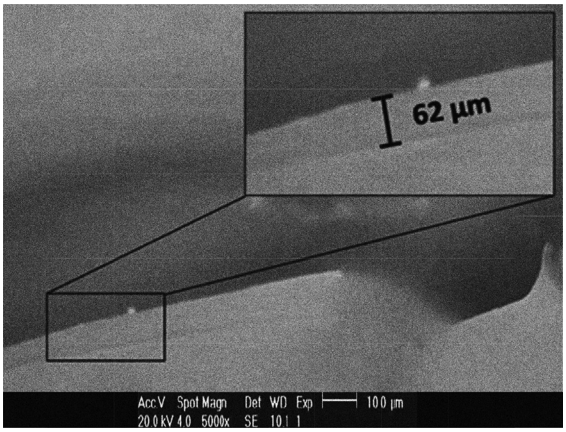
Appendix D. . Full arch bar fabricated with CAD/CAM milling subtractive technique.



Appendix E. . Full arch bar fabricated with CAD/CAM selective laser melting additive technique



Appendix F:. Scanning electron microscope image of the light body index attached to a core of heavy body silicone, in order to determine the light body layer, the samples were not coated and studied under low vacuum technique.



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