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Efficiency of occlusal and interproximal adjustments in CAD-CAM manufactured single implant crowns - cast-free vs 3D printed cast-based

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PURPOSE. The aim of this study was to evaluate the efficiency of occlusal and interproximal adjustments of single implant crowns (SIC), comparing a digital cast-free approach (CF) and a protocol using 3D printed casts (PC). **MATERIALS AND METHODS.** A titanium implant was inserted at position of lower right first molar in a typodont. The implant position was scanned using an intraoral scanner and SICs were fabricated accordingly. Ten crowns (CF; n = 10) were subject to a digital cast-free workflow without any labside occlusal and interproximal modifications. Ten other identical crowns (PC) were adjusted to 3D printed casts before delivery. All crowns were then adapted to the testing model, simulating chair-side adjustments during clinical placement. Adjustment time, quantity of adjustments, and contact relationship were assessed. Data were analyzed using SPSS software ($P < .05$). **RESULTS.** Median and interquartile range (IQR) of clinical adjustment time was 02:44 (IQR 00:45) minutes in group CF and 01:46 (IQR 00:21) minutes in group PC. Laboratory and clinical adjustment time in group PC was 04:25 (IQR 00:59) minutes in total. Mean and standard deviation (±SD) of root mean squared error (RMSE) of quantity of clinical adjustments was 45 ± 7 µm in group CF and 34 ± 6 µm in group PC. RMSE of total adjustments was 61 ± 11 µm in group PC. Quality of occlusal contacts was better in group CF. **CONCLUSION.** Time effort for clinical adjustments was higher in the cast-free protocol, whereas quantity of modifications was lower, and the occlusal contact relationship was found more favourable. [J Adv Prosthodont 2021;13:351-60]

KEYWORDS
CAD-CAM; Cast-free; Digital workflow; Single implant crown; 3D printing; Time-efficiency

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INTRODUCTION

Prosthetic-driven implant planning, implant placement, and implant-supported restorations can be made with modern digital workflows, which comprise the acquisition of data, data processing, and the fabrication of the workpiece.[1] Digital approaches in implant dentistry promote improved efficiency, greater predictability, reduced invasiveness, and fewer complications.[2,3]

Direct digitization, i.e., intraoral scanning, is the first step into any digital dental procedure. Intraoral scanners (IOSs) have been proven to be competitive, presenting clinical suitability and potential for further development. Current IOS devices demonstrate equal or superior accuracy at least for up to quadrant size scans.[4,5] Also, intraoral scanning of single implants is an efficient and straightforward procedure,[6-8] and thus well received by clinicians and patients.[7,8]

Fabrication of single implant crowns (SICs) and fixed dental prostheses from data obtained by IOSs has proven to be a reliable option.[7,8] However, several factors can affect the accuracy of intraoral scanning of implants regarding surface data and implant position,[7,9,10] and determine, alongside with computer-aided design/computer-aided manufacturing (CAD-CAM) software characteristics,[11] the maximum achievable degree of exactness of the latter restoration on part of the underlying data.

The final step in the digital work chain, after data acquisition and data processing, is the CAM fabrication of the workpiece. While milling is reliable and broadly established, additive manufacturing has been adopted for dental applications not until much later.[1] Applications include surgical templates, occlusal splints, impression trays, metal frameworks, single-tooth restorations, castable wax or resin patterns, and dental casts.[12,13]

3D printed dental casts have become popular practice in dentistry and dental technology. They can be used as a work fixture for finalization; for instance, it can be used when a framework is milled and the ceramic veneering is added in a manual procedure and contact points must be created.[12] However, even though there has been considerable progress,[14] accuracy of printed casts might not yet suffice for creating frameworks or monolithic restorations.[12,15]

Since many dentists and dental technicians, perhaps by habit and tradition, prefer working with a physical model or cast, printed casts are employed where their use is dispensable. Especially in 3D printed implant casts, inaccuracies of the cast itself or the transferred implant position[16] can accumulate to a considerable amount of deviation, affecting the accuracy of the final restoration; the establishment of a sufficient contact relationship to opposing and adjacent teeth may become impeded. Inaccuracies might result from, inter alia, scan strategy and type of scanbody,[9] software features, the printing technology,[16,17] and the implant analog.[18] Accuracy of the implant position in 3D printed casts is comparable with conventional casts in general, but presents considerable variance,[19] thus rendering the particular outcome difficult to predict.

This leads to the idea that a completely digital, cast-free workflow, evading many possible sources of error, might help enhance the accuracy of the final restoration and reduce clinical effort.[20] Moreover, since a cast-free approach enables straightforward laboratory and clinical procedures, it is supposed to be mutually beneficial from an economic point of view. However, chairside time is the most expensive factor and time efficiency of digital workflows for SICs has been previously addressed.[6,21-26]

The purpose of the present study was to investigate if interproximal and occlusal modifications using a 3D printed cast provide benefit in terms of working time, effort, and quality of static occlusal and interproximal contacts compared to a cast-free protocol without any preliminary dental lab adjustments. Therefore, adjustment time and quantity of modifications of the crowns processed by two different approaches were examined, and the achieved contact relationship was assessed. The hypotheses were that there is no difference in time efficiency, quantity of clinical modifications, and quality of occlusal contacts between digital cast-free or cast-based workflows in fabrication and placement of SIC.

MATERIALS AND METHODS

The experimental setup is given in Fig. 1. A mandibular typodont (AN-4; Frasaco, Tettnang, Germany) was molded using silicone (Heraform RS Type A+B; Kulzer, Hanau, Germany) and cast from plaster (ResinRock, ISO Type 4; Whip Mix Europe, Dortmund, Germany). After removing the lower right first molar (FDI #46), an implant site was prepared. The cast was then digitized using a laboratory scanner (S900 ARTI; Zirkonzahn, Gais, Italy) alongside with the corresponding maxillary denture model. The data were post-processed using Geomagic Qualify 2012 software (3D Systems; Rock Hill, SC, USA) and the corresponding testing models were laser sintered from a Co-Cr alloy powder (EOS Cobalt Chrome RPD; EOS, Krailling, Germany) using the EOSINT M270 system (EOS). Support structures were removed, and the models were finalized and mounted into an adjustable articulator (Artex CR; Amann Girrbach, Koblach, Austria) according to average setting. Static occlusal contacts were recorded and adjusted using shimstock foil (Hanel Shimstock Foil, 8 µm; Coltene, Altstätten, Switzerland) and occlusion foil (Hanel Foil, Ds red 80 mm; Coltene).

An implant (BL, Ø 4.1 mm, SLActive 14 mm, Loxim; Straumann, Basel, Switzerland) was fixed (Multilink Automix, Opaque; Ivoclar Vivadent, Schaan, Liechtenstein). It was then provided with a scan post (Scan-Post S BL 4.1 L, Bone Level RC; Dentsply Sirona, York, PA, USA) and the corresponding scanbody (Gray Scan Body, Omnicam L; Dentsply Sirona) (Fig. 2A).

All of the following procedures were conducted by one skilled professional. Ten scans were performed using an intraoral scanner (Cerec Primescan; Dentsply Sirona) including scans of the lower jaw, the scan-

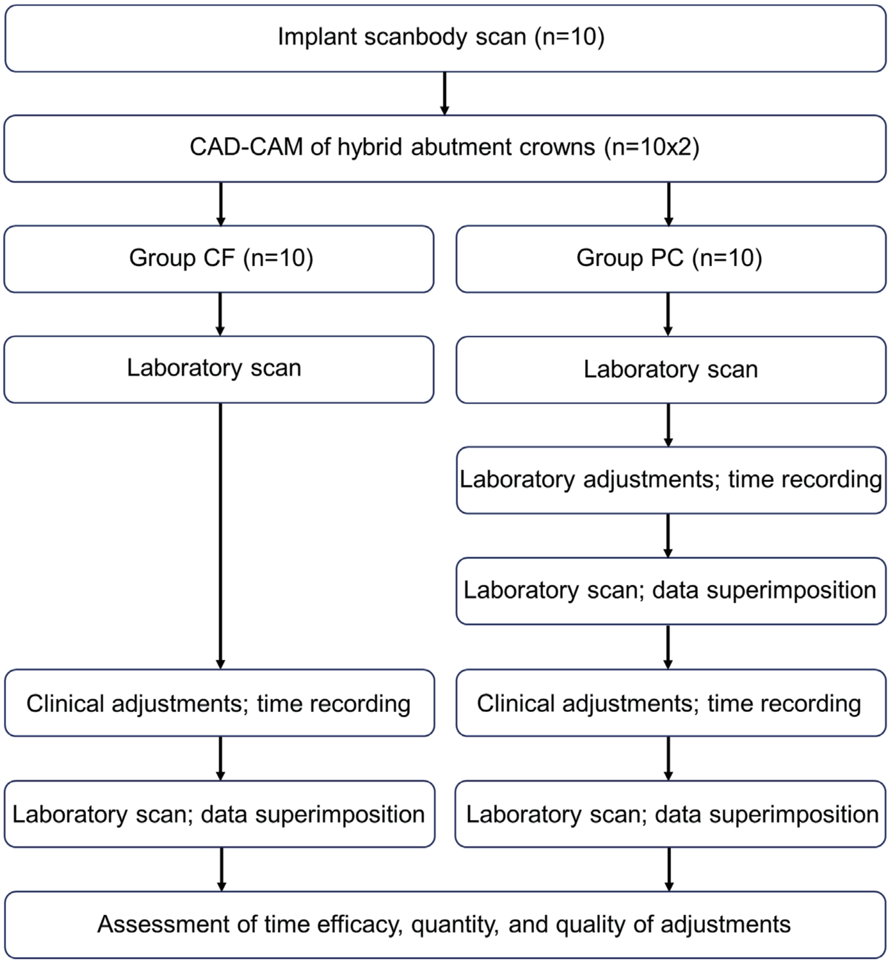

Fig. 1. Experimental sequence.

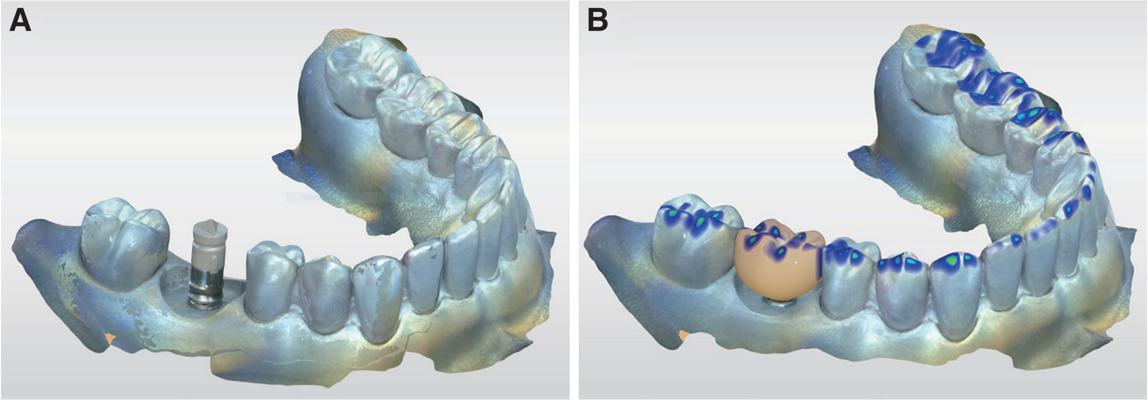

Fig. 2. Intraoral scanners of testing model (Co-Cr alloy) equipped with scan post and scanbody (A). CAD of hybrid abutment crown (B).

Fig. 3. Hybrid abutment crowns (random selection) mounted on referencing scan fixture (A), on testing model, mimicking the clinical situation (B), and placed on 3D printed cast (C).

body, the opposing jaw, and the bite registration. Scan post and scanbody were removed and reassembled before each scan. One SIC (hybrid abutment crown) was designed based on each scan (Fig. 2B) and milled twice (CEREC MC XL Premium; Dentsply Sirona) from a polymer-infiltrated ceramic-network (PICN) (Enamic for IS-14L 3M2-T; Vita Zahnfabrik, Bad Säckingen, Germany). The crowns (N = 20) were adhesively luted on titanium bases (TiBase S BL 4.1 L; Dentsply Sirona) using a self-curing resin cement (Multilink Hybrid Abutment; Ivoclar Vivadent). Post-processing was limited to removing the holding pin, but no further finalization was done. Ten 3D printed casts (Lab Model IMPLANT; Infinident, Darmstadt, Germany) were fabricated based on IOS data using digital light processing (DLP) and equipped with laboratory analogs (Dim Analog, L 5.DIM.414; NT Trading, Karlsruhe, Germany).

Identical crowns for two test groups (n = 10/each) were fabricated. Surfaces of all crowns were digitized using a laboratory scanner (S900 ARTI) and a special referencing stainless steel scan fixture manufactured for this purpose, provided with an implant (Fig. 3A). Crowns were tightly hand screwed. In group CF ("cast-free"), a second scan was performed after interproximal and occlusal "chairside" adjustments, i.e., before placing onto the metal testing model (Fig. 3B). Crowns of group PC ("printed cast") were adjusted using the 3D printed casts (Fig. 3C) regarding interproximal and occlusal fit, and subsequently scanned for a second time. Modifications were performed using diamond burs and silicone polishers. A third scan of group PC was conducted after clinical chairside adjustments.

Time for interproximal and occlusal adjustments was recorded in minutes and seconds to evaluate time efficiency. In group CF, time for clinical modifications (CF_{cli}) was measured. In group PC, laboratory adjustments

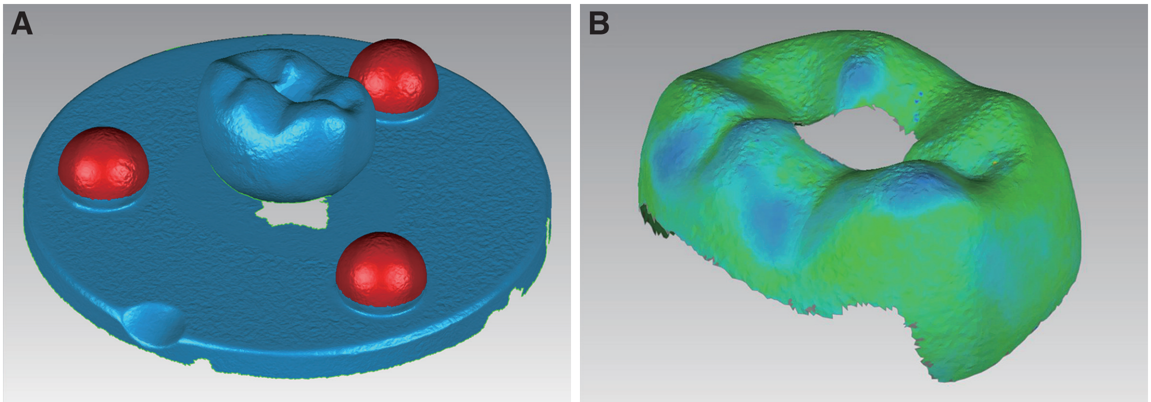

Fig. 4. Spherical geometries selected (red) for data alignment (A) and difference image of contact areas after superimposition (B).

(PC_{lab}) were performed using the 3D printed casts before clinical modification at placement (PC_{cli}); time was recorded for both. Clinical (CF_{cli} vs PC_{cli}) and total adjustment times (CF_{cli} vs PC_{tot}) were compared. Crowns were mounted with the recommended torque before occlusal modifications. Contacts were assessed using 8 μm and 24 μm shimstock foil for interproximal and static occlusal contacts, respectively. The interproximal and occlusal modifications in all specimens were carried out by one skilled practitioner. Dynamic occlusion, i.e., lateral excursive and protrusive contact relationships, was checked for interfering contacts in the adjustable articulator. Time recording was done by an independent observer.

The quantity of interproximal and occlusal adjustments to the crowns was calculated using Geomagic Qualify 2012 software (3D Systems, Cary, NC, USA). STL data of the digitized surfaces of the crowns at baseline and after laboratory (PC_{lab}) and clinical (CF_{cli} and PC_{cli}) modifications were aligned using a best-fit algorithm to the spherical surfaces of the referencing fixture (Fig. 4A). Critical and nominal deviation for superimposition were set at ± 300 μm and ± 30 μm. Quantity of clinical adjustments (CF_{cli} and PC_{cli}) and quantity of total adjustments (CF_{cli} and PC_{tot}) of both groups were compared. A difference image is depicted in Fig. 4B.

Static occlusal relationship was defined "balanced" when contact was found on a supporting cusp of both, the SIC and the opposing tooth. "Detectable" described the presence of contact on only one contact on a supporting cusp, either on part of the SIC or the opposing tooth. No detectable contact was classified as "none".

Statistical analysis was conducted applying SPSS Statistics software v.26.0 (IBM, Armonk, NY, USA). Kolmogorov-Smirnov test was used to analyze the normality of data distribution. Results were statistically assessed regarding median and interquartile range (IQR) of time necessary for adjustments. Data were analyzed using Mann-Whitney-U test to assess significant differences. To evaluate the quantity of adjustments, mean and standard deviation ± SD of root mean square error (RMSE) of the occlusal surface, maximum occlusal modification, and maximum of interproximal modification were calculated. In data of quantity of adjustments, Levene's test and t test were applied. The Fisher-Freeman-Halton exact test was used to analyze and compare the quality of occlusal relationship. Level of significance was set at $P < .05$.

RESULTS

Descriptive statistics are depicted in Table 1 and Table 2. Boxplots and a bar chart are given in Fig. 5 and Fig. 6. Data of clinical adjustment time were not normally distributed, while data of quantity of adjustments were. Median (IQR) clinical adjustment time was 02:44 (00:45) minutes in group CF_{cli}, significantly higher than in group PC_{cli} (01:46 (00:21) min) ($P < .001$). Total adjustment time was 02:44 (00:45) minutes in group CF_{cli} and 04:25 (00:59) minutes in group PC_{tot} (*P*

Table 1. Descriptive statistics of time effort of testing groups CF_{cli}, PC_{cli}, and PC_{tot}, including mean, standard deviation ± SD, median, interquartile range (IQR)

Time [min:sec]	CF_{cli}	PC_{cli}	PC_{tot}
Mean ± SD	02:47 ± 00:22	01:47 ± 00:14	04:44 ± 00:34
Median (IQR)	02:44 (00:45)^{a}	01:46 (00:21)^{b}	04:25 (00:59)^{c}

Different superscript letters indicate statistical significance based on the Mann-Whitney-U test ($P < .05$).

Table 2. Descriptive statistics of quantity of clinical adjustments of testing groups CF_{cli} and PC_{cli}, and occlusal adjustments CF_{cli} and PC_{tot}. Values include mean, standard deviation ± SD, median, interquartile range (IQR) of RMSE, mesial, distal, and total occlusal adjustments

Quantity [μm]	CF_{cli}	PC_{cli}	PC_{tot}
Mean ± SD RMSE	45 ± 7^{a}	34 ± 6^{b}	61 ± 11^{c}
Median (IQR) RMSE	43 (12)	33 (8)	62 (23)
Mean ± SD occlusal	144 ± 22^{a}	55 ± 20^{b}	165 ± 24^{a}
Median (IQR) occlusal	139 (35)	46 (35)	176 (45)
Mean ± SD mesial	74 ± 12^{a}	47 ± 12^{b}	81 ± 14^{a}
Median (IQR) mesial	74 (22)	45 (18)	87 (38)
Mean ± SD distal	77 ± 14^{a}	42 ± 14^{b}	78 ± 14^{a}
Median (IQR) distal	83 (30)	43 (20)	77 (28)

Different superscript letters indicate statistical significance based on the t test ($P < .05$).

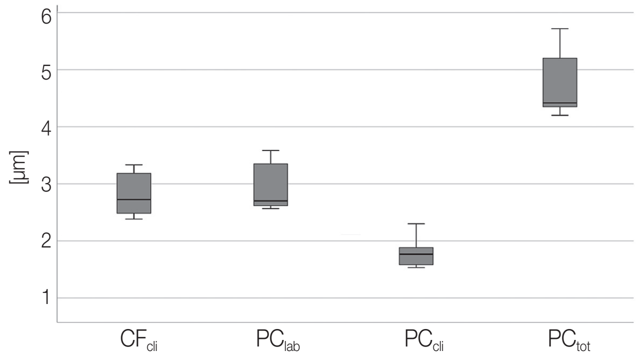

Fig. 5. Median adjustment time in the different groups and at different processing stages in minutes.

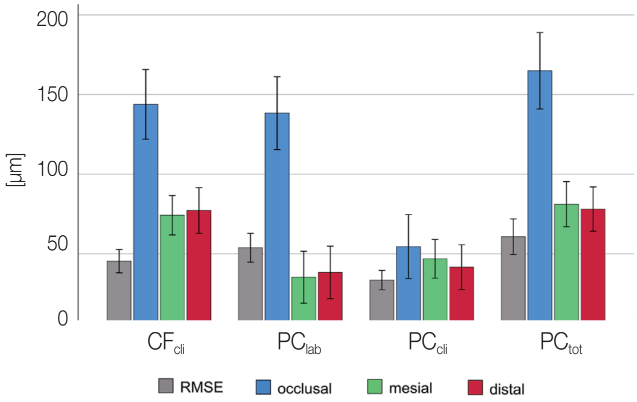

Fig. 6. Mean quantity (± 1 SD) of adjustments in the different groups and at different processing stages in microns.

< .001). Laboratory adjustment time was 02:42 (00:46) minutes in PC_{lab}.

Mean RMSE of occlusal and interproximal modifications was 45 ± 7 μm in group CF_{cli}, 34 ± 6 μm in group PC_{cli}, and 61 ± 11 μm in group PC_{tot}. Occlusal substance reduction was 144 ± 22 μm (CF_{cli}), 55 ± 20 μm (PC_{cli}), and 165 ± 24 μm (PC_{tot}). Interproximal adjustments showed a similar ratio. All results were significant comparing CF_{cli} and PC_{cli} ($P < .001$); regarding the difference between CF_{cli} and PC_{tot}, only RMSE displayed statistical significance ($P = .002$).

"Balanced" static contact on a supporting cusp of both the SIC and the opposing tooth was found in all specimens of group CF and in five crowns of group

PC. Another four crowns of group PC showed contact between only one supporting cusp of either SIC or opposing molar and the opposing structure, hence “detectable” contact. One crown of group PC exhibited no static occlusal contact (“none”). The_quality of occlusal relationship achieved was significantly different when comparing the two workflows (*P* = .032). No interfering lateral dynamic contacts were found.

DISCUSSION

Two digital workflows for the fabrication of SIC were investigated regarding their time efficiency and quantity of interproximal and occlusal adjustments, and quality of occlusal contacts was attained. Time effort for clinical modifications in the cast-free approach was almost twice as high as for the protocol applying 3D printed casts for primary adjustments. By contrast, total adjustment time, including laboratory modifications, was considerably higher when casts were used. While quantity of clinical occlusal and interproximal alterations was smaller in the 3D printed cast-based approach, RMSE of total amounts of adjustments was significantly larger. Static occlusal contact relation was found to be more appropriate in the in cast-free workflow. These findings led to the rejection of all hypotheses.

All testing was conducted by one skilled and experienced professional to ensure an optimum level of standardization and preclude operator-change related distortions. The testing model was laser sintered from Co-Cr alloy, which has proven to be the most appropriate material for testing models in CAD-CAM studies, to ensure reliable testing.[27] Specimen preparation was conducted strictly in accordance with manufacturers' specifications, complying with the clinical workflow, whenever applicable. Bearing in mind that there is certain rotational freedom at the interface between titanium base and crown, and relating to the common dental technical procedure, it was attempted to distribute the mismatch evenly to both sides. The IOS device[28] and the laboratory scanner[29] used in this investigation have proven to be accurate for the given applications.

Using the referencing fixture allowed for reliable data superimposition via three semi-spherical geometries. To ensure a reproducible positioning of the crowns, each crown was turned clockwise until stop and then torque was applied, and screws were hand tightened before scanning. For the implant type used in the present investigation, a mean vertical misfit of only 2 to 3 µm when hand tightening the screw was found after reassembly,[30] whereas, when the recommended torque is applied, vertical misfit is considerably larger.[31] Post-processing, such as glazing or polishing, was supposed to reduce processing related irregularities and enhance standardization. Applying the RMSE in assessing the quantity of overall modifications aimed to prevent misleadingly low total deviations caused by the possible nullification of positive and negative values after best-fit alignment.[32]

Contact strength was evaluated using 8 µm shimstock foil for occlusal contacts in adjacent teeth and for interproximal contacts in the SICs. When checking static occlusal contacts on the SICs, 24 µm foil was applied. This was done to meet the demand for a light occlusal contact at heavy bite, which is suggested for SICs with natural adjacent teeth to protect from overloading.[33] As postulated for implant-supported SICs, lateral occlusal loading was avoided by means of anterior and canine guidance and sufficiently shallow cusp inclination without interferences on the SICs during lateral and protrusive movements.[33] When dynamic loading occurs in SICs or static occlusal contacts are too strong or not evenly distributed, unfavorable stress peaks or non-axial forces might occur, putting strain on restoration, implant components, implant, and bone.[34] In the present study, dynamic interferences were not found in any of the specimens. Regarding static occlusal contact relationship, the present study did not only evaluate the effort until the defined occlusal contact strength was detectable but also intended to assess the quality of the contact relationship. From a (bio-) mechanical point of view, providing at least one contact on a supporting cusp of both the SIC and the opposing tooth, resulting in balanced and axial loading, appears desirable, since it can protect from overload.

In this respect, static occlusal contacts were regarded better in the cast-free protocol, indicating a certain degree of misfit within the crown-laboratory analog-3D printed model complex compared to the clinical situation. The analogs were supposedly positioned slightly too high and laboratory adjustments may therefore have resulted in a more heterogenic pattern of the latter clinical occlusion. Not only a vertical but also an inevitable rotational misfit at the analog-cast interface could have contributed to the occlusal inaccuracies, since it leads to a difference in horizontal positioning of the occlusal contacts on the inclined planes compared to the clinical situation. The greater the angle of rotation and the further a contact is from the center of rotation, the greater the inaccuracy. This assumption is emphasized by the fact that RMSE in SICs was significantly larger in the 3D printed-cast group, suggesting more extensive but in parts pointless overall modifications or a "double adjustment".

In the present study, the printed-cast based protocol led to a quicker clinical delivery with less modifications necessary, which is desirable on economic terms and in the patient's best interest. The total adjustment effort, however, was considerably larger than the work required for clinical adjustments in the cast-free approach. This can be explained by the fact that the casts differ from the clinical situation, resulting in the abovementioned additional incorrect alterations. Thus, clinical time efficiency is achieved to some extent at the expense of occlusal relationship quality, which is undesirable.

Comparing the results of the present study with preceding research must be done carefully, since experimental setups differ in several facets, affecting time effort measurements and quantity of adjustments. Researchers around Joda have addressed the topic of time efficiency in digital workflows in several scientific contributions. They have proven a positive relationship regarding the use of prefabricated titanium bases in a cast-free workflow,[21] the improved efficiency of digital over conventional workflows,[6,22,26] and the enhanced performance of a cast-free compared with a milled model-based approach.[23] Other researchers later confirmed the superiority of a digital workflow compared with conventional protocols in terms of time efficiency.[20,24,25] The exact time required for the adjustments in the present *in vitro* study cannot be readily transferred to the clinical situation. However, this was not the aim, as the focus was rather on the relationships between the workflows in order to derive relevant findings regarding the superiority of one of the methodologies.

The results of preceding investigations, however, largely comply with the ones obtained from the present study. When inserting CAD-CAM fabricated 2-piece implant crowns *in-vivo*, Joda *et al*. required 2.2 minutes[22] and 3.3 minutes[6] for modifications respectively. Adjustments in screw-retained SICs took 3.3 minutes in a 3D milled model-based hybrid workflow and 0 minutes in a cast-free approach, suggesting that a standardized, entirely digital cast-free workflow is more accurate and efficient.[23] Di Fiore *et al*. needed two minutes for clinical adjustments in a digital cast-free and about three minutes in a conventional workflow.[25] In line with the present study, it took Pan and coworkers more time to perform clinical adjustments, when casts where completely dispensed with. The authors also assessed the quality of outcomes, i.e., the presence or absence of occlusal and interproximal contacts, and, in contrast to the present outcomes, found no differences.[24] This fact might be, for instance, due to different CAD-CAM parameter settings. Investigating clinical adjustment time and quantity of modifications, Zhang *et al*. recently found the IOS based digital approach (237 ± 112 µm; 2.00 ± 1.09 minutes) to be more efficient than a hybrid workflow (485 ± 112 µm; 3.00 ± 1.05 minutes),[20] also corroborating the present findings.

Limitations of the investigation are the limited number of specimens and the fact that only one implant system, one type of 3D printed models, and one sort of laboratory analogs were investigated. This limitation, however, emphasizes a disadvantage of the cast-based approach, since there are countless possibilities for combinations of fabrication technologies, systems, and components. The fact that the quality of 3D printed casts can differ substantially[16,17] and the kind of laboratory analog affects the outcome[18] must be taken into consideration as sources of possible deviations, which are difficult to estimate. However, as the two groups were identical in every aspect except the use of a 3D printed cast for preliminary laboratory adjustments, the impact of this aspect is supposed to be evidently discernible in the present experimental setup. The *in vitro* character may be considered limiting in terms of the transferability of the results to the clinical reality. It holds, nonetheless, undeniable benefits regarding standardization and allows for valid conclusions regarding the comparison between the two approaches. The *in-vivo* procedure, by contrast, especially with a limited number of patients, comprises considerable distorting influence due to the patient related variability of the situation.

The results of this study lead to conclude that applying 3D printed casts for laboratory adjustments might help lower clinical effort but increases total expenditure. Costly time at the chairside can be reduced but at the expense of occlusal contact quality. Future effort, however, should broach the subject of further optimizing and standardizing the cast-free protocol. Dispensing with casts not only renders cast-related sources of error pointless by method but holds certain benefits regarding the straightforwardness of the procedure and preserving resources.

CONCLUSION

Within the limitations of this investigation, it was found that the application of a 3D printed cast helped reduce clinical adjustment time. The cast-free approach, however, was superior regarding overall adjustment time, total amount of necessary adjustments, and the quality of occlusal contacts achieved. Based on these results, alongside with economic and ecological considerations, efforts should focus on further optimizing the cast-free approach.

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