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Research Article

Variables Affecting the Accuracy of Implant Master Casts: An In Vitro Pilot Study

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Impression and master cast accuracy have been identified as being the major determinants of superstructure fit in implant-supported restorations. The goal of this in vitro investigation was to determine the effects of different transfer components, impression materials, disinfection, storage time, and stone type on master cast accuracy. Following impression making from a reference model with two internal-hex bone-level implants and master cast fabrication (eight experimental groups; $n = 5$), a bar-type measurement device equipped with a strain gauge was fixed on all master casts while strain development was recorded. Statistical analysis was performed applying ANOVA and paired t-tests with the level of significance set at $\alpha = 0.05$. The transfer components with plastic sleeves caused maximum misfit strain which was significantly greater as compared to click ($P = 0.02$) and open tray transfer components ($P = 0.00$). No significant effect on master cast accuracy was recorded for the parameters impression material, impression disinfection, and storage of impressions or casts. Lower strain development was observed in casts poured in type 3 stone as compared to casts poured in type 4 stone ($P = 0.01$). For the bone-level implant system considered here, the great levels of accuracy could be achieved using pick-up impressions with either click or open tray impression components.

1. Introduction

Due to the ankylotic fixation of dental implants in alveolar bone which is considerably more rigid than the periodontal ligament in natural teeth, restorations splinting several implants require a passive fit [1, 2]. If this cannot be achieved, static implant loading will occur thereby increasing the risk for technical complications such as loosening of restorative screws and biologic complications such as bone loss [3].

In this context, it has been clarified that every step in the restorative process contributes to the amount of misfit present in a specific restoration [4]. Although the term "passive fit" has never been defined, most authors agree that the amount of misfit stress evoked by a certain restoration can only be minimized, for example, by using CAD/CAM technology [5], but no procedure described so far is capable of producing a totally passive fit [6]. While it has been claimed based on an in vivo pilot study that static implant loads may induce bone adaptation thereby reducing the restorations' amount of misfit, reliable insight in bone response to static loading is missing so far [7]. The restorative team should therefore still strive to optimize fit at the implant-restoration interface.

Given the high levels of accuracy reported for implant components as well as the potential of modern manufacturing techniques, impression making and master cast fabrication appear to be the most critical steps involved in superstructure fabrication. In a previous investigation on this subject, it was found that about 50% of the misfit strains evoked by an implant-supported restoration are due to inaccuracies resulting from these early steps in the fabrication process [3].

In a recent literature review on multiunit implant impression accuracy, existing knowledge has been summed up as follows [2]. Polyvinylsiloxane and polyether impression materials [8] and pick-up transfer components [9] seem to positively affect impression accuracy while splinting

Table 1: Materials and parameters applied for impression making and master cast fabrication.

Transfer coping	Impression material	Disinfection	Impression storage	Plaster	Cast storage
Click transfer	Polyether	No disinfection	1 h	Type IV stone	1 h
Transfer with plastic sleeve Open tray transfer	Polyvinylsiloxane	Immersion in disinfection solution for 5 min in	24 h	Type III stone	24 h

(i) Polyether (Impregum, 3M Espe, Seefeld, Germany).
(ii) Polyvinylsiloxane (Affinis, Coltene/Whaledent AG, Altstätten, Switzerland).
(iii) EuroSept Max Impression Liquid (Henry Schein Inc., Melville NY, USA).
(iv) Type IV stone (FujiRock, GC Germany GmbH, Bad Homburg, Germany; 20 mL water : 100 g powder; 45 s mixing time in vacuum plaster mixer).
(v) Type III stone (Hera Moldano blau, Heraeus Kulzer GmbH, Hanau, Germany; 30 mL water : 100 g powder; 30 s mixing time in vacuum plaster mixer).

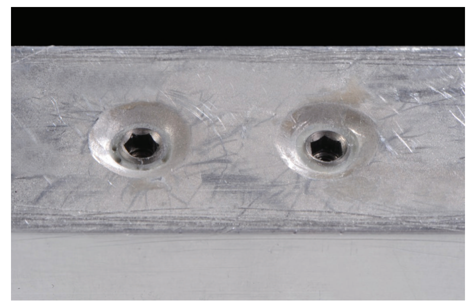
of the transfer components may not bear an advantage [8]. Severe implant angulation negatively affects multiunit implant impression accuracy [2]. Similarly, Gonçalves and coworkers published a review article on the dimensional stability of elastomeric impression materials [10] stating that temperature and humidity as well as time until pouring may affect impression accuracy.

While several authors have addressed single aspects of impression and master cast accuracy using a variety of implant designs, a comprehensive evaluation of all parameters affecting master cast accuracy is missing. Therefore, it was the goal of this in vitro investigation to study the effects of different implant transfer components, impression materials, disinfection, impression, and cast storage as well as stone type on master cast accuracy using one implant system as a reference.

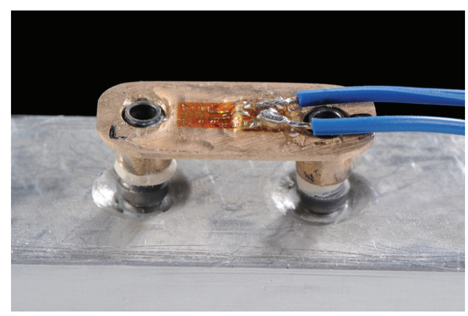
2. Materials and Methods

Using polyurethane resin (Biresin, Sika Deutschland GmbH, Bad Urach, Germany), two bone level implants with an internal hexagon connection (AlfaGate SCIP 3.75×11.5 mm; LOT: S031307-03) were positioned at an inter implant distance of 14.7 mm from center to center in an aluminum block to form a reference model [11]. The implants were positioned according to an existing patient situation with two implants placed in the region of the lower left first premolar and first molar with the premolar implant being perpendicular while the molar implant was slightly tilted mesially (Figure 1(a)).

Abutments for cement-retained restorations (Cementing post with shoulder, AGM-602-2, AlfaGate) were fixed on the implants and a bar structure with a centrally positioned flat surface connecting the abutments was waxed and cast in dental training alloy (Phantom-metal; Ag 56%, Cu 22%, Zn 17%, Sn 5%; DeguDent, Hanau, Germany). The finished bar structure was adhesively joined (Nimetic Cem, 3 M ESPE, Seefeld, Germany) with the abutments on the reference model following silica coating and silanating (Rocatec, 3 M ESPE, Seefeld, Germany) of relevant surfaces. A strain gauge (LY11-0.6/120; 120 Ω reference resistance; Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany) was positioned on the occlusal surface of the bar structure with the sensing element oriented in the mesial-distal direction (Figure 1(b)). A measurement amplifier (Spider 8; Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany) and analyzing software (BEAM for Spider, AMS Gmbh, Chemnitz, Germany) were used for capturing strains occurring in this measuring device due to its fixation on the implants.



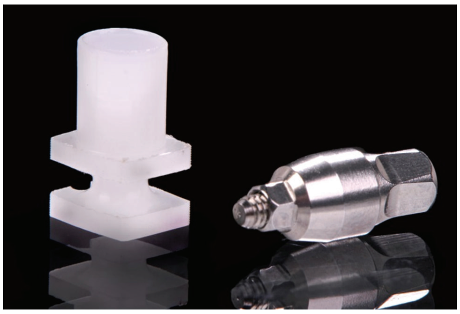
(a)



(b)

Figure 1: (a) Two internal-hex bone-level dental implants with a distance of 14.7 mm from center to center were embedded in an aluminum block to serve as reference model for the study. (b) Abutments for cement-retained restorations were passively connected on the reference model using an individually cast metal plate which was adhesively joined with the abutments. A strain gauge was fixed on the occlusal surface of the plate which allowed capturing unidirectional deformations during fixation of this measuring device.

A total of 40 impressions ($n = 5$) [12] were made from the patient model, using all types of the implant manufacturer's transfer components (Figure 2) in combination with custom-made impression trays (Palatray XL; Heraeus Kulzer, Hanau, Germany). Implant analogs were attached to the transfer copings and standardized master casts (Figure 3) were fabricated using a silicone mold (Sil 18 Doubliersilikon, Dr. Ihde Dental AG, Gommiswald, Switzerland). The parameters varied during impression making and master cast fabrication are detailed in Table 1.

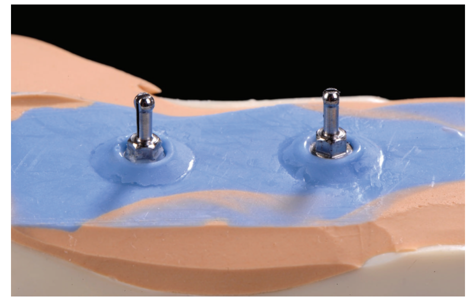


(a)

(b)

(c)

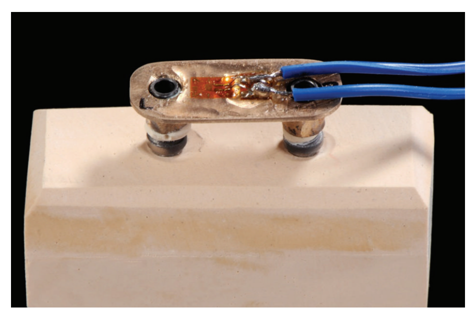
Figure 2: Transfer copings used for the study: (a) transfer with plastic sleeve; (b) click transfer; (c) open tray transfer.



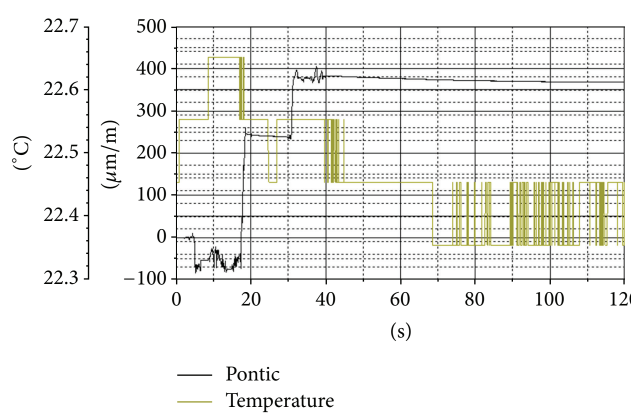
(a)

(b)

Figure 3: Examples of impressions made with the use of click transfer components and (a) polyvinylsiloxane (b) polyether.



(a)



(b)

Figure 4: (a) Measuring device mounted on the master cast. (b) Screen shot of the analyzing software displaying strain development on the measuring device as resulting from fixation on the master cast.

For evaluating the accuracy of the master casts, the strain gauge on the measuring device was set to zero followed by positioning of the device on a specific master cast and tightening of the abutment screws to 25 N cm using the implant manufacturer's manual ratchet [9, 13]. The final strain values after 2 min were recorded for analysis (Figure 4).

Statistical analysis for evaluating the effect of the parameters varied (Table 1) was based on the absolute strain readings. Following analysis of variance (ANOVA), pairwise t-tests were conducted with the level of significance set at $\alpha = 0.05$.

3. Results

Mean strain development on the master casts ranged from 116.6 μm/m to 693.65 μm/m (Table 2) with ANOVA indicating significant differences between the groups tested ($P = 0.01$). The results from pairwise comparisons between the experimental groups are given in Table 3.

Table 2: Mean strain values and standard deviations measured for all combinations of parameters tested.

Group	Transfer coping	Impression material	Disinfection	Impression storage	Stone type	Cast storage	Mean strain value [μm/m]	Standard deviation
1	Click	Polyether	No	1 h	FujiRock	1 h	252.84	119.87
2	Plastic sleeve	Polyether	No	1 h	FujiRock	1 h	506.82	114.78
3	Open tray	Polyether	No	1 h	FujiRock	1 h	116.16	51.26
4	Click	Polyvinyl-Siloxane	No	1 h	FujiRock	1 h	174.58	151.08
5	Open tray	Polyether	Yes	1 h	FujiRock	1 h	195.78	57.71
6	Click	Polyether	No	24 h	FujiRock	1 h	693.65	566.17
7	Plastic sleeve	Polyether	No	1 h	Moldano Blue	1 h	149.34	13.22
8	Open tray	Polyether	No	1 h	FujiRock	24 h	253.86	135.11

Table 3: P-values resulting from pairwise comparisons between groups based on t-tests; significant differences ($P < 0.05$) are written in bold.

Group	1	2	3	4	5	6	7	8
1		**0.02**	0.10	0.41	0.44	0.16	0.18	0.99
2			**0.00**	**0.01**	**0.01**	0.51	**0.01**	**0.03**
3				0.45	0.09	0.08	0.29	0.13
4					0.78	0.11	0.73	0.43
5						0.12	0.21	0.47
6							0.10	0.16
7								0.22
8								

Comparing the different impression copings used, the transfer components with plastic sleeves caused maximum misfit strain which was significantly greater as compared to click ($P = 0.02$) and open tray transfer components ($P = 0.00$). No significant difference in master cast accuracy could be found between open tray and click transfer ($P = 0.10$).

The use of polyvinylsiloxane impression material had no significant effect on misfit strain as compared to the use of polyether impression material ($P = 0.41$). Similarly, disinfecting polyether impressions made with open tray transfer copings had no significant effect on resulting master cast accuracy ($P = 0.09$). Due to a dramatically increased variability in strain development measured in master casts which had been poured after 24 h of impression storage, no significant difference compared to casts produced after 1 h storage time could be detected ($P = 0.16$). Similarly, cast storage for 24 h also led to an increase in variability which resulted in a nonsignificant difference as compared to casts stored for one hour ($P = 0.13$). On the contrary, significantly lower strain development was observed in casts poured in type 3 stone as compared to casts poured in type 4 stone ($P = 0.01$).

4. Discussion

Considerable strain development was found in each master cast tested indicating that none of the impression procedures employed allowed transferring the original implant positions without positional errors [3, 5].

While no difference in accuracy could be found between master casts made from pick-up impressions (click and open tray impression copings; groups 1 and 3), the use of repositioning impressions (transfer coping with plastic sleeve; group 2) led to significantly greater distortions. A possible explanation for that may be the fact that the plastic sleeve is completely covered by impression material not allowing for visual control when the implant analog is reattached. This may be specific for bone level implants as in previous investigations; no difference between pick-up and repositioning impressions could be found when a soft-tissue level implant was used [3].

In the study at hand, the choice of impression material used had no effect on the resulting master cast accuracy which is consistent with a comparable in vitro study using tissue level implants [13]. However, the literature is inconclusive in this matter as both reports favoring polyvinylsiloxane [8] or polyether [14] can be found.

It has been argued that disinfection of impressions may alter material properties such as wettability [15] and cause dimensional changes [16, 17] which may in turn affect master cast accuracy. The disinfecting procedure employed here comprised immersion of the impression in disinfection solution for 5 min followed by rinsing under tap water. Similar to two in vitro studies conducted by Melilli and coworkers as well as by Yilmaz and coworkers, no negative effect of this procedure on master cast accuracy could be detected [18, 19].

Delayed pouring of impressions has also been shown to negatively affect dimensional stability [17] particularly in polyether based materials which may absorb water due to their hydrophilic material properties [20]. In the study at hand, no significant effect of impression storage for 24 h was noticed although delayed pouring caused an increased variation in master cast accuracy. This limited effect of impression storage seems to be consistent with a study conducted by Franco and coworkers where only minor changes were found when pouring of the impressions was performed within 24 h [21]. Similar findings were reported for polyvinylsiloxane duplicating materials even after several weeks of storage [22].

Whereas delayed pouring of the impression cannot be often avoided especially when working with commercial dental laboratories, the timepoint of when to start working on a master cast can be determined by the technician. In this context, it has been shown that expansion of the model material continues for several hours after the start of the mixing phase [23] followed by a contractive phase which may last several days [24]. In the current study, no significant effect of cast storage could be detected although a trend towards greater mean strain values was observed after 24 h of storage time. Besides possible dimensional changes in the master casts, a reduction in moisture content of the stone could have increased the elastic modulus of the model material which would have also caused an increase in strain development on the measuring device. A comparable difference in elastic modulus between type 3 and type 4 stones used may have led to significantly lower strain readings in casts produced from type 3 stone which is normally expected to be less accurate.

A variety of potential measurement techniques which could have been used for the purpose of this study have been described in the literature including coordinate measurement machines [9], 3D image correlation procedures [22, 25], and μCT scanning [26]. As repeatedly described, a strain gauge equipped restoration fitting a reference model may also be used for assessing the accuracy of master casts [9, 12, 14, 27, 28]. Although it may be claimed that more sophisticated techniques provide data in all directions of space separately [11], the major advantage of the measurement method applied here seems to be that these deformations are integrated in one strain value [25]. This amount of strain could also be captured in a clinical situation where a restoration fabricated on a specific master cast was positioned and measured in the patient's oral cavity [7]. Nevertheless, the data presented only allow for relative comparisons to be made based on the particular situation tested here [2] and it has to be taken into account that numerous combinations of 3D deformations could cause an identical strain signal with the set-up chosen. For this reason, the absolute values of the strain readings were used for statistical analysis [3].

Although comparable studies have been conducted with a similar sample size [12], the limited number of samples tested and the in vitro test setting chosen as well as the fact that only one implant system was used have to be seen as systematic limitations of this investigation. In addition to the variables tested here, implant angulation [2, 28, 29] and splinting of the transfer components [2, 8, 12, 28] would have represented additional parameters. However, based on the literature available, these variables seem to have only a minor effect as compared to the parameters evaluated in the present study.

5. Conclusion

Within the limitations of this in vitro study, it appears that the transfer components chosen have a prevailing effect on master cast accuracy. For the bone-level implant system considered here, the greatest levels of accuracy could be achieved using pick-up impressions with either click or open tray impression components.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

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