



Effect of impression holding time and tray removal speed on the dimensional accuracy of impressions for artificial abutment tooth inclined

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Abstract

Oral scanners allow dental impressions to be taken in a short time without the use of an impression material. However, it has been noted that high impression accuracy cannot be obtained in cases where the abutment is inclined or in cases where the span is long. Consequently, in daily clinical practice, impressions are often created using silicone impression material. When taking an impression using silicone impression material, the curing time or the removal time of the impression material are often based on the intuition of the dental staff. This study investigated the effects of impression holding time and impression tray removal speed on the dimensional accuracy of impressions. A specimen with an abutment inclined 30° to the removal direction of an impression was prepared. Four types of silicone rubber impression materials were used. Impressions were taken with two levels of holding time and two levels of removal speed using an autograph. The diameter of stone models was measured at 3, 6, and 9 mm from the baseline of each. The height of the inclined and opposite sides was also measured. Two-way analysis of variance was used to analyze data regarding the assessment of the effects of holding time and tray removal speed. The reproducibility of the impressions was affected by the volume of undercut caused by the inclined abutment. For a large undercut, longer holding times and faster tray removal speeds are recommended to reduce the deformation of silicone rubber impressions.

Keywords Silicone rubber impression · Impression accuracy · Holding time · Tray removal speed · Inclined abutment tooth

Introduction

From the perspectives of esthetic reproduction, the protection of periodontal tissue, and the prevention of secondary caries, restorations that are placed inside the mouth need to have excellent conformance accuracy. Restorations are manufactured by taking an impression using an impression material and then fabricating a working model, or by making an impression of the inside of the mouth directly using an oral scanner in a technique developed through recent advances in CAD/CAM technology [1]. Oral scanners allow an impression to be taken in a short time without the use of impression materials [2]; however, at present, the oral

scanner cannot scan large undercuts. Furthermore, its accuracy is limited [3], and the equipment is costly. Impression acquisition by an oral scanner requires that the abutment teeth should be parallel, and thus, its application is limited. On the other hand, in the clinical setting, as in implant treatment, the implant placement directions are not always parallel, and a conventional impression using an impression material is often used in routine clinical applications. The adaptation of the restoration to the abutment tooth is greatly affected by the manufacturing process. The first stage of using the impression material to create an accurate impression of the teeth for the working model is the most important for adaptation.

In the field of crown and bridge restorations, silicone rubber impression material is widely used in the clinical setting because it is highly accurate [4]. Silicone rubber impression material may be condensation or addition type, depending on the polymerization method; addition-type polymerization silicone is mainly used because of its dimensional stability after hardening.

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Silicone rubber impression material is highly fluid and has excellent elastic recovery, but various factors have been shown to affect the accuracy of the impression, including the inclination of the tooth or implant body from which the impression is taken, the impression removal time, the time from taking the impression to injection of the model material, surface wettability, and room temperature [5]. Even if an accurate impression material has excellent material properties, the reproducibility of inherent details, surface properties, and positional relationships may be damaged because of the effects of clinical conditions such as handling of the impression material or undercutting of the object from which the impression is taken [6, 7]. Silicone rubber impression material is mainly used in the clinical setting to take impressions from dentate patients, but there may be some misgivings about the reproducibility of the fit of the abutment tooth or other teeth that are not parallel to the direction of removal when the impression is being taken. This may happen if the teeth have differing axes, as in the case of the front teeth and the molars, or if there are inclined teeth. With implant restorations, implants are sometimes placed at an inclination, and in all such cases, the superstructure needs to have high conformance accuracy.

The purpose of this study was to investigate abutment deformation of silicone impressions by measuring the holding times of the tray and its removal speed using an abutment model tilted by 30° with respect to the impression removal direction and an additional polymerization silicone rubber impression material.

Materials and methods

Impression materials

Four types of addition polymerization silicone impression materials were used for the experiment: Aquasil Ultra Monophase (Dentsply Caulk, Bensheim, DE; A) and Fusion Monophase (GC, Tokyo, Japan; F), which are both classified as Type 2 under Japanese Industrial Standard (JIS) T 6513 [8], and Imprinsis Regular (Tokuyama Dental, Tokyo, Japan; I) and Standout Wash (Kerr, Orange County, CA; S), which are both classified as Type 3 (Table 1).

Inclined abutment model

The inclined abutment tooth model used for the experiment was a metal model in the shape of a circular truncated cone with taper 5°, base diameter 10 mm, height 12 mm. This was inserted into a hole prepared in the base at an inclination of 30° and fixed into place (Fig. 1).

For the impression tray, a cylindrical vinyl chloride custom tray was manufactured with a fixed thickness of impression material. To set the direction of impression removal, the tray was held in place by a double guide allowing vertical movement so that there was no influence from the direction of inclination of the inclined abutment model. The tray removal speed was regulated by means of the crosshead speed of an autograph (AGI, Shimadzu, Kyoto, Japan) (Fig. 2).

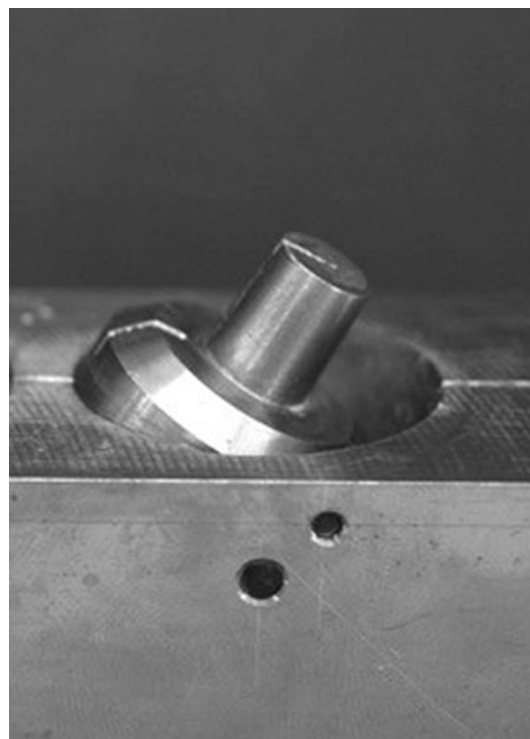


Fig. 1 Experimental model with 30° inclined abutment

Table 1 Impression silicone materials tested in the present experiments

Impression materials	Aquasil Ultra	Fusion	Imprinsis	Standout
Symbol	A	F	I	S
Manufacturer	Dentsply Caulk	GC	Tokuyama Dental	Kerr
Lot no.	060601	0603302	D29066	5-1021
Hardening* time (min)	5	4	4	4

*Specified by the respective manufacturers



Fig. 2 Experimental tray fixed on an autograph

Impression taking and measurement of stone models

The experimental environment complied with JIS T 6513 [8]. In the experimental conditions, the factors were holding time and removal speed. The two conditions for holding time were the hardening times specified by the respective manufacturers minus 40 s as the time usually taken for mixing and pouring (T), and 1 min less than this time ($T - 1$). The two conditions for removal speed were crosshead speed 10 mm/min (S10) and 1000 mm/min (S1000). The experiment was carried out six times for each set of conditions in random order, a total of 24 times, for each silicone type, totaling 96 times for all four silicone types.

Silicone mixing was carried out using a cartridge dispenser (GC) and the mixing tip specified by the manufacturer. Impressions were taken by the single impression method. The impression procedure was carried out in 40 s from the start of mixing, after which, the tray was placed on the inclined abutment model under a load of 2 kg in warm water at 35 ± 1 °C, and the impression material was hardened for the required holding time.

The experimental apparatus was fixed to the autograph, which took a mean of 90 s, and the tray was removed at the

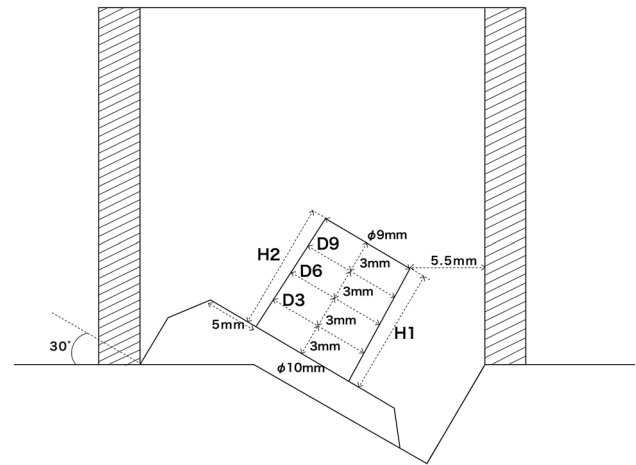


Fig. 3 Dimensions of the inclined abutment model and measuring points

required removal speed. The impression removed was placed in an incubator at 23 ± 2 °C and humidity $55 \pm 2\%$ for 1 h, after which, the stone model was fabricated by mixing dental stone (New Plastone; GC) with water in a powder–water ratio of 0.24, according to the manufacturer’s specifications, pouring this into the impression, and hardening in the incubator for 1 h. The stone model was then removed from the impression.

The diameter of the stone model at 3 mm, 6 mm, and 9 mm from the base of the model tooth (D3, D6, and D9, respectively) and the height of the inclined (undercut) side (H1) and its opposite (non-undercut) side (H2) were measured using a digital caliper (NTD12-15C; Mitutoyo, Kanagawa, Japan), with each measurement taken three times by the same measurer. The amount of change in the stone model for evaluation was taken to be the difference between the mean measured value on the stone model and the value for the corresponding site on the master metal model. The difference in height between the inclined side and the opposite side (dH) in the stone model was also compared with the difference in height in the master metal model (Fig. 3).

The effects of holding time and removal speed on shape reproducibility were evaluated by two-way analysis of variance with Tukey’s post hoc test for each material. In addition, differences between the four types of material were evaluated by means of a one-way analysis of variance, using the condition with the largest amount of change in diameter.

Measurement of abutment model

Deformation in the stone model of the abutment was determined by measuring the diameter of the abutment

at 3 mm, 6 mm, and 9 mm from the base and the height of the inclined (undercut) side and the non-inclined side using a digital caliper accurate to 0.01 mm. Each measurement was taken three times, and differences between the mean measured values and the corresponding dimensions of the original metal mold were taken to be the amount of change. Measured values were in the range of ± 0.08 mm or below, and sufficient accuracy was ensured by taking the mean of three measurements. The size of the original metal mold, which was the reference, was measured 12 times, and the mean value was used.

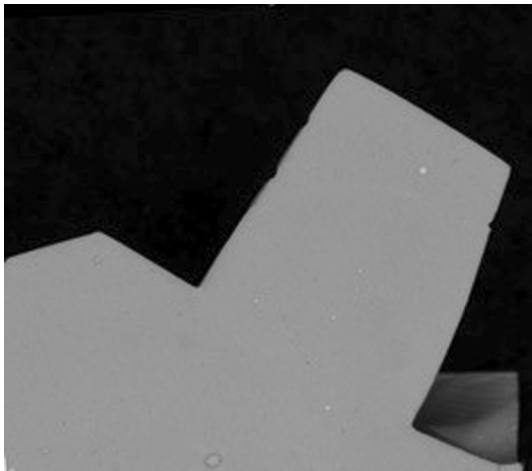
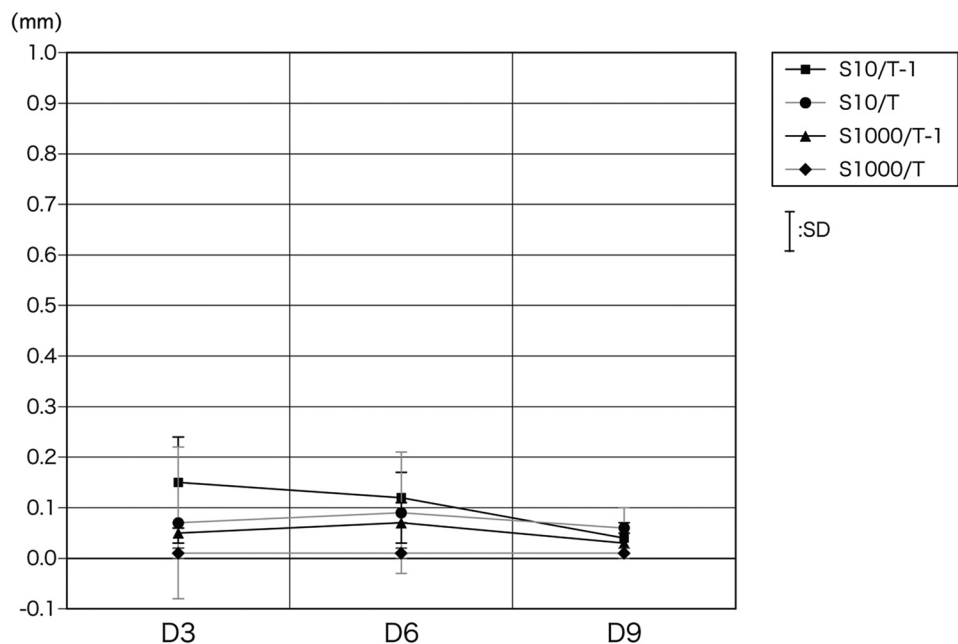


Fig. 4 Cross-section of the stone model

Fig. 5 Amount of deformation in impression material A at D3, D6, and D9



Results

Diameter of the model

With all impression materials, the greatest amount of change tended to be at D3, with progressively less at D6 and D9. As shown in Fig. 4, deformation occurred mainly at the base of the inclined side. The amount of change at D6 and D9 showed the same trends as that at D3, but there were few conditions in which the differences were significant. The following results are all for D3.

With material A, for holding time ($P=0.0145$), the difference in diameter was significantly greater at $T-1$ than at T , and for removal speed ($P=0.0014$), the difference was significantly smaller at a greater removal speed. The amount of change was ≤ 0.1 mm under all conditions except S10/ $T-1$ (Fig. 5).

With material F, for holding time ($P=0.01751$), the difference was significantly greater at $T-1$, and for removal speed ($P < 0.0001$), the difference was significantly smaller at a greater removal speed. The amount of change was ≤ 0.1 mm under all conditions except S1000/ T (Fig. 6).

With material I, there was no significant difference at $T-1$, but the difference was significantly smaller at a greater removal speed ($P=0.0057$). The amount of change was ≤ 0.1 mm under all conditions (Fig. 7).

With material S, for holding time ($P=0.0129$), the difference was significantly greater at $T-1$, and for removal speed ($P < 0.0001$), the difference was significantly smaller at a greater removal speed. The amount of change was ≤ 0.1 mm under both S1000 conditions (Fig. 8).

Fig. 6 Amount of deformation in impression material F at D3, D6, and D9

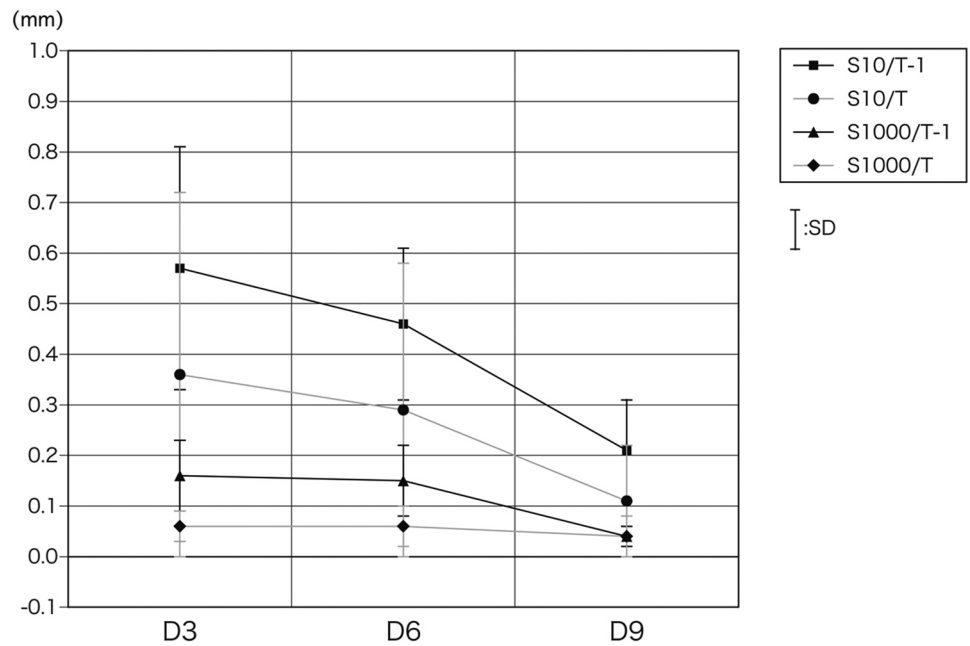
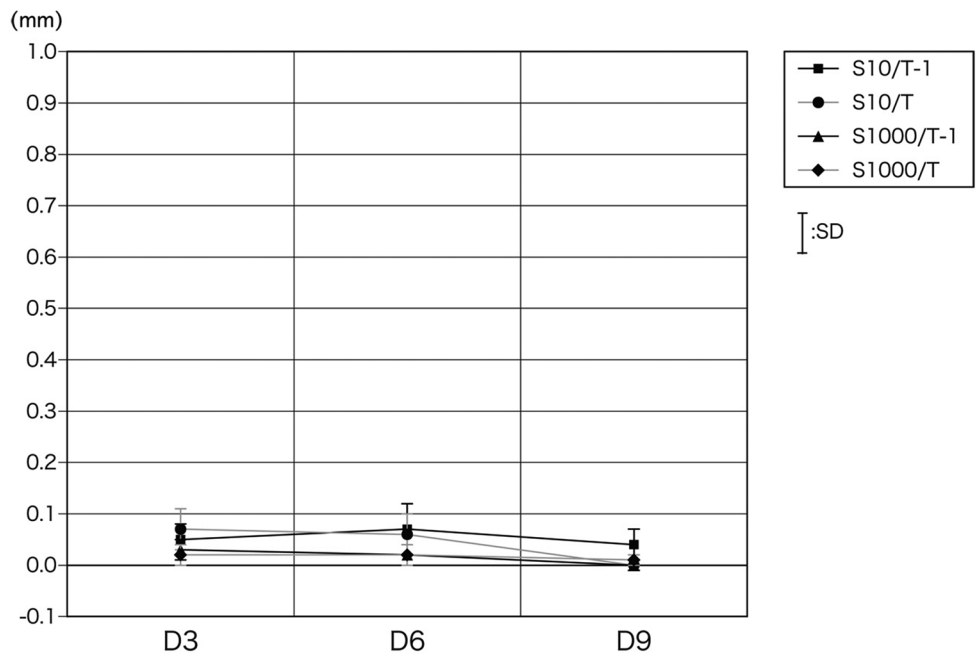


Fig. 7 Amount of deformation in impression material I at D3, D6, and D9



Evaluation of the amount of change under optimal conditions for D3 showed no significant differences between A, I, and S, but the change was significantly greater ($P=0.0006$) with F than for the other materials (Fig. 9).

Height of the model

With all impression materials, the non-inclined side (H2) tended to be slightly lower in the stone model than in the experimental model, and with the exception of material I, the inclined side (H1) tended to be higher.

With regard to impression material A, H1 ($P=0.0163$) and dH ($P=0.0063$) showed a significant difference that was greater at holding time, as did H2 for the removal speed. H1 and dH were significantly longer at T-1 than T at holding time. Additionally, H2 was significantly shorter at S1000 than S10 for the removal speed. Furthermore, dH tended to decrease with a higher removal speed (Fig. 10).

With material F, there were no significant differences owing to holding time or removal speed, but in all conditions, there was a tendency for the difference to be greater on the inclined (undercut) side than on the non-inclined

Fig. 8 Amount of deformation in impression material S at D3, D6, and D9

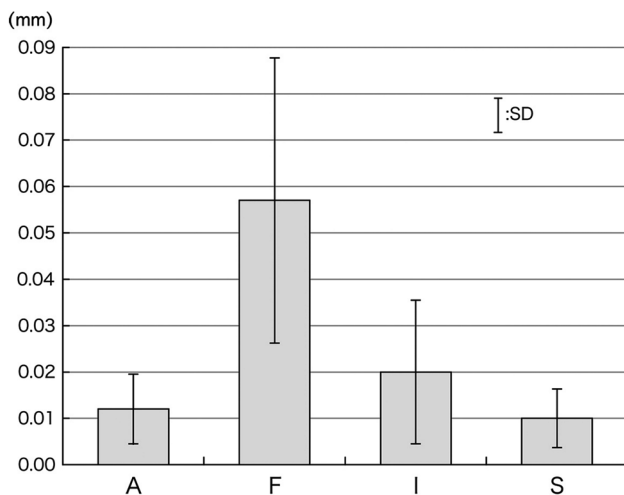
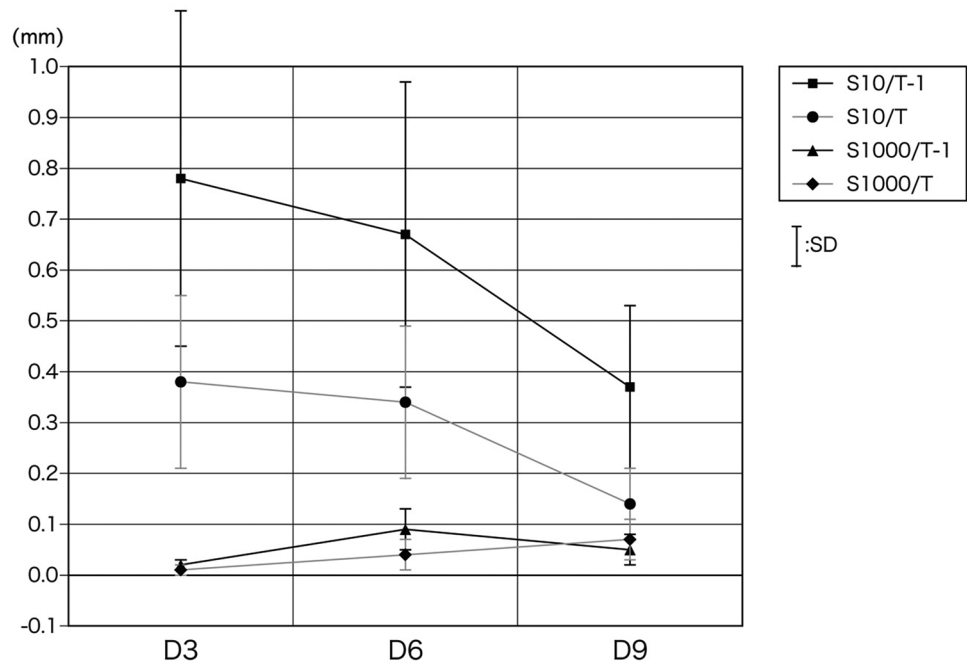


Fig. 9 Amount of deformation under optimal conditions at D3

(non-undercut) side. The value of dH was roughly constant, regardless of holding time or removal speed (Fig. 11).

With material I, H1 ($P=0.0445$) and dH ($P=0.0330$) were significantly greater at holding time $T-1$, but the interaction was not significant. At S10/T-1, the difference was greater on the acute than on the non-acute side, but under all other conditions, dH was close to 0 (Fig. 12).

With material S, H1 ($P=0.0003$) and dH ($P=0.0103$) were significantly greater at a lower removal speed. Under all conditions other than S1000/T, the difference was significantly greater on the acute than on the non-acute side, and dH was roughly constant, regardless of holding time

or removal speed. Even at S1000/T, the difference on the inclined (undercut) side tended to be slightly greater than that on the non-inclined (non-undercut) side (Fig. 13).

Discussion

Selection of impression material

If elastic impression materials are ordered from the most satisfactory first, taking into account both advantages and disadvantages, the order would be polyether rubber, agar, polysulfide rubber, silicone, and alginate [9]. Rubber-type impression materials were subsequently improved, and the leading type of material changed over time from agar to polysulfide rubber and condensation silicone, and has now become addition silicone [10]. Silicone that has greater hydrophilic properties, smaller contact angles, and greater tensile strength, which not only gives higher dimensional accuracy, but also improves the reproducibility of details and ease of use, has been developed. Thus, rather than just addition silicone alone, innovations and variations in composition have been produced, such as the addition of various types of denatured silicone oil [11–14].

In the present study, four relatively new types of addition silicone material with improved hydrophilic properties and tensile strength were selected. Of these four types, two are classified as type 2 (medium viscosity) and two as type 3 (low viscosity) precision impression materials according to JIS T 6513, and with hardness after hardening

Fig. 10 Amount of deformation in impression material A at H1, H2, and dH

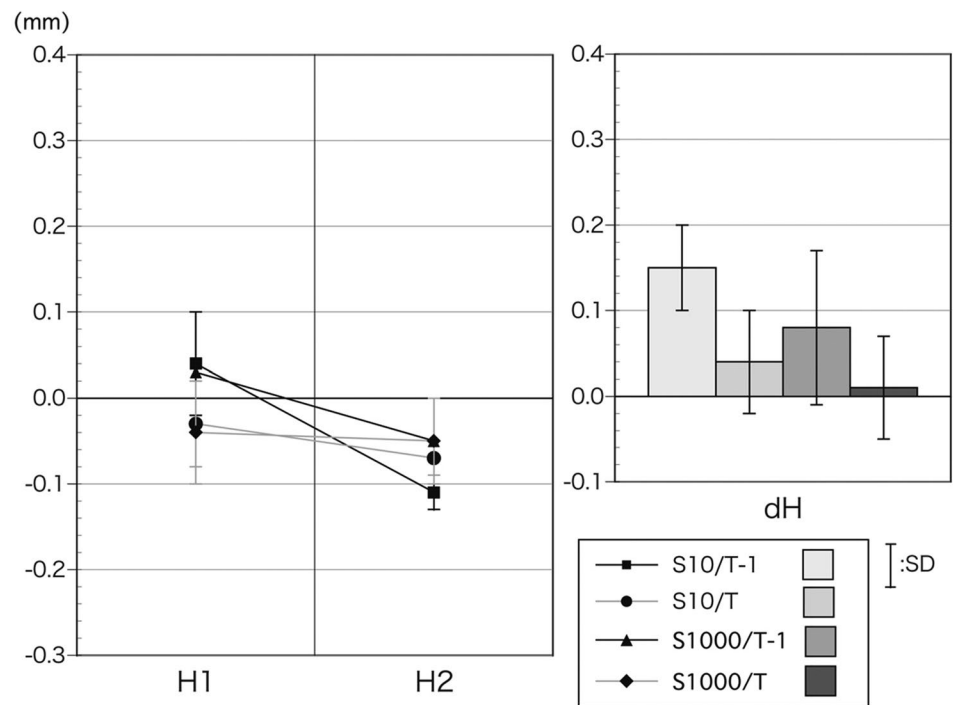
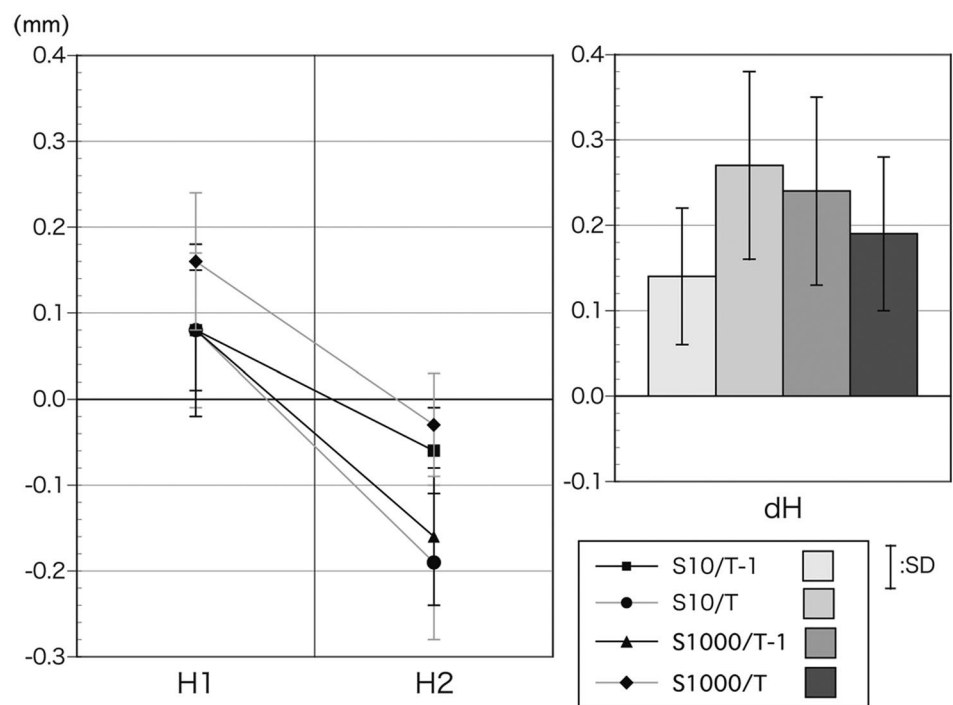


Fig. 11 Amount of deformation in impression material F at H1, H2, and dH



in the range 42–67 (Hs A), they included both soft and hard materials. As there were no differences between the removal time and retention time between Type II and Type III, which have different viscosities, consistency was not considered to have been affected.

Inclined abutment model

The accuracy of an impression is affected by the distortion of the impression material when the impression is taken as a result of undercutting of the mold. Even if there is no undercut in the abutment tooth, undercutting may be

Fig. 12 Amount of deformation in impression material I at H1, H2, and dH

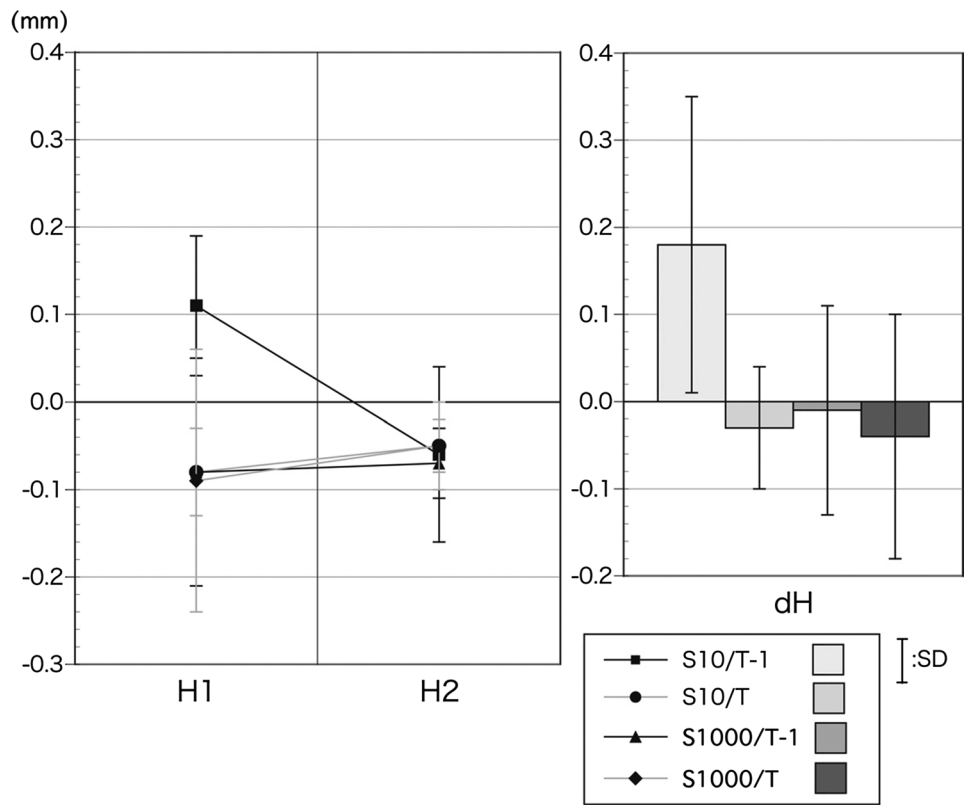
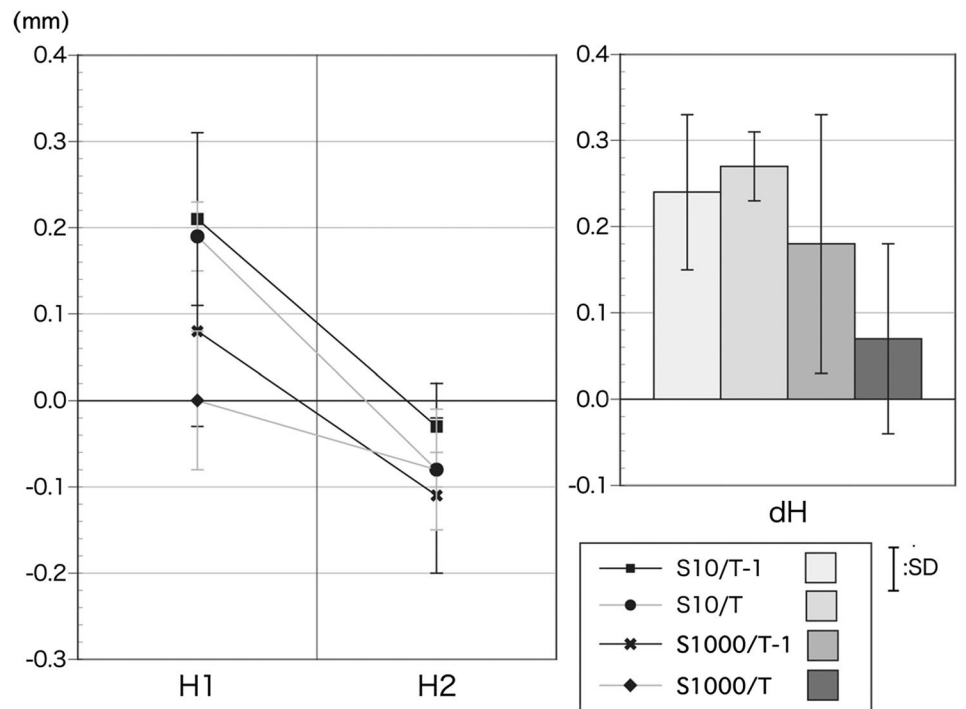


Fig. 13 Amount of deformation in impression material S at H1, H2, and dH



caused by the direction of the impression removal or the inclination of the abutment tooth. In addition, the reproduction of undercut areas on the root side of the margins is important [15–17].

The abutment model used in the present study was inclined 30° before fixing to the base, and after the impression was taken, the cylindrical vinyl chloride tray was pulled away vertically by means of a guide until it had parted from

the tooth. Thus, the effect of the undercut on the inclined (undercut) side.

Various clinical situations may be envisaged in which an impression is taken of an abutment tooth with a large angle of inclination such as this. For example, when a crown is selected as treatment for a lingually displaced, inclined premolar with caries, the tooth is often not involved in occlusion, and to preserve the pulp if the tooth is vital, an abutment tooth is sometimes formed with the inclined tooth axis left unchanged. In addition, with an implant prosthesis from the incisor region to the molar region, the difference in implant direction may occasionally exceed 30°, which is problematic when using the closed tray method [18, 19]. It is known from prior studies that an undercut of 10–15° will not produce sufficient deformation with silicone to be a problem clinically [12, 14].

Several research reports have been published on the impression accuracy of angulated implants [20, 21]. Conrad et al. [20] reported the effects of the combined interaction of impression techniques, implant angulation, and implant number on the accuracy of definitive casts. They found that the implant angulation affects the impression accuracy. Assunção et al. [21] examined the impression accuracy of implant abutments at various angles and concluded that the oblique insertion angle of the implant could affect the accuracy of the master cast.

Experimental conditions

As well as the effects of undercut at impression removal that could be produced with an inclined abutment tooth in a clinical setting, a holding time of 1 min less than the optimal time specified by the manufacturer was set as a simulation of the error in measuring the impression time frequently experienced in clinical practice.

In daily clinical practice, the impression material is cured using a timer; however, the dental staff must sometimes determine whether the material is set based on their own intuition given the specific room temperature or season. From this perspective, it is important to clarify the clinical impact of changes to the accuracy of the impression if it is removed in less time than indicated. In addition, a slow and a fast speed of removal were set to investigate rapidly snapping out the impression, which is generally said to be the best way.

The effects of inclination

As the abutment shape was tapered 5°, a 30° inclination of the abutment resulted in an undercut of 27.5° on the inclined (undercut) side. The amount of undercut at the base of the abutment was 5.54 mm, and the distance from the tip of the inclined side of the abutment to the inner surface of the tray

was at 5.5 mm. This means that when the impression was removed, the impression material in the undercut region was compressed as far as half its size, and it is therefore likely that distortion exceeding the elastic limit was produced. At the same time, as there was no undercut on the non-inclined side, removing the impression produced almost no distortion, and therefore, the permanent deformation observed in the cross-section of the stone model mostly occurred only on the inclined side.

With all four types of impression material, the amount of change in the diameter of the stone model and the difference in the amount of change between conditions tended to be greatest at D3 and to decrease toward D9, on the tip side of the abutment. This is probably because diametric deformation is the result of permanent compression strain, and the amount of compression is proportional to the amount of undercut.

At the same time, the deformation in the height of the stone model indicates that the impression material on the inclined side was stretched when the impression was removed, and the lengthwise elongation resulted in tension set. Under conditions in which deformation occurred, in all cases, the inclined side showed greater deformation than the non-inclined side. As the non-inclined side is also subject to tensile stress, longitudinal deformation is to be expected. The difference in deformation between the inclined side and the non-inclined side (dH) is likely to be a reflection of the effect of the inclination.

The values for dH showed different trends depending on the type of impression material. With material F, and with material S under all conditions other than S1000/T, dH showed a roughly constant value. It therefore appears that under the experimental conditions, F and S produce a constant amount of tension set, regardless of the holding time or removal speed.

Effects of holding time

Holding time had no significant effect on the diameter of the tooth model with material I. Thus, the diametric deformation was smaller with I than with the other materials, suggesting that differences with respect to the original model are less readily produced. I therefore appears to be a material with low compression set.

Holding time had a significant effect on F and S. With F, the amount of change was greater for $T-1$ than for T under all conditions, while with S, the amount of change was greater for $T-1$ than for T only at removal speed S10. With F, a longer holding time is therefore desirable regardless of the removal speed. With S, there appears to be an interaction between the holding time and removal speed, and within the scope of the experiment, the effects of holding time disappear if the compression time is short.

With regard to the height of the model, which corresponds to the tension set of the material, dH was significantly greater at S10/T–1 with I than with the other materials. From this, it appears that with I, when the removal speed is low, the effects of holding time are seen, whereas holding time has no effect at a high removal speed within the scope of this experiment.

With A, there was a significant difference between T–1 and T, but no effects due to holding time were found with F or S.

Thus, holding time had an effect, independent of removal speed, on compression set in F and on tension set in A and I. Compression set in S was affected by holding time with an interaction with removal speed. The effects of holding time therefore show different trends for each of the four impression materials.

The experimental conditions for holding time in the experiment were set such that the time from the start of mixing to lifting out of the warm water corresponded to the hardening time specified by the manufacturer (T) and to 1 min less than this (T–1).

Effects of removal speed

Significant differences in the diameter of the model abutment due to removal speed were found for all four impression materials, with significantly greater deformation at S10 than at S1000. With all the impression materials, compression set was proportional to compression time, and thus, there was less deformation at a greater removal speed. With S in particular, at S1000, the deformation was so small that the effects of holding time were offset; therefore, it appears that removal speed greatly affects compression set in S.

With regard to the height of the model, no significant effects for removal speed were found with F or I. The dH value showed a significant effect due to removal speed with S, and H2 showed a significant effect with A. The dH value tended to be smaller at a high removal speed with A.

Thus, removal speed had an effect, independent of holding time, on compression set in F, A, and I, and on tension set in A and S. Compression set in S was affected by removal speed with an interaction with holding time. The effects of removal speed therefore show different trends for each of the four impression materials.

In the literature on removal, it has been reported that dimensional accuracy generally increases with greater removal speed [10, 12], which agrees with the results of the present experiment. However, as seen with F, there are also impression materials in which the tension strain of the material is not affected by removal speed or holding time. In addition, the present results did not have any particular implications with regard to factors such as modulus of

elasticity, hardness, or contact angle, which are expected to have some involvement in deformation of the impression.

Here, the experiment was carried out using four types of addition silicone impression materials, and from the results of measurement of the amount of deformation in the manufactured stone models, it was possible to investigate the permanent distortion of the impression materials. In particular, the use of an inclined abutment model allowed compression set and tension set to be separated to some extent for evaluation from simple measurements. This experiment did not observe the fitness at the margin part with the crown, but it did measure the deformation of the stone model after the impression of the abutment tooth.

In this study, deformation of the axial face of the abutment that is inclined with respect to the direction of removal of the impression was measured, and it is considered that this deformation affects the cervical marginal fitness of a crown. Clinically, it is not necessarily the case that the tooth axis and the direction of removal of the impression are parallel. From this point, it is also important in clinical practice to clarify how this relates to deformation at the time of acquisition of impressions.

This experiment examined how to use these impression materials and the condition of the abutment at the time of impression. The present results indicate that the four impression materials each show different tendencies, suggesting that when dealing with impression materials, it may not be safe to generalize by referring to them all as addition silicone impression materials.

Conclusions

Using an inclined abutment model, the effects of holding time and removal speed on deformation when the impression is removed from a mold with a pronounced undercut was investigated for four types of addition silicone impression materials by measuring the diameter and height of the corresponding stone model. From the results, the following conclusions were obtained:

1. The undercut formed by inclination of the abutment mainly affected the reproducibility of the diameter of the basal level of the abutment.
2. The amount of deformation of the diameter and height of the model abutment decreased when the tray removal speed was increased.
3. Reducing holding time by 1 min greatly increased the amount of deformation in diameter with Fusion and Standout, and the amount of deformation in height with Aquasil Ultra and Imprints.
4. The effects of combinations of holding time and removal speed varied according to different impression materials.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human participants and animals rights This article does not contain any studies with human participants or animals performed by any of the authors.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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