



## Research article

## The influence of undercut depths on the accuracy of casts poured from irreversible hydrocolloid impression materials

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## ABSTRACT

**Objectives:** To evaluate the elastic recovery of a typical irreversible hydrocolloid impression material in terms of the amount of undercut identified and additional thickness of spacer provided before custom tray fabrication.

**Methods:** This study surveyed the undercut depths of the teeth surfaces and lingual sulci of one hundred partially dentate mandibular dental casts which were subsequently scanned and the data exported as STL files. A typical cast from each undercut category (0.5mm, 1mm, 1.5mm, 2mm, 2.5mm, 3mm, 4mm, 5mm) was 3D printed. Three custom trays were constructed with spacer thicknesses representing 20%, 30% and 50% compression against the wall of the custom trays on removal, impressions recorded, and casts fabricated in dental stone. Measurements for elastic recovery of irreversible hydrocolloid were done using an internal caliper and a digital caliper. All measurements were done by the principal investigator. Non-parametric analyses were used for comparisons of the undercut values between the 3D printed and poured casts to determine the amount of elastic recovery of the irreversible hydrocolloid impression material.

**Results:** There was no statistically significant difference in measurements between the original 3D printed casts and the poured casts, irrespective of percentage compression ( $p > 0.05$ ).

**Conclusions:** In removable partial denture construction, casts should be blocked out parallel to the path of insertion and then an additional 3mm of spacer applied as a standard technique before custom tray fabrication to ensure elastic recovery of the irreversible hydrocolloid impression.

**Clinical implications:** In severe undercut situations, accurate impressions can be taken using irreversible hydrocolloid by blocking out all undercut surfaces on the teeth and lingual sulci before adapting additional three-millimetre wax spacer on casts when constructing custom trays thereby ensuring accurate and reliable impressions for removable prosthesis construction.

## 1. Introduction

Accurate master casts are fundamental to the successful rehabilitation of partially edentulous patients with removable partial denture (RPD) prostheses. One of the greatest challenges in the treatment of partially dentate patients is lack of fit of the RPDs [1]. Such RPDs will usually fit the master cast but not intraorally; this is an indication that the master cast may have been poured from an inaccurate impression. Irreversible hydrocolloid impression material is one of the most frequently used materials to record impressions for both acrylic and CoCr RPDs [2, 3]. Although irreversible hydrocolloid impression materials do not reproduce the finer details as accurately as elastomeric impression materials, they are considered sufficiently accurate for RPD construction [4].

Positional movement of teeth (such as drifting, tipping and over-eruption following extraction of adjacent teeth) can create severe teeth undercuts. The degree of positional movement accentuates the magnitude of undercuts in the partially dentate arches, especially in the posterior region of the mandible [5]. Distortion of irreversible hydrocolloid impressions due to the presence of severe tooth or tissue undercuts in the arch is one of several possible causes of an inaccurate impression and subsequent master cast [5, 6, 7].

Use of custom trays for definitive partial denture impressions has been described as best practice because the impression tray is designed to specifically fit the patient and thereby produce an accurate impression [2, 5, 8, 9]. However, there have been conflicting guidelines for providing appropriate spacer thicknesses in the custom trays for

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irreversible hydrocolloid impressions to avoid distortion; these range from 3 to 5 mm in thickness [4, 10, 11]. The wide variation in recommended spacer thickness does not account for the deeper mandibular lingual sulcus areas below the molar region, whereby the path of removal can also result in a large depth of irreversible hydrocolloid impression material being compressed to the side of the impression tray wall during removal, thereby causing tearing or distortion in the impression.

Accordingly, the aims of this study were to evaluate the elastic recovery of a typical irreversible hydrocolloid impression material in terms of the amount of undercut depth, and make recommendations on the thickness of spacer required when designing special trays for taking definitive irreversible hydrocolloid impressions for partially dentate mandibular casts in relation to undercut depths.

## 2. Materials & methods

Partially dentate Kennedy classification I, II & III mandibular dental stone casts ( $n = 100$ ) of adults aged 22–88 years that were being routinely used in the manufacture of RPDs were collected from the dental laboratory at the Faculty of Dentistry, University of Otago, New Zealand, under ethical approval for minimum risk health research reference no. HD18/029. Apart from sex and age, no personal identifying information was recorded.

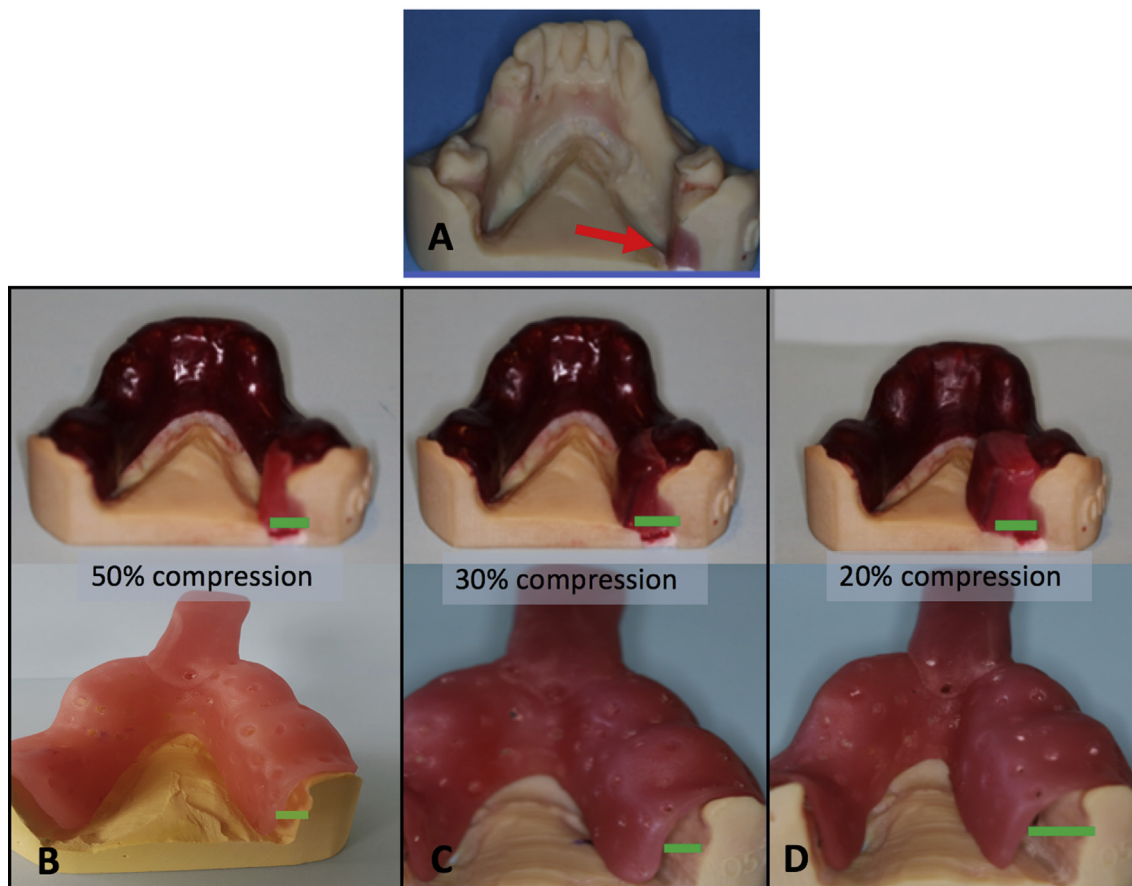
The mesial, distal and lingual undercut depths of all posterior teeth adjacent to the edentulous spaces, and the undercuts on the lingual sulci on the casts, were measured using a Williams periodontal probe positioned at 90° to the analysing rod of a Ney dental surveyor with the occlusal plane of the cast's remaining dentition being set parallel to the base of the surveyor. The largest undercut for each surface was recorded. A single examiner carried out all the measurement. The casts were then

scanned (AG Ceramill map400 system, Amann Girrbach, Austria) and data exported as STL files.

An inter-rater reliability study was conducted to verify the repeatability of the measurements. For this procedure, 10% ( $n = 10$ ) of the casts were picked at random and the undercuts re-measured by an independent observer. That examiner was unaware of the previous readings to eliminate possible bias. Undercuts on the mesial, lingual and distal surfaces of the abutment teeth were re-measured and the surface with the largest undercut was recorded. The same procedure was followed to measure the lingual sulcus undercuts on both sides of the arch on the cast.

The surveyed casts were categorized into eight groups according to the undercut depths (0.5mm, 1mm, 1.5mm, 2mm, 2.5mm, 3mm, 4mm and 5mm). Undercut depths of 3.5mm and 4.5mm were not recorded in any of the cast surveyed. One typical cast representing a lingual sulcus depth from each category was printed using a Stratasys Object30 Dental Prime 3D printer set at high quality of 16-micron (0.0006 in.) resolution with matte finish.

The 3D printed casts were surveyed, and the undercuts blocked out to create parallel surfaces on the teeth surface and lingual sulcus areas. A 3mm thickness of wax spacer as recommended by Anusavice et al [4], was adapted on all surfaces of the cast covering the teeth and extending to the lingual sulcus depth except the surface of the undercut on the lingual sulcus being investigated. For the lingual surface undercut being investigated, varying thicknesses of wax were adapted so that, for each category of undercut, there was 50%, 30% or 20% compression of irreversible hydrocolloid impression material against the side of the custom tray upon removal of the impressions from the casts. A combination of modelling wax (Metrodent Limited, United Kingdom) of 1.75mm thickness, boxing wax (Yeti Dental, Germany) of 1.5mm and preparation wax (Bego, USA) of 0.5mm and 0.6 mm wax was used to achieve the desired



**Figure 1.** (A) Shows parallel block out of the undercut on the original cast. (B to D) Shows the cast with an overall 3mm additional wax spacer to provide 20% (B), 30% (C) and 50% (D) compression of the impression material above the commensurate completed custom trays with the spaced area shown by the green coloured bar.

spacer thicknesses (Figure 1). The thickness of the spacer was confirmed using a Williams periodontal probe where applicable.

The thickness of the wax spacer for the intended compression of irreversible hydrocolloid impression material was calculated using the following equation:

$$\% \text{ Compression} = \frac{\text{UD}}{\text{UD} + \text{ST}} \times 100$$

(UD = Undercut Depth, ST = Spacer Thickness)

Custom trays were fabricated using 2.2mm thickness preformed sheets of light cured acrylic material, MP-Tray (Maga Physik, Germany). The trays were cured using a light curing polymerisation unit (Dentalux 2 Mega-Physik, Germany) for 5 min following the manufacturer's instructions. Tissue stops were incorporated, and the walls of the trays were perforated with 2 mm holes in a square grid pattern with 5 mm spaces to increase the mechanical retention. The trays were fully extended to the sulcus depth.

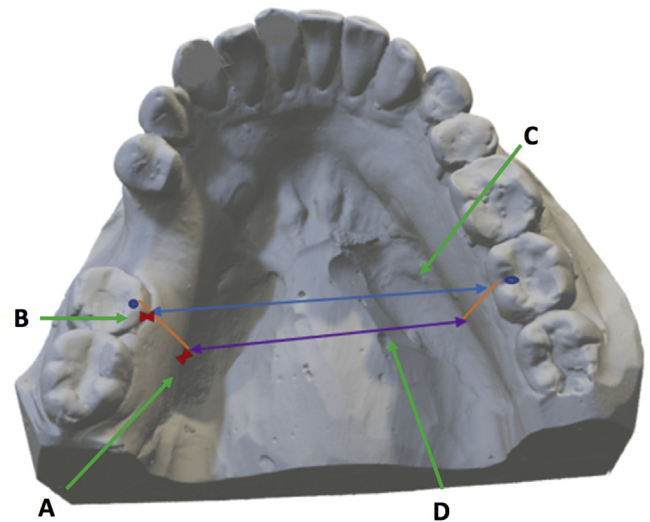
The custom trays were sprayed with irreversible hydrocolloid impression material adhesive (Dentsply Fix Adhesive, Dentsply, Germany) and left at room temperature for 3 min to dry before impressions were taken. The combination of perforations and tray adhesive was used to maximise retention of the impression material to the tray during removal over the undercuts. The irreversible hydrocolloid impression material (Aroma Fine plus Normal Set, GC Corporation, Japan) mixing was standardised by using an automatic mixing unit (Algimax II GX300, Monitex Industrial Co., Taiwan) for eight seconds using a water/powder ratio of 8.4g powder to 20ml of distilled water, conditioned to room temperature,  $\sim 23^\circ$ , as per the manufacturer's instructions. All impressions were placed in a sodium hypochlorite cross-infection control solution (HAZ Tab, Selles Medical Ltd., UK) for 5 min before being poured in dental stone to replicate typical clinical conditions. The impressions were poured using a vibrator with 160 g of Type III dental stone (Hinridur, Hinrichs Dental, Germany) and 48ml of distilled water dispensed from an automatic dispensing unit (Smartbox X2, Amann Girrbach, Germany) into a mixing bowl and mixed for 30 s using a vacuum mixing unit (Twister, Renfert, Germany). Casts were poured within 15 min of impression removal.

### 2.1. Measurements

Measurement were made on the poured casts and the 3D printed casts from which the impressions had been taken. The lingual groove of the abutment molars and lingual cusp tips of the abutment premolars were two reference points selected on the abutment teeth and marked on the casts. Lines were drawn on the casts from the lingual groove or the lingual cusps tip to the lingual sulcus depth of the abutment teeth on both sides of the arch (Figure 2). These lines were used as the third reference point and measurements were taken on and between these lines to establish: the lingual tooth undercut, the lingual sulcus undercut, the distance between the cervical margin of the abutment tooth on the right side and the cervical margin of the contralateral tooth on the left side and the distance between the lingual sulcus depth on the right side and the lingual sulcus depth on the left side. Three measurements were taken and recorded for each surface. An average value was calculated for statistical analysis. A 200mm internal caliper (Starrett 73A-4 Solid Nut Inside Spring Caliper, Starrett, USA) and a 150mm digital caliper (RS Pro 150mm Digital caliper 0.01mm, RS Components Ltd, UK) were used for the measurement.

### 2.2. Scanning electron microscopy

To evaluate changes in the irreversible hydrocolloid impression material structure, cryogenic scanning electron microscopy (SEM) was conducted to image the irreversible hydrocolloid impression material structure before and after being compressed at 25% and 50%. Auto-



**Figure 2.** Reference points used for measurements on the casts: (A) lingual sulcus undercut, (B) lingual tooth undercut, (C) Distance between the cervical margin of abutment tooth on the left and the cervical margin of the contralateral tooth on the right, and (D) distance between sulcus depth on the right and left.

mixed irreversible hydrocolloid impression material was filled into a 10ml syringe (BD, Singapore) which had the end cut off at the zero graduation on the Luer lock end, and allowed to set. The set irreversible hydrocolloid impression material was then extruded and cut into three 4mm long specimens. Two specimens were compressed, by inserting into the cut off end of a 20ml syringe (BD, Singapore) and pushing against a flat surface to compress the first specimen to the 2ml line (50% compression) and the second specimen to the 3ml line (25% compression) and held for 2 s. The third specimen was not compressed at all. The three specimens were then sectioned across the middle and a thin slice cut out from the centre area and placed in liquid nitrogen at  $-196^\circ\text{C}$  and stored overnight before being processed and sputter coated with palladium for insertion into the cryo-SEM. The irreversible hydrocolloid impression material was imaged to observe the normal and damaged polysaccharide polymer chains of the material.

### 2.3. Statistical analysis

Statistical analysis was performed using Statistical Package for Social Sciences Software (SPSS V20, IBM, USA). The comparison of elastic recovery of the three-compression irreversible hydrocolloid impression material impression poured casts with the master cast was done using non-parametric analyses (independent samples Mann-Whitney U test and Kruskal-Wallis test). The level of statistical significance was set at  $p \leq 0.05$ . Inter-rater agreement on undercut measurement was calculated using Cohen's Kappa.

## 3. Results

There was a strong inter-rater reliability agreement in terms of measurement of undercuts between the observer and the investigator, with a Cohen's kappa score of 0.85. Of the one hundred casts, 55% were from women and 45% were from men. There were 87 posterior edentulous spaces, involving a total of 149 premolars and 108 M. A total of 604 abutment teeth surfaces were measured to record the mesial, lingual and distal surface undercuts, and 200 lingual sulcus undercut surfaces (right and left side of the arch) were measured.

The undercut depth of the posterior teeth adjacent to the edentulous area ranged from 0mm to 5mm. The individual differences in three surfaces of the tooth undercut depth were statistically significant ( $p <$

**Table 1.** Teeth surface undercuts.

Side	Mean (mm)	SD (±)	95% Confidence Interval for Mean	
			Lower Bound	Upper Bound
Mesial	1.54	±0.93	1.38	1.70
Distal	0.73	±0.81	0.62	0.83
Lingual	1.34	±0.81	1.23	1.45

0.001) (Table 1). The mean teeth surface undercut was 1.15mm (SD ± 0.93mm).

The range of undercut values for premolar abutments was 0mm–3mm while it was 0mm–5mm for the abutment molar teeth. The overall test did not show a statistically significant difference in undercut depth across individual teeth (p = 0.649). There was statistically significant difference in terms of severity of tooth surface undercut compared by age (p = 0.01). There was no statistically significant difference in the distribution of undercut depth when compared by sex (p = 0.26).

The undercut depth of the lingual sulci also ranged from 0mm to 5mm and the mean value was 1.45mm (SD ± 1.41mm). The mean value for lingual sulcus undercuts on the right side was 0.92mm (SD ± 1.14mm) and for the left side was 1.61mm (SD ± 1.24mm). There was no statistically significant difference between left and right lingual sulcus undercut values (p = 0.46) (Figure 3).

There were no statistically significant differences in elastic recovery among the three (20%, 30%, and 50%) compression ratios for the casts produced from impressions taken with custom trays spaced with additional wax spacer (Table 2). The SEM analysis showed that, with greater compression of irreversible hydrocolloid impression material, there was greater tearing and snapping of the polysaccharide chains (Figure 4).

**4. Discussion**

This study was conducted to determine whether the depth of undercut and different compression rates had any effect on the accuracy of irreversible hydrocolloid impressions. Casts with a range of undercut depths and custom trays fabricated on these casts to compress the alginate by 20%, 30% and 50% were used for this investigation. Different devices have been used for measuring teeth dimensions and positions on the cast such as rulers, callipers, periodontal probes and more recently digital measures. The most commonly used instruments for measuring undercut depth are the Ney undercut gauges (Ney and Jelenko) which are available in three sizes: 0.25mm, 0.5mm, and 0.75mm. They are limited to the ideal depth of undercut required to retain a partial denture and not the maximum undercut available. For this study, a Williams probe was used since the undercuts being measured were larger than the

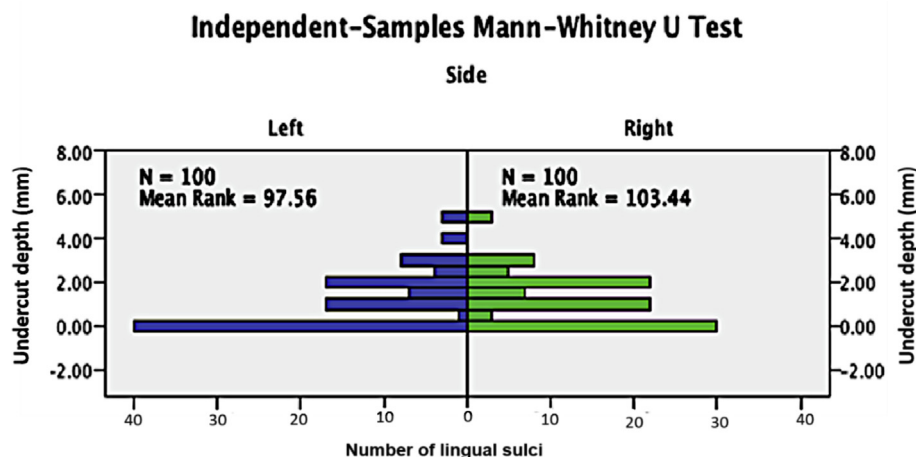
**Table 2.** Mean and Standard Deviation of the measurements on the casts.

Measurement surface	Cast	Mean (mm)	SD (mm)
Lingual Tooth undercut	Original	1.6	±1.2
	50% compression	1.4	±1.2
	30% compression	1.6	±1.2
	20% compression	1.5	±1.2
Distance between teeth	Original	35.2	±8.0
	50% compression	34.9	±7.95
	30% compression	35.2	±8.0
	20% compression	35.1	±7.9
Distance between lingual sulcus	Original	40.1	±5.1
	50% compression	39.6	±5.2
	30% compression	40.6	±5.2
	20% compression	39.6	±5.5
Lingual sulcus undercut	Original	2.1	±1.7
	50% compression	1.9	±1.4
	30% compression	2.1	±1.7
	20% compression	2.0	±1.5

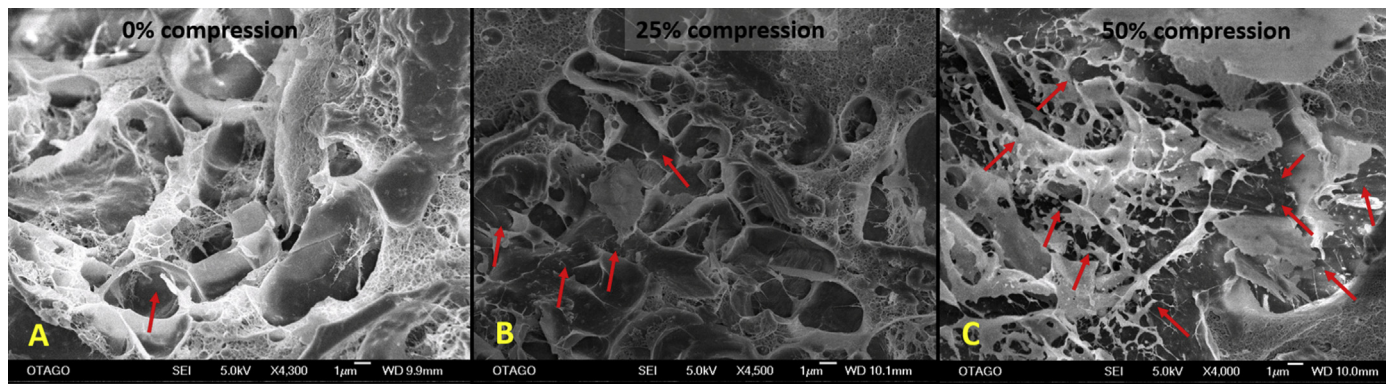
Ney undercut gauges. These measurements are important when assessing the capability of an impression to record undercuts, enabling the fabrication of accurately fitting prosthesis. The effect of undercuts on the accuracy of impression materials has been well reported.

The differences in the three teeth surface undercut measurements were statistically significant. The mesial surface showed the greatest measurement value followed by the lingual surface undercut. This finding confirms the greater magnitude of mesial and lingual post-extraction movement of the posterior abutment teeth, which is in accordance with previous publications [12, 13, 14, 15], which reported that mesial drift of teeth posterior to the edentulous space was prevalent in the mandibular arch. The lingual surface undercuts were greater than the distal surface undercuts. This is also consistent with the finding of Craddock et al. [13], that the mesial drift of teeth is associated with rotation hence the reason for greater lingual teeth undercuts when compared with distal tooth undercut.

There were significant differences in distribution of undercut depths by age. Studies have reported conflicting findings in relation to the rate of post-extraction tooth movement. Gragg et al. [16], reported that the greatest movement takes place within two years of teeth extraction and that the rate lessens after this period. Petridis et al. [17], reported that the post-extraction movement becomes substantial five years after tooth loss, and that age at the time of tooth loss is not significant. Petridis et al. [17], further reported that the rotation of abutment teeth increases after 11–20 years of tooth loss. It can therefore be assumed that the significant



**Figure 3.** Distribution of undercut on both sides of the lingual sulcus.



**Figure 4.** SEM images showing that the tearing and snapping of the polysaccharide chains increased with the increase in the amount of compression as indicated by the arrows (A) uncompressed, (B) 25% compressed and (C) 50% compressed alginate impression material.

differences in the distribution of undercut depth by age shown in this study are due to the wide variation in the rate of post-extraction tooth movement.

No differences were observed between the original casts and those poured from the different compression rate impressions when evaluating the elastic recovery of irreversible hydrocolloid impression material. There have been recent claims of improved dimensional stability as a result of improved techniques of production and sophisticated handling of the impression materials in terms of the water/powder ratio and the operating environ [18]. Thus, it may be assumed that the use of an automatic mixing unit with irreversible hydrocolloid impression material and an automatic dispensing unit to dispense the exact amount of dental stone and water (as recommended for every impression poured) may have positively influenced the very good recovery from deformation of the irreversible hydrocolloid impression material impressions in this study.

Our study findings contradict to an earlier investigation by Jasim et al., [7], which reported tearing of irreversible hydrocolloid impression material at a tooth inclination of 35° or a mesial undercut of 50%. In terms of the effect of distortion on the teeth, they reported a maximum distortion of 0.1mm which they stated was not statistically significant. These findings are also not consistent with those of Dubal et al. [6], which also found distortion of irreversible hydrocolloid impression material impression in the presence of undercuts. A possible reason for this difference is that the study by Jasim et al. [7], hand-mixed the irreversible hydrocolloid impression material, while the study by Dubal et al. [6], used a semi-automatic mixing unit (hand-held spatula in a mechanical rotating bowl - Dental Alginator II no. 25231), while our study used a fully automated mixing unit which resulted in a more homogenous mix and fewer air inclusions.

In our findings, the SEM images of irreversible hydrocolloid impression material compressed at the rate of 50% showed more snapping/tearing of the polysaccharide polymer chains than the 20% and uncompressed samples. However, our investigation did not record any significant differences in casts poured with impressions that were taken using custom made trays designed to compress the irreversible hydrocolloid impression material against the casts by 20%, 30% and 50%. It can be assumed that blocking out of undercuts parallel to the path of insertion and then adapting 3mm of spacer reduced the rate of compression of the irreversible hydrocolloid impression material against the casts and hence prevented distortion of impressions. The dimensional accuracy of irreversible hydrocolloid impression material impressions and casts is multifactorial, depending on the chemical composition, manipulative factors and environmental factor [18]. This study has not considered the composition of Aroma Fine Plus Normal Set irreversible hydrocolloid impression material but evaluated only the effects of the spacer thickness. However, the study was standardised by having a single investigator perform all procedures to reduce variations in manipulation.

There were some possible limitations of the present investigation that must be mentioned. The first was the possibility of human error. To limit this, three measurements were taken for each surface and an average value recorded for analysis. A conclusive evaluation is difficult to establish in this study findings since the in vitro experimental conditions do not always correspond to the clinical conditions. Impressions made under clinical conditions have the most practical value when determining the accuracy of casts.

The post-extraction positional changes of teeth affect the relative alignment of the crowns and roots of the teeth which may be involved in prosthodontic treatment. These positional changes can be sufficient to create complications in restorative treatments.

## 5. Conclusion

Within the limitations of this study, we conclude that there is no statistical difference in the mean elastic recovery of irreversible hydrocolloid impression material between the 20%, 30% and 50% compression groups. It can therefore be recommended that casts be blocked out parallel to the path of insertion and then 3mm of spacer be applied as a standard technique before custom tray fabrication in order to ensure elastic recovery of the irreversible hydrocolloid impression material impressions.

## Declarations

### Author contribution statement

Vidya Latchmi Mudliar: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Kai Chun Li: Analyzed and interpreted the data; Wrote the paper.

Ludwig Jansen van Vuuren: Conceived and designed the experiments; Wrote the paper.

John Neil Waddell: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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### Competing interest statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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