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# A comparison of the flexibility and fracture point of cast cobalt-chromium, milled cobalt-chromium, laser printed cobalt-chromium and milled Polyetherketoneketone partial denture clasps

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## ABSTRACT

Removable partial dentures (RPD) are a cost-effective way of replacing missing teeth. Acrylic RPDs can be used successfully, but those with metal frameworks are superior due to their increased strength, durability, retention, fit, longevity and decreased soft tissue coverage. Cast cobalt-chromium (CrCo) metal alloys have traditionally been used in RPDs, but have shortcomings. Metal may increase the weight and is inflexible, making it unsuitable for clasps on small teeth or those with deep undercuts. The casting process can result in unpredictable internal porosity, which can cause irreparable fracturing of the clasps. Furthermore, metal clasps in the aesthetic zone are unsightly. Polyetherketoneketone (PEKK) is a new-generation thermoplastic used in orthopaedic surgery to manufacture prosthetic components due to its desirable physical properties, ease of manufacture and tissue biocompatibility. It may also have possible dental applications if used with computer-aided design (CAD) and computer-aided manufacturing (CAM) processes to make RDP frameworks. Other advantages include good chemical resistance, desirable mechanical strength and flexibility, excellent abrasion resistance, flame resistance, antibacterial properties, and no backscatter, shadows or artefacts during conventional X-ray imaging or radiotherapy. It has flexibility and elasticity comparable to cortical bone, is lightweight and may be used in 3D imaging, printing and milling processes.



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**Author's contribution**

1. Charles Bradfield – primary author (50%)
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Disadvantages of PEKK are the costly CAD/CAM equipment and the material expense. This research compared the flexibility and fracture point of CrCo clasps with those made using CAD/CAM technology in either an additive (laser printed) or subtractive (milled) manner, and whether PEKK could be used as a metal-free alternative.


### Introduction

Removable partial dentures (RPD) are a relatively cost-effective way of replacing missing teeth. Although acrylic RPDs can be used successfully and are relatively cheap, they cover a lot of the mucosa, tend to accumulate plaque, are bulky and have the potential to cause gingival damage. Those with a metal framework, are superior due to their increased strength, durability, retention, fit, longevity and decreased soft tissue coverage.

Cast cobalt-chromium (CrCo) metal alloys are generally used in design and manufacturing. However, the fabrication process requires skilled laboratory technicians and expertise. Clinically, it is also very difficult to adjust. Thus, any misfits often require the entire framework to be re-made. This is both costly and time-consuming. Polyetherketoneketone (PEKK) is a new-generation thermoplastic material commonly used in orthopaedic surgery to manufacture prosthetic components due to its desirable physical properties, ease of manufacture and tissue biocompatibility. Advances have inspired research into the possible dental applications of PEKK in the technology of dental computer-aided design (CAD) and computer-aided manufacturing (CAM).

## 2. LITERATURE REVIEW

A removable partial denture (RPD) is a relatively cost-effective way of replacing missing teeth and supporting oral structures.[1] Although an acrylic RPD can be used, a partial denture with a metal framework is superior due to its increased durability, fit and longevity.[1,2] The metal frameworks have traditionally been designed and manufactured using a high-quality cast cobalt-chromium alloy. They provide stability, support and retention for the RPD and incorporate meshwork areas where artificial teeth and acrylic bases are attached.[1] It is fundamental that these bases are well designed according to biomechanical guidelines, aesthetic and functional needs, and fabrication principles. During the design process, the clinician needs to consider the physical

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properties of the base material, such as strength, flexibility and biocompatibility; the number, location, angulation and occlusal relations of remaining teeth; the anatomical shape and periodontal condition of potential abutment teeth; anticipated stresses and how best to distribute these across the arch; load transfer to hard and soft tissues; the fulcrum line and indirect retention; the occlusal scheme; inter-arch space; as well as the means of attaching the artificial replacement teeth to the denture base to enhance denture function and longevity.[3] The framework design must include clasps and their associated reciprocal elements, rests, major and minor connectors and saddle areas to obtain retention, stability and support for the prosthesis. Clasps serve as direct retainers by having a flexible tip that engages an identified undercut on the abutment tooth, providing retention and preventing denture displacement during functional movements such as chewing and speech.[3,4] It is important to ensure that the clasps do not place excessive stress on abutment teeth or become permanently distorted during use. Additionally, the entire clasp assembly must include other components, such as a reciprocal arm, a rest, a body and a minor connector, providing the six biomechanical requirements of retention, stability, support, reciprocation, encirclement and passivity.[1] The reciprocal elements prevent the clasps from placing undue pressure on the abutment teeth that could "orthodontically" move or loosen them.[3] The rests provide rigid tissue support preventing the denture from pressing tissue-ward during mastication and causing gingival damage.[3] Close adaptation and fit of the framework are essential to minimise tissue trauma and provide comfort to the patient at rest and during function. Precision in all stages of RPD framework fabrication is crucial to ensure an accurate and passive fit.[3,4] A further, often overlooked, factor to incorporate into the design is the use of guide planes and the path of insertion. These features aid in retention, impact the ease of denture seating and removal, and can help improve patient compliance with wearing and cleaning their prostheses. Further advantages of CrCo frameworks are their high strength and resistance to wear, corrosion and tarnishing.[3,4]

### 2.1 Disadvantages of CrCo RPD frameworks

There are specific problems related to CrCo alloys. While the material is strong, it is also relatively inelastic and inflexible, making it difficult to adjust its rigid clasps, rendering them and other minor connectors prone to fracture, especially under repeated dislodging forces. Re-soldering these portions to the major connector is not possible, often necessitating a denture/framework re-make. CrCo is also difficult to adjust if it does not have a near-perfect fit to the abutment teeth, which may lead to "rocking" of the base or gaps between the teeth. These gaps become food traps and promote plaque accumulation, making the teeth susceptible to caries development.

Despite these mechanical drawbacks, a study reported a five-year survival rate of well-designed CrCo RPDs at 96.4%, decreasing to 89.8% over 10 years.[2] As expected, the most common cause of failure was clasp fracture (16.1%), leading to loss of retention.[2] Reasons for the clasp fractures were attributed to the clasp design, especially where a clasp had a small cross-section or length yet engaged a deep tooth undercut, and possible areas of porosity in the material.[5] After 10 years of denture use, 23.1% of patients had at least one clasp fracture. In addition to these fractures, Behr *et al* (2012) also reported that the most common complications of CrCo-RPDs were carious lesions and loss of abutment teeth. They recommended finite element analyses or yield-strength tests to evaluate cast clasps' fatigue behaviour and identify improvement areas.[2]

If a clasp is lost, the retention and stability of the prosthesis are significantly compromised.[2] The consequences are increased mobility of the denture during function, leading to discomfort and, most likely, pain. Consequently, there is decreased patient compliance to wearing the RPD, loss of tooth structure due to wear, and soft tissue damage in the oral cavity.[2,6]

The CrCo metal alloys are potential allergens that can elicit a hypersensitivity immune reaction in the patient depending on their constituent base metals. The most commonly reported allergy is to nickel (Ni).[3,6] Furthermore, the silver colour of the metal-alloy frame can be unacceptable to some patients and may add to the overall weight of the dental prosthesis.[3] The metal-based RPDs must be removed during the acquisition of X-ray views as the metal causes backscatter. In addition, it cannot be worn over a period of time during and post radiation therapy as it may shield certain areas from receiving the total planned dose. Removing dentures for conventional dental imaging is not generally a significant problem or concern. However, in patients whose RPDs are part of a maxillofacial prosthesis, it may not be functionally practical – and/or aesthetically acceptable – to remove their appliances before and during each therapy session.

A further problem with CrCo RPDs relates to the manufacturing process itself. Several studies have reported high porosity in CrCo frameworks.[7,8,9] An example is gas-porosity, which develops during the casting process. It is believed that both oxygen and propane gases can be introduced into the frameworks.[10] Analysis of frameworks where the fractures were suspected to be due to porosity were reported in 10%-20% of cases five years after delivery and 27%-44% after 10 years.[11]

Future research into RPD frameworks needs to either identify alternative means of manufacturing the CrCo framework to reduce issues such as casting porosity and misfits or investigate newer materials that are easy to work with, economical, readily available to clinicians and/or technicians, do not invoke allergic reactions, have an aesthetic colour and are easy to adjust and repair.

### 2.2 Advances in the manufacture of removable partial dentures

Recent developments in dental technology have led to alternative methods to conventional casting for fabricating CrCo RPD frameworks. The two most promising advances are subtractive and additive manufacturing using CAD/CAM technology for design and manufacturing.[13] Additive 3D printing techniques include stereolithography (SLA), digital light projection (DLP), jet printing, fused deposition modelling (FDM) and selective laser melting (SLM), also referred to as "laser sintering".[13]

Within this new realm of production, Takaichi *et al* (2021) reviewed the latest status of the digital workflow of RPDs, including fabrication methods and material choices. They identified a variety of materials, such as CrCo alloys, titanium, zirconia and polyether ether ketone (PEEK), that could be used for CAD/CAM denture frameworks. Initial results indicated that the mechanical strengths of the CAD/CAM frameworks were superior to those of their cast

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counterparts. However, the fit and surface roughness of the frameworks and clasps fabricated using SLM were inferior to those conventionally cast. After analysing several studies and variables, they reported/suggested that the various CAD/CAM fabrication methods tested for RPD frameworks could offer numerous advantages over conventional casting techniques. They further indicated that digital workflow may help reduce the number of human errors.[14]

In addition to the previously discussed challenges with clasp fractures, Tannous *et al* (2011) also reported the aesthetic drawbacks of the CrCo metal shining through where clasps were placed in visible areas. Patients often found this metal display to be aesthetically unacceptable. Gold alloys have a higher yield strength and lower modules of elasticity than CrCo, making them less prone to fracture. They are also round in cross-section, making them ideal for use in Kennedy Class I distal extension situations. In addition, they are easy to repair, and many patients prefer the gold colour. However, gold is relatively more expensive than CrCo and is prone to permanent deformation after long-term use. The metal may also be too flexible to retain an RPD when placed in shallow undercuts. Frank *et al* (1981) suggested that the retentive force exerted on a tooth during denture dislodgement should ideally be between 3 and 7.5N.[18] Gold clasps seldom retain these desired levels.

Wrought wire clasps soldered onto the cast metal framework are more robust and less prone to plastic deformation than gold due to their higher modulus of elasticity. They are also round and thus can flex omnidirectionally, are relatively cheaper than gold, and are far more flexible than CrCo alloys. However, their use is limited due to their unaesthetic colour, and if the solder joint is too close to the origin of the clasp, the heat results in a "dead wire" that is not flexible and prone to fracture.[17]

In an attempt to address these clasping challenges, several possible solutions were proposed. One option was to etch the clasp arm and coat it with a layer of tooth-coloured resin. However, these resin layers fractured off very quickly due to the material having a different modulus of elasticity to the metal.[24] Some researchers suggested altering the clasp design to engage lingual undercuts for retention instead of proximal undercuts (also known as rotational path insertion).[16,19] The latter is only sometimes clinically possible. Others have experimented with thermoplastic resin clasps. However, they were generally found too flexible to provide the desired retention and were prone to permanent plastic deformation after a short wear period.[16,19] However, Tannous *et al* (2011) reported that the retention of properly designed Ackers resin clasps was sufficient for clinical use.[16]

The Ackers clasp, or the circumferential clasp or C-clasp, is a common component in removable partial dentures (RPDs). It is named after the dentist who described it and is widely used due to its simplicity and effectiveness in retaining the denture in place. The structure and design of this clasp consist of:
Arms: The Ackers clasp has two arms – one retentive arm and the other reciprocal arm. The retentive arm is designed to engage the undercut area of the abutment tooth, while the reciprocal arm stabilises the tooth and resists the forces applied by the retentive arm.

Rest: The clasp typically includes a rest, a small extension that sits on the occlusal surface of the tooth. This rest helps transmit occlusal forces along the long axis of the abutment tooth, thereby protecting the soft tissues and providing stability to the denture.

Proximal plate: The proximal plate is a flat surface that contacts the guide plane on the abutment tooth, providing additional stability and helping to prevent the denture from moving laterally.

In 2019, Tasaka *et al* reported the accuracy of the fit of clasps made using one of three new CAD/CAM technologies, namely a pattern framework which was invested and cast, a pattern framework that was computer numerically controlled and milled, and a pattern framework such as selective laser sintering. They found that selective laser sintering for clasp fabrication had an outstanding fit in accuracy and reproducibility during fabrication.[15]

Ongoing research into newer methods of CrCo clasp fabrication and alternative materials prompted the present study.

## 3. AIM

This study aimed to compare the flexibility and fracture point of partial denture clasps manufactured from cast cobalt-chromium (CC), milled cobalt-chromium (MC), laser-printed cobalt-chromium (LP) and Polyetherketoneketone (PEKK).

## 4. OBJECTIVES

The study objectives were:
1. To measure the flexibility of partial denture clasps manufactured from cast cobalt-chromium (CC), milled cobalt-chromium (MC), laser-printed cobalt-chromium (LP) and Polyetherketoneketone (PEKK) when engaging 0.25-, 0.5- and 0.75mm undercut depths.
2. To determine and compare the fracture points of each type of clasp.

## 5. MATERIALS AND METHODS

### 5.1 Study design

The researcher at the Oral and Dental Hospital at the University of Pretoria undertook a quantitative comparative laboratory study, with machine testing performed at the research institute of the Oral and Dental Hospital at the University of the Witwatersrand.

### 5.2 Sample number and sampling

The statistician recommended a minimum sample size of 10 clasps per group (40) to draw meaningful comparisons (Table 1). During production, more clasps than the minimum number required were produced – due to the size of the milling disk or table – thus allowing for possible miscasting. It was decided to include them all in the study rather than randomly selecting 10 samples. This accounted for the different sample numbers across all 4 categories and this was considered during the statistical analyses.

| Group | Material | Method of manufacturing | No |
|---|---|---|---|
| Cast CrCo (CC) | CrCo | Cast | 14 |
| Milled CrCo (MC) | CrCo | Milled | 11 |
| Laser-printed CrCo (LP) | CrCo | Laser printed | 16 |
| Milled PEKK (PEKK) | PEEK | Milled | 15 |

**Table 1:** The four groups of clasps that were compared

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### 5.3 Design of clasps

Frasaco models (Franz Sachs & Co, GmbH DD7992, Tettnang 14, Germany) are widely used in dental preclinical teaching and training. They have replaceable, average-sized, anatomically correct plastic teeth. In this study, one Frasaco maxillary first premolar was selected for clasp design and fabrication. This tooth has been used in several previous studies; thus, standardisation would allow for comparisons.[16,19] This tooth has the following dimensions: a mesio-distal length of 7.0mm and a bucco-lingual width of 9.0mm. The plastic tooth was mounted in an acrylic resin base for scanning and manufacturing. The mounted Frasaco premolar was scanned using the InEos-X5 (Sirona Dental Systems GmbH, Germany) according to the manufacturer's instructions. The scan was then imported into the CAD software of Inlab-18 (Figure 1).

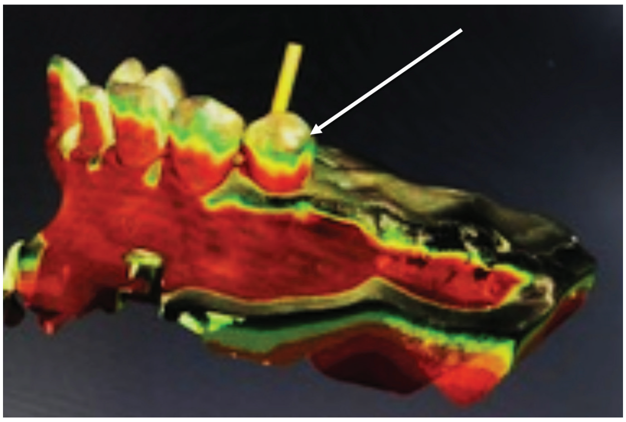

**Figure 1:** A representation of a scan of a mounted Frasaco premolar (indicated by the white arrow) using the InEos-X5.

A circumferential clasp was digitally designed using the InLab-18 software under the framework design mode. (Sirona Dental Systems GmbH, Germany) (Figure 2).

**Figure 2:** A digital representation of the final clasp, designed using the InLab-18.

The clasp comprised a retentive arm, a reciprocal arm, an occlusal rest, a body and a minor connector (in this case, it was a straight arm for mounting and testing purposes). The retentive arm's geometric design was 7mm long, 2mm thick and half-round in cross-section. The tip engaged a mesio-buccal point with a surveyed undercut of 0.25mm. This digitised design was exported as a Standard Triangle Language (STL) file.

### 5.4 Manufacture of samples

#### 5.4.1 Cast CrCo

The cast clasps (CC) were waxed-printed in castable wax patterns. These wax patterns were invested and heat-treated conventionally during standard pattern casting. The heated investment (lost wax technique) was used conventionally in CrCo (Verabond), as seen in Table 2. Conventional flame casting was performed in a laboratory using a propane gas and oxygen combination and a centrifugal casting machine to produce the cast clasp.

#### 5.4.2 Milled CrCo

For the milled clasps (CM), the clasp design (Figure 2 ) was exported as an STL file from the InLab-18 software. Each clasp was milled on the M4 wet, heavy metal milling unit (Zirkonzahn gmbh) using a Chrome-Cobalt CAD/CAD disk of 98.5mm by 16mm (Table 2).

#### 4.5.3 Printed CrCo

Similarly, for the laser-printed clasps (LP) the same clasp design (Figure 2) was exported as an STL file from the InLab-18 software. Each clasp test specimen was prepared and heat-treated as prescribed by EOS. Sixteen specimens were manufactured in an EOSINT M280 Direct Metal Laser Sintering (DMLS) table bed (EOS EOSINT M280-200W laser powder bed). The stress relieving protocol was carried out using a Nabertherm LH120/12 furnace, while the solution annealing was carried out using a Zubler Vario Press 300 EZR dental furnace. After the respective heat treatments, the specimens were machined to ASTM E8 specifications.

#### 4.5.4 PEKK

For the milled PEKK clasps, the same clasp design was exported to InLab-18 as an STL file for the CM and used in the milled CrCo group (CM), and was exported again and milled on the M4 machine. However, a different material, namely Pekkton® ivory (Table 2), was used. Pekkton is a high-performance polymer (HPP). It is the next generation of HPP with 80% higher compressive strength than Polyetheretherketone (PEEK) polymer milled on a disk with the exact dimensions of 98.5mm by 16mm.

| Trademark | Composition | Manufacturers |
|---|---|---|
| Verabond® | Nickel* - 68-80%<br>Chrome - 14%<br>Molybdenum - 8.5%<br>Other** | VeraBond; Aalba Dent Inc, Cordelia, Ca, USA |
| Cocronit Superior | Chrome - 65%<br>Chrome - 28%<br>Molybdenum 6%<br>Other** | Zirkonzahn srl, Gais – ITALY |
| CrCo alloy | CrCo alloy*** | Electro Optical Systems GmbH (EOS) |
| Pekkton® ivory | Polyetherketoneketone | Cendres + Métaux, SA, Switzerland |

**Table 2:** Chemical composition from the manufacturer. *The Ni quantity varies from 68% to 80% for NiCr alloys. **Remaining low concentration below 1% of the constituents is not specified and listed as "other". ***CrCo supplier[23]

### 5.5 Finishing off of clasps

All metal clasps were finished off under laboratory conditions in a standardised manner by the same technician as follows:

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Each clasp was trimmed with *Dedeco® Ultra-Thin Separating Discs, 7/8*" (Dedeco International, Inc.11617, State Route 97, Long Eddy, NY 12760). All surfaces were then abraded with airborne alumina particles (Danville Aluminum Oxide 50 Micron Aluminum Oxide Medical Grade Alpha) of a diameter of 50µm, applied at a pressure of 0.25 Mpa for 30 seconds using a Renfert Sandblaster (Renfert USA).

The PEKK clasp sprue were finished off under laboratory conditions in a standardised manner by the same technician as follows: Each clasp was trimmed with *Dedeco® Ultra-Thin Separating Discs, 7/8*" (Dedeco International, Inc.11617, State Route 97, Long Eddy, NY 12760).

### 5.6 Inspection of samples

Each clasp from all four groups was viewed under a Zumax dental microscope at 12 times magnification (Zumax Medical, 5 Zhiying Street, Suzhou New District, China) to check for fabrication errors or miscastings. In addition, the distance between the tip of the retentive arm and the tip of the reciprocal arm of each sample was measured using an LCD 6"/150mm digital Vernier calliper micrometre gauge (Daniu 6 inch 0-150mm 0.01mm digital calliper stainless steel electronic vernier callipers). This measurement isolated clasps where deformities could have occurred during manufacturing. None was found in any of the test groups.

### 5.7 Sample testing

Tests were carried out to determine the flexibility and fracture point of each sample. Each clasp underwent tests to determine the following:

1. Force (KgF) at the following designated deflection points: 0.25-, 0.5- and 0.75mm
2. The load (N) at the limit of elastic behaviour and the beginning of plastic behaviour: (recorded as Yield strength)
3. The load (N) at the point of fracture (recorded as tensile strength).

An INSTRON 3382 (Instron Corporation, Norwood, MA, USA) was used. The local distributor performed calibration, and training was provided to the user.

A load cell of 2000N was used during the sample testing. Each clasp was placed under a force measured in Newtons (N) and the amount of deflection was measured in millimetres. The data was recorded on an Excel (Microsoft) document operated by the JJ Lloyd tensile tester. The Excel document was exported and stored as the University of Pretoria recommended.

Descriptive analysis was calculated using SPSS statistical software (IBM, SPSS Inc. Volume 27). Table A1 shows the detailed descriptive analysis at different deflection (DEF) values of 0.25mm (DEF25), 0.5mm (DEF50) and 0.75mm (DEF75) . Maximal load (MAX-L) at yield point with maximal extension in millimetres (EXT-MM) before maximal load (TS-MXLOAD) were measured as well as tensile strength at fracture point (TS-MM). One sample statistic was used to determine the mean with Standard deviation (SD) and Standard deviation error (SE). The 95% Confidence Interval of the difference was calculated according to the lower and upper values. KST was used to determine the normality of the data distribution. Shapiro-Wilk (SW) was used to determine abnormal KST data for normality.

Only seven statistically significant different measurements were noted (KST) with PM at (MAX-L), CC, CM and PM at (EXT-MM), PM at (TS-MXLOAD) and CC, CM at (TS-MM).

## 6. RESULTS

Data was put into an Excel (Microsoft Excel) format. Scatter plots were created to identify any wayward values and implausible data elements to ascertain the accuracy of the data. While there was a wide range in values for specific materials and measurements, no elements were considered too questionable to justify omitting them from the study.

The results were analysed using a one-way analysis of variance with a least square difference post hoc comparison depending on the normality of the data. In case of discrepancies, the relative non-parametrical test was used. Findings were then compared with results reported in the literature from similar studies. This study determined the mean forces at the deflection points for each undercut depth and the standard deviation (SD), the clasp yield strength and force at fracture (Table 3). Data were subjected to Whisker and half-box analyses to illustrate the spread and minimum and maximum values at each undercut depth (figures 3, 4 and 5).

## 7. DISCUSSION

At 0.25mm undercut, the LP required the lowest force to deflect of the two metal clasps with the lowest SD (1.30). This indicates it needed the least force to disengage from the shallow undercut. As the undercut rose to 0.5mm, the cast clasps (CC) required larger disengaging forces. However, the milled clasps (CM) was now the lowest of the two metals, but both CC and CM had an increase in SDs compared to the LP. An interesting finding at the 0.75mm undercut was that the disengaging forces for both CC and CM were slightly less than those needed for the 0.5mm undercut. This was attributed to some material weakening (yield strength) that

**Table 3:** Results of findings. *Measurements in Newtons (N). **Measurements in value. ***Measurements in millimetres (mm).

| Samples | Mean Force* at deflection points (mm) and Standard Deviation (SD)** | | | Yield strength* | Deflection mm*** (SD)** | Force* at fracture point |
|---|---|---|---|---|---|---|
| | 0.25 | 0.5 | 0.75 | | | |
| CC | 9.70 (2.83) | 11.80 (5.83) | 10.65 (6.19) | 13.35 | 0.57 (0.86) | 424.91 (45.47) |
| CM | 7.72 (4.09) | 8.86 (5.45) | 8.19 (6.27) | 10.15 | 0.51 (0.74) | 323.13 (55.77) |
| LP | 6.77 (1.30) | 10.60 (2.73) | 11.93 (4.33) | 14.54 | 1.03 (0.12) | 462.87 (33.45) |
| PEKK | 0.58 (0.09) | 0.88 (0.18) | 1.09 (0.34) | 1.42 | 1.31 (0.13) | 45.10 (4.15) |

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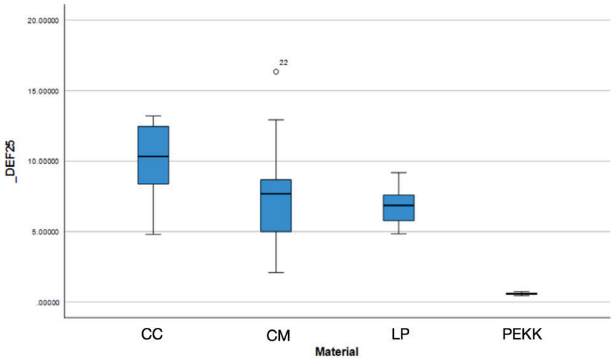


**Figure 3:** Whisker and half-box analysis at 0.25mm undercut depth.

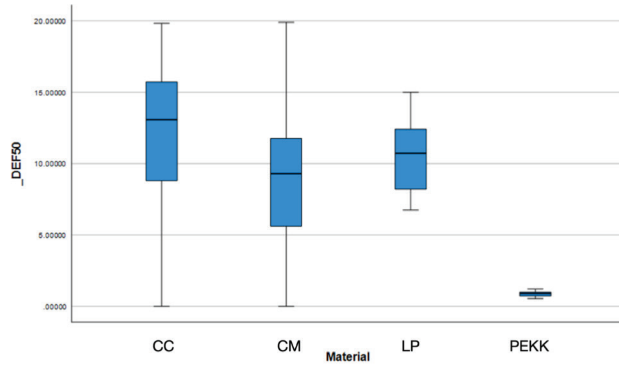


**Figure 4:** Whisker and half-box analysis at 0.5mm undercut depth.

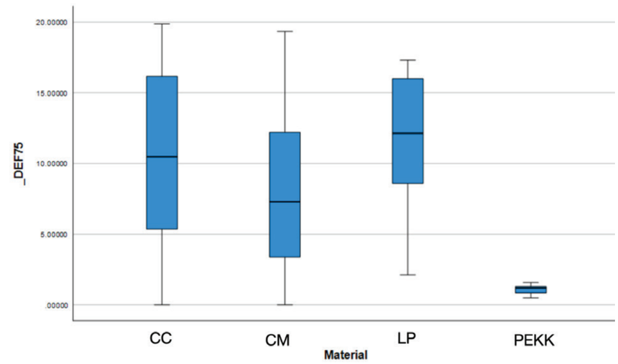


**Figure 5:** Whisker and half-box analysis at 0.75mm undercut depth.

may have already occurred when stretched over the 0.5mm undercut. PEKK was too flexible to be of value for adequate retention, as the literature recommends a disengaging force of at least 5 and 10N to be necessary for the adequate functioning of RPDs.[20,21] Its values ranged from 0.58N to 1.09N. The outstanding feature was that the material was consistent and disengaging values were progressive up to the yield point (Table 3).

The spread between minimum and maximum values (the Whisker and half-box analysis) at 0.25mm undercut was the smallest of the three clasps with the LP value at (4.34) followed by CC (8.39) and CM (14.24). The values for the LP were the most repeatable, while the CM were very inconsistent. The minimum to maximum value of PEKK was extremely low (0.30), but the positive feature was that this material produced repeatable and reliable results (Figure 3). The Q1 to Q3 spread of the materials (blue boxes) is more relevant, as it talks about the consistency of measurements. Once again, the PEKK was most consistent. However, the values were too low for consideration (0.10) in this discussion. The CP box spread was the smallest (1.40), followed by CC (3.56) and then CM (5.50). The latter proves to be the most inconsistent within the sampling.
The spread between minimum and maximum values (the Whisker and half-box analysis) at 0.5mm undercut showed that LP was once again the smallest of the three metal clasps, from CP (8.26) and substantially larger value with CC (19.83) and CM (19.89). This indicates that LP performance was the most consistent of the metal clasps. The minimum to maximum value (the Whisker and half-box analysis) of PEKK was extremely low (0.67), indicating the best repeatable and reliable sampling of the complete group (Figure 4). These values (0.5mm undercut) are higher than the 0.25mm undercut values, indicating reliability decreases as undercut depth increases. The Q1 to Q3 spread of the materials (blue boxes) was again consistent but lower for the PEKK (0.21). The LP box spread was still the smallest (2.91), followed by CC (7.20) and then CM (7.33). Again, these values are larger than at the 0.25mm undercuts.

The spread between minimum and maximum values (the Whisker and half-box analysis) at 0.75mm undercut was even wider for all materials at this depth but still the smallest of the three metals clasps for the LP (15.17). It changed, and CM was higher (19.32), followed by CC (19.86). Even though the values recorded for the LP were the most uniform of the three, none of these figures would be clinically acceptable for consistency. The minimum to a maximum value of PEKK was again the lowest (1.12); however, it had now increased from the previous 2 depths (Figure 5). The Q1 to Q3 spread of the materials (blue boxes) rose in all the CrCo samples, but more so for the LP (4.62), followed by CC (7.29) and then CM (8.43). Thus at 0.75mm deflection, all three CrCo sample materials are very inconsistent in behaviour.

Based on these figures, it is clear that the more the CrCo clasps are deflected (ie the deeper the undercuts), the less reliable they become in predicting disengagement values and the less consistent the materials between clasps of the same material.

When considering yield strength, the highest values were in the LP (14.54), followed by the CC (13.35) and then CM (10.15). This indicates that the CM was the weakest of the three regarding plastic deformation characteristics. The PEKK deformed at only (1.42), again a figure that makes it unsuitable for clinical use in dentures as clasps.

As seen in Table 3, the point of interest was that the CC experienced its yield strength limit at 0.57mm and the CM at 0.51mm, below the tested and commonly used undercuts of 0.75mm. The LP, however, yielded at 1.03mm, making it the most suitable material if a deep undercut is to be engaged.
The force at the fracture point was highest for LP (462.87N), followed by CC (424.91N), then CM (323.13N). The latter was much weaker than the CP and CC. Bonferroni post hoc contrast analysis indicated CC and LP significance level (0.014) at 0.25mm undercut (Table 4 appendix). These figures are similar to those reported by Jabbari *et al* (2014).[22] Once again, the PEKK was too weak to be considered of value for clasp retention and had a low fracture value of 45.10N. These results are from clasps that were manufactured as single units.

Tasaka *et al* (2019) did a similar study looking at the accuracy of fit of clasps fabricated using similar techniques and design.

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They found that the best fit for all three fabrication procedures was at the rest area, with the worst fit being at the clasp tip site. This is expected as the tips are much thinner – thus more prone to distortion during manufacturing than the rest areas where there is a greater bulk of the material. However, the flaw in their study and the present one is that all clasps were made as isolated (single) units, whereas in reality they will be part of a much larger framework. Based on the framework design and fabrication method, larger discrepancies and inconsistencies between assembly areas could exist.

The results of the PEKK were not surprising and in agreement with those found by Sykes *et al* (2002), who concluded that these technopolymers materials were too flexible to provide adequate retention in removable partial denture frameworks. However, their elasticity and fracture resistance are valuable properties and may be of benefit in other dental situations.

One area of interest is for patients with extensive maxillofacial defects due to trauma, cancer or surgery. They often present with teeth that have been widely displaced or splayed due to the trauma, tumour growth or surgery and are subsequently divergent/convergent in orientation. In addition, some who have had facial reconstruction using osseointegrated implants, particularly zygomatic implants, also often present with implants that emerge along various orientation lines. Both these scenarios pose challenges in identifying a suitable path of insertion for the prosthesis and in designing and fabricating a denture capable of clasping the teeth/implants. Conventional CrCo, wrought wire and even gold clasps cannot flex beyond a specific limit before being permanently deformed or fractured (as seen by the results of this study). However, the PEKK, having a much higher yield strength and elasticity, is anticipated to be able to flex over the teeth and implants and still maintain adequate retentive forces to help retain a prosthesis. Given its degree of elasticity, it may also be possible to use it in flange areas instead of hard acrylic resin to engage soft tissue undercuts without placing any excessive force or causing trauma to these compromised tissues. The salient properties of PEKK are that it's flexible, lightweight, easily adjustable (as tumours grow or tissues heal), easy to clean and biocompatible. It is visible on X-ray, yet being non-metallic, the prostheses made using this material can be worn by patients during radiography or radiotherapy procedures, as it does not interfere with the radiation beams, nor cause scatter or shadows that will render the images of no diagnostic value or interfere with dose delivery.

## 8. CONCLUSIONS

Laser-printed cobalt-chromium clasps represent a newer technological advancement, showcasing promising results in retention with little metal deformation at critical undercut sizes of 0.25mm up to 0.75mm. The additive manufacturing technique allows for intricate designs and patient-specific adjustments, although further research is needed to ascertain their long-term performance and biocompatibility. Cast cobalt-chromium clasps exhibit a well-established balance between flexibility and fracture resistance, and they remain a reliable choice for partial denture applications. However, the traditional casting process may lead to slight variations in retention of different depth of undercut and indicate only good properties at the 0.25mm depth. As the undercut increases to 0.75mm, material fatigue sets in. This was attributed to some material weakening that may have already occurred when stretched over the 0.5mm undercut. Milled cobalt-chromium clasps performed the worst as clasp retention units. Milled Polyetherketoneketone clasps may provide a non-metal alternative with inherent biocompatibility and lightweight characteristics. These clasps offer remarkable flexibility and fracture resistance, potentially minimising trauma to compromised abutment teeth. However, their relatively recent introduction may require continued investigation into their durability and clinical feasibility.

### Study limitations

Random errors in recording measurements may occur and are unpredictable. The following methods were planned to reduce errors. The investigator aimed to limit the effect of random errors by including the largest sample permitted by the available data. A scatter plot was used to assess any wayward values, which was investigated for accuracy.

Computer-aided design/computer-aided manufacturing (CAD/CAM) technologies' stability and accuracy are used under manufacturing specifications. The framework fabrication is under computer-controlled subtractive manufacturing (SM) stability and accuracy.

Follow-up studies will thus be required to test the clasps' separating cycles, PEKK's repairability and the bonding properties of PEKK to acrylic. In the current study, only the clasp design on premolars was investigated. As other teeth are also used for retentive purposes, in particular molars, further studies must be undertaken to evaluate clasps used on other teeth considering the differences in the diameter and length of the clasps to be used.

### Ethical considerations

This research protocol was approved by the Research Committee (RESCOM) of the School of Dentistry, Faculty of Health Sciences, University of Pretoria and the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria. Data was collected and stored according to university regulations, and all necessary permissions were gained before the research commenced.

## 11. DECLARATION OF INTEREST

The researcher declares that he teaches and trains CAD-CAM software (Dentsply Sirona Johannesburg, South Africa). The researcher and co-authors of this study declare no other interests regarding the materials, technology or equipment used in conducting this research.

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**Table 4:** Descriptive analysis.

| | | | | | | | | 95% CI | | | | | P-Sig | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample | N | Min | Max | Median | X | SD | SE | L | U | Skew | Kur | KST statistic | KST | SW |
| CC_DEF25 | 14 | 4.81 | 13.20 | 10.34 | 9.71 | 2.84 | 0.76 | 8.07 | 11.35 | -.574 | -0.817 | 0.148 | 0.200* | 0.151 |
| CC_DEF50 | 14 | 0.00 | 19.83 | 13.08 | 11.80 | 5.83 | 1.56 | 8.43 | 15.17 | -.667 | -0.060 | 0.127 | 0.200* | 0.540 |
| CC_DEF75 | 14 | 0.00 | 19.86 | 10.48 | 10.66 | 6.19 | 1.65 | 7.08 | 14.23 | -.181 | -0.749 | 0.132 | 0.200* | 0.609 |
| CC_MAX_L | 14 | 5.48 | 21.71 | 13.37 | 13.35 | 5.35 | 1.43 | 10.26 | 16.44 | .011 | -1.155 | 0.125 | 0.200* | 0.532 |
| CC_EXT_MM | 14 | 0.13 | 1.14 | 0.48 | 0.57 | 0.32 | 0.086 | 0.38 | 0.75 | .988 | -0.059 | 0.267 | 0.008 | 0.014 |
| CC_TS_MXLOAD | 14 | 174.32 | 690.95 | 425.58 | 424.91 | 170.12 | 45.47 | 326.69 | 523.14 | .011 | -1.155 | 0.125 | 0.200* | 0.532 |
| CM_DEF25 | 11 | 2.10 | 16.35 | 7.70 | 7.73 | 4.10 | 1.23 | 4.97 | 10.48 | .892 | 0.814 | 0.197 | 0.200* | 0.520 |
| CM_DEF50 | 11 | 0.00 | 19.89 | 9.30 | 8.87 | 5.45 | 1.64 | 5.20 | 12.53 | .474 | 0.520 | 0.162 | 0.200* | 0.899 |
| CM_DEF75 | 11 | 0.00 | 19.32 | 7.31 | 8.19 | 6.28 | 1.89 | 3.98 | 12.41 | .641 | -0.761 | 0.152 | 0.200* | 0.361 |
| CM_MAX_L | 11 | 3.54 | 20.04 | 9.31 | 10.15 | 5.81 | 1.75 | 6.25 | 14.06 | .724 | -0.883 | 0.188 | 0.200* | 0.135 |
| CM_EXT_MM | 11 | 0.07 | 1.10 | 0.53 | 0.51 | 0.25 | .075 | 0.35 | 0.68 | .897 | 3.870 | 0.284 | 0.013 | 0.030 |
| CM_TS_ MXLOAD | 11 | 112.80 | 637.92 | 296.41 | 323.13 | 184.98 | 55.77 | 198.86 | 447.40 | .724 | -0.883 | 0.188 | 0.200* | 0.135 |
| CP_DEF25 | 16 | 4.85 | 9.19 | 6.86 | 6.78 | 1.31 | 0.33 | 6.08 | 7.48 | .105 | -0.503 | 0.141 | 0.200* | 0.396 |
| CP_DEF50 | 16 | 6.74 | 14.99 | 10.73 | 10.61 | 2.73 | 0.68 | 9.15 | 12.07 | .280 | -1.062 | 0.122 | 0.200* | 0.271 |
| CP_DEF75 | 16 | 2.13 | 17.30 | 12.14 | 11.93 | 4.34 | 1.08 | 9.62 | 14.24 | -.649 | -0.037 | 0.127 | 0.200* | 0.341 |
| CP_MAX_L | 16 | 7.65 | 20.61 | 15.73 | 14.54 | 4.20 | 1.05 | 12.30 | 16.78 | -.247 | -1.341 | 0.170 | 0.200* | 0.298 |
| CP_EXT_MM | 16 | 0.37 | 1.78 | 0.93 | 1.03 | 0.47 | 0.12 | 0.78 | 1.28 | .445 | -0.922 | 0.134 | 0.200* | 0.190 |
| CP_TS_MXLOAD | 16 | 243.63 | 656.18 | 500.79 | 462.87 | 133.79 | 33.45 | 391.58 | 534.16 | -.247 | -1.340 | 0.170 | 0.200* | 0.299 |
| PM_DEF25 | 15 | 0.45 | 0.75 | 0.58 | 0.58 | 0.09 | 0.02 | 0.53 | 0.64 | .055 | -0.551 | 0.116 | 0.200* | 0.730 |
| PM_DEF50 | 15 | 0.54 | 1.21 | 0.91 | 0.88 | 0.19 | 0.05 | 0.78 | 0.99 | -.025 | -0.649 | 0.111 | 0.200* | 0.955 |
| PM_DEF75 | 15 | 0.48 | 1.60 | 1.21 | 1.09 | 0.34 | 0.09 | 0.90 | 1.28 | -.434 | -0.823 | 0.169 | 0.200* | 0.341 |
| PM_MAX_L | 15 | 0.70 | 2.13 | 1.60 | 1.42 | 0.50 | 0.13 | 1.14 | 1.70 | -.333 | -1.494 | 0.193 | 0.136 | 0.066 |
| PM_EXT_MM | 15 | 0.50 | 1.89 | 1.40 | 1.31 | 0.48 | 0.13 | 1.04 | 1.58 | -.401 | -1.505 | 0.232 | 0.030 | 0.058 |
| PM_TS_ MXLOAD | 15 | 22.17 | 67.73 | 50.72 | 45.10 | 16.08 | 4.15 | 36.20 | 54.01 | -.333 | -1.494 | 0.193 | 0.200* | 0.069 |

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**Table 5:** Bonferroni post hoc contrast analysis.

## 15. APPENDIX

| Deflection | Sample | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| DEF-25 | 1 | | | P= 0,014 | P=<0,001 |
| | 2 | | | | P=<0,001 |
| | 3 | P= 0,014 | | | P=<0,001 |
| | 4 | P=<0,001 | P=<0,001 | | |
| DEF-50 | 1 | | | | P=<0,001 |
| | 2 | | | | P=<0,001 |
| | 3 | | | | P=<0,001 |
| | 4 | P=<0,001 | P=<0,001 | P=<0,001 | |
| DEF-75 | 1 | | | | P=<0,001 |
| | 2 | | | | P=<0,001 |
| | 3 | | | | P=<0,001 |
| | 4 | P=<0,001 | P=<0,001 | P=<0,001 | |
| MAX-L | 1 | | | | P=<0,001 |
| | 2 | | | | P=<0,001 |
| | 3 | | | | P=<0,001 |
| | 4 | P=<0,001 | P=<0,001 | P=<0,001 | |
| EXT-MM | 1 | | | P= 0,009 | P=<0,001 |
| | 2 | | | P= 0,011 | P=<0,001 |
| | 3 | P= 0,009 | P= 0,011 | | |
| | 4 | P=<0,001 | P=<0,001 | | |
| TS-MXLOAD | 1 | | | | P=<0,001 |
| | 2 | | | | P=<0,001 |
| | 3 | | | | P=<0,001 |
| | 4 | P=<0,001 | P=<0,001 | P=<0,001 | |
| TS-MM | 1 | | | P= 0,023 | P=<0,001 |
| | 2 | | | P= 0,030 | P=<0,001 |
| | 3 | P= 0,023 | P= 0,030 | | |
| | 4 | P=<0,001 | P=<0,001 | | |



# CPD questionnaire on page 54

The Continuing Professional Development (CPD) section provides for twenty general questions and five ethics questions. The section provides members with a valuable source of CPD points whilst also achieving the objective of CPD, to assure continuing education. The importance of continuing professional development should not be underestimated, it is a career-long obligation for practicing professionals.