A NOVEL DENTAL BRIDGE DESIGN

A thesis submitted to the University of Manchester for the degree of Master of Philosophy in the faculty of medical and human sciences

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AHMED BINOBAID

SCHOOL OF DENTISTRY
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Abstract

Introduction: Various improvements have been accomplished in order to provide a better solution for the restoration of missing teeth, but with limited success. Fixed bridges have been considered one of the most effective dental treatments for partially edentulous patients; however, a major disadvantage of fixed bridges is the aggressive reduction of the healthy natural abutment teeth. Another disadvantage of dental bridges is associated with the use of dental cements as they have issues regarding their relatively low strength and varying level of solubility. Accordingly, a new fixed bridge that is conservative for the abutment teeth and retained without using any cement was introduced in this study. Aims: The aim of this study is to produce a new fixed partial denture design with minimum abutment teeth reduction. The purpose of this in vitro study was to evaluate the maximum tensile force required to dislodge the conventional three-unit fixed partial denture, and to accordingly compare it with a new fixed bridge design. The obtained new bridge design should be fixed using mechanical force rather than chemical force. It has four clasps, each of which will be engaged into the prepared abutment teeth. Materials and Methods: Forty (40) extracted human teeth (20 second premolar, 20 second molars) were collected. A three-unit bridge case was then simulated by mounting one second premolar and one second molar in acrylic resin blocks, leaving the space of the first molar missing. Twenty (20) acrylic blocks were constructed and divided into two groups (n = 10). Teeth preparations were preformed according to each group criteria and with the objective to restore the missing first molar. Following, the prostheses were fabricated and casting was made in cobalt-chromium alloy. The metal frameworks on the first group (conventional three-unit FPDs) were cemented with zinc phosphate cement, and metal frameworks on the second group (new FPD designs) were fixed directly to the prepared teeth without the use of any cement. The specimens were then subjected to tensile loading at a cross-head speed of 0.5 mm/min in a universal testing machine. The mean separation forces in Newtons were recorded and statistically analysed with the application of a one-way analysis of variance (ANOVA). Results: The mean (SD) value of the maximum tensile force required for dislodging the conventional three-unit FPD frameworks were 170.97N (21.09) and for the new FPD framework were 387.80N (22.21). Conclusion: The conventional three-unit FPDs group showed a significantly lower mean dislodgment resistance compared with the new FPD designs group (P < 0.001). The current study indicates that the new suggested FPD can be clinically viable design in terms of mechanical retention, however, further clinical research need to be conducted.
Declaration

No portion of the work referred to in this dissertation has been submitted in support of an application for another degree or qualification, of this or any other university or other institute of learning.
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I would also like to thank Mrs. Rose-Marie Parr for her appreciated help and advice.
Dedication

TO MY MOTHER
TO MY BIG BROTHER
MOHAMMED
TO MY FAMILY
Chapter 1
Introduction and Literature Review
1. Introduction and Literature Review

The first chapter consists of two main parts. It will be structured as follows; firstly, it will provide a literature review of dentistry; secondly, a literature review on mechanics will be mentioned highlighting the most important topics of each part.

1.1. Dentistry

1.1.1. Introduction

Since the beginning of time, human beings have continuously strived to improve their lifestyles in various different ways. Dentistry is and has always been one of those important fields which help people to eliminate their oral pain, be able to eat properly and to look good, improving levels of confidence in many essential life areas.

For a long period of time, scientists, dentists and dental technologists have tried to improve the construction and anchor of dental appliances. Nowadays, those improvements have helped to develop both the tooth’s function and appearance.

Missing teeth is a common problem now affecting many people, especially those who are over 40 years old [1]. Circumstances vary from patient to patient, they might become edentulous (completely without teeth) especially the elderly people, or they may lose just some of their teeth. For each case, there are various ways for replacing the real teeth with artificial teeth by using different techniques. In the following paragraphs, we will discuss the methods for restoring the missing teeth, types of dentures, and we will also provide an overview for each one of main techniques.

1.1.2. History

The first attempt of replacing a missing tooth was made by people in north Italy in about 700BC. They started to make dentures from other human beings’ teeth or from animals’ teeth. This technique was famous and widely adopted until around 1950 [2].

The first denture sets were made out of curved wood in the 15th Century, although it could possibly have been made even earlier. The idea at that time was to remove the
teeth of dead people or to get them from living people who wanted to sell or exchange them. These dentures were, as can be expected, incredibly uncomfortable, and could be easily seen and did not provide cosmetic benefits. Contrary to the sophisticated techniques adopted nowadays, the old-fashioned dentures were held in place by attaching the denture to the natural remaining teeth with either metal or silk [2].

In 1770, Alexis Duchateau made the first porcelain denture around 1770. Then, in 1791, his British assistant Nicholas Dubois made a big improvement to the fabrication of porcelain dentures; he created a composition for making single or multiple teeth as one unit, and discovered new, more successful ways of joining them together and making them better able to fit. More recently, there are different kinds of materials available, such as acrylic resin and plastic, and a variety of systems have now been developed to assisting dentists, dental technologists and patients with getting better results and porcelain is still one of them [3].

1.1.3. Basic considerations

Generally, the chosen method depends on several factors. Some of these factors relate to the patient, while others relate to clinical and laboratory reasons. The following points provide some reasons and circumstances which could subsequently affect the chosen method implemented for tooth replacement:

1. How many units need to be replaced with artificial teeth? [4].
2. The location of the missing teeth/tooth (upper, lower, anterior, posterior, etc.); this is a very important consideration, especially if the patient has anterior missing teeth. In this case, the dentist would normally give the patient the choice of between the available options with the best aesthetic appearance.
3. The condition of the neighbouring tooth/teeth. For example, crooked tooth, caries and unstable abutments affect the stability of the denture, especially with some different types of the fixed bridge, such as the Maryland fixed bridge [1].
4. Patient oral and overall health can also affect the treatment method. For example, when the patient is very old, implants might not be a good option for
him/her as the implant post (screw shape) need to be inserted into the jaw bone. In addition, in some cases, patient’s overall health conditions might not help him/her to do such surgery [4].

5. Although implants is one of the best ways to fill the gap of the missing teeth/tooth, a lot of patients are not in a position to be able to afford this treatment as it is so expensive compared to the other available options, such as fixed and removable dentures. Therefore, in some cases the treatment plan could be changed due to financial reasons.

1.1.4. Circumstances of teeth lost

There are many cases where individuals lose some of their teeth while, in other cases, they may lose all of their teeth. Dentists used to extract the tooth if the tooth was considered to be non-restorable [4]. Also, accidents and hard impacts on the tooth may cause tooth loss. In addition, some people may not have had some of their teeth since birth [4]. While some patients have one or more teeth growing in the wrong place over the jaw (externally or internally). In each one of these cases, the replacement of the missing teeth with artificial teeth is required in order to improve the appearance and the function of the teeth.

1.1.5. Possible problems occurring from injured or lost teeth

The loss of a single tooth or multiple teeth can affect the person appearance and/or health, while ultimately affects levels of confidence and overall life happiness. Losing the anterior teeth (front teeth) affects the way a patient talks and smiles, and that might subsequently make the patient avoid going out in public due to social embarrassment. If the person has lost one (or more) of the posterior teeth (back teeth), the patient will not be able to eat properly, and this might affect his overall health [5]. After a period of time, the gap of the missing teeth is going to allow the movement of neighbouring teeth, which will result in the patient needing orthodontic treatment [12].

Teeth support the lips and cheeks, and missing one or more teeth impinges the way the face looks [1]. Impacts, such as falling on the teeth, may also cause dental
problems and severe pain. Even if the tooth or teeth have not come out entirely, they might nevertheless allow the bacteria to grow and cause severe pain, especially for immature permanent teeth; in this instance, it is highly recommended that the injured or missing teeth are treated or replaced as soon as possible [7].

1.1.6. Ways of restoring missing teeth

The field of dentistry has different opportunities for restoring lost teeth. After the dentist sees the condition of the patient’s teeth he might agree with the patient to do one of the following treatment plans [4]:

- Fixed Partial Denture (FPD)
- Removable Partial Denture (RPD)
- Complete Denture.
- Interim Partial Denture (Flipper)
- Implants Restoration
- Maryland Bridge (Resin Retained Bridge)
- Cantilever Bridge

1.1.7. Types of denture

There are two main types of dentures: complete dentures and partial dentures. Each one of these types has its own requirements and technique. In the following points, we will discuss each one of these individually.

Complete dentures are used only with edentulous patients (without teeth). The dentures cover the entire jaw and can be applied in the upper jaw, lower jaw or both (the maxillary or mandibular arch). It consists of artificial teeth attached to a base made of acrylic raison (Figure 1.1), and is ideally held in place by one of mediums: suction of the saliva or by attaching the denture to implants [4, 8].
Partial dentures are divided into two types: fixed partial dentures and removable partial dentures.

*Fixed partial dentures* are better known as ‘crown and bridge’ (Figure 1.2 and Figure 1.3). Bridges usually consist of one or more abutment (neighbouring teeth/tooth) and one or more pontic (the artificial tooth which is placed in the edentulous area). The fixed bridge always requires preparation of the neighbouring teeth/tooth. The reshape of the neighbouring tooth presents the space for the fabricated artificial abutments to be fitted over the natural teeth/tooth perfectly, and obtain retention which increases the bridge’s stability in the mouth. Before the fixed denture is positioned over the shaped neighbouring teeth/tooth, the retention of the denture is supported by applying suitable cement between the artificial unit and natural teeth/tooth [10].

Types of fixed bridges are classified according to the number of the abutments [11]. When the bridge has one abutment and is supported from one end, it is called cantilever bridge, but if it has two abutments it is called a conventional fixed bridge (Figure 1.2). In some cases, where patient has a lot of caries all over the tooth, the dentist will remove most of the natural tooth. The tooth can be fully covered with an artificial tooth called single crown (Figure 1.3) [12]. Fixed bridges and single crowns can be made of different kind of materials such as: gold, cobalt-chromium alloys, nickel-chromium alloys or porcelain, or even a combination of more than one of those materials. When patients have the choice, they often prefer to cover the prosthesis with ceramic (porcelain) in order to improve the appearance of the teeth/tooth.
Dental implants are also classified as ‘fixed prosthesis’, because they are fixed and permanent. It has a post which looks like a screw, which is placed into the bone of the jaw and works as a substitute root for the lost teeth. The implant screws are usually made from titanium alloy. When they are placed in the jaw bone, they then require from three-to-four months to heal before moving on to the next step. After this stage, the dentist will then make a small opening in the gum in order to load the abutment in place (Figure 1.4), when then takes another two to four weeks to heal a gain. After a period of time, when the gum looks healthy, it is ready for final step. The artificial tooth is then attached to the inserted implants. Implants can be used to replace one single tooth, several teeth, and can be used to support the complete denture stability [1].

Removable partial dentures (RPDs) are completely removable. This method is usually used with patients who are missing some of their teeth but less than all of their natural teeth (Figure 1.5). In some cases, removable prosthesis can be used in order to replace part of the gum when a patient has lost a part of it in an accident or through oral tumours, etc.
Similar to the complete dentures, RPDs consist of artificial teeth/tooth and a gum-coloured plastic base (Figure 1.5) [12]. Each of the parts of the denture is joined together with a metal framework called the ‘major connecter’. The major connecter could be scientifically described as a maxillary palatal metal bar/plate and lingual bar or plate. It provides retention to the denture with the support of clasps which are attached to the natural teeth.

![Figure 1.5 Removable partial dentures in and out of the patient mouth [9].](image)

### 1.1.8. Advantages and disadvantages of dental prosthesis

Advantages of removable partial dentures [4]:

- Not that much more expensive when compared with the other dentures.
- The acrylic resin of the removable denture looks similar to the natural soft tissue of the jaw. When a big part of the bone is lost, the acrylic resin is designated in order to improve the appearance of the jaw.
- When the patient has trouble with hygiene, the RPD will help to overcome this issue.

Disadvantages of removable partial dentures:

- Require a big amount of metal framework to restore one or two teeth.
- Very sensitive and breakable and, therefore, it needs special care if the patient wants to remove it from the mouth.
Advantages of Conventional Bridges (fixed partial dentures) [4]:

- Very good appearance.
- It is fixed in the mouth (not removable) and lasts longer than the RPD. In addition, it makes the patient feel like he/she has permanent teeth.
- It evenly distributes the chowing forces.

Disadvantages of Conventional Bridges (fixed partial dentures):

- It is necessary to prepare the abutments in order to fix the artificial teeth. Usually, the neighbouring tooth preparation leads to destroying the anatomy of natural and healthy teeth since it requires a significant reduction.
- The prepared teeth (abutments) are at risk of recurrent caries [13].
- Expensive to remake if a replacement is required for any reason.
- The unnatural appearance of the denture (between the bridge and gum).
- Very accurate fabrication required.

Advantages of Transitional Partial Denture or Flipper [4]:

- Good natural look, and restores the missing teeth function.
- Flippers could also be a temporary solution during the healing of the implant opening in the jaw.
- Reasonably priced.
- If the patient does not want to have a lot of appointments, or did not want to stay at the dental clinic for a long time, the Transitional Partial Denture would then be a suitable choice.

Disadvantages of Transitional Partial Denture or Flipper:

- Flippers have no rest seat and so the denture pressure over the soft tissue might cause tissue problems after a long period of time.
• The material which is used to fabricate the T.P.D. is able to absorb the saliva and it can then be easily cracked or broken.

Advantages of Maryland Bridge (fixed partial dentures) [4]:

• The idea of the Maryland Bridge fabrication is similar to the fixed partial denture, but with less neighbour teeth preparation (little shaving from the labial side of the teeth).
• Option for the youthful patient rather than the FPD.
• Instead of implant crowns, Maryland bridges are recommended if the patient is not fully grown.

Disadvantages of Maryland Bridge (fixed partial dentures) [1]:

• Failure of the bonding between the denture wings (metal abutments) and the natural teeth.
• The metal wings of the denture might make the abutment teeth look darker.
• The aesthetic of the Maryland Bridges is not as much as with the implants.
• Maryland Bridge is not be applicable if the patient have a big caries in the abutment tooth.
• Patients are not advised to use a toothpick or bite any hard objects.

In 1990, a five years study was conducted to evaluate the survival rate of resin-bonded bridges. The authors reported that, among 203 patients, 77 cases had deboned due to dislodgment or pontic fracture. Also, they conclude that there was no relationship between the bridges failure and the used cement or the retainer type [14].

Although the Resin-Retained Fixed Partial Denture (Maryland Bridge) is one of the cheapest and most useful ways of restoring missing teeth, it unfortunately, has a massive number of reported failures between 10% over eleven years and 54% over 11 months. Unlike with the fixed partial denture, the Maryland Bridge is not appropriate for patients who have crooked abutments [1].
Advantages of Cantilever Bridges (fixed partial denture) [4]:

- The Cantilever Bridge uses only one abutment as a retainer. This technique saves the tooth structure (anatomy) as much as possible, especially if we compare it to the conventional fixed bridge.
- Least expensive.

Disadvantages of Cantilever Bridges (fixed partial denture) [13]:

- It could not evenly spread the forces properly because it is fixed only in one abutment. This kind of bridge may affect the natural abutment of teeth stability and cause teeth dislodgment.
- Unlike the implants, the Cantilever Bridge requires tooth preparation for the abutment tooth. This significant tooth reduction of the abutment is considered to be a major shortcoming as previously mentioned.

Advantages of Implants:

- Do not affect the neighbouring teeth in any ways as it directly connects the artificial tooth to the jaw bone.
- Implants provide high stability, so that it can be used as a retainer to fixed dentures (fixed bridges) or complete dentures.
- It protects the bone by filling the gap of the natural bone.
- The best aesthetic of kinds of dental prosthesis.
- No preparation of the abutment teeth is required.

Disadvantages of Implants [4]:

- Patient must have more then one surgery
- There should be a long-term treatment plan extend to several months.
- After the first surgery, the dentist cannot proceed with the treatment plan as the surgery opening needs to heal completely (time consuming).
- Temporarily prosthesis is required.
• Unnatural appearance between the artificial tooth/teeth and gum.
• Patients who want to have a fixed implant must not be extremely ill or have any kind of disease which may prevent him/her from having the implants. The patient jaw bone should be in a good condition because there should be available bone for the screw to fix into it. Moreover, pregnant women cannot have implant surgery. As such, the patient health condition must be clarified before the dentist can take any decisions.

There are a number of cases where patients are able to use implants instead of the other types of prosthesis. For a long time, dental implants have proved that they can work perfectly. When the patient cannot wear the removable denture (complete denture), dental implants can then solve that problem by fixing more than one implant to the upper or lower jaw bone [1]. The fixed implants can then provide enough stability to hold the denture in place. In addition, it might be used as an alternative to the fixed partial denture (fixed bridge) if the patient does not feel comfortable with the fixed denture. Also, implants could be use if the patient is not happy with the abutments proportion, especially when the abutment teeth are healthy and in good shape.

Implants are very useful if the edentulous area is very large, and the fixed denture needs extra support. Sometimes, patients do not have a fixed partial denture (cantilever or conventional bridge) because there are more than four missing teeth beside each other (in a row), which makes it too difficult for the denture to remain stable over the abutments as they are simply too far away from each other [1]. Depending on the patient case, the dentist can use one implant or more (in the edentulous area) in order to increase the denture stability.

1.1.9. What are fixed partial dentures made from?

Most patients prefer to replace their missing teeth with artificial PFM (Porcelain Fused to Metal) as it looks more like the natural teeth, while some patients still prefer metal or gold prosthesis rather than the porcelain teeth. However, the majority of people prefer to have artificial teeth which are natural looking. Ideally, the porcelain
tooth consists of a combination of porcelain fused to metal, if the missing tooth is posterior (in the back), and full porcelain if the missing tooth is anterior (in the front). The combination of artificial teeth have more strength than the porcelain teeth, which makes the denture stronger, providing it with better resistance with regards to the chewing force. On the anterior teeth, the chewing load is less than the posterior teeth, which is aesthetically better for placing full porcelain dentures over missing teeth/tooth. All-metal fixed dentures are the strongest dentures since they do not break under the chewing pressure. Although PFM is also strong, but it is not considered to be as strong as full-metal prosthesis. All-gold crowns are also one of the best materials for use in dental-fixed dentures, unless they are considered to be more expensive than the other available materials [9].

Generally, casting alloys are divided into two main types. The first type is known as noble alloys, where the second type is known as based metal alloys. The majority of the noble alloys are gold- and palladium-based materials, and the based metal alloys are nickel- and cobalt based materials [11]. The used materials in fabricating FPD are varying. However, some based metals such as cobalt-chromium alloys have been used widely, as they are cheaper than most of the other available material and perform acceptably [15].

1.1.10. Steps to clinically preparing the FPD

Before the treatment initiates, the dentist first examines the situation of the patient to determine if the fixed partial denture is necessary as well as carrying out an X-ray examination. If the dentist agrees with the patient that he or she really does require fixed prosthesis, the dentist will then begin the first steps of the fixed crown or bridge.

After the agreement of applying the fixed partial denture, the dentist then has to start preparing the abutment teeth/tooth. During the patient’s first visit, the dentist will reshape the tooth/teeth in such a way which allows the denture to be placed over the natural tooth/teeth. Normally, there are standard circumstances for the fixed partial denture preparation by making a reduction on all around the tooth/teeth; this reduction
will create the required space for the new prosthesis to be positioned over the prepared units.

When the reduction is complete, the tooth/teeth must then be tapered into shape. If there is any undercut on the surface of the tooth, the restoration will not be able to be removed from the die. The prepared units require specific measurements of two to three degree of taper [12]. Clinically, there are special instruments to aid the dentist to getting that specific degree, and allows the fixed bridge or crown to be placed properly in the mouth. It is also important to note that if the tooth has been tapered too much it will affect the restoration stability as there will not be enough retention for the denture to be held into place. That means, a six-degree of taper all around the tooth is needed in order to give a total of twelve degrees of taper; any more than this could negatively affect the stability of the denture [12].

During the tooth preparation process, it is also important to make the margin ideal. The margin can be described as the line which is present around the tooth at the junction between the artificial tooth and the natural tooth. The fixed denture cannot survive without a good margin, and even if the artificial tooth is perfectly constructed, it will still not last for a long time if the margin experiences any problems. The margin must be smooth and strictly adapted to the finish line. If there is an opening in the margin it will affect the denture stability [16]; moreover, it will also allow food to stick in the openings, which can ultimately lead to poor oral health. The margin is normally located between the natural tooth and the artificial tooth, and so it might be seen when the restoration is in the posterior area; in that case, dentists always try to take care when they draw the margin simply because it must work sufficiently and not be too visible to the naked eye [12].

There are different kinds of margins, which each depend on preparation. The first type of margins is called a ‘chamfer’. This margin type is very popular with full gold prosthesis. It provides the best strength which the crown/bridge needing to be adapted perfectly, and is very effective in removing a very small amount of the tooth structure, which allows the dentist to work with the smallest detail. The second type of margin is called the ‘shoulder margin’. This particular margin is popular with the PFM
(Porcelain Fused to Metal) prosthesis, and it is also useful when preparing the tooth for all-ceramic restorations [16].

After the tooth preparation, an impression of the tooth/teeth is taken and sent to the dental laboratory in order to fabricate the artificial prosthesis. Because of the improvement of the dental technology, there are many different ways of fabricating the dental crowns/bridges.

1.1.11. FPD fabrication procedure in the laboratory

The chosen method of fabrication purely depends on the type of material used with the restoration, for example, whether it is full ceramic, full metal or Porcelain Fused to Metal. When the dental laboratory receives the impression, the dental technician pours and mounts the cast by using different types of dental stone or plaster [12], and when the stone model has dried when the thermal heat disappears the cast is then ditched and trimmed into the required shape. After this stage, the pins are then cemented to the bottom of the cast and another mixture is made in order to mount the base of the cast and attach it to the articulator, which is a device used to attached the upper (maxillary) and lower (mandibular) casts. The articulator provides the link between the upper and lower jaw, as it is in the patient’s mouth which ultimately allows the dental technologist to see how the upper and lower jaw meet with each other and subsequently aids him/her to properly fabricate the tooth to do its function. From this stage, the casts are then taken out of the articulator before they split the cast from the base and split the prepared teeth/tooth from the rest of the cast into individual dies by using a saw [12]. The finished line of every single die (of the prepared tooth) is then exposed using the wax knife and the teeth/tooth fabrication is made using one of the following techniques:

1.1.11.1 All-Wax technique

The all-wax technique is used when the denture if made completely from metal. There are different materials which could be used in the full metal restoration, and gold is one of the best kinds of material. The gold alloys consist of various different elements,
such as gold, palladium, platinum (noble materials), tin, silver and copper (based materials). Although the full gold prosthesis does not look good cosmetically, they do nevertheless have the advantage of being very good quality, as they are considered as high-noble materials, according to the American Dental Association because it contains 75% noble metal [11]. Full metal dentures irrespective of whether it is gold or any other suitable dental material are manufactured with the implementation of a technique called the ‘lost wax technique’. In order to get the final shape by using the lost wax technique, the artificial teeth must first undergo many more stages before getting the final result.

Firstly, a die spacer should be applied over the die/dies in order to provide the space between the artificial teeth/tooth and the prepared tooth. This thin space will allow place for the cementation which will be applied clinically before fixing the denture in the patient’s mouth [12]. After this stage, a die lubricant must then be applied so that the wax pattern can be easily removed the die lubricant prevents the wax pattern from sticking to the die after the wax build-up is completed.

Secondly, the dental technologist will then start to build-up the wax pattern by coping the die. The coping procedure is focused on creating a thin layer of wax over the die. Normally, the coping is made from wax but it is also possible to make the coping from a heated resin sheet [12]. After this stage, the wax is then applied over the coping layer by using a hot wax spatula. Some other instruments might also be used, for example, a wax knife and wax carver, in order to build-up the wax pattern. At some point, the die should be returned to the cast (which is fixed to the articulator) in order to manipulate the wax until the wax pattern appears to be similar to the dimensions of the original tooth, and does not interfere with the opposing teeth (in the opposing jaw).

Thirdly, when the wax tooth/teeth appear to be in a good shape (final shape) the wax pattern is then removed from the die and attached to a special kind of wax stick called a ‘sprue former’, which is a small diameter tube usually mad of wax; the ideal tube width used with crown/bridge is 2.6 mm [12]. The sprue is attached to the wax pattern from one end, while the other end is attached to a conical rubber base. The sprue with the wax pattern is inserted into a special ring while the rubber base works as a base to
that ring. After this stage, the investment material is then mixed and poured into the ring. When the investment material has completely set, the rubber ring is then removed, and the base will then form a crucible shape with a hollow in the middle. This funnel-shape will force the metal to go into the mould during the casting procedure while the hole in the middle of the ring will allow the molten wax to get out the mould. It is highly recommended that the sprue is attached with its angle to the bulkiest area of the wax pattern. Attaching the sprue in angle with the wax pattern will allow the molten metal to flow into the mould easily [17]. It is also important to consider that the wax pattern should be 6 mm away from the end of the ring; if it is too close to the end of the ring, the molten metal might blast through the investment material and, if it is too far from the end of the ring, that may disallow the gases from escaping from the mould during the casting [12].

Fourthly, the investment ring is placed upside down in an oven at a temperature of 600F for thirty minutes [12]. During that stage, the wax will burn out from the mould. At this point, the temperature should then be increased up to 1,200F for one more hour, after which the ring is then removed from the oven and placed into the casting machine (the casting temperature is vary depending on the type of the metal alloy) [18]. It is very important to note that when the investment ring is removed from the oven, the molten metal should be permitted to flow into the mould within thirty seconds because if the ring loses the heat, the mould will then contract and the dimensions of the mould will changed [17]. After placing the ring in the cast machine, a sufficient amount of metal is then placed into the machine whereupon the casting will begin. The metal will be quickly melted and then shot through the opening into the mould. The metal will take the same shape and dimensions of the disappeared wax, which is then called the Lost Wax technique.

At this point, the ring is finally removed from the casting machine and placed at room temperature until it is properly cooled. Then, the ring is de-invested and the crown/bridge is separated from the sprue, which can then be recycled. The crown/bridge is then finished and polished until it shines before it is sent to the dentist to try in the patient’s mouth during the second appointment. Little adjustment might be applied upon the final cementation.
Porcelain Fused to Metal is made similarly, except that after the coping procedure, the wax pattern is not waxed up completely; instead, it just needs to have a suitable wax adjustment, which allows the porcelain to be built up over the metal (after transforming the wax into metal with same steps).

1.1.11.2. Empress

The Empress technique uses the same basic idea and principle of the lost wax technique, only there is a hole in the investment ring. The empress system works in a slightly different way as it has a special design, which is the pressure injection. The main principle of this particular system involves leucite-reinforced ceramic, whereupon the ceramic is pressed into the mould of the artificial tooth in a unique pressable porcelain oven [19]. This machine does the work of both the oven and the casting machine together, which means the restoration is melted then pressed into the mould at the same time. In addition, the Empress machine can do any job the lost wax may require. It can also make any prosthesis for the all-ceramic restoration, such as, single crowns and laminated veneers, which is made only from ceramic and did not have any metals [12].

1.1.11.3. In-Ceram

In-ceram has been introduced by Vita; it is also one of the famous systems which has been used in full ceramic restoration [12, 19]. Unfortunately, all-ceramic crown prosthesis requires too much tooth removal. For in-ceram, the tooth preparation must be 1.5mm arterially and from 1.5mm to 2mm from the occlusal side; although the all-ceramic restoration has the best tooth appearance, it still needs a significant amount of tooth reduction, which most of people consider being a negative thing [12].

1.1.11.4. Procera

Procera is a computer aided milling system (software) which is used to fabricate free metal restorations. It is CAD/CAM method and, generally, it has it is own technique which depends on constructing the artificial prosthesis with Vitadur Alpha porcelain, by overlaying a very strong ceramic coping made of zirconium or alumina referred to
as the ‘core’ [12]. Lately, Procera has been improved widely by being able to produce various kinds of dental restorations, such as veneers, crowns and bridges.

1.1.12. Investment

In order to produce cast metal devices, the investment material is poured over the wax pattern (in the investing ring) and placed into the oven. After the wax melts and runs out, the exact negative of the original model is formed [18]. The investment ring is then casted, and the metal prosthesis is produced.

The process of investing the common types of dental prostheses (such as crowns, bridges or partial denture frameworks) involves common types of investment materials, such as [20]:

1.1.12.1. Gypsum-bonded investments

Gypsum-bonded casting investment is usually used for the purpose of casting metal alloys which have low fusion temperature [21]. Two main techniques (described by B W Darvell [18]) can be used to control mould expansion of this type of materials, those techniques are:

A – Large expansion can be obtained by heating the mould to 700°C.
B – Hygroscopic expansion can be obtained by heating only to 500°C.

It is appropriate to cast gold-based alloys by using gypsum-bonded investments, and heat it up to 700°C, because the fusion temperatures of the metal alloys to be cast within it are relatively low [22]. Furthermore, using high-fusing metal alloys, such as cobalt-chromium, with this kind of investment material might result in various consequences, such as incomplete casting, as the cobalt-chromium alloys melting point goes up to 1,500°C [18, 22]. As such, it is therefore advisable to avoid casting high fusion temperature alloys by using any gypsum products [18].
1.12.2. Phosphate-bonded investments

This type of investment is bonded by a magnesium oxide and a phosphate [18]. The chemical properties of the phosphate-bonded investments make it a suitable option for high-fusing alloy casting [23]. It is commonly used to cast cobalt-chromium alloys [18, 20, 23].

The reactions between the phosphate-bonded investment crystals continue to react beyond 1,000°C, which subsequently helps to more accurately control the amount of mould expansion [18]. However, although there are different products of investment materials which could be used for casting metal alloys, it is always better to use phosphate-bonded investments to cast metals which have a melting point ranging between 1,200 and 1,450°C [18].

1.12.3. Silica-bonded investment

Similarly, this type of investment is used with alloys which require a higher temperature (high-melting point) for the investment mould [24]. The temperature of the mould in this type of investment reaches up to 1,200°C, and larger expansion will occur during heating [18]. However, although there are some disadvantages of using this type of investment (such as the possibility to crack at the casting temperature), this option nevertheless still provides very accurate detail of the original melted wax, which ultimately makes using the silica-bonded investment become more useful in some cases, particularly when compared with phosphate-bonded investments (as long as each one of them is used for high fusion alloys) [18].

In some cases, special types of investment material which have particular chemical properties are recommended in order to control shrinkage and to therefore make the casting procedure even more accurate whilst reducing the chance of any changes occurring in the original dimension of the wax pattern [25].

There are some laboratorial factors which can affect the dimensional accuracy of the cast metal, the most important of which include the investment setting material expansion and investment expansion on heating [18]. Accordingly, the dimension of
the original wax pattern might change slightly (if phosphate-bonded investments or gypsum-bonded investments are used). Researchers have improved the chemical properties of the investment materials in order to provide accurate casting until they were able to devise the High Speed Investment Material (such as, Microstar HS, Ceramay and SC High Speed Investment Material). Using this type of investment helped to provide an exact reproduction of the wax pattern surface [26].

In conclusion, the total expansion can be perfectly controlled and a very exact reproduction of the original wax pattern can be obtained using High Speed Investment Material. This procedure will therefore avoid any expected gaps and help to obtain more accurate fit, therefore increasing overall denture stability.

1.1.13. Remaining problems even with the new generation of the fixed partial dentures (crown and bridge)

Commonly, there have been a few experienced problems with each type of dental prosthesis. During the past few years, there have been significant improvements in the construction of dental appliances; some of these changes were clinical changes while some were laboratory changes. Mainly, the improvement was concentrated on one of the following two fields, or in both of them together:

- The material which has been used in the field of dentistry;
- The technique of fabricating the tooth restoration.

One of the main problems with fixed partial dentures is that they require a significant amount of preparation on the abutment tooth (neighbouring teeth/tooth) [4]. Usually, destroying virgin teeth comes about as a result of irreversible preparation, and so patients nearly always prefer to have implants rather than the fixed partial dentures, unless they are not as cheap as the fixed bridges, which makes it an unacceptable option for most people.

Another problem with crowns and bridges is that it is could encounter caries after a while [13]. The decay occurs as the abutment tooth/teeth is/are fully covered with
artificial crowns/bridge. After the prosthesis is cemented over the treated tooth/teeth, it is very difficult to be removed again [10], and a piece of the natural tooth can sometimes come out when the dentist tries to remove the restoration. In this situation, the prepared tooth/teeth cannot be cleaned (brushed) as long as the denture is placed over it, and, subsequently, more problems will present themselves internally (at the surface between the natural tooth and the artificial tooth).

Moreover, if the prosthesis needs to be completely replaced, it will be very expensive [4]. If the crown/bridge falls down and the denture requires adjustment, a new denture should be fabricated again, as neither the dentist nor the dental technologist will be capable of adjusting the old artificial unit.

1.1.14. Previous studies, and FPD development

There was a large expansion in solving the troubles associated with restoring missing tooth. Until this moment, a lot of disadvantage have appeared, even with the latest technology and techniques which have been used in this specific field of dentistry.

However, there have been many new inventions and techniques, which have proved that there is the ability to solve some of the major problems with old designs or dental materials by improving the used materials, such as fibres [27], methods, construction, such as the Maryland Bridge, Computer-Aided Design and manufacturing equipment (CAD/CAM) [12, 19]. Although, these new inventions have been being used more recently, some of them still experience aesthetical troubles or functionality issues, but they are nevertheless being used anyways in order to prevent some of the more major problems.

The Maryland Bridge is one of the most famous new ways of replacing a missing tooth. The first development took place in 1980 at the University of Maryland, which is where it got its name [28]. The Maryland Bridge consists of single artificial tooth attached to two metal wings on the sides. After preparing the neighbouring teeth which requires little shaving, and only some from the inner side the wings of the artificial tooth are bonded with appropriate cement to the back sides of the prepared
tooth on either side of the missing tooth [1]. This type of dental restorations is claimed to be one of the best ways of replacing the missing teeth because it considered being cheap, simple and conservative method. Most patients would subsequently chose to have this type of bridges rather than the implant, conventional or cantilever-fixed bridge, as they then do not have to pay a massive amount of cash to have an implant or destroy the anatomy of their own natural healthy teeth (abutments).

Unfortunately, there are some aesthetic and functional problems with this kind of bridge: Because the teeth are translucent, the metal backing the tooth is bounded onto the back side of the front teeth, which then causes the teeth on either side to turn a little grey; these teeth will then obviously not match in colour [4]. On the other hand, dentists do not recommend this type of bridge to be placed in the posterior teeth simply because it is attached to the neighbouring teeth only from one side. For this reason, the denture will not be able to resist the applied force during mastication [1]. In addition, the Maryland Bridge is not appropriate for all patients and it does not last forever, even with the appropriate circumstances due to teeth dislodgment. This type of fixed bridges is not suitable if the patient has a deep bite or fractured abutment teeth, because the denture will fail sooner or later [1]. Moreover, according to the sensitivity of Maryland Bridges, the patient is always advised avoiding the use of toothpicks and to not bite on tough objects.

In conclusion, the field of dentistry is always aiming to replace the lost teeth with the best possible appearance and function. When the patient has lost one or more of his/her natural teeth and considers restoring the missing teeth, he usually will be looking forward to treat it without causing any more damage to the healthy teeth. However, even with these negative points of choosing the Maryland Bridge as an alternative treatment solution, patients still consider it to be a good choice. With this in mind, we can understand that, as along as the applied restoration saves the natural tooth structure (anatomy) with an good appearance, the patients will be happy to select this option.

Since this study will present a novel fixed bridge design, there is a need to understand the forces that applied on human teeth during mastication. The following literature review will be helpful to detect the relation between physics/mechanics and dentistry.
1.2. Mechanics

1.2.1. Introduction

For a long time, people have been trying to improve their ways of life in various different aspects. As a result, there have been developments in a vast number of areas, including astronomy, physics, chemistry, biology, human anatomy and mathematics.

Mechanics is one of the most important aspects of physics, which describes objects’ behaviour using mathematical equations [29]. This is one of the main study areas that has helped human beings to develop their understanding concerning the mechanisms of objects’ movements [29, 30]. More recently, researchers have been accurately and sufficiently analysing their experiment results in order to produce a variety of materials with the best quality. As a result, a large number of inventions have been revealed (such as cars, Internet, different types of drug and artificial teeth).

1.2.2. History

In the 15th Century, there was dramatic growth in scientific knowledge, especially in physics. Such significant improvements have been ensured by many scientists, all of whom have played a major role in science development, such as Galileo Galilei, Isaac Newton, Charles Darwin and Albert Einstein [31-33].

In 1546, Galileo Galilei was the first to deal with physics, mathematics and astronomy as one subject. The studies that he carried out helped to achieve the telescope [31]. However, one of his most famous experiments in physics was dropping two balls from the Pisa Tower, subsequently determining that the two balls reached the ground at the same time. His work and experiments have subsequently had a major influence on human mechanical experiences.

The English physicist, Sir Isaac Newton, had the biggest influence in the history of science. He published his book ‘Principia’, and revealed the theory of universal gravity, as well as the three laws of motion [34]:

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• ‘Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.

• ‘The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed’.

• ‘To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts’.

Newton describes the objects movements in terms of it velocity, acceleration and position [35]. These laws of motion can be applied in the case of any object. He is considered as one of the scientists who laid the foundation for the classical mechanics. Newton’s principles are still applicable in physics at the present day.

Charles Darwin, for example, was one of the most remarkable physicists during this period, and scientists would refer to him as the father of science, simply because of his success in physics field [33]. Furthermore, Maxwell’s electromagnetic theory was a very important and remarkable step, which gives other scientists the opportunity to discover the modern physics world [37].

Following Newton’s steps, Albert Einstein, explains gravity and its laws more sufficiently. His new ideas and thoughts have played a significant role in changing the classical mechanics into new physics generation [37]. His achievements began when he first attempted to understand the reasons behind the speed of light being constant [38]. Einstein’s theory of relativity was and is considered as one of the biggest victories in physics. His accomplishments subsequently helped physicists to develop their understanding concerning definite facts in the physics world. Furthermore, he has made many astonishing discoveries such as [37]:

• Einstein proved in his theory of relativity that time can be change depending on the velocity of objects [38]. This phenomenon is known as Time Dilation.
• Einstein proved a relationship exists between time and length/space and, from his perspective, they were one unit [36, 37].

• It has been confirmed in classic physics that a mass is a fixed unit and the velocity does not have any effect on it. However, Einstein proves that the mass of the electron is increased by increases in velocity [41].

• Einstein discovered the relation between internal mass and energy through his theory of relativistic mechanics \( (E = mc^2) \), where \( E \) refers to the energy of the system and \( m \) is the internal mass [40].

According to many papers published by many physicists, Einstein was able to link classical physics with the modern physics. He worked to improve his ideas regarding the electrodynamics of moving bodies and energy quanta [37]. His findings were then used as the basis of modern quantum mechanics [36].

1.2.3. Classical mechanics

The area of physics, which is concerned with the forces and the causes of objects’ movements under specific circumstances/environments, is known as mechanics [36, 42]. Furthermore, the area encompasses studying the mechanical properties of the material (such as, elasticity and density) [42]. The reason for studying mechanics is to anticipate the reaction of certain bodies under specific external force(s). It has been confirmed that this area of physical phenomena can be effectively described using a mathematical equation.

Generally, mechanics is considered to be a specific type of physics. This branch of physics is divided into smaller branches, as described below [36]:

1. The field of mechanics which studies the circumstances where objects are at rest is known as static mechanics.
2. The field of mechanics which is interested in studying the factors that cause object movement is called dynamic mechanics.
3. The branch of mechanics which is interested in movement geometry is known as kinematic mechanics.

Classical mechanics describes any object motion in the planet as a particles/atoms system [35]. The movement of these particles/atoms is identified by their mass, position and the applied force [35, 36]. However, a number of basic terms which relate to physics/mechanics should be understood if we are to familiarise ourselves with the principles of classical mechanics. As such, the following definitions will introduce some of the important physical terms/concepts, in order to ensure an understanding of the principles of classical mechanics (solid mechanics):

1.2.3.1. Rigid bodies

The rigid body can be identified as any object which contains more than one particle, where the distance between any two partials does not change, even if the force is acting on it. Ideally, in physics, rigid bodies are the objects which resist change when a force is applied [39].

1.2.3.2. Matter

For the sake of simplicity, everything around us consists of small bits of matter; for example, molecules and atoms [43]. Matter can be solid, liquid or gas. Furthermore, matter can also be invisible, such as in the form of particles. Generally, the definition of matter is anything which occupies space and has a weight (volume and mass). The units used for matter measurement are milligrams, grams and kilograms [36].

1.2.3.3. Scalars and Magnitudes

There are many types of physical quantity which require a specific real number in order to be analysed using a suitable mathematical equation, such as time, mass, force, length, volume, velocity and momentum. The quantity of these units of measurement is known as scalar, and the real number is referred to as quantity magnitude. Every
unit is expressed using a unique scalar; for example, we write \((l)\) for length, \((t)\) for time, \((V)\) for volume, and \((F)\) for force [36].

1.2.3.4. Position

This term refers to place, space, area, direction, point and displacement. The measurement of the position is referred to in length or distance. It can be described as the place of mass of a system of particles according to another point or origin [40]. Length can be measured by many units, such as centimetre, metre, feet and inch [36].

1.2.3.5. Time \((t)\)

The meaning of time can be imagined according to our experience. The concept of time is expressed when an event is taking place before, after or during another event. The official unit of time is seconds [36].

1.2.3.6. Vectors

In some physical quantities, displacement, both of the magnitude and direction should be specified. Therefore, the description of this kind of quantity is referred to as vectors [36]. Generally, vectors can be analytically described as a symbol of a bold-faced letter such as \(\mathbf{A}\). Moreover, it can be geometrically represented by an arrow which has two points: one of them \((G)\) at the beginning of the arrow, and the other \((H)\) at the end of the arrow (Figure 1.6). The first point \(G\) is called the initial point, and the second point \(H\) is called the final/terminal point. The length or the magnitude of the vector can be identified as \(A\) or \(|A|\) [36].

![Figure 1.6 Analytical description of Vector [36].](image)
The relationship between vectors and algebra creates the possibility of using vectors in physics and mathematics. There are some methods which can be used to describe and/or represent vectors, such as [36]:

1. Despite the initial points, vector \( \mathbf{A} \) is equal to vector \( \mathbf{B} \) when they have the same directions and magnitude (Figure 1.7) \( \mathbf{A} = \mathbf{B} \).
2. The vector can be described as \(-\mathbf{A}\) when it is parallel to vector \( \mathbf{A} \), has the same length but has the opposite direction (Figure 1.8).
3. The sum of vectors \( \mathbf{A} \) and \( \mathbf{B} \) (if they are not parallel to each other) can be obtained by calculating vector \( \mathbf{C} \). Vector \( \mathbf{C} \) is calculated by drawing a third arrow between \( \mathbf{A} \) and \( \mathbf{B} \). The initial point of vector \( \mathbf{C} \) starts at the initial point of the first vector \( \mathbf{A} \), and the terminal point ends at the terminal point of the second vector \( \mathbf{B} \) (Figure 1.9). Thus, \( \mathbf{C} = \mathbf{A} + \mathbf{B} \).

![Figure 1.7](image1.png)  
**Figure 1.7** Vectors with the same directions and magnitude.

![Figure 1.8](image2.png)  
**Figure 1.8** Vectors with the same length and opposite direction.

![Figure 1.9](image3.png)  
**Figure 1.9** Multiple vectors calculation.

1.2.3.7. Force \( (F) \)

Force can be defined in two ways:

1. Logically: can be defined as ‘a measure of the pull or the push on an object’ which causes movement [36]; or
2. Can be described by Newton’s second law as the force which places an object and cause movement/acceleration. The change of the velocity will be in the direction of the force [38].

The unit which is used to measure the force is **newton**, and can be described as:

\[ N = \text{kg m s}^{-2} \]

**1.2.3.8. Mass (m)**

Generally, the concept of mass is referred to ‘the measure of the quantity of matter in an object’ [36]. The word ‘mass’ is normally related to weight, but can also have another meaning in physics. The unit which is used to measure mass is the kilogram. Nowadays, under the general heading of mass, there are two main properties [40]:

1. Internal mass: this is concerned with measuring the resistance of the object to any change in its movement. The measurement of the internal mass of the object can be achieved by using ballistic pendulum.

2. Gravitational mass: this mass is shown in Newton’s law of universal gravity, and the expression which is developed from it, such as the potential energy of the object. The measurement of the gravitational mass can be obtained by weighting the object.

**1.2.3.9. Velocity (v)**

Velocity is a vector quantity which requires direction and magnitude [38]. The relationship between the velocity, length and time can be identified as \( v = \frac{l}{t} \) [40], where \( v \) is the particle of velocity, \( l \) is the length and \( t \) is the time. The description of the object’s movement requires identification of the speed and what direction it is moving at some instance of time. Velocity can be measured by metre pre second, kilometre per hour, or mile per hour.
1.2.3.10. Acceleration ($a$)

Acceleration is the ratio of change of velocity with time [44]. Therefore, the average acceleration can be identified as:

\[
\text{Average acceleration} = \frac{\text{Change in velocity}}{\text{The time required to change velocity}}
\]

According to Newton’s law of universal gravitation, the acceleration of an object during free fall always varies between zero and 9.8 m s$^{-2}$ [32]. The unit which is used to measure acceleration is metre per second squared [40].

1.2.3.11. Work ($W$)

If we suggest that a force $F$ is applied to an object and that the force causes object movement from the point $a$ to point $b$, the work which is achieved by the force $F$ can then be identified as a scalar product $W = F \cdot ab$. The displacement product is equal to the work done by the force [39].

When the motion of the object from point $a$ to $b$ is in multiple small steps/displacements $ab^1, \ ab^2, \ ab^3, \ldots$ and the forces are $F^1, \ F^2, \ F^3, \ldots$, the work of these displacements and forces will be given as the following:

\[
W = F^1 \cdot ab^1 + F^2 \cdot ab^2 + F^3 \cdot ab^3 + \ldots, \quad \text{or} \quad W = \int C F \cdot ab,
\]

Where the $\int C$ gives the sum of the forces and displacement along the movement path $C$ (line integral) from the first to last point of the line [40]. The work done in the conservative force depends only on the last point of the line, but in the situation above, the achieved work is dependent on every single point along curve $C$. The unit for the measurement of work is Joule [40].
### 1.2.3.12. Power ($p$)

This term refers to the time ratio at which the work is done [36]. It is also called the instantaneous power. As the power is a relationship between work and time, the power could then be calculated as following:

$$p = \frac{W}{t}$$

In mechanics, if a force $F$ is applied to an object and causes the object movement with the velocity $v$, then the equation which can be used to calculate the power is:

$$p = F \cdot v$$

### 1.2.3.13. Energy

Energy can be described as the work quantity ($W$) which is achieved by the applied force ($F$) upon an object/particle. There are several forms of energy, including:

1. **Potential energy**: the measurement of the achieved work of an object/particle according to the virtue of its position. It is also known as the scalar potential [36, 39].
2. **Kinetic energy**: the measurement of the achieved work of an object/particle according to the virtue of its velocity. The kinetic energy is a scalar quantity [40].

The total energy ($E$) is the sum of the potential energy and the kinetic energy. According to the principles of conservation energy, the total energy is constant (on which the force acts) where [36].

$$E = T + V = \text{CONSTANT}$$

The conservation of energy holds for the particles that move with conservation forces [12]; however, the force is not always conservative. Joule is also a unit for measuring energy [39].
1.2.3.14. Momentum

This is a vector quantity toward the same direction of the particle/object velocity [40]. In the case of classical mechanics, the product of the particle velocity \((\mathbf{v})\) and the internal mass \((\mathbf{m})\) is referred to as momentum. Momentum is related to kinetic energy when the object is moving with a low speed. In this case, the relation between the velocity and mass is not important \((\mathbf{m} - \mathbf{m}^\circ)\). Therefore, the equation will be \(\mathbf{p} = \mathbf{m}^\circ \cdot \mathbf{v}\), where \(\mathbf{m}^\circ\) is the particle rest mass.

In the case of relativistic mechanics (when the particle is moving with high speed), the total energy \((E)\) is related to the momentum as [40]:

\[
E^2 = c^2 p^2 + m^\circ c^2,
\]

where \(E = T + m^\circ c^2\) and \(m^\circ c^2\) is the energy of the rest mass.

1.2.3.15. Moment

The figure below (Figure 1.10) shows the force moment \(\mathbf{F}\) about the point \(x\). The moment of the force is the vector which contains the point \(x\) and the line of the action of the force \(\mathbf{F}\) [40]. The magnitude is \(|\mathbf{F}|h\), where \(h\) represent the distance between the line of the action \(\mathbf{F}\) and the point \(x\). If we suggest that \(\mathbf{O}\) is the vector \(xg\) and \(g\) is located at any point on the line of the action \(\mathbf{F}\), the moment \(\mathbf{M}\) can therefore be obtained as \(\mathbf{M} = \mathbf{O} \times \mathbf{F}\). The moment unit is m² kg s⁻² [45].
If a rigid body (disc) rotates around the axis of rotation. The linear velocity of each particle of the body is \( v_i \) and the distance between the rigid body particles and the rotation axis is \( r_i \). Therefore, \( v_i = r_i w \), where the velocities and the distances of the body particles vary from one to another, and \( w \) is the same for all of them. The kinetic energy, such as the rigid body, will be [39]:

\[
T = \Sigma i \frac{1}{2} m_i v_i^2 = \frac{1}{2} \Sigma i m_i r_i^2 w^2
\]

And the moment of inertia \( (I) \) will be:

\[
I = \Sigma \frac{1}{2} m_i r_i^2
\]

Generally, in the case of physics, mathematical equations contain samples which refer to one or more of the aforementioned terms. The value of each one of them is inserted into an appropriately selected equation and results is then accordingly analysed.

In the case of dentistry, most of the experiments which are launched in the laboratory are concerned with solid materials. Therefore, it is important to understand the principles of solid mechanics in order to test and predict the prosthesis behaviour during service. In order to study the principle of mechanics, different aspects, such as forces, moments, stress and strain, will all be involved [42].

1.2.4. Mechanical testing

Mechanical testing can be defined as laboratory experiments which test material properties and how the materials react to a specific task. The mechanical property of the material is one of the main factors which affects the way in which materials respond to the test. Testing the mechanical properties of the material in advance is considered to be an important step when making sure that the produced item/device will be appropriate for use in the service [42].

There are several types of laboratorial studies for mechanical testing. Those studies have significantly helped to improve the material properties. Depending on the
purpose of fabricating the required item and by using the suitable equipment, researchers can effectively determine the ability of the material to resist various external forces. Therefore, it is important to understand a number of principles/concepts relating to the field, such as:

1. Postulate of consistency [46]: despite the size or shape of the tested material, the reaction of a known material/sample to a specific known force under the chosen condition is expected to be similar every time.

2. Bearing capacity [42]: this is the term which refers to the ability of an object to take the applied load before the object experiences distortion/failure occurs in any sense. Identifying the load-bearing material is the purpose of making the material mechanical testing.

3. Hooke’s law [42]: if a force is applied to a spring constant $K$ and it causes a small deformation (Figure 1.11), force $F$ which causes a deformation (change in the original length $L$) can then be calculated by using the following equation:

$$F = K \cdot \Delta L$$

![Figure 1.11 The change in a spring original length [42].](image)

4. Principle of uniformity [42]: this is a version of the postulate of consistency. For simplicity, if a body has a uniformed structure and composition, the reaction of that body to the applied load is expected to be similar in the case of each layer. This phenomenon is known as the principle of uniformity.
5. Stress [42]: the acting force on an object applies to every section throughout the object. As such, stress ($\sigma$) can be defined as the amount of force ($F$) that acts per unit area ($A$) of the object. The stress units are $N/m^2$ or $Pa$, and it can be calculated as the following:

$$\sigma = F/A$$

6. Strain [42]: the applied force causes changes in the object/sample length. Therefore, strain ($\varepsilon$) can be defined as the change in a rigid body length per unit original length ($l$) (the ratio of the length). Again, the strain in each unit of the body is expected to respond similarly. It is calculated as the following:

$$\varepsilon = \Delta L/L$$

7. Springiness or Flexibility [42]: this is the term related to the deformation that occurs in the material. When a force is applied to an object, the object dimensions start to change. All materials have an elastic limit (which is the limit between the elastic and plastic deformation) where it is able to return to its original shape when the force is released. This concept of the material’s physical changes is known as proportional limit (Figure 1.12). The springiness/flexibility can be calculated by the relationship obtained between stress and strain as:

$$1/E = \varepsilon/\sigma$$

where ($E$) refers to the modulus of elasticity or Young’s modulus,

$$E = \sigma/\varepsilon$$
According to these definitions, we can note that there is a direct proportional relation between stress and strain. The strain in every unit of a chosen material increases according to the increase of the stress. The applied force on an object causes stress to occur throughout the object unit and accordingly increases strain, which causes object deformation (changes in size and shape). These changes/deformations will occur only in the cross-sectional area and along the load axis [42].

During laboratory experiment, the compressive load causes the tested sample to experience expansion and the tensile force causes contraction. This is known as Poisson Strain. Therefore, the Poisson ratio (ν) can be calculated according to the changes that exist in the horizontal and vertical axes of the object (Figure 1.13) as the following [42]:

\[ \nu = -\frac{\varepsilon_y}{\varepsilon_x} \]

where (\(\varepsilon_x\)) is the new length after the force is applied and (\(\varepsilon_y\)) is the new width.
In the case of ceramics and metals, the value ($v$) is expected to be between 0.2 and 0.4. If $v < 0.5$, this then means that there will be a change in the volume of the tested object when the force is applied. The volume strain ($\varepsilon_v$) can be identified in terms of Poisson’s ratio and axial strain. The volume strain can be calculated from the magnitudes of the lateral and axial strains as [42]:

$$\varepsilon_v = \varepsilon_x (1 - 2v)$$

There are several types of mechanical testing. These tests are used in order to determine the required experimental data to be statistically analysed. The obtained results must be summarised and compared with any available similar studies. By using the suitable equipment, an understanding of the physical sense of material/sample can be achieved by adopting several ways of material/strength testing, such as [42]:

- **Tensile**: is a uniaxial test which determines the relationship between stress and strain. The purpose of this kind of test is to determine the maximum required force before separation or deformation of the tested sample occurs. The test takes place by fixing the sample to a proper testing machine (for example: universal testing machine) from one end to a fixed part in the testing machine, and attaching the other end of the sample to the removable part of the machine. After this, the removable part then starts to move in the opposite direction with a constant speed until the point when the sample breaks.
- **Compression:** this type of test is carried out in order to examine the material/sample’s resistance to the uniaxial compression load prior to the material failing. Similarly, the compressive strength can be determined by using the universal testing machine. Usually, the compressive strength is greater than the tensile strength.

- **Shear:** the shear test is mainly considered to be a uniaxial test, such as compressive and tensile. Under the shear stress, the particles of the material tend to slide over each other [47]. During the shear strength tests, a load is applied at the interface of the two bonded materials until the sample ruptures. This kind of tests is similar to the torsion test.

- **Flexure strength:** the capacity of the material to take the maximum force before it cracks or breaks. This test is also known as bending strength.

- **Impact strength:** the energy required to cause a fracture in the sample during an impact test.

- **Fracture toughness:** for simplicity, when a specimen is subjected to an impact force, the fracture toughness can be described as the ability of the sample to resist the crack propagation.

- **Shrinkage:** is the ratio of the material contraction/volume reduction [135].

- **Creep:** this term refers to the movement or permanent deformation (plastic deformation) of the solid material under stress [136].

- **Hardness:** can be described as the resistance of the material to stretching. Also, it could be identified as the measurement of the tested sample to resist localised plastic deformation. Hardness can be measured by different ways, such as MPa and GPa.

- **Fatigue:** refers to the deformation that occurs to the material after being subjected to cyclical load (stress and strain).

During practice, different types of load might be applied to an object, such as compression, tension and shear (Figure 1.14). With this in mind, several types of testing methods/machines are available in order to test these applied loads. All three types of load which have been mentioned previously are presented in any test [42].
In some cases, a complex load from the three kinds is applied to the same sample/object at the same time (for example, we can find a mixture load of compression, tension and shear in the three-point bending test) (Figure 1.15). The three types of load can be identified in the same sample as the following classification [42]:

- **Compression load**: applied from the top to the middle of the tested sample (approximately on the upper half of the beam).
- **Tension load**: applied from the bottom to about the middle of the tested sample (approximately on the lower half of the beam).
- **Shear load**: applied to the whole region between the compression and tension area.

**Figure 1.14 Type of loads [42].**

**Figure 1.15 Three-Point Bending Diagram [42].**
1.2.5. Mechanical testing machines

There are several types of material-testing machine. Each type is used in order to evaluate the different kinds of mechanical tests, such as impact strength, bend strength, tear resistance, tensile force, compression force, shear force, toughness, puncture, adhesion, peel, as well as hardness and fatigue resistance [42, 48, 49].

The corporatisation between two common testing machine used to investigate the mechanical properties in particular materials can be achieved by using one of the following machines:

Table 1.1 Types of mechanical testing machine [50]

<table>
<thead>
<tr>
<th>Products</th>
<th>Application</th>
<th>Testing Mode</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Universal Testing Machine</strong></td>
<td>Non-metal</td>
<td>Tension/Compression/Flexure/Shear/Peel</td>
<td>CMT2000, CMT4000, CMT6000, CMT7000, CMT8000</td>
</tr>
<tr>
<td></td>
<td>Metals</td>
<td>Tension/Compression/flexure/Shear</td>
<td>CMT5000</td>
</tr>
<tr>
<td><strong>Hydraulic Universal Testing Machine</strong></td>
<td>Metals</td>
<td>Tension/Compression/Flexure/Shear</td>
<td>CHT4000, SHT4000, SHT4000W, SHT5000, SHT5000P, SHT4000G</td>
</tr>
<tr>
<td></td>
<td>Metals</td>
<td>Double Axes Fatigue Testing</td>
<td>BIA5205</td>
</tr>
<tr>
<td><strong>Compression Testing</strong></td>
<td>Cement-brick</td>
<td>compression/flexure/break</td>
<td>CDT</td>
</tr>
<tr>
<td>Machine</td>
<td>Material/Testing</td>
<td>Tool/Standard</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------------------------------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td><strong>Pendulum Impact Tester</strong></td>
<td>Cement/concrete/rock compression</td>
<td>YAW</td>
<td></td>
</tr>
<tr>
<td>Package box</td>
<td>compression</td>
<td>CPT</td>
<td></td>
</tr>
<tr>
<td>Plastics</td>
<td>PPR PE Pipe Charp Testing</td>
<td>ZBC1501</td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td>Metals Charpy Impact Testing</td>
<td>ZBC1400</td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td>Metals Charpy/Izod/Tensile Impact Testing</td>
<td>ZBC1251</td>
<td></td>
</tr>
<tr>
<td><strong>Drop Weight Impact Tester</strong></td>
<td>Plastics PVC PPR PE Pipe Impact</td>
<td>ZCJ1000</td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td>DWTT / NDT Testing</td>
<td>ZCJ2000</td>
<td></td>
</tr>
<tr>
<td><strong>Rebar Bending Testing Machine</strong></td>
<td>Steel rebar Bending testing</td>
<td>ZLW401</td>
<td></td>
</tr>
<tr>
<td><strong>Dynamic Testing Machine</strong></td>
<td>Steel rebar Re-bending</td>
<td>ZFW401</td>
<td></td>
</tr>
<tr>
<td><strong>Ring Stiffness Testing Machine</strong></td>
<td>Plastic pipe compression</td>
<td>RST</td>
<td></td>
</tr>
<tr>
<td><strong>Torsion Testing Machine</strong></td>
<td>Metals Torsion</td>
<td>CTT</td>
<td></td>
</tr>
<tr>
<td><strong>High Temperature Creep Testing Machine</strong></td>
<td>Metals Creep/Stress rupture/relaxation</td>
<td>GWTA</td>
<td></td>
</tr>
<tr>
<td><strong>HDT-VICAT Tester</strong></td>
<td>Plastics HDT&amp;VICAT Testing</td>
<td>ZWK1000</td>
<td></td>
</tr>
<tr>
<td>Pipe Pressure Testing Machine</td>
<td>PVC PPR PE Pipe</td>
<td>Hydrostatic and burst testing</td>
<td>ZNY1000</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------------</td>
<td>-------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Rubber pipe</td>
<td>Hydrostatic/burst/pulse testing</td>
<td>ZNY2108</td>
<td></td>
</tr>
<tr>
<td>Steel Bottle &amp; Steel Pipe</td>
<td>Hydrostatic/burst/fatigue/water-tightness testing</td>
<td>ZNY3208</td>
<td></td>
</tr>
<tr>
<td>Plastic bottle</td>
<td>fatigue testing</td>
<td>ZNY4305</td>
<td></td>
</tr>
</tbody>
</table>

The machines in the schedule above should be carefully utilised (according to their operating manual). In addition, the specimen must be properly prepared before placing it in the testing machine. The test result will be displayed in a computer screen which is usually attached to each one of the machines. After this, the data will be analysed using the suitable statistical test system.
1.2.6. Biomechanics of teeth

Mechanics is a field of knowledge which concentrates on the action of force on the form and motion of objects. The relationship between the oral biological system and mechanical force can be obtained by studying the biomechanics of teeth [4, 51]. Teeth are usually subjected to complicated dynamic loads which involve resultant forces and moment. The movement/growth of the teeth is affected by different factors, such as teeth loss and/or providing the patient with a dental prosthesis without re-establishing the occlusal plane [12]. These factors can cause tooth malocclusion which makes teeth require dental treatment to restore the tooth aesthetic and/or function.

Mainly, teeth grow and appear in an organised row. However, when the tooth has malposition, it can be reorganised by using either fixed or removable orthodontic appliances. Treating the tooth orthodontically can change their position or growth by delivering forces to the tooth, bone and/or muscles. These applied forces accordingly create load within the periodontal ligament and alveolar bone, and subsequently cause tooth movement [52, 53]. The teeth movement requires soft tissue between the alveolar bone and tooth structure in order to achieve tooth movement [54]. The following figure (figure 1.16) is showing the anatomy of the tooth structure:

![Figure 1.16 Human tooth structure](image)
Generally, the force applied to the tooth will tend to move the tooth to a different position in space (unit of force is grams [40]). Normally, the resistance of the free object to any applied force is concentrated at the centre of it mass, but the centre of resistance to movement in the tooth is located at the tooth root (halfway between the root apex and crest of alveolar bone) [53] (Figure 1.17). The moment arm of the applied force upon the teeth is presented perpendicularly between the tooth centre of resistance and the point of the force application. Therefore, the teeth will tend to rotate around the centre of resistance (Figure 1.17) [53].

![Diagram](image)

**Figure 1.17 The centre of resistance to movement in the tooth [53].**

Generally, there are some factors which are known to affect the teeth biomechanics. In 1979, a study was conducted with the aim of studying a number of aspects, including the biomechanics of the natural teeth. The author has calculated the stresses (by using a computer program) which are associated with a given applied force on the teeth. A model of a normal tooth has been created, and a load was subsequently applied to the centre of the crown. The model of the natural tooth was created twice (both with and without the periodontal ligament). The models were created in order to identify the role of the presence of the periodontal ligament. Following, the reaction of the tooth in response to the applied force was studied in each case. The results show that the periodontal ligament controls the biomechanics of the natural teeth as it reduces the stress concentration at the socket wall and works as a good shear translate layer [55].
Brunski J.B. and Hipp J.A. carried out an *in vivo* study in 1984 with the aim of measuring the applied forces on endosteal dental implants. During the study, the researchers exposed the factors for consideration when applied forces are measured. The authors designed a recording system and transducer to measure the force components along the occlusal-apical axis on dental implants in a number of dogs. Titanium implants were made and provided with a hole in the neck portion, thereby allowing the transducer to be inserted. After this, three unit prostheses were fabricated and casted using cobalt-chrome alloy. Moreover, six implants were placed in the premolar surgically and allowed to heal. Following, the fabricated fixed prostheses were cemented on the prepared abutments using glass-ionomer cement; the results were subsequently recorded. The study reports that there was a satisfactory *in vivo* measurement of the forces, and that no failure occurs because of the corrosion or moisture at the intraoral environment. Moreover, it has been found that, the location of the implants in the mouth can affect the results as the applied loads vary from one place to another within the mouth/teeth. Furthermore, the obtained results can be affected by the material properties of the abutments teeth and the tissue between the teeth and the implants [56].

We can conclude that the condition of the oral soft tissue influence the biomechanics of teeth. These soft tissues are considered to be an important element when reducing the stress of the applied loads on teeth/prosthesis. The place of the applied force varies from one location to another along the tooth’s surface/location (anterior or posterior) [57-59]. Moreover, the condition of the abutment teeth/tooth has an influence on the denture stability [1]. The used materials on the dental prosthesis have an affect on the denture resistant to any external force. However, the *in vitro* studies can simulate the oral environment and provide acceptable results and anticipation to the oral environment, whereas an *in vivo* study of the exact applied forces on a fixed denture (placed at the patient mouth) can be achieved by using a suitable equipment; for example, the transducers and the recording system.
1.2.7. Methods of measuring bonding and attachments in dentistry

Because the field of dentistry has various branches, each kind of dental prostheses is retained in different way. These dental appliances are subjected a variety of applied forces on different areas along the dental restoration. Accordingly, it would be useful to point out that, dentists are classified according to their speciality. Each type of these specialities is concerned with a particular type of dental restoration, for example:

1. Prosthodontic: is concerned with dental prosthesis. This is the treatment achieved by replacing the missing natural teeth/tooth with artificial teeth/tooth, such as by utilising a fixed or removable partial denture.
2. Endodontic or (inside the tooth): this branch is concerned with treating anything which occurs in the tooth itself, such as caries, cracks, and root canal infection.
3. Orthodontic: concerned with treating the tooth malocclusion (when the teeth are not in their normal position).
4. Maxillofacial: this branch is concerned with restoring the oral soft tissue with artificial parts, such as replacing part of the jaw (with artificial teeth and/or jaw). Moreover, this field includes restoring some other facial parts, for example eyes, ears and nose.

Dental prostheses include single crowns and fixed bridges experience many loads applied in different directions and locations. Mainly, these loads could be tensile, compressive or shear [42]. During mastication, one or more of these loads will apply to the restoration. As a result, the artificial restoration might bend or break. However, the oral prostheses are not affected by the mastication forces only, although they might be subjected to other forces occurring from bad habits or sociological problems, such as biting tough objects and sleep bruxism [60].

The artificial crown/bridge particles slide over each other under the shear stress [47]. In order to obtain the shear bond strength, two materials are bonded with each other by using a appropriate adhesive material. After this, the load is applied at the junction
between the two materials until they separate from each other [61]. Although the bond strength might vary from one place to another along the tested sample, a lot of studies consider this way of testing the bone strength as an ideal way of testing the shear bone strength. There are different ways to test the material behaviour in such a situation; for example, flexural and tensile test. However, the shear bond strength test is the most popular test [62].

The best selected bonding test which could be used in order to test the material behaviour in service can be obtained by using a model simulated by using FEA. This model is able to analyse the stress distribution in any suggested clinical case. Therefore, it gives researchers the opportunity to make the best choice between tensile and shear bonding test [63].

There are a number of environmental differences between in vitro test and in vivo circumstances, such as temperature and saliva [64]. Furthermore, the presence of the tensile stress on the dental prostheses usually causes separation between the porcelain and metal [65]. So that, failure could be a result of the abnormal stress distribution within the tested sample [66].

In 1997, a study was undertaken with the intention of investigating the cohesive failure in the shear tests. The study did not concentrate on increasing or reducing the adhesive agent properties because it suggests that the reason of the cohesive failure of the shear test is related to the mechanics of this type of tests. Therefore, the specimens were prepared by making two-dimensional finite element models for dentine/composite. Following, a series of loads were applied at the junction between dentin and composite. The experiment shows that the fracture occurred in the composite surface (beside the loading point) and continued along the junction. After this, the fracture extended in the dentine. The dentine fraction was about 40 to 50% of the fractures. The outcome of the study identified that, by increasing the bond strength the cohesive failure will increase. The conclusion is that, regardless of the adhesive material properties, the cohesive failure in dentine will occur because of the brittle nature of the used materials and the test mechanics [67].
Another study was conducted in 1980 in order to estimate the stress distribution within a number of porcelain fused to metal samples. Each sample was tested using a different type of bonding test: three-point flexure test, four-point flexure test, semi-circular arch flexure test, tension/shear test, pull shear test, push shear test conical interface shear test, and parallel shear test. It was obvious in all types of test that the stress was abnormally distributed and not concentrated at a single point. However, the study reports that the lowest opportunity of having a tensile stress concentration and normal stress distribution can be achieved by using the rectangular parallel shear test with rectangular-shaped bonded surface, where the force is applied to the junction of the tested sample [66].

In 2003, another author used a microscope to examine the samples on a study of micro-tensile bond strength of resin-composite to ceramics. During the experiments, he noticed that the fracture between the two materials always started adhesively. In addition, no bulk fracture has been identified in the composite or ceramic. The observation in this study shows that when comparing to the conventional tensile and shear tests, the stress was normally distributed in the micro-tensile test [68].

However, this type of test cannot be carried out easily because the specimens need to be fixed (using cyanoacrylate resin) to stainless steel grips which are presented in the micro-tensile machine. Furthermore, the samples take a lot of time in order to be prepared. Moreover, sometimes, the samples might be separated from grips when the force is applied (if they are not properly fixed to a machine) and the results obtained might not be accurate. In conclusion, it is simpler and easier to use the micro-shear test rather than this type of tests [69, 70].

In 2006 and 2005, two studies were conducted in order to investigate the bond strength of zirconia-based ceramic crowns by using different types of cement. A number of natural extracted teeth were prepared, and the crowns were cemented to the extracted teeth. The authors used a pull-off test to examine the bond strength of the cemented crowns. The crowns were fabricated with retentive bars in order to be attached to the universal testing machine, which pull the crowns off and measures the force to failure in each group. The results show that there is no significant different in
the retention between these types of cement. The methodologies which were used in both studies were considered similar to the situation in patient mouth [71, 72].

Many studies suggest using a tensile load to measure attachment strength. In 1995, a study was undertaken to investigate the amount of force required to dislodge two types of dental clasp. The author tested the retention of these clasps in three different situations, and tooth preparations were made on the upper right first premolar and second molar. After this, three casts were poured (two prepared teeth were presented on each cast) and six full crowns were casted using cobaltchromium alloy. The crowns were cemented to the casts and the clasps were attached to each crown. The experiment took place using universal testing instruments. For each cast, the tensile load was applied until the clasps completely dislodged from the crowns and the maximum force was recorded. The results show that there is no significant difference between the mentioned groups. However, the study indicates that retention can be increased by increasing the clasp length [73].

In an attempt to compare the retention between C clasps and I bar with hidden clasps, a study was launched in 1996. Two extracted natural teeth (first premolar and second molar) were fixed into an acrylic resin model. After this, the framework, including the required clasps and a bar, was fabricated without the guiding planes. Form each design, nine frameworks were tested using a tensile test machine. Artificial saliva was lubricated over the natural teeth. The frameworks were then placed into the empty space between the two teeth and pulled ten times; the retention force was recorded. The study shows that the retention of the frameworks which carry the hidden clasp vary when compared with the other formworks. Furthermore, the absence of the guide plane caused the removable denture withdrawal [74].

In conclusion, many aspects should be taken into consideration during testing the bond strength, such as the test mechanics, materials involved, place of the load, type of the adhesive material. These components can make the bond strength results vary from one experiment to another even the shape and the bonded surface area of the sample might have an effect the bonding strength [75]. The shear testing considered as easy, fast simple, ideal, and the most popular test. Also, it is more accurate the comparing to some other types of bonding strength test. The shear bond strength
results are influenced by the cross-head speed; the suggested head speeds are 0.5 and 0.75 [64]. However, by using FEA, a model can be simulated to analyse the stress distribution and to accordingly give the researchers the best choice between tensile and shear bonding tests. On the other hand, it would be more appropriate to use the tensile test to identify the retention strength of the attachments which are retained mechanically. If clasps are used to in order to fix dental attachments, the longer the clasp used, the better retention will be obtained. Generally, the obtained results regarding the bond/retention strength should be taken with caution in order to obtain the correlation between in vitro and in vivo situations [64].

1.2.8. Denture life span and the factors which affect longevity of the dental prostheses

Dentures do not last indefinitely. Over time, they will need to be adjusted, rebased or remade periodically. The time taken before the need to replace the denture varies depending on many factors. An additional consideration is that the tissue of the mouth and gum can change in shape as long as the patient is getting older [76]. The material which is used in the removable denture must be wet at all times and, because of this reason, should be placed in quite hot water when it is removed out of the patient’s mouth [77]. If the denture becomes dry, it might change in dimensions; such changes cause the denture to loosen, thereby causing it not to fit properly. In addition, the removable partial dentures have sensitive parts which could potentially bend or easily break; therefore, required conscientious care when removing from the mouth is required. Moreover, a patient may have caries or teeth dislodgment, which also affects the denture’s stability; as such, it is wise to visit the dentist every six months for a check-up [12].

In 1993, a study was conducted in order to evaluate the clinical variables affecting the adhesion of fixed prostheses. A total of 141 fixed partial dentures were subjected to controlled circumstances from 1985-1992 (six years). Many aspects of the tested samples have been recorded, such as measuring the sample’s mobility, level of attachment, and the pocket depth. After this, dental preparations were made by
different dentists, and dental impressions were taken and sent to the dental laboratory. The required fixed prostheses were fabricated and cast with chromo-cobalt alloy.

During this study, three factors were estimated: prosthesis location (mandible/maxilla, anterior/posterior), metal condition (pyrolytic/tribochemical silane coating and/or sandblasting/electrolytic etching) and tooth preparation (less invasive/retentive). Only 24 failures of the examined fixed partial dentures were recorded. Most of the observed failures occurred due to adhesion dislodgment between the metal and cement. Despite the location of the dental restoration (mandible/maxilla, anterior/posterior), the result shows that the preparation technique increases the possibility of the prosthesis’s survival. Furthermore, the metal conditioning (sandblasting/electrolytic etching) has no influence in increasing the survival rate of the FPDs [78].

In 1984, a study was established by Sigvard Palmqvist and Bjorn Soderfeldt with the objective of determining the factors which affect the FPDs, retainer, and abutments longevity. The study finds that the most important reason associated with the longevity of prostheses is the materials which are used for the denture fabrication, such as gold and cobalt-chromium alloys. In addition, the findings also suggest that the gender (male/female) and the age of the patient have critical influence on the denture’s overall lifespan. The study also reports that the risk of losing the FPDs increases when the abutment tooth is endodontitally treated. The researchers further state in their study that having a combination of the previously mentioned factors decreases the length of required denture service [79].

On the other hand, many studies suggest that the increase of the patient’s age has no influence on the denture’s longevity. In 2009, a study was carried out in order to investigate the relationship between the increase of patient age and the fixed prostheses’ survival. The study includes medical databases between 1980 and 2008 for studies on humans, reporting on the influence of age on the longevity of fixed dentures. The database also includes a hand search to a number of journals and any available relevant articles and databases; however, the chosen studies were published between 1985 and 2007, for a total of 2,811 patients aged between 17 and 94 years old. However, although the study reports that there are some evidences of higher failure rates in the case of middle-aged patients, the study nevertheless concludes that
there age increase is not considered to have an impact on the survival of the fixed prostheses [80].

Another study was undertaken in 1997 with the aim of evaluating the longevity of fixed partial dentures and the reasons behind the failure of fixed partial dentures. Fifty patients were included in the study with a total of eighty-nine FPDs (384 units). A clinical and retrospective chart was designed for those patients during a six-month period. More than fifteen percent (53 unites) of the fixed partial dentures failed: the prostheses failures were due to caries, porcelain failure, defective margins, fracture on the tooth structure, fractured post and core, periapical involvement and perforated occlusal surfaces. In this study, the majority of FPD failures were due to the presence of dental caries. The study states that the rate of the fixed partial dentures’ longevity ranges from 4.1 to 16 years. However, another study suggests that the FPDs length of service is 11 years, and that all restoration lengths of service are about 8.3 years [81-83]. Many studies suggest that the failure of FPDs occurs due to the same previous reasons [84, 85].

In conclusion, there is no risk of denture loss according to age increase, especially if the patient has a good tooth and generally good health. The accurate tooth preparation increases the denture stability/retention, as well as the denture’s overall length of service. The metal conditioning such as sandblasting/electrolytic etching and the location of the denture such as anterior/posterior, tooth/teeth all have no influence in the denture’s longevity. The most important elements which affect the denture’s overall lifespan are the teeth preparation, the condition of the abutments and debonding of the cement, as well as the material used for the fabrication of the prostheses.

There is no agreement surrounding how long dentures can actually survive. After a period of time often several years they will undoubtedly experience problems during chewing and a loss of appearance (natural appearance) [76]; even with the right set of circumstances, the denture could still be broken or not fit perfectly. However, removable of the partial/complete denture often lasts for four to seven years, whilst fixed partial dentures or ‘crown and bridge’ may last for more than that. Implants, on the other hand, could last forever [12].
Chapter 2

Aims and Objectives of the Study
2. Study Aim and Objectives

2.1. Problem statement

Owing to the implications occurring from losing one or more natural teeth, new types of extracoronal or intracoronal dental prostheses have been developed in order to provide patients and practitioners with better alternatives to dental treatment options. Notably, restoring the missing teeth along with the conservation of the tooth’s structure has been one of the most important goals of any related dental treatment [86].

Fixed dentures are one of the most popular dental treatment solutions as they are considered to have a reasonable price and provide good function. Conventional fixed bridges, cantilever bridges and Maryland bridges are examples of such fixed restorations.

Although a great deal of years have passed since various fixed bridge designs have been used, there are nevertheless some major problems associated with these, including destroying neighbouring tooth anatomy owing to massive preparation, debonding (adhesive failure), and recurrent caries in the abutment prepared tooth [1, 4, 14, 82]. Furthermore, once the denture is cemented, it is most likely that the prosthesis would need to be remade if the abutment root canal needed to be treated or dental caries were presented [14].

In this study, a number of new fixed partial denture models have been suggested in an attempt to determine the possibility of producing them at the dental laboratory. The selected bridge designs will be studied individually. Subsequently, it will be fabricated by using a suitable biocompatible dental material. The usefulness of the new design will be examined by testing the level of stability and the ability to resist the oral force, such as the mastication force, in order to assess the new design’s overall effectiveness.
2.2. Study aim

The aim of the current study is to produce a new fixed partial denture design with minimum abutment teeth reduction.

2.3. Study objectives

1. To obtain a new type of bridge which is able to be fixed using mechanical force rather than chemical force (i.e. cement).
2. To evaluate the dislodgment resistance of the new design by comparing it with the conventional three unit fixed bridge.

2.4. Hypotheses

1. Null hypothesis: There is no significant difference between the dislodgment resistance of the new bridge design and the conventional three-unit fixed bridge design.

2. Alternative hypothesis: There is a significant difference between the dislodgment resistance of the new bridge design and the conventional three-unit fixed bridge design.
Chapter 3
The New FPD Design Development
3. The New Design Development

3.1. Introduction

Many studies have suggested different denture designs in order to examine the opportunity of obtaining varying dental appliances and treatment options. Those attempts have concentrated on establishing a new way of fabricating a new type of dentures that are possible to be made, retained acceptably and minimise the negative consequences of selecting a particular dental treatment.

Some of the studies have suggested designs, which have succeeded sufficiently whilst others have failed. The success of the new designs has significantly helped to improve the appearance and overall function of dental prostheses. Nevertheless, the failure of any tested design is considered to be important and is highly respected, owing to the fact that it confirms the failure of the tested model and accordingly explains the reason why it is not possible to use that design for a particular service. The obtained results from the failed attempts and subsequent studies can be used in the future to save the researcher’s time by avoiding the repetition of any similar models. Moreover, it can also be used in order to determine a way of solving the problems associated with the failed design.

One of the main aims of this study is to produce a new fixed bridge design which provides retention by only macro-mechanical means (clasps) in order to fix the bridge in the patient mouth and to thereby restore the missing tooth/teeth. The idea of the new bridge is focused on fabricating an artificial tooth with two clasps. These are embedded into each abutment tooth from the buccal and lingual sides (four clasps in total). The clasps should be fixed to the abutments with out any cement and the bridge is then will have the ability to be removed at any time. Fixing the denture without using any cement would be helpful to avoid numerous disadvantages associated with cemented fixed prostheses. Disadvantages such as: difficulties of cleaning the covered abutments, failures due to the de-bonding of the cement and difficulties of treating abutments teeth after cementation [87].

The new FPD design should be able to achieve the following goals:

- Be permanent, but can be removed occasionally for cleaning.
- Decreases neighbour teeth preparation (natural teeth).
- Offers a lower cost than dental implants.

In this study, a number of new fixed partial denture designs will be suggested and investigated in an attempt to improve the negative aspects of the fixed partial dentures [87], which have been used recently. Subsequently, the mechanical properties of the recommended design will be tested in order to determine the possibility of considering this bridge design as an alternative treatment option.

According to the problems associated with the utilisation of the cement to retain fixed prostheses, and also owing to the massive natural abutment teeth preparation, an idea emerges in an attempt to retain a fixed prosthesis with the use of four clasps to be embedded into the abutment teeth. When the shape of the new design (original design) is considered and the fabrication procedure has been initiated, the design has highlighted various technical difficulties in terms of its fabrication. Accordingly, a number of modifications were made to the original design prior to the final shape of the design being considered.

3.2. The original design (first model)

The first model comprises five components: one major component and four minor components. The first component is the major part of the model, which functions as a pontic. This part has two clasps, which are a feature of the major component (Figure 3.1) These clasps are designed to fit into the grooves, which are prepared in advance on the buccal side of the abutment teeth.

![Figure 3.1 The original design pontic.](image)
Once the pontic is constructed, four minor parts will be designed. The four minor parts include two individual clasps and two bolts (Figure 3.2). The two bolts are rectangular-prism shaped. The clasps at the location of attachment to the pontic feature a hollow rectangular column. The pontic features two hollow cube-shaped projections at the upper and lower parts of the lingual side of the pontic. These projections overlap the upper and lower parts of the rectangular column of the clasps; this is where the clasp will be bolted in place vertically; thus, fixing the clasp in place to the pontic (Figure 3.3).

![Figure 3.2 The Original design components.](image1)

![Figure 3.3 Five components of the original design fixed together.](image2)

3.2.1. Problems with the original design

Upon fabricating the first suggested model and carrying out further reading, it became apparent that the model required modification in order to solve two main issues:
1. Casting difficulties of the invested wax pattern; and

2. Fabricating difficulties and time-consuming in-laboratory activities.

It became clear that this design cannot be cast into a metal framework owing to the small parts of the design; more specifically, the hollow-cube projections from the pontic, as well as the rectangular prism of the clasps. The remaining mould from the wax-burnout procedure was not able to resist the speed at which the metal entered the mould. Importantly, during the flow of the metal within the mould, the thin layers were found to break easily.

The wax fabrication of this model, although possible, was found to be very difficult to execute precisely owing to the small parts contained within the design. It may be possible to construct this model in a factory due to the standard of precision available in modern technology; however, considering the practicalities of constructing this model, the two main issues concerning the wax fabrication and the casting procedure justify further modification in order to enhance the suggested design.

3.2.2. Modifications to the original design

In light of the problems established with the first model, a series of adjustments were made in order to overcome the previous design issues, which will form an enhanced second model. The problems which occurred owing to the casting and fabrication difficulties were minimised during the design of the second suggested model.

Generally, the second design will consist of more than one part joined together, and will act as one unit. The first part (major part) will work as a pontic. It will include two clasps extended only from the buccal side to each abutment tooth (Figure 3.4). The clasps will be inserted into a groove shape, which will be prepared, in advance, on each abutment tooth. At the distal-occlusal and mesial-occlusal surface of the major part, there will be two rest seats to increase the denture stability against the compressive force. Furthermore, the major part will include an appropriate space in order to adapt the second part and to thereby fix them together with the use of a suitable denture locker.
The second part of the bridge can be referred to as the minor part. This part also has two clasps which are extended from the artificial unit toward the lingual side of the abutments (Figure 3.5). When the major and the minor parts are joined together, each clasp from each part will be adapted into the prepared abutment teeth groove in order to surround the neighbour teeth buccally and lingually, and to thereby hold the denture in place so as to provide retention. In addition, the minor part will include small vertical opening in which the connecting device will be inserted.
The third part, the bridge locker, works as an attachment between the two other parts, and prevents bridge movement. By using suitable instrument (e.g. screwdriver), the locker will be fixed in place and the bridge will remain stable. If an instrument can be made for this purpose, the patient will be able open and close the locker for cleaning.

In conclusion, the idea of the second design will be focused on fabricating an artificial tooth, which consists of three parts. The two main parts will have two clasps/each, which will be extended from each part towards the neighbour teeth (buccally and lingually). Firstly, the major part will be placed into the gap of the missing tooth and the clasps will be inserted into the buccal grooves of the prepared teeth. Secondly, the minor part will be attached to the major part and the clasps will be inserted into the lingual grooves of the prepared abutments. Subsequently, the two parts (major and minor part) will be fixed together using a suitable bridge locker.

3.3. The modified original design (second model)

This second model has only three parts rather than five; this was decided in an attempt to facilitate the fabrication procedure, thus minimising the complications associated with the fabrication. Furthermore, the design of Model 2 does not feature the multiple small parts which were recognised as causing difficulties in casting Model 1.

The first part of the second model is referred to as the major part. The major part is a single entity comprising two clasps extending from the pontic to the neighbouring teeth on the buccal side (Figure 3.6). On the occlusal surface of the pontic, there is a box-shaped indent, at the bottom of which there is a hole into which the screw is placed in order to fix the first (major) part to the second (minor) part (Figure 3.7).

The minor part also has two clasps extending from the pontic but from the lingual side, similar in design to the major part. An exception in the design is a box-shaped projection rather than an indent (Figure 3.8). This projection will fit into the major part’s indent, which will enable the screw fix to be put into place vertically, thus bringing the two parts together whilst the clasps surround the neighbouring teeth on the buccal and lingual sides (Figure 3.9). As the projection is located at the centre of the occlusal surface of the pontic, it will be possible to make it as thick as possible in order to be casted without experiencing those difficulties associated with Model 1.
The third part, the bridge locker, worked as an attachment between the two other parts, and notably prevents bridge movement (Figure 3.10). Through the use of an appropriate instrument (e.g., screwdriver), the locker/screw is fixed into place, thus enabling the bridge to remain stable. With the same instrument, it will be possible to remove the locker for cleaning purposes.
Figure 3.9
Occlusal view of the second model

Figure 3.10
Side view of the second model
3.3.1 The second model fabrication

The fabrication procedure of this design involved fabricating the major part first and the minor part second. It is recommended to fabricate the major part first because it is practical to use the indent to shape the projection rather than the other way around. It is noted that this will be helpful in shaping the projection of the minor part more precisely, thus maximising the precision of the fit when the parts are brought together. Although this practical step was taken towards an acceptable standard of precision, soft wax was used to ensure the maximum fit when forming the projection of the minor part inside the indent of the major part. In order to achieve this, the major part is fabricated completely (Figure 3.11); the minor part is then fabricated out of wax but without the projection.

In order to fabricate the projection of the minor part, a procedure is carried out whereby the two parts are placed together, with the wax melting on the underside of the pontic at the point at which where the two parts meet, temporarily bonding the major and minor parts. The screw is then partially fixed in place inside the major part and the die lubricant applied to the inner walls of the indent and the screw so as to prevent the wax from sticking to the inner walls of the major part. The soft wax (soft tooth carding wax 500g, kemdent, Purton, UK) was then adapted into the presented gap using the fingertips. Once the wax has been precisely adapted to the presented gap, the wax then needs to be melted in order to securely join the formed projection to

![Figure 3.11 The second model major part.](image)
the minor part (Figure 3.12). The screw is then removed, leaving a hollow space in the projection, and the two parts are then separated from each other to be cast (Figure 3.13)

![Figure 3.12 The second model (Major and minor part).](image1)

![Figure 3.13 The second model wax pattern.](image2)

3.3.2. Problems with the modified original design (second model)

There are two main problems with this design which will jeopardise the functionality of this bridge design:

1. The precision of the fit between the indent of the major part and the projection of the minor due to the limited working area; and
2. The horizontal groove on the occlusal surface of the pontic.

Although a micro-millimetre gap will occur between the indent and the projection of the two parts, when the bridge is fabricated, this first problem is of particular concern as it will be liable to structural instabilities. Furthermore, it may allow particles of food to enter, thus meaning the design will be unlikely to be sufficient for patient use.

Furthermore, there is a second problem concerning the groove that appears on the occlusal surface of the pontic, which extends from the distal side of the pre-molar through to the mesial side of the molar. This is owing to the junction between the two individual parts, i.e. the major and minor parts. The main problem is that food particles may enter this groove. As the groove is on the occlusal surface, this problem is compounded by the mastication force pressing the food into the groove, which will cause difficulties in cleaning, therefore causing bad odour.

In light of these two problems, further modification is required to overcome these issues in this second suggested design; therefore, a third suggested model will be represented below.

Due to the problems associated with each design (first model and second model) we have suggested that the hollow parts of both models to be closed and fixed to the major part by using suitable dental cement. In this case, although those designs/models did not achieve the aim of being removable, they will be considered as conservative restorations and may show an acceptable resistance against the mastication force if they have been cemented. Both designs will require further investigations.

3.3.3. Modifications to the second model

In light of the problems established with the second model design, a series of adjustments were considered in an attempt to overcome the previous models’ design issues, which will therefore form a third and final model. The two problems occurred owing to the unsatisfactory fit between the indent and the projection, as well as the groove that was present on the occlusal surface of the pontic, both of which are rectified in this final design.
3.4. The final design of the new suggested FPD

This model comprises three parts. The first part referred to as the major part works as main part of the pontic. It has two clasps, both of which are adapted into the buccal side of the prepared abutment teeth. The major part has a thin projection extended from the lingual side in order to form a full occlusal surface as one unit (Figure 3.14). On the mesial-occlusal and distal-occlusal surface of the pontic, two rest seats are fabricated (adjacent to the pontic) (Figure 3.15).

Figure 3.14 Distal view of the final design (new FPD design).

Figure 3.15 The new FPD design attached to abutment teeth.
The second part referred to as the minor part also has two clasps, both of which are to be adapted into the prepared abutment teeth on the lingual side. The minor part is designed so to allow the major part’s projection to form the occlusal surface. Notably, both the major and minor parts are fabricated with a hole located lingually at the centre of each wall of the two parts (Figure 3.16). Furthermore, when the two parts are brought together, the pontic is formed (Figure 3.17). The two holes then allow a screw to be fixed horizontally in place in order to fix the two parts together.

Figure 3.16  Horizontal view of the major (up) and minor (down) parts.

Figure 3.17  Buccal (Horizontal) view of the New FPD design.
3.4.1. Advantages of the final design

The final model was designed with the aim of removing the junction on the occlusal surface of the pontic to the lingual side. The final design now features an occlusal surface which is fabricated as a single entity; this will drastically minimise the possibility of food particles being pressed into the junction between the two parts during mastication, whereas this was a certainty with the second model.

The final model was also designed with the aim of rectifying the problem of poor fit between the indent and projection in Model 2. In order to achieve this, the projection and the indent aspect of the design were removed completely; thus, the final model no longer relies on a screw being fixed at this point where structural instability is a risk. As stated, the final model retains structural stability by a horizontal screw attaching the two parts together at the bulkiest possible area.

The third model, Model 3, has ensured that the previous design flaws in the first and second designs are not repeated. The final model does not include very small parts which are difficult to be fabricated or which are otherwise impossible to cast, as was experienced previously.

3.5. Advantages of this type of bridge (why it is better?)

When comparing the conventional and cantilever-fixed bridge, the new bridge will be able to save most of the remaining teeth (abutments) structure. It is clinically quicker than all types of FPD protheses, less expensive to implement than the implants and does not require any surgery. Although the Maryland Bridges save most of the tooth structure, it is usually placed over the anterior teeth. The new FPD design has the advantage of being more capable of resisting the chewing force, and can be applied in the posterior area. Unlike with the Maryland Bridges, this new bridge should not be affected by teeth dislodgment [1] as the bridge is tightly fixed to the abutment teeth.

Another advantage could be by carrying out the experiment of fixing the bridge without any cement, and whether the outcome is successful; in this case, the denture is going to be fixed when it is placed into the patient mouth and the locker is closed, which is then removable upon opening the locker. Unlike the other types of fixed
partial denture designs, the success of this experiment will give the patient the chance to remove the denture from his/her mouth. This will then increase the advantages of that bridge, owing to the fact that the patient will be able to take it out to clean his/her teeth and the denture frequently. The decay which occurs under the fixed denture is considered to be one of the main factors affecting fixed partial dentures lifespan [4], and so this experiment could help to overcome this issue.

One of the fixed dentures disadvantages is that it is not adjustable; when the denture experiences any problems or issues and needs to be replaced, it will then be very expensive for the patient. Because the new bridge consists of two parts, this means that the denture is more likely to be replaced in one part only when the decay appears on one side of the abutment tooth; therefore, the prosthesis will be replaced partially, accordingly saving materials. Subsequently, the denture might then be able to live indefinitely. Also, it might be possible to treat the root canal of the abutment teeth without removing the bridge, owing to the occlusal surfaces of the abutment teeth being clear.

3.6. Evaluation of enamel thickness

3.6.1. Introduction

Enamel is the external layer of the tooth and the toughest mineralised tissue of the human body. It consists of nanorod-like hydroxyapatite crystals, which are organised into a micro-architectural unit [88]. Many studies have conducted to measure the enamel thickness and subsequently determine that an individuals’ dental enamel varies in thickness depending on many factors including species, sex and type of the examined tooth [89-96]. However, if the two teeth from the same type was examined a slight deference might be found.

Generally, the upper part of the tooth enamel is the thickest part especially in the cusps which gets thinner towards the gingival area [96]. According to many studies which have been conducted to measure the enamel thickness, they have subsequently determined that the maximum thickness of human enamel (upper third molar) are located in the range of up to more than ~2.25 mm at the cusps area [90, 97, 98].
The second layer of the tooth structure is known as the Dentin; it is covered and protected by the enamel. Dentin mainly consists of minerals [99], and has small channels which extend from the inner tooth pulp to the enamel border [100]. When the tooth has a crack or caries, the Dentin is exposed and patients can then feel sensation or pain through those channels [100]. Therefore, it is highly recommended that tooth reduction be kept to a minimal and within the enamel area [101].

3.6.2. In vitro study to evaluate enamel thickness

In the current study, an in vitro study has been launched with the objective to measure the enamel thickness of a number of adults’ permanent second premolars and second molars. This study has focused on measuring the enamel thickness both buccally and lingually in order to determine the accurate location and exact depth of the tooth preparation so as to obtain suitable space to set the clasps of the new suggested design. The enamel thickness has been measured approximately half way between the tooth cusp tip and the enamel-dentin junction (the bulkiest enamel area) (Figure 3.18).

![Figure 3.18 The location of the measured area of the sectioned teeth [6].](image)

In order to evaluate the enamel thickness, a number of second premolar and second molar (n=10) have been sectioned from the middle of the tooth (cut into two halves)
and the enamel has been measured. The measurements were carried out by using electronic caliper (SPS electronic caliper, 432-025, Mitutoyo) (Figure 3.19).

![Electronic caliper](image)

**Figure 3.19** Electronic caliper (SPS, 432-025, Mitutoyo).

**Table 3.1** Illustrates the enamel thickness of the second molar in mm:

<table>
<thead>
<tr>
<th>Tooth</th>
<th>Buccal Depth</th>
<th>Lingual Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second Molar</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.29</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>1.19</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>1.47</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>1.57</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>1.62</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>1.64</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td>1.59</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>1.77</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>1.56</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>1.38</td>
<td>1.21</td>
</tr>
<tr>
<td>Mean</td>
<td>1.51</td>
<td>1.34</td>
</tr>
</tbody>
</table>

The Depth is the distance between the dentin and the external surface of the second molar at the bulkiest enamel area (horizontally).
Table 3.2 Shows the second premolar enamel thickness in millimetres:

<table>
<thead>
<tr>
<th>Tooth</th>
<th>Buccal Depth</th>
<th>Lingual Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second Premolar</td>
<td>1.62</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>1.52</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>1.18</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>1.62</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>1.65</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>1.19</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>1.34</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>1.45</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>1.29</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>1.38</td>
<td>1.20</td>
</tr>
<tr>
<td>Mean</td>
<td>1.42</td>
<td>1.23</td>
</tr>
</tbody>
</table>

The Depth is the distance between the dentin and the external surface of the second premolar at the bulkiest enamel area (horizontally).

3.7. The dimensions and location of the new bridge

According to the previous study, we can conclude that the suggested design clasps can get into the abutments tooth (enamel) with a maximum depth of ~1.5mm in the buccal side and ~1.3mm from the lingual side of the second molar, to be within the enamel level. The preparation depth on the second premolar can be made up ~1.4mm on the buccal side and ~1.2 from the lingual side. These findings coincide to a large extent with the previous study of Anthony et al. [102]. Moreover, by looking at a number of previous studies it might be possible to conclude that the enamel thickness of the second molar (lingually and buccally) may be approximately in that range [98, 102-104].

The tensile strength of the new bridge might be improved by making sharp angles in the inner surface of the tooth preparation, where denture toughness can be increased by making the clasps thicker during fabricating the bridge in the dental lab. However, in this stage the preparation will be made according to the standard criteria, as a sufficient place is available for the clasps to be inserted (Figure 3.20).
The depth and width of the tooth preparation/grooves will be 1.0mm each for both the premolar and molar (Figure 3.20). During the metal framework fabrication, a 0.5mm will be added to the clasps thickness (externally), thus bringing the total clasp thickness to 1.5mm. The length of the preparation (along the buccal and lingual sides) is recommended to be as long as possible in order to increase retention. As a result, clasps will gain the maximum available toughness because they have been made as thick as possible. Also, by extending the clasps to the maximum length, the new FPD design should be more flexible and capable to resist mastication loads [105].

Figure 3.20 Side View from the distal side of the tooth showing the suggested preparation.

The measurement was made especially in that chosen area because the thickest part of the enamel is located at the tooth cusp tip and gets thinner toward the gum. Accordingly, making the preparation at this location will subsequently obtain more space for the clasps to get deeper into the tooth/abutment and increase denture stability and to be as far as possible from the soft tissue of the jaw as well as the dentin. Moreover, there will be sufficient space between the clasps and the cusp tip, which will be helpful in avoiding the prepared tooth from getting easily broken when the tensile force is applied.

Finally, two standard rest seats will be prepared on the disto-occlusal and mesio-occlusal surface of the abutment teeth. Those rest seats will prevent the rotation
movement and transmit occlusal forces along the axis of the abutments, and accordingly provide vertical support against the mastication force [106, 107]. It has been proven that the occlusal rest seat can also take more pressure than mastication force, and it is also impossible to break during chewing [108, 109]. Thus, there is no importance in examining the new FPD design performance against the compressive force.
Chapter 4
Materials and Methods
4. Materials and Methods

The study was conducted with the aim of investigating two groups of fixed partial denture prosthesis. Both groups were fabricated on extracted adult, human teeth in an attempt to simulate the oral condition [110]. The teeth were collected from different sources, and subsequently disinfected, cleaned and stored in distilled water. Forty (40) teeth (20 second premolar, 20 second molars) were checked carefully and accordingly selected. A three-unit bridge case was then simulated by mounting one second premolar and one second molar in acrylic resin blocks leaving the space of the first molar missing. Twenty (20) acrylic blocks were constructed and divided into two groups (n = 10).

Group I: Conventional three-unit FPDs (n = 10).

Group II: New FPD design (n = 10).

The blocks are then sent to a clinic for teeth preparation according to each group criteria and with the objective to restore the missing first molar. The preparation was performed by a professional dentist. The occlusal reduction was vary between 1.5 to 2.00 mm (functional and non-functional cusps respectively) and the axial walls were reduced by 1.2 mm with a diamond bur [12]. In the first group, the preparations were made to prepare adequate space for a conventional three-unit FPD framework. In the second group, only the occlusal rest seats were prepared in the dental clinic, where the buccal and lingual grooves were prepared in the dental lab according to the new preparation criteria described previously (last section-chapter 3). The bridges are then constructed and applied to the prepared teeth in each group to be investigated. Furthermore, all metal frameworks were cast using non-precious dental alloy.

4.1. Specimens preparation

There were seven steps carried out during the fabrication of the specimens. Firstly, forty (40) natural human, adult extracted teeth (second premolars and second molars) are selected in order to be placed into a base made out of acrylic resin. In order to do this, a boxing wax is used to mould the acrylic resin into a rectangle shape in which the selected teeth will be fixed in place.
The second step entails boxing wax sheets (soft tooth carding wax 500g, DWS303, kemdent, Purton, UK) being cut into six individual sheets with the use of a wax knife. Four pieces of the sheets are cut to a minimum dimension of 2cm x 3cm, with two remaining pieces cut to a minimum dimension of 2cm x 2cm.

The third step saw these sheets are then put together to form a hollow rectangular prism-shaped base. With the exception of the horizontal top surface, the individually cut sheets are then sealed together using a hot wax sculpture (Figure 4.1).

At this stage, there is one remaining 2cm x 3cm boxing wax sheet, which is to be placed on the surface of the open top ‘box’. The forth step is to place one second premolar, one first molar, and one second molar in their respective positions within the one remaining 2cm x 3cm boxing wax sheet. When setting the teeth into the sheet, the accuracy of forming the buccal row and the lingual row is taken into consideration.

The fifth step is to remove the first molar, which now leaves a hole in the centre of the boxing wax sheet where the removed tooth was inserted. The boxing wax sheet now has two remaining teeth. The sheet is placed on top of the open top ‘box’ and sealed using a hot wax sculpture (Figure 4.2).
The sixth step is to mix a suitable amount of powder and liquid of the acrylic resin (Autopolymerising Powder, Veined, Metrodent, England) in line with the manufacturer’s recommendation. The mixture is then poured carefully into the hole from which the first molar was removed until the hollow box is filled to the top. The acrylic resin is then permitted to be polymerised completely, and the sticking wax around the base is removed with the use of a wax knife. The base unit is then steamed using a steam cleaner (steam-cleaner, Aquaclean 3, Degussa, Germany) to ensure any excess sticking wax is removed.

The seventh step is to create a textured surface on the acrylic base unit so as to ensure that maximum grip is achieved when placed in the vice-grip for testing. This texture is achieved through sand-blasting (using aluminium oxide 50 μm in size) the acrylic blocks with the use of a micro-blaster (micro-blaster, dentalfarm, Torino, Italy). The acrylic blocks are then rinsed under running tap water. All prepared acrylic blocks specimens are stored in distilled water for the teeth preparation procedure.

4.2. Teeth preparation

4.2.1. Group I: Conventional three-unit FPDs’ teeth preparation

The prepared specimen (n = 10) were sent to a clinic to be prepared in terms of the adequate space for applying the fixed bridge framework and restoring the missing
tooth according to conventional three-unit FPD criteria. In line with known procedural quality standards, the preparation was performed by a professional dentist. A chamfer diamond bur was used for the abutment teeth preparation. The occlusal surface reduction was varying between 1.5 mm and 2.00 mm (functional and non-functional cusps) and the walls were reduced 1.2 mm by using the same bur.

4.2.2. Group II: New suggested FPD design teeth preparation

In the second group, only the occlusal rest seats were prepared in the dental clinic. The rest seats were prepared in the disto-occlusal side of the second premolar and the meso-occlusal side of the second molar (adjacent to the missing tooth area). The buccal and lingual grooves of the new design were prepared in the dental lab as described below.

The abutment teeth fixed at the acrylic resin blocks were prepared according to the decided preparation. A round bur was used to prepare a horizontal groove on the abutment teeth in order to apply the new design. The preparation is at the bulkiest point of the tooth both buccally and lingually. The depth of the preparation was a groove 1mm deep along the buccal and lingual surface (Figure 4.3 and Figure 4.4). The groove was prepared to the greatest length possible, on both the buccal and lingual surface, in order to maximise the retention of the new bridge design. Water was applied during this procedure in order to keep the teeth moist and cool. The procedure was performed with caution in order to achieve the exact requirements of the preparations shape, depth and location.
In order to examine the preparation requirements, die-lubricant is applied into the prepared grooves. Hard wax (Inlay Wax, hard, GC, Germany) is then melted and applied into the grooves, which is subsequently removed in order to examine whether or not the preparation requirements are satisfied. The wax length and depth is measured using a wax thickness gauge where further adjustment to the preparation is performed if deemed necessary. The abutment teeth are then steamed using the steaming-machine to remove any remaining wax in the prepared grooves.

Finally, the prepared teeth are rinsed under running tap water. The acrylic resin blocks are then stored in distilled water.
4.3. Prostheses fabrication

4.3.1. Group I: The conventional three-unit FPD fabrication

The bridges framework fabrications were carried out in the dental laboratory. The steps of fabricating the conventional three-unit FPD samples comprises seven stages, each of which will be outlined below.

The first step is to apply die-spacer (LC die spacer, Yeti, Germany) on and around the occlusal surface, which is then left until it dries completely. The die spacer will provide an adequate space in which the dental cement will be applied.

The second step entails the die-lubricant (Yeti die lube, Yeti dental, Germany), which is applied everywhere on the abutment teeth surface. This procedure is conducted to ensure that, once the wax pattern is ready, it can be removed easily.

The third step is to build up the wax pattern using build-up wax (K2 exact modelling wax, bredent, Germany). This step initiates the coping procedure, after which the wax is applied with the use of a wax sculpture. The wax sculpture is heated and put into the wax, whereby the wax can then be carried and built up on the abutment teeth.

The fourth step entails manipulating the wax which has been built up on the abutment teeth. The excess build-up wax is then cut back and formed using a wax knife and a wax carver until the required abutment shape is produced. The pontic is then created by attaching a sprue (2.5mm) between the two abutment teeth, and accordingly melted from both ends, thus attaching itself to the wax that was built on the abutment teeth.

The fifth step is to add more wax on the pontic/sprue itself, as well as at the junction between the pontic/sprue and the abutments until the final shape of the bridge is obtained. The connecting area should be made with caution to ensure that there is enough rigidity between the pontic and the abutment teeth. A wax sprue of 2.5mm in diameter is then bent into a hook shape and joined to the occlusal surface in the middle of the pontic with the use of a hot wax sculpture. The hook will be used to facilitate the tensile force measurement. Finally, the wax pattern is removed and is ready to be invested.
4.3.2. Group II: The new suggested FPD fabrication

As described previously, the new suggested FPD comprises three parts: the major part, the minor part, and the bridge locker. In this study, the metal framework fabrication was created using an individually adapted technique. However, the fabrication could be carried out through the use of alternative techniques. For example, the major and minor parts may be able to be fabricated in one step prior to the casting procedure. This would be achieved by fabricating the major part out of wax (completely). Die-lubricant is then applied to the major part wax pattern. After that, the minor part is fabricated over the major part; thus, both parts are fabricated prior to casting.

The individually adapted technique applied in order to fabricate the new FPD designs entails fabricating and casting the major part. The minor part is then fabricated over the cast wax pattern of the major part. The fabrication technique steps is described in the following section.

4.3.2.1. The major part fabrication

Firstly, die-lubricant is applied over the abutment teeth with particular attention paid to the prepared grooves. Secondly, the major part is first fabricated on the buccal side of the teeth. The wax is then built up using build-up wax. In order to do this, the wax is melted around the screw (bridge locker) until a piece of rounded wax, thick in diameter, is formed. This piece is made until the required shape of the pontic is achieved. The screw, along with the fabricated pontic, is placed horizontally in the place of the missing tooth. More wax is added and a cut-back is made until the final shape of the major part pontic is obtained. The major part is fabricated, with enough space remaining for the minor part to be created.

Thirdly, the clasps of the major part were fabricated by melting the wax and filling the grooves. Subsequently, the wax sculpture is then heated and inserted into the grooves through the wax to ensure that the wax is perfectly sealed to the inner surface of the grooves. Moreover, more wax is then added to the clasps to increase the clasp rigidity. The clasps will be exposed by 0.5mm out of the tooth surface, thus bringing the total clasp thickness to 1.5mm. The clasps are then joined to the major part by adding the melting wax to the junction between the major part and the clasp.
Fourthly, the major part is removed from the abutment teeth. The screw is then removed from the major part, to which final adjustments are made to the major part, with the measurement of the clasp thickness is then confirmed. Finally, the hook was then shaped by using sprue-wax and attached to the centre of the occlusal surface of the pontic by melting the wax at the respective joining parts. The wax pattern and hook are then ready for the procedure of sprueing, investing, and casting.

4.3.2.2. The minor part fabrication

When the major part is cast, the sprue at the top of the hook is then cut. The lingual side of the major part of the pontic is then finished and polished until a shiny and smooth surface is obtained. The major part is accordingly fixed in place on the abutment teeth with the use sticky-wax (model cement, sticky wax 500g yellow, DWS412, kemdent, Purton, UK). The screw is then inserted through the hole in the major part. Following, the die-lubricant is applied to the lingual side of the major part, the screw, and the prepared groove. Through the application of the same technique of the major part fabrication, the wax is then applied around the inserted screw to build-up the minor part pontic.

During the minor part fabrication procedure, the wax is applied carefully so as to ensure the best contact is obtained between the minor and major parts. After shaping the pontic of the minor part, the cut-back is then made until the satisfactory shape of the pontic is produced. The minor part clasps are then fabricated and attached to the pontic. The cut-back is then made until a satisfactory shape of the entire minor part is obtained. The minor part is subsequently removed, the screw taken out and the measurement of the clasps’ thickness and the parts’ path of insertion checked. The minor part is now ready to be invested and cast. Unlike the major part, no hook is attached to the minor part.

4.4. The sprueing procedure

The sprueing procedure comprises four main steps. The first stage is to remove the fabricated wax pattern from the abutment teeth. Subsequently, another sprue 1.5mm in diameter is attached to the hook at a suitable angle (40-55 degree).
The second step is to acquire a ready-made disposable plastic cone former (plastic cone, Bracon Ltd, England). The unit is then cut down in size horizontally across the base so as to achieve the required height. The cone is then cut to ensure that the wax pattern is located at the correct height. The hollow conical plastic unit is accordingly filled with wax and then placed over a pink wax sheet (JW WIN-WAX No. 5, John Winter & Co. Ltd, England). The borders between the ready-made plastic conical unit and the pink wax sheet are then sealed tightly with build-up wax using a hot wax sculpture.

The third step entails joining the sprue of the wax pattern to the top of the plastic conical unit. The wax is melted at the point where the sprue meets the top of the plastic conical unit, with more build-up wax added to make the joint a bit thicker.

In the fourth step, a liner (3X ring liner, Bracon, England) is then placed on the inner surface of the casting ring (3X ring, Bracon, England). The wax pattern is then placed inside the casting ring, ensuring the wax pattern is placed accurately within the thermal zone. Again, the outer border of the casting ring is sealed to the pink wax sheet. Finally, the excess of the pink wax sheet is cut into a square shape around the base of the casting ring. The wax pattern is now ready to be invested.

4.5. Investing the wax pattern

Firstly, after sprueing is complete, the wax pattern is sprayed all over with a de-bubbleizer (sheramaster, shera, Germany) particularly on the fitting surface of the wax pattern. This step is performed with the aim of minimising the possibility of air bubbles occurring on the surface of the metal framework.

Secondly, a high-speed investing material pack (Shera-Rapid 160g, Shera, Germany) is poured into a special plastic bowl. Notably, 42ml of investing material liquid (Shera expansion liquid, Shera, Germany) is poured into the same bowl. Using a plaster spatula, the mixture is then mixed gently to ensure that no powder in the investing material remains in the bottom of the bowl. It is important that the powder is fully dissolved to ensure that the powder does not stick to the bottom of the bowl.
Thirdly, the bowl is placed into a mixer (vacuum mixer, mestra, koala, Spain) and left for the fixed amount of time (forty seconds). The contents of the bowl are then mixed with the use of the mixing machine. The bowl is then removed from the machine.

Fourthly, the casting ring, along with the wax pattern, is placed on the vibrating table. The investing material mixture is then poured into the casting ring at the points closest to the inner perimeter until it has filled to the top.

Finally, the investing material is allowed to set for twenty minutes. After the investing material is set completely, the wax is removed from the bottom of the casting ring. The casting ring is then placed into a burnout furnace (Ugin, dentaire, France) at a temperature of 850°C. The temperature of the oven is gradually increased over a period of two hours until it reaches 950°C. The casting ring is then removed from the oven in order to be cast.

4.6. The casting procedure

After the casting ring is left in the oven, they are then taken out to be cast. All metal frameworks are cast using cobalt-chromium alloys. The casting and finishing procedure comprises five main steps, each of which is presented below.

Firstly, when the casting ring is ready to be cast, it is removed out of the burnout furnace and placed immediately into the casting machine (IQ, Heraeus Kulzer, Heracast, Germany). A sufficient amount of cobalt-chromium alloy ingots are placed into the appropriate place within the casting machine. The metal framework is then cast automatically (melting range between 850-900°C).

The second step entails the casting ring being removed from the casting machine and is then placed outside at room temperature to cool. The casting ring is then placed in water for five minutes in order to avoid dust diffusing during the removal of the metal framework out of the investing material.

The third step requires the metal framework to be taken out of the investing material by gentling tapping the entire surface of the casting ring by using a hammer. When the investment material is separated from the ring, the remaining parts of the investing material surrounding the metal framework are removed with the use of plaster nippers.
The fourth step requires the metal framework to be placed into the micro-blower (micro-blower, dentalfarm, Torino, Italy). The substructure is then cleaned using a micro-blower containing aluminium oxide (50 μm in size) in order to remove the small, hard residue left by the investing material on the surface of the metal framework. This procedure directs particular emphasis to the fitting surface of the bridge in order to remove the remaining sticking investing material and assure that good retention is obtained when the bridge is cemented to the natural teeth.

The final step is to cut the sprue attached to hook of the bridge. The procedure is performed using a cut off disc (25 x 0.25mm thick). The finishing touches are then made by using an appropriate finishing bur in order to remove visible air bubbles located anywhere on the metal framework especially on the fitting/contact surface so as to ensure that the bridge fits perfectly on the prepared teeth. The same procedures are accordingly repeated for each sample in each tested group. The bridges are then ready to be fixed to the natural teeth.

4.7. Samples cementation

Only the first group are cemented to the natural teeth, which are fixed to the acrylic resin blocks. As the second group samples were retained using mechanical interlocking system, no cement was used to fix the fabricated samples in place (Figure 4.5). The major and the minor part of the new FPD design were fixed together, on the prepared abutment teeth, using a screw and nut (Slotted machine screw, M3x10, Stainless Steel A4, clas ohlson, UK) (Figure 4.6). The cementation of the conventional FPD samples were made with the steps described below.

Firstly, the acrylic resin base and the embedded natural teeth are cleaned using the steam machine, and subsequently washed, cleaned with alcohol and dried. Following the fabricating and casting procedure, the conventional fixed bridge frameworks are cemented to the prepared teeth, which are embedded within the acrylic resin blocks using zinc phosphate cement (Detrey®Zinc, dentsply detrey gmbh, De-trey-str.1, Germany).

The cement consists of powder and liquid are mixed on a glass slab. The powder and liquid are then placed on the slab and mixed together according to the manufacturer’s
instructions. The fitting surface of the fabricated bridge metal framework is then filled with the mixed cement. The bridge is then placed over the prepared teeth and pressure is applied with finger tips for five minutes to ensure a strong and tight fit. Following the initial set of the cement, the excess cement, i.e. that which seeps from within the fitting area upon the bridge being applied to the abutment teeth, is removed (Figure 4.7). The cemented samples are then stored in distilled water.

![Figure 4.5 The major and minor parts after the wax-pattern cast.](image)

![Figure 4.6 Horizontal view of the new FPD design after the wax-pattern cast.](image)

![Figure 4.7 Conventional three-unit FPD framework after the wax-pattern cast.](image)
4.8. Testing methodology

The cemented/fabricated bridges are fixed to the base of the Zwick/Roell Z020 universal testing machine (Zwick GmbH & Co. KG, Germany) which grips the acrylic resin blocks/specimens (Figure 4.8). The fabricated hook which is created within each sample is then attached to the removable part of the universal testing machine using chain. The maximum tensile force required to dislodge the bridges is measured at a cross-head speed of 0.5 mm/min.

![Zwick/Roell Z020 universal testing machine](image)

**Figure 4.8** Zwick/Roell Z020 universal testing machine.

The measurement procedure is accordingly repeated for each sample in each tested group (n = 10). The mean dislodgment resistance (maximum tensile force) of each sample is record in Newtons. The separation forces in the first group (conventional three-unit FPDs) are compared with the forces in the second group (new suggested FPD designs).
4.9. Statistical analysis

Mean tensile force of the two groups was compared using independent sample t-test (SPSS ver 16 Inc., Chicago, USA) to test any significant difference ($A = 0.05$). The test was used to compare the means of maximum dislodgment force (N) of conventional three-unit FPD framework group to that obtained from the new suggested FPD framework group.
Chapter 5
Results
5.1. Results

The mean and standard deviation for maximum tensile load required to dislodge the bridges are recorded in Newtons for both groups. The mean value of the maximum tensile force required for dislodging the conventional three-unit FPD’s frameworks (Group A) is 170.97N (SD±21.09); and the new FPD’s framework (Group B) is 387.80N (SD±22.21).

Table 5.1 The mean values and standard deviation of the maximum dislodgment force for the conventional three-unit FPD’s frameworks (Group A) and the new FPD’s framework (Group B).

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>170.97</td>
<td>21.09</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>387.80</td>
<td>22.21</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The previous table (Table 1) reveals that the mean value of dislodgment resistance for the new FPD designs was found more than two times higher than the conventional three-unit FPD’s. This indicates that mechanical interlocking system (undercuts) has significantly increased the bridge resistance against the tensile force.

5.1. Statistical analysis

Table 2 shows results of independent sample t-test (SPSS ver 16 Inc., Chicago, USA) comparing the means (SD) of maximum dislodgment force (N) for conventional three-unit and new FPD’s frameworks. The mean values were compared to test any significant differences between the two groups (P < 0.05).
Table 5.2 Statistical significance presented between the two groups.

<table>
<thead>
<tr>
<th>Levene’s Test for Equality of Variances</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>F</strong></td>
<td><strong>Sig.</strong> (2-tailed)</td>
</tr>
<tr>
<td>Equal Variances Assumed</td>
<td>.034</td>
</tr>
<tr>
<td>Equal Variances not Assumed</td>
<td></td>
</tr>
</tbody>
</table>

The results are obtained using independent sample t-test (SPSS ver 16 Inc., Chicago, USA) which indicates that there was statistically significant difference between the two groups (Table 2). The first group conventional three-unit FPDs exhibited a significantly lower mean dislodgment resistance compared with the second group new FPD designs ($P < 0.001$).
Chapter 6
Discussion
Discussion

This study aims to produce a modified fixed partial denture design, which helps to conserve the abutment teeth reduction. In addition, it also aims to produce a new FPD design that provides retention with the use of only macro-mechanical features (undercuts/clasps) as opposed to the conventional retention facilitated by the use of dental cement. The new bridge should have the capacity to be removed occasionally for cleaning. The current study compared the means of maximum dislodgment force for conventional three-unit and new FPD’s design. The results show that there was a statistically significant difference in the dislodgment resistance between the two tested groups (P < 0.001). Accordingly, the null hypothesis was rejected.

The new suggested bridge design was fabricated and the retention of the new design was compared with the retention of the conventional three-unit fixed partial denture. In the present experiment, the bridges were fixed to extracted human teeth in order to simulate oral conditions [110] as closely as possible. The maximum tensile forces required to separate the bridges from the prepared teeth of each type were recoded and statistically analysed. The mean separation force of the new FPD designs was found to be more than twice that of the conventional three-unit bridges. The mean and standard deviation for the maximum tensile force required to dislodge the new FPD design samples were 387.80 Newtons (SD±22.21) and, for the conventional three-unit FPDs, were 170.97 Newtons (SD±21.09).

Our new fixed bridge design is divided into two main parts. Two clasps were fabricated within each part (four clasps in total). The clasps are used to hold the bridge in place to provide retention. The two main parts come together from different paths of insertion, with the clasps adapted into preparations/grooves, which are prepared in each abutment teeth in advance. The two main parts are then accordingly fixed securely using a screw.

The new FPD design has a significantly higher mean separation force compared with the conventional FPD. This was owing to the mechanical prosperities of the cast alloy and the mechanical dislodgment resistance against the uni-axial movement which has been provided by the tooth undercuts/clasps. The metal clasps of the bridge design
which are engaging inside the teeth undercut work as a mechanical interlocking device; therefore, a greater tensile force was required to pull-off the bridge.

According to this study results, the conventional three-unit FPD has lower dislodgment resistance value when the bridges were exposed to tensile load. Thus, it can be stated that the conventional three-unit FPDs depend only on the bond strength of the cement as the main retention feature of the bridge. As a result, the conventional three-unit FPD group was found to be more likely to dislodge when compared with the new FPD group.

The use of luting agent with better mechanical properties could significantly improve the resin bonded fixed partial dentures retention [111-116]. However, it can be concluded that the common reason for failure in the case of RBFPD is owing to the de-bond of the cemented framework from the abutment teeth [87,117-119,120]. This indicates that, even with the new cement generation, it is considered to be insufficient to retain the cemented bridges in the long-run; therefore, depending only on improving the dental cements properties may not be reasonable when seeking to overcome the issues associated with the fixed prostheses failures, and further modifications to the bridge designs might be necessary in this stage.

It has been suggested that the use of tooth undercut is useful in enhancing the posterior RBFPD’s retention in the long-term [116-119]. Notably, the use of readymade pins/bio-pins which are inserted into the prepared teeth/tooth with two different path of insertion can significantly improve the FPD’s overall retention [119]. It is expected that a large resistance values will be achieved owing to the use of different paths of the pins’ insertion. This suggestion is supporting the current design principle, which recognise that, with the use of different paths of insertion (mechanical interlocking), comprising different angles than the tensile force direction provides additional mechanical strength and significantly increases the FPD’s performance against the dislodgment forces by as much as two times higher. However, although the suggested pin-retained design has a high retention value, it has been indicated [119] that there are some significant disadvantages, such as being difficult to prepare clinically owing to the limited space in the oral cavity, and also that the inserted pins can cause pulp irritation, as they should be inserted deep into the abutment teeth. Furthermore, such process seems to be time-consuming and requires
high precision during the prosthesis preparation and fabrication. Moreover, these
designs cannot provide an alternative solution to replacing anterior teeth owing to the
fact that the abutment teeth involved requires sufficient space and shape in addition to
enough enamel space into which to insert the pins; notably, the anterior teeth
thickness is smaller than the posterior teeth [121]. Importantly, it is recognised that
further researches are essential in order to ensure that these types of FPD’s have
sufficient stability to resist different mastication forces before deciding on their
clinical efficiency [119].

In the current study, it is recognised that there might not be any vital need to conduct
further investigations to test the new bridge design stability against different force
application as it is tightly fixed, has occlusal rest seats, and shows superior strength
against the tensile force compared with the conventional three-unit FPD.

One study compared a conventional posterior three-unit RBFPD (Maryland Bridge)
with the conventional three-unit FPD. In this study, the Maryland Bridge had the
lowest dislodgment value comparing with different FPD designs [119]. Unlike our
current new FPD design, most likely, the low dislodgment resistance value of the
Maryland bridge was recorded as the Maryland Bridges are retained to the abutments
only from the lingual side, which therefore may not allow the applied force to be
distributed equally along the abutment teeth area [12]. For such reasons, Sadeghi [122]
recommends further adjustments to the preparation to improve the dental bridges
overall retention.

Generally, some of the aforementioned results (such as the study which was
established by Re-Mee & Keun-Lee [119]) cannot be compared directly with the
current study for a number of reasons. These reasons involve the use of different
materials, as well as differences in the testing methodology. Firstly, the authors
cemented their bridges to resin teeth models, where our FPD designs were applied to
natural extracted teeth. The mechanical, chemical and physiological differences
between the artificial teeth and natural teeth will have an influence on the obtained
results [110]. Secondly, in regard to their testing methodology, the cross-head speed
was 4 mm/min, but was 0.5 mm/min in our study. Notably, it has been indicated that a
higher cross-head speed is associated with higher dislodgment values [123].
Furthermore, in their study, Type III gold alloy was used to cast the metal frameworks, where Co-Cr alloy was used in the current study.

Although cobalt-chromium alloy is performing acceptably as an FPD [15], it has nevertheless been proven in some in vitro studies that the dental cast metal alloy has no significant role to play on the FPD’s retention [115]. This may suggest that using Co-Cr casting alloy is sufficient for use in similar in vitro studies since it provides acceptable retention proprieties besides being cost-effective.

One useful way to improve the fixed bridge retention is to provide the prepared tooth/teeth with retentive coves/undercuts [116]. This evidence supports the notion that the use of undercuts does improve the prosthesis retention. It has been identified that the retention can be improved significantly with the use of modern luting cement products; however, several years later, their statement cannot be considered as a solution to the fixed bridges failure as other present studies demonstrate that the main reason for the cemented bridges is owing to the weak bond at the metal-resin-dentin junction [87,117] or with those who draw the researcher’s attention to the need of improving the macro-retentive features as opposed to the micro-retentive one [119,120,122].

Whilst in vitro studies seeking to improve the FPDs’ metal framework are still lacking, a number of in vivo studies, on the other hand, have been conducted with the aim of enhancing the fixed bridges designs. Yoshinori et al. [124], for example, report two new stages of RBFPD restoration, whilst Harald [125] reports a new technique for replacing single missing anterior teeth with all-porcelain units. In the case of both studies, the designs are considered to be both conservative and quick; however, it is nevertheless recognised that their designs seem to be extremely weak, and are very likely to dislodge. Furthermore, when considering the clinical and laboratory processes in both cases, it can be seen that the preparations looked similar to the Maryland Bridge preparation. Accordingly, it can then be stated that improved retention might not be expected as the Maryland Bridge has major de-bonding problems [1]. Therefore, it might be strongly advised to include small attachments to improve the retention [126], or to otherwise manipulate the abutments preparation by somehow gaining mechanical interlocking strength in order to enhance the dislodgment resistance; this is suggested by both Sadeghi [122] and the current study.
In another attempt to develop the dental FPD prosthesis construction, Lembert [127] describes a new technique utilising a cross-pin fixation embedded in the posterior abutment teeth from the mesial or distal side. Similarly, the bolt inlay technique was introduced by Burton [128] in an attempt to facilitate repairing and modifying FPDs. These descriptions suggest that the retention and resistance of the FPDs can be improved with the application of such techniques; however, owing to the limited space in the oral cavity, technical difficulties might be applicable in order to make the teeth preparations in both cases as the inserted pins should get into the abutments in the exact place and have sufficient depth. This may involve some risks associated with the tooth pulp [119] especially during the posterior teeth preparation. In addition, although the retention may be increased, the techniques appear to be time-consuming both in dental clinic and laboratory. Moreover, they seem to be difficult to achieve accurately, and are viewed as being problematic and not conservative to the teeth involved.

Bonding is a crucial part of restorative dentistry. Studies identified a strong link between the retention of the casting and the cavity area available for bonding the metal framework [137]. Furthermore, it was found that the cavity wall roughness has a significant role in enhancing the mechanical retention [138, 139]. The bond strength of luting cements which are used to bond the fixed prosthesis to the natural teeth play major role in the long term success of the cementation of these bridges [140]. In the present study, zinc phosphate was used as a luting cement to bond the conventional bridge to the underlying tooth structure. Chemical bonding and mechanical interlocking are critical aspects in the fixation mechanisms of luting cements, and are essential for achieving suitable dislodgment resistance for the cemented metal frameworks. Zinc phosphate has succeeded as non-adhesive luting cement because it only adheres to crown and tooth irregularities by mechanical retention [141]. Conversely, the glass-ionomer cement adheres by chemical bonding. The chemical reaction is ionic and occurs between the calcium of the natural tooth structures and carboxyl ions of polyacrylic acid [142]. However, zinc phosphate was reported in one study to have stronger bond strength than glass ionomer cement [140].

In the current study, the new FPD design has succeeded in terms of preserving the majority of the natural abutments teeth structure, which was one of the main aims of
this study. The new FPD design shows superior dislodgment resistance compared with the conventional three-unit FPD. For these reasons, the design may be considered an acceptable alternative FPD solution for both patients and dentists, owing to the fact that the design requires just a 1mm groove along both the buccal and lingual side in each abutment tooth in order to be applied; therefore, extra clinical chair time is not required. The new bridge design preparation is, by far, a clinically quicker and easier method compared with all types of fixed prostheses.

The new bridge design may also provide an alternative solution to the FPD when technical difficulties are anticipated, such as short clinical crown or sub-gingival finish line. The short clinical crown might not provide the ideal retention especially if significant occlusal reduction is required [129]. On the other hand, however, sub-gingival finish line associated with difficulties in making the impression for mutable reasons, such as moisture control difficulties due to bleeding and inflamed gums, and continuous flow of gingival crevicular fluid [130,131]. Moreover, the impression will be challenging owing to the fact that the gingival overgrowth will prevent the impression of flowing into the right required depth.

Even if the impression was taken and the prosthesis is applied, a biological problem will be most likely to appear as the bridge-finish line junction will be difficult to clean [132]. In addition, the retraction cords’ placement during the impression making is time-consuming, and might subsequently cause discomfort for some patients. All of these disadvantages and technical difficulties are not applicable with the new FPD owing to the fact that all preparations for this design are supra-gingival.

The new bridge has also succeeded in achieving the second objective of the study by gaining retention through only macro-mechanical means (mechanical interlocking). This means that the current bridge design is the first permanent FPD to be fixed in the mouth without the use of cement. Accordingly, all disadvantages associated with using the dental cements [87,120] were eliminated, and another approach to retain the FPDs will be valid.

With a suitable instrument (i.e. screwdriver), the new design may have the ability to be taken out frequently by the patient for cleaning purposes, which may decrease the possibilities of abutment tooth decay, and thus increase the new FPD design’s lifespan.
As a prophylactic measure, we may recommend the utilisation of fluoride varnish with this current bridge (on the border between the metal framework/clasps and the tooth) to reduce the possibility of dental caries. It has been proven that fluoride varnish is effective in minimising the risks of tooth decay (adult teeth), as has been indicated by Hawkins et al. [133].

Another advantage of this design is that the caries’ cleaning and filling can be made on the abutment teeth whilst the bridge is fixed in place. More importantly, the root canal treatment which has been established as one of the major concerns before applying FPDs [87] could still be carried out following the prosthesis application since the occlusal surface of the abutment teeth are exposed, and enough of a working area is available; therefore, the restoration can be applied even if the abutment teeth are in a doubtful condition and both time and the natural tooth might be saved.

The new FPD design could be considered as a reversible restoration as only small grooves/preparations on the abutments are required to fix the bridge in place. This may make it an acceptable alternative temporary solution during the soft tissue healing period when patients have undergone implant surgery. Following implant fixation, the prepared grooves are filled again with composite, and the shape of the abutment teeth is then restored. Moreover, the new design may also be considered as more cost-effective to repair owing to the fact it has two parts, with only one part possibly needing to be repaired/replace.

In the case of the present study, the new design required preparations along the buccal and lingual sides of the abutment teeth. Owing to this limitation, the teeth should be caries- and restoration-free in both buccal and lingual surfaces of the abutments. Notably, the new bridge is not recommended if the abutment teeth are tilted because the forces will not be evenly distributed throughout the abutment teeth, also, it may cause difficulties/problems to the bridge path of insertion [12]. Another limitation for the new FPD design is that the metal framework construction is more time-consuming in the dental lab compared with the conventional FPD bridges as the two parts are fabricated and cast in two different steps. Moreover, another disadvantage is related to the denture aesthetic owing to the metal clasps; therefore, the new design is advised to be limited to the posterior teeth.
Chapter 7

Conclusion
Conclusion

Within the limits of this in vitro study, the new FPD’s design showed significantly higher value in dislodgement resistance compared to conventional three-unit FPD’s ($P< 0.001$). The current study indicates that the new suggested FPD can be clinically viable design in terms of mechanical retention, however, further clinical research need to be conducted.
Chapter 8
Recommendations for Future Studies
Recommendations for future studies

As the aesthetic of the new FPD design needs to be enhanced and the bridge was recommended for use to replace missing posterior teeth, it would be valuable to try to use other materials and fabrication techniques in order to obtain the new bridge design with better aesthetic appearance; suggestions include all-porcelain and PFM. Furthermore, it might be helpful to construct the bridge framework with the use of modern technology programmes, such as CAD-CAM. When better aesthetics are achieved, materials involved are tested in further dislodgment resistance investigation. Moreover, because encouraging results were achieved in the current study, the retention of the new bridge design might be tested with different smaller depth preparation to conserve more of the natural tooth structure. Furthermore, the dislodgment resistance of the new bridge might be studied when more than one tooth is missing.

In an attempt to facilitate fixing and removing the new bridge design, another version of this type of bridge might be introduced through the use of a different bridge locker. Instead of using a screw to fix these two parts together, different kinds of locking system could also be useful, such as: Stud Snap attachments (Figure 8.1). Notably, each version of the new bridge will require research in order to determine whether it could be used as permanent restoration, temporary restoration, or only as a space maintainer.

Figure 8.1 Stud Snap attachments [134].
For future clinical trials, the possibilities of observing dental caries can be examined in a long-term study. Depending on the result obtained, further investigation could be applicable when attempting to reach a decision to determine which choice will be more reasonable in order to decrease the teeth decay on the abutment teeth enamel: for instance, is it better to leave the bridge as a fixed-removable prosthesis to be cleaned frequently by the patient, or is it better to cement the bridge permanently and transform it into permanent fixed prosthesis? Notably, if the cement is used along with mechanical interlocking, it is most likely that the retention of new bridge design will be enhanced [120].

Another study involving the application of the new bridge to the anterior teeth can also be conducted. This will include the abutment anterior teeth preparation depth, dimensions of the anterior bridge design, and the retention value of the new bridge design. Finally, for future study, a research from the cost-effectiveness prospected can be conducted in order to compare the new bridge design with different types of dental prosthesis.
References
References


