A COMPARISON OF THE EFFICACY OF TWO TECHNIQUES FOR REMOVING FRACTURED ABUTMENT SCREWS FROM THE INTERNAL WELL OF TWO DIFFERENT DENTAL IMPLANT SYSTEMS: AN IN-VITRO STUDY

A thesis submitted to the University of Dublin in partial fulfilment of a Doctorate in Dental Surgery D.Ch.Dent (Periodontology)

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DECLARATION

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university and it is entirely my work. I agree to deposit this thesis in the university’s open access institutional repository or allow the library to do so on my behalf, subject to Irish copyright legislation and Trinity College library conditions of use and acknowledgement.

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SUMMARY

Abutment screw fracture is a common mechanical complication that can sometimes lead to dental implant failure. A number of clinical reports have been published, presenting a plethora of different techniques for the management of fractured abutment screws. Despite the abundance of case reports, this complication is still managed by trial and error and no consensus on a standardised management protocol exists.

Commercially available screw fragment retrieval kits are either universal or designed to fit only one specific implant system. Most of them include specially designed drills which can create a small hole in the centre of the fractured abutment screw. This notch allows a metal extension to engage and rotate the otherwise-flat headed fragment in an anti-clockwise direction and successfully remove the fragment. Such kits also include a series of drill guides which align the drill in an axial plane with the implant in order to reduce the risk of damaging the implant’s internal threads.

The main aim of the study herein was to compare the efficacy of a commercially available abutment screw retrieval kit with a homemade kit. It also attempted to examine possible associations between several independent variables such as operator experience and screw fracture morphology and the ability of the two retrieval techniques to successfully remove the fractured abutment screw fragments.

Overall, 64 implants from two different dental implant systems were used. 32 were Osseotite® Certain dental implants and the other 32 were Osseotite® micro mini external hex connection dental implants (n=32). A Certain Gold-Tite™ Screw and a standard Gold-Tite™ screw with a square screw head were used for the abutment connection respectively. The abutment screws were partially sectioned with a diamond disc at the level of the first/second coronal thread and in four different ways in order
to mechanically weaken them and to develop different patterns of fracture morphology. The screws were then tightened using a calibrated torque driver until they fractured. The torques at which the screws fractured were recorded. A pair of edentulous maxillary and mandibular typodont models were duplicated with an auto-mixed, autopolymerising silicone material and type IV dental stone was poured over the silicon models. In each cast, four cylindrical cavities were prepared. The cavities were prepared in sites 1.6, 1.2, 2.2, 2.6 for the maxilla, and in 4.6, 4.2, 3.2, and 3.6 for the mandible. The implants were embedded within their respective cylindrical cavities and secured using an autopolymerising resin. After embedding the implants, the specimens were distributed between four operators with varying clinical experience. Each operator was to attempt retrieving 16 fragments. A flow chart was used to rotate operator type, implant system, implant location, and retrieval kit used in an even manner. Two different kits were used for the retrieval of the fractured abutments screws. A conventional or homemade kit consisting of standard and modified standard dental instruments and a universal removal kit which included claws attached to a driver handle and guided by a number of internal, external, or conical connection guides and reverse drills.

Success was defined as the retrieval of the screw fragments within 15 minutes without irreversibly damaging the implant's threads. To assess integrity of the implant threads an impression coping from the same system was placed, and the threads were considered not to be damaged when the impression coping could be completely seated.

56 fractured screws were successfully retrieved in less than 15 minutes, representing an (87.5%) success rate. Three screws failed to be retrieved in that time frame (15 minutes) and five could not be retrieved at all. Of the three implants that were retrieved in over 15 minutes, only two were retrieved without damaging the implant’s internal threads. No difference was observed between the standard dental instruments and commercially
available kits in their efficacy to successfully remove fractured abutment screws. \( (p=0.708) \).

Overall, the mean screw retrieval time was 2.84 ± 2.66 minutes \( (p<0.001) \) (internal connection 4.16 ± 3.13 min; external connection 1.85 ± 1.72 min), indicating that fractured abutment screws can be retrieved successfully within a short time. Significantly more screws were retrieved from the external connection group of implants compared to the internal connection group \( (p=0.002) \). There was no association between the level of operator experience and success rate in abutment screw retrieval \( (p=0.257) \). Abutment screw fracture morphology, the location of the implant in the dental arch (anterior vs. posterior) and the position of the implant in the mouth (upper vs. lower) had no impact on the success rate of fractured abutment screw retrieval or the time it took to remove the screw fragments.
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CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW
1.1 Introduction

Nowadays, dental implants are seen as a safe method of replacing missing teeth (Pjetursson et al., 2012). However, biological and mechanical complications are frequent. The most frequent of these complications are fractures of the veneering material (13.5%), peri-implantitis (12.5%), soft tissue complications (8.5%), loss of the access hole restoration (5.4%), and abutment or screw loosening (5.3%) (Pjetursson et al., 2012). Mechanical failures in particular, might develop due to occlusal overload, poorly fitting frameworks, higher than recommended screw preload and overtightening of the abutment screw, which can lead to screw loosening and subsequent abutment screw fracture (Goodacre et al., 1999). Prosthesis screw loosening has been cited as the most common complication for a single tooth implant (Goodacre et al., 2003). The incidence of mechanical failures due to abutment screw fractures has been reported by a number of studies to be between 1% - 8% (Agustín-Panadero et al., 2017, Sprenger et al., 2018).

Numerous case reports described techniques designed to assist in the retrieval of fractured screw fragments from dental implants. Some of them employed a range of instruments readily available within the dental operatory (de Souza Batista et al., 2018, Azpiazu-Flores and Lee, 2020) and sometimes, modification of the fractured screw fragment was required to facilitate removal (Walia et al., 2012, Gooty et al., 2014). Commercially-available screw fragment retrieval kits, either universal or designed to fit only one specific implant system, are available from a number of different companies. They not only enable modification of the coronal aspect of the screw fragment but also include drill guides designed to protect the threads of the screw channel of the dental implant from these rotary instruments. One recent study (Agustín-Panadero et al., 2017) suggested that the use of dental instruments like an explorer and an
ultrasonic scaler may be as effective as a professional screw retrieval kit in retrieving fractured abutment screws, but a later study by the same author suggested that professional kits might be more effective (Agustín-Panadero et al., 2020).

Despite the range of kits, techniques and instruments used for this purpose, there is no standardised procedure, and the retrieval of fractured abutment screw fragments is usually done empirically.

1.2 History of Dental Implants

An unintentional discovery in 1952 led to a practice now widely used by dentists around the globe. Per-Ingvar Brånemark, an orthopaedic surgeon, began studying bone healing and regeneration in rabbit femurs. A few weeks after the implantation of titanium chambers into the rabbits' tibias, he discovered that the titanium chambers integrated into the bone. Following a histologic evaluation, he observed that bony particles had grown into thin spaces within the titanium surface (Brånemark et al., 1977). Titanium implant surfaces were covered by a thin oxide layer, which prevented bone cells from identifying them as a foreign body, and as a result, osseointegration was possible (Wheelis et al., 2018). This observation led to the principle of osseointegration, which was subsequently defined as “a structural and functional connection between ordered living bone and the surface of a load-carrying implant” (Brånemark et al., 1977).

Electron microscopy demonstrated that collagen filaments' attachment to titanium looked similar to the Sharpey's fibers extending from the periosteum to bone (Albrektsson et al., 1981). Further observations, strengthened the belief that bone is working in harmony with titanium, through a direct chemical bonding between these two components and a tendency for the spongy bone around the dental implant to “corticalize” (Breine and Brånemark, 1980). Similar to the way osteoblasts attach to titanium, soft tissues were also closely adhering to the titanium implant
surface. This attachment forms a biological seal, preventing microorganisms infiltrating along the implant neck (Albrektsson et al., 1981).

1.2.1 Two-stage Threaded Titanium Root-form Implant and Emergence of 'Osseointegration'

The threaded titanium-based implant was introduced by Dr. P.I. I Brånemark and experimented with by utilizing titanium screws called fixtures (Brånemark et al., 1985). In 1965, Dr. Brånemark placed the first titanium dental implant in a human volunteer. His goal was to restore an edentulous space, re-establish the patient's function and aesthetics, as well as restore his muscle and chewing abilities (Adell et al., 1981, Gowd et al., 2017). Dr. Brånemark's patient had multiple problems (congenitally missing teeth, jaw and chin deformation, and misaligned teeth). He placed four implants into this patient's mandible and the implants remained fixed and fully functional for almost 4 decades up until the patient's death in 2006!

1.3 Implant Designs

Over the last 50 years, a wide range of dental implants of various sizes and shapes were developed to offer patients the best possible outcomes. Cylindrical shaped threaded implants have been the most popular as their shape creates maximal contact between bone and implant (Gehrke et al., 2016).

1.3.1 Micro and Macro Implant Designs
Dental implant design (micro and macro) is the main predictor of its primary mechanical stability (Gaviria et al., 2014). The micro-design pertains to the surface topography and surface coating of dental implants. On the other hand, macro-design pertains to the main body, thread design, and pitch (Gehrke et al., 2015). For macro-design, the distribution of stress forces around the implant is affected by thread geometry. Implant stability is positively associated with decreased thread pitch. In poorer bone quality, deeper threads seem to have an important effect on the stability of the implant. Also, micro-threads up to the crystal module of an implant increase the amount of contact between implant and bone surface, thus, reducing marginal bone loss (Abuhussein et al., 2010). Furthermore, the length of the dental implant is directly proportional to implant stability. More threads are engaged with longer implants, leading to increased bone stability and decreased bone stress (Kong et al., 2008). The dental implant diameter is also key to the dental implant’s strength (Jones and Cochran, 2006).

1.3.2 Internal and External Hexagon Implants

The implant platform includes the implant's cervical portion and it connects to the prosthetic part of the implant. The geometry of the interface between the implant platform and prosthetic part is an essential component for joint strength and rotational stability. The connection system initially utilized was the External Hexagon (Fernandez-Estevan et al., 2018). The external hexagon connection implants had simple butt and bevel joints initially used mainly for full arch cases where the implants were joined with a rigid metal superstructure (Sailer et al., 2018). The external hexagonal connection platform has advantages that include high prosthetic combinations, reversibility, even stress distribution, anti-rotation, convenience for impression making, and compatibility between different systems (Binon, 2000). It’s main shortcoming is micro-
movement due to the short hexagon stature (an average of 0.7mm),
leading to loosening of the screw, particularly in partially edentulous
patients where the interface and connecting screw are exposed to more
rigorous load applications (Binon, 2000).

Internal hexagon implants were produced to counteract the weaknesses
noted with the external hexagon design (Khraisat et al., 2004). They
provide a reduced vertical height, which leads to an internal distribution of
the lateral load within the implant wells. The internal hexagon implant
wall also provides a better microbiological seal and lowers the restorative
interface to the implant level which gives an aesthetic advantage (Khraisat
et al., 2004).

Internal hexagon implants are categorized as passive or frictional based on
joint type. These are further subdivided as 12-point internal hexagon,
internal tripod, and internal octagon connections. Studies have
demonstrated that internal hexagon implants offer high mechanical
strength which can bear high-stress load and provide higher maximum
load resistance (Devaraju et al., 2018).

A number of studies suggest that internal hexagon connection systems are
superior because they offer a strong contact between the abutment and the
implant's inner wall. This in return, decreases the chances of micro-
movements during loading. It also allows significantly less stress to be
applied to the abutment screw (Chun et al., 2006, Siadat et al., 2017) and
creates a steady interface, high resistance, and less complications such as
loosening or fracture of this screw. While it has many advantageous
features, two main drawbacks are that the walls surrounding the internal
connection are thinner, and angulation divergence adjustment between
dental implants is difficult (Chun et al., 2006, Siadat et al., 2017,
Fernandez-Estevan et al., 2018).

The Morse tapered connection is another type of the internal connection. It
has a tapered post (1-2 degree) that fits into a smooth shaft within the
implant and the abutment. The morse taper provides a substantial friction fit, yet, it isn't easy to transfer the exact abutment locations with consistency and repeatability (Binon, 2000)

### 1.4 Dental Implant Survival

Dental implant survival has been described as the presence of the fixed prosthesis as well as the dental implant regardless of any mechanical and/or biological complications (Simonis et al., 2010). A handful of research studies have assessed dental implant survival (Simonis et al., 2010, Beschnidt et al., 2018, Adler et al., 2020). A review study by Pjetursson et al. (2007) confirmed 90%-97% of dental implant survival over a period of 5 years (Pjetursson et al., 2007). Another study reported a 16-years cumulative implant survival rate in 82.9% of the patients (Simonis et al., 2010). A comprehensive review by Zarb and Schmitt. (1993) cited a 94.3% implant survival rate of patients with posterior partial edentulism (Zarb and Schmitt, 1993). Finally, a study that assessed the survival rate of dental implants observed a cumulative 5-years survival rate of 98.6% (Beschnidt et al., 2018).

Romeo et al. (2004) studied the cumulative survival rates for dental implants that supported single-tooth, fixed partial, fixed complete, fixed cantilever partial, tooth/implant-supported prostheses, and overdentures. Interestingly, no differences in the survival rate were observed between maxillary and mandibular implants, and implant size had no impact on the survival rate (Romeo et al., 2004). Finally, a systematic review and meta-analysis critically appraised 18 eligible studies for 10-years survival rate of a dental implants. They reported a survival rate of 96.4% and sensitivity analysis suggested a survival rate of 93.2% (Howe et al., 2019).
Recently, similar investigations have been conducted on patients with chronic comorbidities such as type II diabetes mellitus. One study by Eskow and Oates (2017) observed high dental implant survival rates; (98.6%) after 1 year and 96.6% after 2 years. The patients involved had poor glycaemic control, suggesting implants are an ideal treatment option to restore oral function (Eskow and Oates, 2017).

1.5 Dental Implant Success

Dental implant success is greatly reliant on their osseointegration (Pommer et al., 2012). Implant success is defined as the absence of complications during the entire clinical observation period (Simonis et al., 2010). The first-ever dental implant success criteria were introduced by Albrektsson et al. (1986), and suggested implant immobility, absence of peri-implant radiolucency, <0.2 mm of bone loss annually following the first year of dental implantation and no consistent/persistent pain or infection. (Albrektsson et al., 1986). Success rates of endosseous implants have been investigated in numerous studies and 85% success rate at 5 years and 80% at 10 years are the minimum acceptable levels of success (Pjetursson et al., 2012, Jung et al., 2012, Hjalmarsson et al., 2016).

Several studies have investigated the success rate of endosseous implants in private dental settings. In their longitudinal prospective study Cochran et al. (2007), examined 990 implantations performed in a private setting. They reported high cumulative success rates; > 99% at 3-year and 97% at 5-year post-loading (Cochran et al., 2007). These findings were very similar to the success rates achieved in an earlier clinical trial (Cochran et al., 2002). A more recent clinical trial study by Charyeva et al. (2012) investigated long-term success (observational period of 6 years) outcomes of dental implants. They reported a success rate of 94.3% (Charyeva et al., 2012). Finally, an 8 years' follow-up study with over 13,000 implants by Busenlechner et al., reported a 97% success rate (Busenlechner et al.,
Overall, nearly 0.5 million osseointegrated dental implantation procedures are performed annually with a success rate of over 95% and low risks and complications (Gaviria et al., 2014).

1.6 Factors Affecting the Survival of Dental Implants

Successful outcomes of dental implants rely on some critical factors (Seth and Kalra, 2013). An essential one is biocompatibility. It comprises two main components; tissue compatibility of the implant material and capability to achieve its designated function. So, this feature relies not only on the physicochemical and mechanical nature of the material but also on its application. The biocompatibility is assessed through reviewing healing between the dental implant and bone tissues, which gauges the degree of osseointegration (Searson, 2005, Vidyasagar and Apse, 2004). For optimization of osseointegration, factors in dental implant design, for instance, components of biomaterials, length, width and geometry of implant, surface and biomechanical features, patients’ health status, quality of bone and surgical method must be taken into account (Sullivan, 2001, Seth and Kalra, 2013, Triplett et al., 2003).

1.6.1 Patients’ Demographic and Health Status

In determining the outcome of any dental procedure, demographic and health status matter. The ideal dental implant outcome rate is 90-95% in healthy patients; however, many other variables such as age, implant length, and diameter, quality of bone, and implant region can play their part in influencing outcomes (Diz et al., 2013). Studies have suggested that bone health status and quality are key predictors of the longevity of implant (Paquette et al., 2006, Searson et al., 2019). Generally, the health status and a number of environmental risk factors, and conditions such as smoking, cardiovascular disease, coronary artery disease, stroke,
osteoporosis, endocrine disease, infection, immunodeficiency, and chemotherapy have been outlined as risk factors for dental implant failure (Paquette et al., 2006, Diz et al., 2013).

1.6.2 Age

Age is regarded as a susceptibility factor that might affect dental implant survival (Raikar et al., 2017). However, a review by Ikebe et al. (2009) suggested that age itself might not be a single determining factor rather, multiple factors such as bone quality and quantity and chronic diseases may collectively play their role in the survival of dental implants (Ikebe et al., 2009). A retrospective study by Jang et al. (2011) confirmed age as an important factor affecting dental implant survival (Jang et al., 2011). A higher number of dental implant failures have been reported in patients' aged over 60 years (Raikar et al., 2017).

1.6.3 Smoking

Smoking affects dental implant survival (Kasat and Ladda, 2012). Randomized clinical trials have reported smoking as a determining factor for endosseous implants failure, and failure rates in smokers have ranged between 8% and 16% (Moy et al., 2005, Khraisat et al., 2004, Sánchez-Pérez et al., 2007). The pathophysiology of a smoking-associated reduction in survival and increased failure rate could be attributed to local and systemic inflammation mediation. Local absorption of nicotine into the bloodstream and resultant vasoconstriction has been demonstrated to be associated with implant failure (Kasat and Ladda, 2012). It is believed that the adverse impact of smoking is significantly more prominent when the trabecular bone is of poor quality (Klokkevold and Han, 2007).
1.7 Early and Late Implant Failures

Existing data suggest that dental implant failure rates range between 1% and 19% (Adell et al., 1981, Romeo et al., 2004, Do et al., 2020). These failures have been categorized as early and late depending on the time of failure. Early dental implant failures occur due to lack of osseointegration, whereas late dental implant failures occur post-occlusal loading either due to biological or mechanical factors (Tonetti and Schmid, 1994, Do et al., 2020).

Factors contributing to implant failure are divided into implant-related factors such as implant dimension, surface coating, loading time and patient-related factors such as oral hygiene, plaque control, smoking, quantity of supporting bone, and patient health status (Schwartz-Arad et al., 2008).

A large population-based retrospective cohort study conducted by Lin et al. (2018) investigated the risk factors associated with early and late implant loss at patient and implant level. They recruited 18,199 patients with 30,959 dental implants over a 1-6 years observation period. Early implant failures (before or at abutment connection) occurred in 183 patients (194 implants) representing a 0.6% failure rate. Late implant failure (post occlusal loading) occurred in 193 patients (209 implants) reflecting a loss rate of 0.7%. A multivariate regression analysis demonstrated that risk factors related to early implant loss were associated with the location of the implant (anterior segment of the mandible), male gender, and age ≥ 41 years. On the other hand, late implant failure significantly increased with shorter implants, sites requiring ridge augmentation procedure, males, and patients aged ≥ 41 years (Lin et al., 2018).
A systematic review and meta-analysis defined early implant failure as a failure that occurs from any time between implant insertion and prosthetic loading from baseline to 6 months (Troiano et al., 2018). On the other hand, late implant failure was regarded as between fitting the final prosthesis and up to a year of follow-up (Troiano et al., 2018). In their study, 684 non-submerged and 721 submerged implants were analysed in the early implant failure group. The total events of early implant failure in the non-submerged group were 31, and the total events of early implant failure in the submerged group were 12, which revealed a statistically significant difference ($p = .008$) between the two groups. Therefore, the non-submerged implants showed an increased relative risk ratio of early implant failure $RR = 2.34$ (95% CI: [1.25, 4.39]), with an increased risk for the one-stage approach. However, there was no statistically significant difference between the submerged and non-submerged implants in the late implant failure groups ($p = 0.22$) (Troiano et al., 2018).

Esposito et al. (2009) conducted a Cochrane systematic review of 5 randomized controlled clinical trials. 761 implants were included and 375 implants were inserted with the one-stage approach in 121 patients, and 386 were inserted with the two-stage procedure in 123 patients. Within the follow-up period which ranged between 6 months and one year, 23 implants failed in 11 patients (one-stage approach), and nine implants failed in 8 patients (two-stage approach). However, the meta-analyses failed to show statistically significant differences between the one-stage and two-stage approach in prosthesis and implant failures ($p = 0.48$, $p=0.45$ respectively) (Esposito et al., 2009). Yet, there was a trend of increased risk of early implant failure when the one-stage approach was used in edentulous arches (Becktor et al., 2007, Esposito et al., 2009). Significant limitations observed in Esposito et al.’s (2009) study included a small sample size in the majority of the included studies, a short follow-up
period (6 months-1 year), patient-level analysis, and finally 4 out of the five included studies revealed a high risk of bias.

### 1.8 Implant Complications

Implant complications can be either biological or mechanical (Liaw et al., 2015). The most frequent biological complications are peri-implant mucositis, per-implantitis, and soft tissue problems such as fistulas, swellings, and hyperplasias (Pjetursson et al., 2012).

#### 1.8.1 Biological Complications

Biological complications comprise bacterial infections, accumulation of microbial plaque, and eventually progressive bone loss leading to loss of implant osseointegration (Berglundh et al., 2002). Biological complications are further stratified into early and late complications. Early infection may occur during the first weeks of implant placement due to exposure of the dental implant during the healing phase or due to contamination at the time of surgery (Polyzois, 2019). Additionally, operator-related factors such as overheating during implant placement has been shown to contribute to early implant failure (Esposito et al., 1998). To this effect, an interim investigation evaluating implant early failure rates and bone quality, reported a high failure rate when implants were placed in type I quality bone (4.3%) and associating this failure with overheating the dense cortical bone (Truhlar et al., 1994).

In a 2015 systematic review, Renvert & Polyzois reviewed 107 articles, with 15 studies fulfilling the inclusion criteria, in order to assess risk indicators for peri-implant mucositis. The authors found substantial evidence to identify plaque biofilm, poor oral hygiene, and smoking as a
risk indicator for peri-implant mucositis. There was also some evidence implicating residual cement (Renvert and Polyzois, 2015).

1.8.1.1 Oral Hygiene, Peri-implant Mucositis, and Peri-implantitis

Good oral hygiene is necessary for long term dental implant survival (Tanner et al., 1997). Animal-based studies have shown an early host response to plaque biofilm formation, causing peri-implant mucositis and representing a causal association (Berglundh et al., 2007). The latter was subsequently defined as “soft tissue and mucosal inflammation around the dental implant with an absence of bone loss” (Rosen et al., 2013, Heitz-Mayfield and Salvi, 2018).

Under the new classification of Periodontal and Peri-implant Disease and Conditions (workgroup 4), peri-implant mucositis was defined as “Presence of bleeding and/or suppuration on gentle probing with or without increased probing depth compared to previous examinations and absence of bone loss beyond crestal bone level changes resulting from initial bone remodelling” (Berglundh et al., 2018).

Under the 2018 classification, Peri-implantitis was defined as "plaque associated pathologic condition occurring in the tissue around dental implants, characterized by inflammation in the peri-implant mucosa and subsequent progressive loss of supporting bone" (Schwarz et al., 2018). Furthermore, the peri-implantitis diagnosis was based on the following criteria:

- “The presence of bleeding and/or suppuration on gentle probing”.
- “Increased probing depth compared to previous examinations, and”
“Presence of bone loss beyond crestal bone level changes resulting from initial bone remodelling”.

However, in the absence of previous examination data peri-implantitis diagnosis can be made based on the following criteria:

- "The presence of bleeding on probing and/or suppuration"
- "Probing depths ≥ 6mm”.
- "Bone levels ≥ 3mm apical to the most coronal portion of the intraosseous part of the implant” (Berglundh et al., 2018).

In a 2015 systematic review, Derks et al., included 11 studies for meta-analysis. The included study designs were prospective, retrospective, cross-sectional, and observational cohort studies. Population samples of the included studies varied between 100-662 patients with ≥100 subjects per a study, and the mean follow-up ranged between 3.4-11 years. A meta-analysis of the included studies reported that the weighted mean prevalence of peri-implant mucositis was 42.9%, and the weighted mean prevalence of peri-implantitis was 21.7% (Derks and Tomasi, 2015).

1.8.1.2 Bacterial Biofilm

Studies have shown that exposed dental implants are at risk of bacterial contamination and this can happen within 30 minutes of installation (Fürst et al., 2007). Dental implants with a later diagnosis of peri-implant disease demonstrated an increased load of gram-negative anaerobic bacterial organisms such as Treponema denticola, Porphyromonas gingivalis, and Tanerella forsythia (Heitz-Mayfield and Lang, 2010). A study by Renvert et al., demonstrated an increased count of Staphylococcus aureus detected in patients diagnosed with peri-implant diseases. Interestingly, this is an organism not frequently associated with periodontitis (Renvert et al., 2008).
1.8.2 Mechanical Complications

Pjetursson et al. (2014) conducted a systematic review to compare implant-supported prostheses survival and complication rates from data published up to the year 2000, with those reported in studies published after 2000. In the older publications, the total annual rate of mechanical complications ranged from 2.32% to 10.46%, corresponding to five-year complication rates ranging from 10.9% to 40.1% (Pjetursson et al., 2014). The highest complication rates in the older studies were associated with implant-supported fixed partial dentures (40.1%) and screw-retained prostheses (33.3%). Furthermore, the annual rate of the mechanical complications in the more recent studies ranged from 3.55% to 15.19%, corresponding to five-year complication rates ranging from 16.3% to 53.4% with an overall significant increase in the mechanical complications ($p = .028$). The recent studies' most significant mechanical complications were associated with implant-supported fixed complete dentures (Pjetursson et al., 2014). For the screw-retained prosthesis, the incidence rate of mechanical complications was similar ($p = .808$) when comparing the older studies with the more recent ones. However, there was a significant decrease in the total complication rate reported for implant-supported fixed partial dentures in the most recent studies ($p = .005$); this reduction in complications rate with implant-supported fixed partial dentures was due to the improvement in the design and materials of the prosthetic components over the years (Pjetursson et al., 2014).

Mechanical complications can be divided into three categories based on their extent and management: (1) major mechanical complications such as implant fracture, abutment fracture, and framework fracture; (2) intermediate complications including abutment screw fracture and fracture of the veneering material; and (3) minor mechanical complications such as screw loosening, loss of access hole restoration, de-bonding of cement-
retained restoration, and occlusal adjustment (Pjetursson et al., 2012, Heitz-Mayfield et al., 2014).

1.8.2.1 Screw Loosening

Abutment screw loosening has been cited as a frequent minor mechanical complication in multiple studies (Goodacre et al., 2003, Salvi and Brägger, 2009, Pjetursson et al., 2012, Pjetursson et al., 2014, Heitz-Mayfield et al., 2014).

In the older publications, the annual rate of abutment screw loosening ranged from 0.79% to 6.08%, corresponding to five-year complication rates ranging from 3.9% to 26.2%, the highest incidence of abutment screw loosening was reported for screw-retained prostheses (26.2%) and implant-supported single crowns (24.4%). The lowest complication rate was reported with cement-retained prostheses (3.9%) (Pjetursson et al., 2014).

In the more recent studies, the annual rate of abutment or screw loosening ranged from 0.62% to 2.29%, corresponding to five-year complication rates ranging from 3.1% to 10.8%. A higher incidence of abutment screw loosening was still observed with screw-retained prostheses; however, the incidence rate significantly decreased between the studies from 26.2% (17.3–38.6) to 10.8% (7.1–16.3) for screw-retained prosthesis and from 24.4% (5.8–72.9) to 5.6% (3.2–9.6) for implant-supported single crowns ($p = .002, .045$ consecutively) (Pjetursson et al., 2014).

Implant abutment screw loosening incidence rate has decreased over the years; this is due to replacing the titanium screws used with the first generation single-unit crowns on Brånemark implants with new gold abutment screws (Henry et al., 1995, Pjetursson et al., 2014). Since the
change of abutment screw material from titanium to gold, in addition to the use of standardized screw fixation torque, the incidence of screw loosening has decreased (Sailer et al., 2012).

Gracis et al. in 2012 reported a lower incidence rate of screw loosening with internally connected abutments (1.5%) compared to externally connected abutments (7.5%) (Gracis et al., 2012). Similarly, a systematic review by Pjetursson et al. (2018) reported significantly more screw loosening for implants with an external implant-abutment connection. The incidence of screw loosening was considerably higher for metal abutments with external implant-abutment connections (Pjetursson et al., 2018).

**1.8.2.2 Abutment Screw Fracture**

In the above mentioned review by Pjetursson et al. (2014), it was reported that for older publications, the annual rate of abutment screw fractures ranged from 0.16% to 0.44%, corresponding to five-year complication rates ranging from 0.8% to 2.2%. In the more recent studies, the annual rate of abutment screw fracture ranged from 0% to 1.20%, corresponding to five-year complication rates ranging from 0% to 5.8%. (Pjetursson et al., 2014).

The incidence rate of abutment screw fracture with implant-supported fixed partial dentures significantly decreased over the years. The reported 5-year complication rate dropped from 2.2% (1.1–4.1) in the older published data to 0.8% (0.4–1.6) in the most recent published studies (Pjetursson et al., 2014). In a more recent systematic review by the same author, it was reported that the rate of abutment screw fracture over 5-year was significantly higher ($p = 0.010$) for implant-supported fixed dental prostheses with external implant-abutment connections (1.8%) than for internal implant-abutment connections (0.2%) (Pjetursson et al., 2018).
The highest 5-year incidence rate of abutment screw fracture (5.8%) was reported for implant-supported fixed complete dentures, followed by all other types of screw-retained prosthesis (4.1%). Implant-supported single crowns had a screw fracture incidence rate of 0.3%, and the lowest screw fracture rate was associated with an implant-supported cemented prosthesis (0%) (Pjetursson et al., 2014).

1.9 Screw Joint Mechanics

Implant abutment screws have three components: head, shank, and threads. When abutment screw threads engage the internal implant threads, it generates a force called a preload, a tensile force that develops in the stem of the screw when tightened into place—this force creates a screw joint contact between the implant and the abutment (Mizumoto et al., 2018).

A stable connection between the implant and the abutment develops when the abutment screw tightening forces approach the manufacturer's recommended torque values for any particular screws. The preload forces must be greater than the separating forces to maintain a tight screw joint contact (Cho et al., 2004). Once the screw is tightened, and the joint mating parts are in contact, the screw will experience external forces applied to the clamped parts. In circumstances where the external loads exceed the initial screw preload it can/will result in joint separating forces and eventually opening the screw joint. Tightening the abutment screw to the correct specifications increases screw preload, resulting in equal forces distribution between external loads and screw preload, thus decreasing screw fatigue and preventing screw loosening and subsequent screw fracture. (Burguete et al., 1994).
1.10 Factors Contributing to Abutment Screw Fracture

1.10.1 Screw Preload

Higher than recommended screw preload and over-torqueing of the abutment screw can lead to screw loosening and subsequent abutment screw fracture. Over-torqueing can reduce preload, resulting in either wear of screw-implant interface due to tightening friction or distortion of the screw material, inducing abutment screw fracture (Piermatti et al., 2006). It is recommended that the rotational force of the screw does not exceed 75% of its yield strength, since excessive tightening forces may lead to permanent screw deformation (Goldstein et al., 2020).

Moreover, an imbalance between implant-abutment connection and the prosthetic units could result in dental implant failure, primarily because of mechanical stress due to excessive lateral forces (Sailer et al., 2018).

Screw loosening and subsequently screw fracture occurs in two steps; first external pressure such as mastication ensuing micro-motion at the implant-abutment interference, resulting in the release of screw preload. The second step includes a continuous reduction in preload below the threshold, causing threads to turn counter clockwise and screw joint junction loss; this mechanical complication is due to metal fatigue and repeated load below the material's maximum strength (Haack et al., 1995, Attiah et al., 2020). The most critical cause of screw fracture is insufficient preload, as a higher torque value provides greater resistance (Attiah et al., 2020). Additionally, implant position, variations in fit or microgap between the restorative supra-structure and the implant platform, differences in internal hex and external hex anatomy, screw design, and excessive occlusal overload are all contributing factors to the implant abatement screw fracture (Wiskott et al., 1995, Attiah et al., 2020).
1.10.2 Abutment Connection

Abutment screw fractures are frequently reported with external implant-abutment connection corresponding to a 0.2% fracture incidence rate for implant-supported single crowns and implant-supported fixed dental prosthesis (Pjetursson et al., 2018). These findings were consistent with these from a systematic review conducted by (Zembic et al., 2014), reporting a higher incidence of abutment screw fracture: 0.7% over 3.6 years and screw loosening rate of 8% over 3.6 years.

The load on the abutment screw is usually lower in implants with an internal connection, which is due to higher resistance to bending and lateral forces (Norton, 2000, Khraisat et al., 2004, Pjetursson et al., 2018). As a result, the incidence of abutment screw loosening and eventually fracture significantly decreased since their introduction.

1.10.3 Occlusal Forces

Mastication forces range between 383 N to 678 N for females and 512 N to 1019 N for males (Cosme et al., 2005). During active function, the occlusal forces are disseminated to the crestal bone, with the applied forces mainly concentrated at the area of implant-abutment interference (Pjetursson et al., 2018). Therefore, precise implant position is essential to ensure that the occlusal forces are directed along the long axis of the implant and are evenly distributed. Implant malpositioning leads to an unfavourable occlusal scheme, thus creating technical complications, including abutment screw fracture (Mendonça et al., 2009). Excessive occlusal forces arise either from parafunctional habits such as bruxism or from functional loading. Bruxism induces additional occlusal forces through increased frequency and load of the buccal-lingual mandibular movement, which increases the risk of abutment screw fatigue fracture and marginal bone loss caused by excessive bending overload (Rangert et
al., 1995, Conrad et al., 2008). The non-axial pressure created on the prosthesis increases the risk of screw loosening and subsequently results in screw fatigue (Schwarz, 2000, Quek et al., 2006). Donkin et al., reported that screw loosening indicates premature contacts requiring occlusal adjustment to prevent occlusal interference during lateral excursions or excessive occlusion (Donkin et al., 2018).

1.10.4 Implant Platform

Wider diameter implants with wide prosthetic platforms result in less tipping forces and, thus, less stress on the abutment screws than narrow diameter platforms. An in-vitro study demonstrated an inverse relationship between implant platform diameter and axial load; as the diameter of the implant platform increases, the load on the abutment screw decreases. A 44% reduction in stress was applied to the abutment screws when the diameter of the implant platform was increased from 4 to 5 mm (Boggan et al., 1999).

1.11 Assessment of Fractured Abutment Screw

A thorough assessment is essential for the management of abutment screw fracture. Several techniques have been listed in an article by Mizumoto et al. (2018) which gives clinicians information as to how to comprehensively assess the fracture through direct vision, tactile assessment with a probe, a sharp explorer as well as with intra-oral radiographs. For screw fractures that occur more apically, a prosthetic component of the same system, such as an impression coping, can help with locating the broken segment as it will prevent it from fully seating. The clinician can then remove the impression coping and compare the length of the retrieved segment with the length of a pristine screw from the same system (Mizumoto et al., 2018). If the abutment screw fracture occurred while the crown and the abutment were still attached, Donkin et
al. (2018) proposed drilling the crown with diamond or tungsten carbide burs and using crown removal forceps or a reverse hammer to allow direct access to the implant well. However, if the implant-supported prosthesis had been missing for some time, the peri-implant soft tissue may have grown over the implant obscuring the screw access hole (Donkin et al., 2018, Mizumoto et al., 2018). If that happens, a gingivoplasty is recommended to provide access to the implant well. Reyhanian et al. (2010) proposed a technique for removal of the excess peri-implant gingival tissue by using a low-frequency Er:YAG diode laser and without producing thermal damage to the adjacent soft and hard tissues (Reyhanian et al., 2010).

1.12 Fractured Screw Retrieval Techniques

Several case series and case reports described a number of techniques for the retrieval of fractured abutment screws (Walia et al., 2012, Carneiro Tde et al., 2016, Leung, 2017b, Donkin et al., 2018), which can be categorized either as a conservative techniques or techniques that require the use of rotary instruments to modify the coronal part of the broken fragment.

1.12.1 The Conservative Approach

The conservative approach requires no modification of the fractured abutment screw and can be accomplished utilizing the standard dental instruments available to the clinician. If the broken screw is visible and above the implant body, most authors discussed about using a hemostat or sharp explorer applied to the fragment in a counter-clockwise direction. If retrieval of the fragment with these instruments is not possible, an ultrasonic scaler has been recommended (Agustín-Panadero et al., 2017). The ultrasonic scaler has been used to progressively turn the abutment screw in a counter-clockwise direction by positioning its thin tip above the
screw. The idea behind this approach is that the oscillations from the tip will loosen the fragment and the spray will wash away any debris that is potentially blocking the free turning of the fragment. Eugenol or mineral oil have been also been used as lubricants to lessen resistance and smoothen clamping forces (Pow and Leung, 2008). Using a fork-shaped end instrument from Astra Tech on a slow-speed handpiece to engage the fragment was discussed in a number of case reports: Once the instrument had engaged with the head of the screw, reverse torque was applied at low speed to retrieve the fragment (Yilmaz and McGlumphy, 2011). Table 1.1 presents a summary of a number of conservative approaches published in the literature.

**Table 1.1: Summary of Reported Conservative Retrieval Techniques**

<table>
<thead>
<tr>
<th>Author</th>
<th>Screw Retrieval Technique</th>
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<tbody>
<tr>
<td>(Satterthwaite and Rickman, 2008)</td>
<td>Authors managed to remove a dislodged apical fragment which had fractured away from the body of the screw by using a curved endodontic file.</td>
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<tr>
<td>(Bhandari et al., 2013)</td>
<td>Utilized a piezoelectric ultrasonic scaler tip which was applied to the occlusal surface of the fractured screw. They initiated the oscillations at minimal power in reverse motion. Once the fractured segment started spinning, the tip’s contact with the screw fragment progressively decreased and then a tweezer was used to pick up the loose screw.</td>
</tr>
<tr>
<td>(Barbosa et al., 2014)</td>
<td>Managed an apical abutment screw fracture using an explorer in counter-clockwise rotation to move the fragment coronally.</td>
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Then they shortened the handle of a cotton swab (Johnson & Johnson) and used the cotton swab as a screwdriver. The head of the swab was pressed against the fractured screw and twisted slowly in reverse rotation. When retrieval with the cotton swab was unsuccessful, an ultrasonic scaler (Cavitron) was used in a counter-clockwise direction, and the procedure was repeated as many times as necessary.

(de Souza Batista et al., 2018)

They trimmed a sterilized rubber band to a size that fits the implant chamber coronal to the fractured segment. They then attached a screwdriver onto a torque wrench and inserted the tip within the implant well. They then turned it in a counter-clockwise direction with firm finger pressure directed downwards the screw. The rubber-band slice, placed between the fractured segment and the screwdriver would cause friction, loosening the broken fragment.

(Chen and Cho, 2018)

The authors used a 2 x 2 inch gauze for airway protection. Initially, they used an ultrasonic scaler in a counter-clockwise direction to mobilize the fractured fragment, they then rotated the broken fragment with a sharp explorer until it was above the implant body. If the sharp explorer failed to turn the fractured segment, a hand scaler was used in a counter-clockwise direction.
If all the above techniques failed a different approach was used. The authors dried the screw fragment with oil-free compressed air, then placed an adhesive dental restoration holder on the occlusal surface of the fractured screw. Following this, they rotated the adhesive holder one-quarter turn clockwise, and again in the reverse direction. They repeated this process until the fractured segment got loose. The loose segment was removed with a curved hemostat. Integrity of the implant was assessed using a pristine impression coping.

(Gaonkar et al., 2019) In a case where the abutment screw fractured 2 mm apical to the implant platform, the authors used a fine tapered diamond bur. The spinning action of the bur pulled out the broken screw away from the implant well without the need for creating a groove on the occlusal surface of the fractured screw. An x-ray confirmed complete removal of the screw.

(Yang and Wu, 2019) Authors fabricated a customized screwdriver using the following steps: (1) The tip of an 18-gauge hypodermic needle was flattened using Howe pliers. (2) A K-file was inserted into the needle to round its tip. Then the needle was bent and inserted into the implant for friction fit to disengage the fractured
abutment screw in a counter-clockwise direction.

1.12.2 Rotary Instruments and Fractured Abutment Screw Fragment Modification

When attempts to remove the fractured screw with conservative retrieval methods fail, it has been recommended by a number of authors to utilize rotary instruments (Lau and Pang, 1994, Williamson and Robinson, 2001). A case series conducted by Donkin et al. (2018), suggested using a round high-speed bur to create a straight-line slot into the head of the screw, which would convert it into a flat head. After that, a flat head screwdriver was used to engage and loosen the prosthetic screw. In the same case series, another technique was described. The implant collar was initially covered by soft tissue but it was removed using a diode laser to avoid bleeding. A 2 mm hole was created on the occlusal surface of the fractured screw using Endodontic Munce Burs and the depth of the hole was verified with a periapical x-ray. This 2 mm hole allowed for a connection with a gold tapered Robertson square-head driver, enabling the operator to retrieve the fractured screw (Donkin et al., 2018). Due to the increased risk of damaging the internal implant threads with the rotary instruments when attempting such retrievals, Lau and Pang suggested polishing the sharp cutting edges of these instruments (Lau and Pang, 1994). They modified a low-speed tapered fissure bur by smoothening the lateral blades and retaining the end cutting blade with a high-speed stone. The modified bur was polished with rubber points and mounted to a handpiece with an electric torque controller (Nobelpharma Inc., Gothenberg, Sweden). The modified bur was inserted into the implant well, and the fractured screw was retrieved with a counter clockwise rotation below 20 N.cm (Lau and Pang, 1994).
Yi et al. (2021), presented an alternative approach to rescue an implant with a fractured abutment screw fragment where two implants suffered fractured screws in the mandibular posterior area. The first fractured screw was retrieved with a sharp explorer. The second could not be retrieved and despite numerous failed attempts using low-speed rotary instruments and ultrasonic scalers, the authors used a tungsten carbide bur in a high-speed hand-piece on a clockwise direction in order to push the fractured fragment gently apically. Then, a new screw was prepared by trimming the tip of the screw to the length of the remaining upper part of the internal threads. The reduction in length of this gold screw was about 3mm. The passive fitting of the new screw was confirmed when the prosthesis was loaded. The screw was fully seated, engaging the implant threads, and tightened with the manufacturer-recommended torque of 30 N.cm. The authors reported that the modified screw remained stable for 11 years (Yi et al., 2021).

Satwalekar et al. (2013) reported a case with a fractured abutment screw at the level of the first thread. A groove was made on the occlusal surface of the screw using a round bur, and a spoon excavator was modified by cutting the working end of the instrument perpendicularly. The modified spoon excavator was used as a screwdriver to engage the prepared groove on the fractured abutment screw and reverse out the broken fragment (Satwalekar et al., 2013). Finally, Leung (2017a) reported a similar technique where the author flattened the abutment with a round bur, and a slot configuration was made on the occlusal surface of the screw. The abutment with the attached screw was removed with a slotted driver applied in a counter-clockwise direction (Leung, 2017a).
Table 1.2: Summary of Reported Retrieval Techniques Involving Rotary Instrumentation

<table>
<thead>
<tr>
<th>Author</th>
<th>Screw Retrieval Technique</th>
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<tbody>
<tr>
<td>(Luterbacher et al., 2000)</td>
<td>The authors created a small indentation on the fractured screw with a small round bur. They then used a fissure bur in a counter-clockwise direction to reverse the screw out. In cases where this method was unsuccessful, a repair service set by the ITI Dental Implant System (Institute Straumann AG, Waldenburg, Switzerland), which had a different set of drills and drill guides, was used.</td>
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<tr>
<td>(Williamson and Robinson, 2001)</td>
<td>Introduced a small dimple onto the centre of the screw with a ¼ round bur, then extended a groove buccally and lingually without engaging the threads. Next, they deepened the groove while leaving the mesial and distal walls intact. A round #1 bur was then modified, by sharpening the cutting end of the bur with a stone and was used as a screwdriver to remove the screw.</td>
</tr>
<tr>
<td>(Yilmaz and McGlumphy, 2011)</td>
<td>Used a stainless-steel fragment removal instrument with a long shank and a fork-shaped tip (Fragment Fork; Astra Tech, Waltham, Mass). This instrument has two different diameters, 1 mm and 1.4 mm, and is connected to a slow-speed handpiece. The authors engaged the tip of the instrument with the centre of the exposed fractured screw surface, and applied reverse torque on the</td>
</tr>
<tr>
<td>Year</td>
<td>Methodology</td>
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<tr>
<td>(Imam et al., 2014)</td>
<td>Used the same technique described by (Yilmaz and McGlumphy, 2011) above. If the fractured abutment screw was apical within the implant body with damaged internal threads, the authors recommended using an Astra Tech fork-shaped tip with a long shank stainless-steel instrument connected to a slow-speed handpiece. The fork-shaped tip instrument was used to displace the broken fragment apically into the implant well, allowing space for the re-tapping tools. Then, a Zimmer Dental re-tapping tool was used to re-tap the internally damaged threads of the implant by rotating it clockwise no more than 180 degrees and then rotating it counter-clockwise. After re-tapping the threads above the fragment, the loose fractured abutment screw was removed with a fork-shaped tip instrument. When the fork-shaped tip instrument was unsuccessful in removing the fragment, the authors recommended applying ultrasonic instrumentation in combination with the fork-shaped tip instrument.</td>
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<tr>
<td>(Yoon et al., 2016)</td>
<td>Described a technique to retrieve a fractured screw 2 mm below the implant platform using the following steps: (1) Initially, an endodontic explorer was used in a counter-clockwise direction to retrieve the screw fragment. When this technique was unsuccessful,</td>
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<tr>
<td>Step</td>
<td>Methodology</td>
</tr>
<tr>
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<tr>
<td>1.</td>
<td>A customized drill guide with a reverse tap drill was used. (2) An access hole was made in the centre of the broken screw with a tungsten carbide bur, which was guided by a customized device. (3) The customized drill guide was fabricated using an implant impression coping, and the impression coping was modified using auto-polymerizing acrylic resin. (4) A bur was inserted within the impression coping, and was moved back and forth until a hole with a depth of 0.5 mm was made. Consequently, a reverse tap drill was used in a contra-angle hand piece and in a counter-clockwise direction.</td>
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<tr>
<td>2.</td>
<td>Used a titanium sleeve seated on the implant platform to guide the drilling procedure. Then used a 1.6 mm helicoidal drill under irrigation to drill the screw out completely. The diameter of the bur was smaller than that of the fractured screw. A re-tapping tool was used and torque was applied manually to re-tap the damaged internal threads.</td>
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### 1.12.3 Professional Kits

Most professional screw retrieval kits are designed to create a notch in the centre of the fractured abutment screw. They include a series of drills and drill guides which align the drill in an axial plane with the implant well to reduce the risk of damaging the implant’s internal threads (Leung, 2017b). A series of tapered shaped screw removers, designed to engage with the created notch are also included. Other professional kits only contain a
series of claws which are connected to a shank driver. These screw retrieval kits are either universal (compatible with different implant systems) or designed only for an individual implant system.

Agustín-Panadero et al. (2017) conducted an *in-vitro* study comparing the efficacy of three different abutment screw retrieval methods. The authors included 135 internal connection implants with 135 fractured abutment screws while fractures happened at different depths within the well of the implants (coronal or middle, or apical third). The three applied retrieval methods were

- A conventional method (45 samples): explorer and an ultrasonic scaler;
- A mechanical retrieval kit with a guiding cylinder (45 specimens); and
- A mechanical retrieval kit without the guiding cylinder (45 samples).

The mechanical retrieval kit without the guiding cylinder successfully retrieved 42 screws, reflecting a (93.3%) success rate, and the mean retrieval time was 2 min 56 sec ± 2 min 9 sec. The conventional method retrieved 33 screws, representing a (73.3%) success rate, and the mean retrieval time was 3 min 15 sec ± 1 min 48 sec. The mechanical retrieval kit with the guiding cylinder retrieved nine screws, and had the lowest success rate amongst the groups (20%). The mean retrieval time was 13 min 34 sec ± 7 min 25 sec. The overall results demonstrated no significant association between screw retrieval success and fracture depth (*p*=0.338). However, there was a significant difference in retrieval success between the conventional method and the mechanical retrieval kit with a guiding cylinder (*p*=0.034) and between the mechanical retrieval kit with a guiding cylinder and the mechanical retrieval kit without guiding cylinder (*p*=0.022). Yet, no significant differences were found between the
conventional method and the mechanical retrieval kit with a guiding cylinder (\(p=0.60\)). It seems that the guiding cylinder prevented the drill from reaching the apically located fractured screws, thus affecting screw retrieval success. Moreover, the retrieval kit with a guiding cylinder caused the most damage in the internal threads of the implants during the retrieval (Agustín-Panadero et al., 2017).

A recent in-vitro study conducted again by Agustín-Panadero et al. (2020) aimed to compare the efficacy of a mechanical system with that of a conventional method in retrieving fractured abutment screws. The authors divided 60 screws into two cohorts based on their anatomy and exposed them to fatigue and load until fracture occurred. Shape A represented 30 titanium screws with a smooth shaft and a threaded apical section, and shape B represented 30 titanium screws with a threaded body all the way to head of implant. These samples were then allocated to three operators with diverse experience in removing fractured abutment screws. Every operator was assigned 20 specimens: 10 from shape A and 10 from shape B. The distribution of 10 samples per cohort per operator was then separated into two groups based on the method of removal. The conventional method consisted of a sharp explorer and ultrasonic scaler, and the mechanical extraction kit used was the Broken Screw Extractor Kit; Rhein83, which included a claw reamer bur and centring device. The mechanical method exhibited a (96.7\%) success rate, while the conventional method showed a (73.3\%) success rate, and the difference between both retrieval methods was statistically significant (\(p=0.032\)). The mechanical method showed a 20-times higher probability for screw retrieval success compared with the conventional method (OR=0.240; \(p=0.088\)).

Moreover, the probability of screw retrieval with the mechanical method was higher when the fracture was coronally located (\(p=0.05\)). The stopper on the upper part of the centring device could prevent the drill from
reaching an apically fractured screw. The smooth shaft and threaded apical part (shape A) were extracted more easily and in less time than the completely threaded body (shape B): 1.22 min and 2.42 min, respectively ($p=0.022$). Furthermore, the results failed to show any significant relationship between operator experience and its influence on the two extraction methods (Agustín-Panadero et al., 2020).

Sprenger et al., (2018) carried out an in-vitro study investigating the effect of the removal of fractured abutment screws on the quality of the implant-abutment connection in terms of early abutment loosening, when using a Straumann rescue kit. The authors used 10 tissue-level regular platform implants (4.1 mm) and 10 bone-level mini implants (3.3 mm). The test group consisted of eight abutment screws for each implant type that were weakened by being sawed halfway through the screw thread and then intentionally fractured by applying torque of 35 N.cm. The control group had two intact implants with pristine abutment screws. The retrieval kit contained guiding drills with selective burs inserted within the guiding tube and rotated counter-clockwise to reverse the screw out. Once the fractured screw was retrieved, the internal implant threads were re-tapped, and new abutments were torqued. With a customized mastication stimulator, thermal cycling and mechanical loading were performed. The results indicated that following fractured screw retrieval, and following loading of the new abutment screws, no screw loosening was observed, and the new implant-abutment connection didn’t seem to be compromised from the retrieval procedure. (Sprenger et al., 2018).

Igarashi et al. (2019) conducted a pilot in-vitro study assessing the success rate of a repair service set (Straumann service set) for retrieving fractured abutment screws. Success was measured in four ways: (1) evaluating the complete removal of the fractured screw including testing the threads with an impression coping; (2) photographs taken with a dental surgery microscope in order to observe the state of the internal threads; (3)
injecting light-body polyvinyl siloxane (PVS) impression material into the implant well (making a silicon replica), and examining this replica with a stereoscopic microscope; and (4) examination of the implant by stereoscopic microscope. When the impression coping technique was applied, the screw retrieval was considered successful if the Straumann impression post fully engaged the implant threads. With the second method, the screw removal was deemed successful when no screw remnants were visible in the magnified images. The third technique was the Bernese silicone replica technique, which consisted of several steps (Igarashi and Afrashtehfar, 2018):

1. After retrieval of the fractured abutment screw, rinsing of the well with 10 mL saline.
2. Drying the inner well with a 3-way syringe and cleaning with a micro brush.
3. Inserting the intraoral tip of an impression cartridge as deeply as possible into the implant body.
4. Injecting the light-body impression material till it oozes out from implant shoulder.
5. Inserting an interproximal wooden wedge into the middle of the impression in one motion ensuring that no air bubbles are created.
6. Allowing impression material to polymerize, then comparing the control silicone pattern from a pristine implant with the removed silicone pattern.

In the fourth technique, which was examination by stereoscopic microscope, the implant was sectioned following screw retrieval by a slow-speed diamond saw and the microscope was used to display the images. A complete screw retrieval in this method would be considered successful if the metal debris at the bottom of the internal implant well did not exceed 1.2 mm (Igarashi et al., 2019).
The removal technique had a number 1 Straumann drilling guide placed into the implant well and a 1.6 mm bur was used through the drilling guide in counter-clockwise rotation at 600 rpm. Following this, a number 2 drilling guide was mounted into the implant well. A series of conical and cylindrical taps were used through the drilling guide in clockwise rotation followed by a counter-clockwise rotation to release the tension. Success rate of the Straumann service set for screw retrieval was (75%), and results of the four evaluation methods were as follows: Impression coping showed (100%) complete screw removal. The dental surgery microscope and photographs showed an (83.3%) screw retrieval success rate. The silicon replica technique showed (66.7%) screw retrieval success, and the stereoscopic assessments showed a (75%) screw retrieval success rate. The authors concluded that impression coping may provide a false positive result and may leave undetected apical broken remnants. Furthermore, the silicone replica technique and dental surgery microscope had similar diagnostic values to the stereoscopic assessment (Igarashi et al., 2019).

1.13 Surgical Removal of an Implant in Case of Failure of Fractured Screw Retrieval

When retrieval techniques fail to remove the broken fragment, implants can’t be used to support the prosthetic superstructure and need to be removed. A number of surgical techniques have been introduced to remove an already integrated implant. The main goal is to remove the implant without compromising the site so that it can be used again in the future without the need for extensive augmentation.

1.13.1 Counter-Torque Ratchet Technique

This is the least traumatic technique and usually requires minimal bone removal. The technique needs an intact implant connection (external or
internal hex), without damage to the internal implant threads and without a broken abutment screw lodged into the coronal part of the implant in order to facilitate insertion of the abutment or the extraction tool within the implant. Removal of the implant is accomplished with reverse torque. According to Solderer et al. (2019), implants with internal connections demonstrated easier extraction with greater torque than implants with external connections. In addition, tapered implants exhibited easier removal than parallel-wall implants. Narrow diameter implants showed an increased fracture risk, particularly with increased torque forces applied (Solderer et al., 2019).

A longitudinal study by Anitua & Orive. (2012) included 91 implants from 42 patients from different implant systems with different diameters and lengths. The implants were removed either due to fracture, peri-implantitis, or implant malposition. An implant Biotechnology Institute (BTI) extraction kit was used to remove the implants. The kit includes a wrench allowing up to 200 N.cm counter-torque force, different extractors for internal and external connection implants, and a rachet handle extension. Once the extractor engages with the implant well, a controlled counter-torque force is applied to prevent bending and subsequent implant fracture. In their study, 78 implants were extracted with the reverse torque technique, and the torque forces varied between 50-200 N.cm. However, for 13 implants forces of more than 200 N.cm were necessary. Therefore, a combination technique was applied where a trephine drill was used to decrease the amount of bone implant contact by about 2-3 mm around the implant before the attempt to counter torque the implant out. (Anitua and Orive, 2012).
1.13.2 High-Speed Burs

While high-speed burs can remove failed implants very efficiently, they can cause surgical emphysema and the process is destructive/invasive. Diamond burs are reportedly superior to the tungsten carbide burs as they reduce the cutting vibration, thus making it easier to control. When anatomical structures lie in the area of surgery, it is suggested that cone beam computerized tomography (CBCT) scans are used in order to identify and protect them. High-speed burs can also leave titanium residue from the implant surface inside the wound which should be removed through regular saline irrigation and a surgical suction (Bowkett et al., 2016, Solderer et al., 2019).

A case report described a technique for implant removal utilizing a diamond-coated fissure bur. The implant had failed due to mechanical complications. The authors created a 2-3 mm gap surrounding the implant shoulder using a diamond-coated fissure bur; a carbide surgical round bur was then used to perforate the titanium walls and split the implant into two pieces up to its apical third. An elevator was wedged into the space created by the bur, and forceps were used to extract the remaining sections by rotational movement. An osteotomy was prepared in the same site, and a new implant was inserted with good primary stability (Li and Chou, 2014).

Another technique for implant removal which used high-speed burs but without splitting the implant has been described. It involves using a round or a fissure bur from the buccal side down to the implant apex. The implant is then extracted with dental forceps. If not possible to remove the implant this way, a three-wall bony defect is created around the implant with a round bur to ease luxation towards the buccal side where the bone was removed (Stajčić et al., 2016).
1.13.3 Trephines

Cylindrical blades characterize most trephine burs. They exist in different diameters but because it is a very invasive technique it must be emphasized that they should only be used as the last option (Solderer et al., 2019). It is also advised to use the smallest trephine size for the implant that needs to be removed in order to minimize bone removal and reduce the necessity for bone augmentation procedures (the trephine’s internal diameter should be somewhat larger than the implant to evade engagement with the implant body) (Bowkett et al., 2016). The speed of 1200 rpm – 1500 rpm is favoured with maximal water cooling to avoid thermal necrosis. Stajčić et al., advised using pins and guiding cylinders or healing abutments of the smallest emergence profile while using trephine burs to follow the implant axis and avoid excessive bone removal. Trephines are contraindicated when a narrow gap exists between the failing implant and the neighbouring teeth as teeth can be damaged during the extraction procedure (Stajčić et al., 2016).

Many clinical complications have been reported following the use of trephine burs, including leaving a very thin cortical plate, vertical defects and mandibular fractures. (Bowkett et al., 2016, Stajčić et al., 2016, Solderer et al., 2019).

1.13.4 Piezosurgery

Piezosurgery allows for a less traumatic surgical removal of the failed implants and has been demonstrated not to have a negative effect on bone healing post-operatively. The osteotomy should be performed with a diamond coated insert through intermitting application mode close to the implant surface in order to remove the least possible amount of bone (Messina et al., 2018). Piezosurgery offers the advantage of not affecting
soft tissues as it efficiently cuts shallow bone and allows for precise and selective cutting to conserve sensitive structures such as nerves and blood vessels around the dental implant (Messina et al., 2018, Solderer et al., 2019). It has been observed that the piezosurgery instrument is less effective for deeper bone cuts and abundant saline irrigation is necessary throughout the procedure. (Bowkett et al., 2016, Solderer et al., 2019).
CHAPTER 2
MATERIALS AND METHODS
2.1 Aim of the Study

The study herein was designed to compare the efficacy of two techniques which were developed to facilitate the removal of fractured abutment screw fragments from the internal well of two implant systems with different internal and external anatomy. It also attempted to examine possible associations between a number of independent variables and the ability of the two retrieval techniques to successfully remove the fractured abutment screw fragments.

2.2 The Null Hypothesis

There is no difference, in the efficacy of the commercially available implant abutment screw retrieval kit and the homemade abutment screw retrieval kit in retrieving fractured abutment screw fragments from the two different dental implants examined.

2.3 Sample Calculation

The sample size calculation was based on our primary outcome (retrieval success) based on a previous article (Agustín-Panadero et al., 2017). In their study, a sample size of 16 (for each group) would have 95% power to detect a difference between group mean and hypothetical mean of 5 min (difference in retrieval time) with a significance level alpha of 0.05 (two-tailed). Taking into consideration that there were some differences between implants/screws, retrieval methods, fracture level and operator experience between the two studies, we doubled this sample size number and used 32 screws/implants in each group and an overall number of 64 implants/screws.
2.4 How Will this Research Contribute to the Field?

Although commercially available universal screw retrieval kits claim to assist clinicians in removing fractured dental implant abutment screw fragments in a safe and effective manner, evidence for the relative efficacy of these retrieval kits and other reported means of retrieving the fractured screw fragments is lacking. In addition, there is limited evidence related to the association between dental implant design, abutment and screw design, abutment screw fracture morphology, torque at which the abutment screw fractured, location of the implant within the oral cavity and the efficacy of retrieving fractured screw fragments. Therefore, the study herein was designed to provide us with more information about a number of available techniques for retrieving fractured abutment screws and factors that might affect their efficacy.

2.5 Study Design

The two-implant types that were utilized for this *in-vitro* study were:

A. Osseotite® Certain, Dental Implants (Dual Acid Etched. ZIMMER-BIOMET™, Palm Beach, Florida, USA) with an internal abutment connection and a standard head diameter of 4.1 mm (n=32). (Figure 2.1)

WITH

Gold-Tite Screws, Certain® Internal Connection. (SureSeal Technology Screw) – ZIMMER-BIOMET™ (n= 32). (Figure 2.1). The recommended insertion torque for this screw is (20 N.cm). The diameter of the screw, as
measured by an electronic calliper across the threads, was 1.5 mm (Holex Digital Outside Micrometer 0 – 25 mm, Hoffmann group) (Figure 2.3). This screw has a long shank coronally, with only a small number of threads apically.

Figure 2.1: Osseotite® Certain, (4.1 mm) Dental Implant and a Gold-Tite Screw, Certain® Internal Connection.

AND

B- Osseotite®, micromini External hex connection Dental Implants (Dual Acid Etched. ZIMMER-BIOMET™) with an external abutment connection, and a micro-mini head diameter of 3.25 mm (n=32). (Figure 2.2)

WITH

Gold-Tite Square Screw, External Connection – (ZIMMER-BIOMET™) (n =32). (Figure 2.2). The recommended insertion torque for this screw is (35 N.cm). The diameter of the screw, as measured by an electronic calliper, from the external thread body part was 1.95 mm across the threads (Figure 2.3). and the threads of the screw extended coronally 1-2 mm away from the screw head. (Figure 2.2).
Figure 2.2: A, Osseotite® External hexagonal Connection micromini implant (size 3.25 mm) ZIMMER-BIOMET™; B, Gold-Tite Square Screw – ZIMMER-BIOMET™

Figure 2.3: The electronic calliper used to measure the diameter of the screws
2.6 Retrieval Kits

Two different kits were used for the retrieval of the fractured abutments screws.

2.6.1 Conventional or Homemade Kit

The conventional or homemade kit included:

1- Home made claw tools using modified black and green ParaPost drills (Figure 2.4), and a screw driver handle (Figure 2.5).

The ParaPost drills' tips were modified with a diamond disc (NTI diamond disc Handpiece D918-190, Kerr rotary) to resemble a claw. (Figure 2.4) A size 6 black ParaPost drill with a diameter of 1.5 mm (ParaPost Drills, Two-Fluted, #6 (Black), (Coltene Whaledent), and a size 7 green ParaPost drill with a diameter of 1.75 mm (ParaPost X System Drill #7 Green (Coltene/Whaledent, Inc.) were used. (Figure 2.4)

![Figure 2.4: Modified size 6 and 7 ParaPost drills](image)
2- Screw Driver handle

Both ParaPost drills were inserted in the driver handle (L-TIRW Standard ISO 1797 Adapter (C9980) driver tip ZIMMER-BIOMET™) (Figure 2.5)

![Image of modified ParaPost drill connected to the screw driver handle.](image)

**Figure 2.5:** Modified ParaPost drill connected to the screw driver handle.

3- A connection guide (Yoon et al., 2016)

This connection guide was assembled using a stainless steel ratchet (Art. No0.46.108) (Straumann AG, Basel, Switzerland) and on it two impression copings (Figure 2.6 A and B) were stabilized using a polymerized resin. A Polymethyl Methacrylate (PMMA) polymer powder mixed with a liquid monomer and the mixture underwent polymerization. The mixture was applied to the ratchet, and the impression copings were embedded in the holder with the acrylic resin (Figure 2.6 A).
Impression copings were connected to the implants and the ParaPost drills were inserted within the impression copings (Figure 2.6 B). The impression copings were used as guides to align the drills to the centre of the well of the implant. Depending on the implant system and diameter of the screw, the appropriate ParaPost drill (green or black) was selected. There was an attempt to engage the modified tip of the ParaPost with the fractured screw fragment by applying pressure and counter rotating the driver handle.
4- The home-made kit overall included the following instruments:

A. Kelly Artery Forceps Curved, SKU: A10-1275-02, Hu-Friedy®, Hu Friedy Co., Frankfurt, Germany. (Figure 2.7 A)
B. Single-sided dental mouth mirror (#3 HD Mouth Mirror | MIR3HD, Hu-Friedy®, Hu Friedy Co., Frankfurt, Germany (Figure 2.7 B)
C. Spoon excavator, 127/128 EXCAVATOR EXC127/8, Hu-Friedy®, Hu Friedy Co., Frankfurt, Germany (Figure 2.7 C)
D. DG16 Endodontic explorer, (9EXDG166, Hu-Friedy®), Hu Friedy Co., Frankfurt, Germany (Figure 2.7 D)
E. Home-made connection guide using impression copings embedded in a metal holder with acrylic resin (Figure 2.7 E)
F. Modified black ParaPost drill (Coltene/Whaledent, Inc.) inserted in a screw driver head (L-TIRW Standard ISO 1797 Adapter (C9980) driver tip ZIMMER-BIOMET™ (Figure 2.7 F)
G. Modified green ParaPost drill (Coltene/Whaledent, Inc.) (Figure 2.7 G)

H. LM-ERGOGRIP ULTRA Dental ultrasonic scaler (LM dental, Planmeca group) (Figure 2.7 H)

**Figure 2.7 A:** A, Artery Forceps; B, mouth mirror; C, spoon excavator, D, DG16 Endodontic explorer; E, Home-made connection guide; F, modified black ParaPost drill connected to the screw driver handle; G, Modified green ParaPost drill.
2.6.2 Universal Removal Kit: Neobiotech Screw Removal Kit (SR) Kit-II Version 1

The Neobiotech screw removal kit is an autocavable plastic cassette which includes a number of specially designed instruments which are fabricated from stainless steel and displayed in an ascending order of size. It is compatible with different implant systems.

Figure 2.8: Neobiotech screw removal kit
The Neobiotech kit includes the following:

A. The Claw:

The kit includes claws which are used depending on the size of the fractured screw. The claws are attached to a driver handle (Figure 2.9, A and B) and are guided by a number of internal, external, or conical connection guides (Figure 2.9 C). For the Zimmer Biomet, Certain, standard implants, an internal connection guide was used, and for the Zimmer Biomet, External hexagonal Connection micromini implants, an external connection guide was used. The claws come in four different diameters, CD16 = 1.05mm, CD18 = 1.25mm, CD20 = 1.40mm, and CD25 = 1.85mm (Figure 2.9 D). By pressing the claw against the fractured screw and rotating counter-clockwise the claw engages with the screw fragment (Figure 2.9 E). A screw remover (SR) driver holder is also included in the kit. This holder is designed to hold the conical, internal, and external guides (Figure 2.10 A, B)

Figure 2.9: A, Claw; B, A claw connected to a shank driver; C, guiding fixture to align the drill in proper axial direction; D, claws designated for screw fracture removal with four different diameters; E, remover of the fractured screw in the reverse direction by a claw.
B. Reverse Drill:

The kit includes three end-cutting stainless steel drills of different diameters (1mm (RCD10), 1.2 mm (RCD12), 1.4 mm (RCD14)). They have a nickel titanium coating which increases strength, and they are designed to create a notch/hole at the coronal part of the screw fragment. The drills are sold as single use components (Figure 2.11 A). These drills are used in combinations with connection guides which are transferred by Perfect Guide (PG, GH00, 2.4Hex) hand driver to engage the inner implant threads (Figure 2.11 B and C). These guides help to align the drill in proper axial direction to the implant in order to prevent damage to the internal threads of the implants. The screw remover can also be used in combination with shank driver (SDD00) in order to remove the screw fragment manually. (Figure 2.11 D)

The drills have to be used in reverse direction at 2000 rpm, and it creates a 1-2 mm notch or a hole on the occlusal surface of the fractured abutment screw. (Figure 2.11 E) Following this, a screw remover is used in a reverse mode (80 rpm) to retrieve the fractured screw. (Figure 2.11 E and F).

Screw remover comes in three sizes 1mm (SR10), 1.2 (SR12) mm, 1.4 mm (SR14).
**Figure 2.11**: A, Reverse drills; B, centering device; C, centering device transferred by a perfect guide hand driver for proper axial alignment; C, screw remover attachment; D, a shank driver to be used with the screw remover drills to remove the fractured screws manually; E, once a hole is created on the occlusal surface of the fractured abutment screw by the reverse drill, a screw remover attachment was utilized in a reverse mode to retrieve the broken screw; F, screw remover attachment used in the reverse direction to retrieve the fractured abutment screw.

### 2.7 Screw Fracture Morphology

A total of 64 abutment screws were sectioned in four different ways (Figures 2.13–2.16). To achieve this, a straight laboratory handpiece was used (EXPERT matic™ E10C- Low-Speed, Straight Handpiece, Kavo, Dental Excellence) in combination with a grinding disc (NTI diamond disc
Handpiece D918-190, Kerr rotary). The screws were partially sectioned at the level of the second coronal thread. The purpose of this was to mechanically weaken the screw and to develop different patterns of fracture morphology at the coronal end of the fractured screw. The appropriate prefabricated implant abutments were connected to the implants and stabilized using the pre-sectioned abutment screws (Certain® Internal connection UCLA abutment 4.1 mm seating surface IGUGA1C for Osseotite® Certain, dental Implants (size 4.1 mm), and External Hex Connection UCLA abutment 3.4 seating surface MUCG1C for Osseotite® External hexagonal Connection micromini implants (size 3.25 mm), ZIMMER-BIOMET TM Palm Beach, Florida). Each implant was secured by a desk vice and the screws were then tightened using a calibrated torque driver (Tohnichi, Tokyo, Japan) (Figure 2.12, Appendix I) until the screws fractured. The torques at which the screws fractured were recorded, and the cross-sectional morphologies on the coronal aspect of the fractured screw was confirmed and recorded.

Figure 2.12: Torque driver (Tohnichi, Tokyo, Japan)
Fracture morphology shape I

Figure 2.13: A, diamond disc; B, the occlusal surface of the screw, where a semilunar cut was made by a diamond disc to weaken the screws; C, then the screws were tightened until the abutment screws fractured; D1 and D2, as shown in the photos the fracture developed into a semi-rectangular shape.
Figure 2.14: A, diamond disc; B, the occlusal surface of the screw, where two semilunar cuts were made on opposing sides halfway through the second threads by a diamond disc; C, then the screws were tightened until the abutment screws fractured; D1 and D2, as shown in the photos, the fracture developed into a quadrilateral (trapezoid) shape.
Fracture morphology shape III

Figure 2.15: A, diamond disc; B, the occlusal surface of the screw, where three cuts were made on different sides halfway through the second threads by a diamond disc; C, then the screws were tightened until the abutment screws fractured; D1 and D2, as shown in the photos, the fracture developed into a triangular shape.
Fracture morphology shape IV

**Figure 2.16:** A, diamond disc; B, the occlusal surface of the screw, where four semilunar cuts were made on opposing sides halfway through the second threads by a diamond disc; C, then the screws were tightened until the abutment screws fractured; D1 and D2, as shown in the photos, the fracture developed into a semi-rectangular shape.

Although there was an attempt to equally distribute the screws into four groups depending on their fracture morphology, when they were examined under magnification, the morphology identified was not always the one that had been planned for. As a result we had overall 21 type I, 13 type II, 13 type III, and 17 type IV.
2.8 Embeding of the Implants With the Fractured Screws into Maxillary and Mandibular Casts

The implants with the fractured screws were embedded into maxillary and mandibular casts made of type IV dental stone (ELITE STONE - PLASTER TYPE IV – Zhermack). Eight sets of casts were made- eight maxillary and eight mandibular models. Four maxillary and four mandibular casts would receive four (Osseotite® Certain, dental Implants (size 4.1 mm) ZIMMER-BIOMET TM) in each stone model. The other four maxillary and four mandibular casts would receive four (Osseotite® External hexagonal Connection micromini implants (size 3.25 mm) ZIMMER-BIOMET TM) in each stone model. Two of the implants in each cast were to be placed in the lateral incisors area and two in the first molars area.

2.9 Preparartion of the Wokring Casts

A pair of edentulous maxillary and mandibular typodont models (FB-# CSP Edentulous typodeont, hard plastic designed for removable prosthodtics with natural anatomy. ANA-4 series typodont #40300690. Frascao USA) were inserted into duplicating flasks (Figures 2.17 A and B).
Figure 2.17 A: FB-# CSP Edentulous typodeont, hard plastic designd for removable prosthodtics with natural anatomy. ANA-4 series typodont #40300690. Frascao USA

Figure 2.17 B: Upper and lower Frasaco typodont models placed within the duplicate ring.

An auto-mixed, autopolymerising silicone material was poured into the duplicating flasks containing the Frasaco typodont models all the way to the top of the flask (Addition Silicon, Dosing and Mixing Unit Sidomix, Wassermann. Hamburg, Germany), (Figures 2.18 A, B, C, and D). The silicon was allowed to set for 45 minutes and the Frasaco typodont models were then removed from the duplicate silicon models, and type IV dental stone was poured over the silicon models and was allowed to set for 60 minutes (ELITE STONE - PLASTER TYPE IV – Zhermack).
**Figure 2.18 A:** Dosing and Mixing Unit Sidomix II mixing and dosing of low-viscous, addition cross-linking duplicating silicones, to duplicate the edentulous Frasaco typodeont models.

**Figure 2.18 B:** Silicone mixture was poured into the duplicate ring or the duplicate tray, using a small stream to minimize bubbles until the mixture was uniform. Allowing silicon to set for 30-40 minutes.
A round magnetic disc (Round Disc Magnets 12x 10mm The Artex® Splitex System, Jensen Dental) was placed at the top of the setting stone (Figure 2.19), and a mounting plate was embedded on top of the magnetic disc to imprint on the fitting surface of the stone. This would allow us to connect the casts to the phantom heads' mounting plates. (Frasaco AG3 Fit, mounting plates, Frasaco, Germany), (Figure 2.20). The casts were then removed from the duplication flasks, and any
excess stone at the base of the cast was trimmed using a silicon carbide disc trimmer at 1500 rpm (Talleres Mestraitua, S.L. MESTRA®, Spain)

Figure 2.19: Magnetic discs attached to the fitting surface of the setting stone.
In each cast four cylindrical cavities were prepared (≈15 mm depth, and 5 mm width). The cavities were prepared in sites 1.6, 1.2, 2.2, 2.6 for the maxilla, and in 4.6, 4.2, 3.2, and 3.6 for the mandible. A dental tungsten carbide bur (R&S Tungsten Carbide Burs: Tapered Fissure Plain Cut and Cross Cut - 699L, Dental sky) was utilized together with a laboratory handpiece (EXPERT matic™ E10C- Low-Speed, Straight Handpiece, Kavo, Dental Excellence, 30.000 Rpm) (Figure 2.21)
Figure 2.21: Maxillary and mandibular casts with 4 prepared cavities in each cast.

Implants were embedded within their respective cylindrical cavities, and secured using an autopolymerising resin Polymethyl Methacrylate (PMMA) which was left to set for 24 hours. A total of four sets of casts were made with Zimmer Biomet, Certain, standard implants Internal connection (Figure 2.22 A and B) embedded in them, and four sets of casts with the Zimmer Biomet, External hexagonal Connection micromini implants (Figure 2.23 A and B).
Figure 2.22: A, Osseotite® Certain implants embedded in upper and lower stone models; B, upper and lower models containing the Osseotite® Certain implants were mounted to the phantom head.
Figure 2.23: A, Osseotite® micromini External hex connection implants embedded in upper and lower stone models; B, upper and lower models containing the Osseotite® micromini External hex connection implants mounted to the phantom head.

2.10 Specimen Distribution

After embedding the implants, the specimens were distributed between four operators with varying clinical experience. Two of the operators had extensive experience (consultants), and the other two operators were less experienced (postgraduate students). Each operator was to attempt retrieving 16 fragments. This in-vitro study was part of a wider study which included 128 implants and 4 different dental implant systems. A
flow chart (Appendix II) was used to rotate operator type, implant system, implant location, and retrieval used in an even manner.

2.11 Clinical Simulation

The head-rests were removed from the dental chair, and they were replaced by the phantom head containing the mounted casts with the implants under investigation. The operators attempted to remove the fractured screws by using the designated kit and loupes with a magnification of 3.4x (ZEISS EyeMag Pro S Loupes) and indirect vision (Figure 2.24).

Figure 2.24: Frasaco phantom head attached to the dental chair.
2.12 Flow Chart (Appendix II)

A flow chart was used to ensure that all operators removed an equal number of fragments from the same area in the “mouth” Each cast was divided into half, and in one half the professional kit was used, and for the other half the home-made kit was used. Each cast had 2 codes and one assigned operator (Figures 2.25 A, B and 2.26 A, B). During and after the procedures the following data were recorded:

1. The dental implant system used
2. Retrieval kit used
3. Fracture morphology
4. Implant position
5. Time taken to retrieve the fragments
6. Retrieval outcome
7. Torque at which the screw fractured
8. Operator experience
9. Presence/absence of damage to the internal threads of the implant
Figure 2.25 A, B: Zimmer Biomet, Certain, standard implants (flow chart). A, mandibular cast with four Osseotite® Certain implants (size 4.1 mm) embedded in 3.6, 3.2, 4.2, 4.6; B, the flow chart for the corresponding cast, where A stands for the anterior implant, P stands for the posterior implant; time = time taken to retrieve the screw fragment.
Figure 2.26 A, B: Zimmer Biomet, External Hexagonal Connection micromini implants (flow chart). A, maxillary cast with four Osseotite® micromini external hex connection implants 3.25 mm diameter embedded in 1.6, 1.2, 2.2, 2.6; B, the flow chart for the corresponding cast, where A stands for the anterior implant, P stands for the posterior implant; time = time taken to retrieve the screw fragment.

2.13 Retrieval Success or Failure

Success was defined as retrieving the screw fragment in less than 15 minutes without irreversibly damaging the threads. One of the four clinicians involved in the study was always present to record the time taken to retrieve the screw fragments and to test if the threads have been damaged following retrieval. If the screw fragment was not retrieved
Within 15 minutes or if the internal threads were damaged it would be classified as failure.

2.14 Evaluation of the Integrity of the Internal Threads

The integrity of the internal threads was evaluated by placing an impression coping into the implant and verifying whether or not it was seated properly and without difficulty. (Figure 2.27 A, B, C)

Figure 2.27 A, B: A, Impression coping for Osseotite®, micromini external hex connection dental implant. (Pick-Up Impression Coping 3.4 mm diameter ZIMMER-BIOMET™); B, Impression coping for Osseotite® Certain, dental implants (size 4.1 mm), (Pick-Up impression coping 4.1 mm diameter, ZIMMER-BIOMET™).
Figure 2.27 C: Pick-Up Impression Coping 3.4 mm diameter ZIMMER-BIOMET™, used to analyse the integrity for the corresponding implant internal threads.

2.15 Statistical Analysis

The data were recorded into an excel spreadsheet and when they were all collected, they were transferred to a specified statistical software program (IBM SPSS Statistics, v24.0; IBM Corp) for analysis. Initially, descriptive analysis was conducted, and data were expressed by means, percentage, and standard deviation (SD). The table below gives a brief description of the tests conducted (Table 2.1)
Table 2.1: Summary of the Statistical Tests Employed

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Time taken for screw retrieval (Min)</th>
<th>Retrieval success (Yes, No)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous</td>
<td>Categorical dichotomous</td>
</tr>
</tbody>
</table>

| Implant system: Categorical dichotomous |
|----------------------------------------|--------------------------------------|-----------------------------|
| Osseotite®, Certain, Osseotite®, micromini External hex. | Mann-Whitney test X²=chi-square test/ Fisher's exact test |

| Operator’s experience: Categorical dichotomous |
|-----------------------------------------------|---------------------------------------------|
| Experienced                                    | Mann-Whitney test X²=chi-square test/ Fisher's exact test |
| Inexperienced                                  |                             |

| Kit: Categorical dichotomous |
|------------------------------|-----------------------------|
| Professional                 | Mann-Whitney test X²=chi-square test/ Fisher's exact test |
| Homemade                     |                             |

| Position: Categorical dichotomous |
|-----------------------------------|-----------------------------|
| Anterior                         | Mann-Whitney test X²=chi-square test/ Fisher's exact test |
| Posterior                        |                             |

| Arch: Categorical dichotomous     |
|-----------------------------------|-----------------------------|
| Upper                            | Mann-Whitney test X²=chi-square test/ Fisher's exact test |
| Lower                            |                             |

| Fracture Morphology: Categorical nominal |
|------------------------------------------|-----------------------------|
| I                                        | A Kruskal-Wallis test X²=chi-square test |
| II                                       |                             |
| III                                      |                             |
| IV                                       |                             |

| Torque force at which screw fracture occurred: Continuous |
|----------------------------------------------------------|-----------------------------|
|                                                          | Pearson correlation       |                             |
CHAPTER 3
RESULTS
3.1 Descriptive

In the study herein, a total of 64 implants were used. 56 abutment screws (87.5%) were successfully retrieved in less than 15 minutes, three were retrieved in more than 15 minutes and five could not be retrieved at all (Table 3.1 A). Of the three implants that were retrieved in more than 15 minutes, only two were retrieved without damaging the implant’s internal threads. The one implant abutment screw that caused damage to internal implant threads was retrieved after 27 minutes (>15 minutes).

The mean torque force at which screw fracture occurred was (23.13 ± 8.93 N.cm) (Table 3.1 A). Most screws had fracture morphology type I (n=21; 32.8%), followed by type IV (n=17, 26.6%), and the numbers of screws with type II and type III fracture morphology were similar (n=13; 20.3%) (Table 3.1 B).

Table 3.1 A: Descriptive Analysis

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group</th>
<th>N (%) Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time taken for screw retrieval (min)</td>
<td>&lt;15 minutes</td>
<td>56 (87.5%)</td>
</tr>
<tr>
<td></td>
<td>&gt;15 minutes</td>
<td>3 (4.68%)</td>
</tr>
<tr>
<td>Abutment screws that couldn’t be retrieved at all</td>
<td>Cut- off point 45 minutes</td>
<td>5 (7.81%)</td>
</tr>
<tr>
<td>Retrieval success (&lt;15 minutes and implant’s internal threads were usable following retrieval)</td>
<td>Yes</td>
<td>56 (87.5%)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>8 (12.5%)</td>
</tr>
<tr>
<td>Mean torque force at which fracture occurred</td>
<td></td>
<td>23.31±8.93</td>
</tr>
</tbody>
</table>
Table 3.1 B: Distribution of Different Screw Fracture Morphologies in Each Implant System

<table>
<thead>
<tr>
<th>Fracture morphology</th>
<th>Implant system</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal Connection (%)</td>
<td>External Connection (%)</td>
<td>Total n(%)</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>12 (37.5%)</td>
<td>9 (28.1%)</td>
<td>21 (32.8%)</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>4 (12.5%)</td>
<td>9 (28.1%)</td>
<td>13 (20.3%)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>8 (25.0%)</td>
<td>5 (15.6%)</td>
<td>13 (20.3%)</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>8 (25.0%)</td>
<td>9 (28.1%)</td>
<td>17 (26.6%)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32 (50%)</td>
<td>32 (50%)</td>
<td>64 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Association Between Retrieval Success and a Number of Independent Variables

3.2.1 Implant System and Screw Retrieval Success

Twenty-four out of the 32 fractured abutment screws were retrieved from the well of the Osseotite® Certain, dental implants representing a success rate of 75%. All of the Osseotite®, micromini external hex connection dental implants (32) were retrieved representing a success rate of 100%. Statistical analysis, identified a statistically significant association between abutment screw fragment retrieval success and implant system used ($X^2=9.143, \ p=0.002$), (Table 3.2).
Table 3.2: Association between Implant System (Internal Connection Vs. External Connection) and Abutment Screw Retrieval Success

<table>
<thead>
<tr>
<th>Implant system</th>
<th>Retrieval success</th>
<th>Total</th>
<th>Chi-square $X^2$</th>
<th>Fisher exact $p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes N (%)</td>
<td>No N (%)</td>
<td>N (%)</td>
<td></td>
</tr>
<tr>
<td>Osseotite® , Certain, dental Implants</td>
<td>24 (75%)</td>
<td>8 (25%)</td>
<td>32 (100%)</td>
<td>$X^2=9.143$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$p=0.002^*$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osseotite®, Micromini External Hex connection dental implants</td>
<td>32 (100%)</td>
<td>0 (0)</td>
<td>32 (100%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>56 (87.5%)</td>
<td>8 (12.5%)</td>
<td>64 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

$X^2=chi-square; ^*p<0.05$

3.2.2 Operators’ Experience and Screw Retrieval Success

The experienced operators managed to retrieve 26 out of the 32 fractured abutment screws (81.3%). The inexperienced operators retrieved 30 out of the 32 fractured abutment screws (93.8%). No significant association was observed ($X^2=2.286, p=0.131$). (Table 3.3)
### Table 3.3: Association between Operator Experience and Screw Retrieval Success

<table>
<thead>
<tr>
<th>Operator’s experience</th>
<th>Retrieval success</th>
<th>Total N (%)</th>
<th>Chi-square $X^2$</th>
<th>Fisher exact $p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes N (%)</td>
<td>No N (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experienced operator</td>
<td>26 (81.3%)</td>
<td>6 (18.8%)</td>
<td>$X^2= 2.286$</td>
<td>$p= 0.131$</td>
</tr>
<tr>
<td>Inexperienced operator</td>
<td>30 (93.8%)</td>
<td>2 (6.3%)</td>
<td></td>
<td>$p= 0.257$</td>
</tr>
<tr>
<td>Total</td>
<td>56 (87.5%)</td>
<td>8 (12.5%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$X^2=chi-square; \ *p<0.05$

#### 3.2.3 Retrieval Kit Type Used (Professional/Homemade) and Screw Retrieval Success

When using the homemade kit, operators successfully retrieved 27 out of the 32 fractured abutment screws (84.4%). When using the professional kit, they successfully retrieved 29 out of the 32 fractured abutment screws (90.6%). No significant association was observed ($X^2=0.571, p=0.450$). (Table 3.4)
Table 3.4: Association between Types of Retrieval Kit Used (Professional/ Homemade) and Screw Retrieval Success

<table>
<thead>
<tr>
<th>Retrieval kit</th>
<th>Retrieval success</th>
<th>Total</th>
<th>Chi-square</th>
<th>Fisher’s Exact p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes N (%)</td>
<td>No N (%)</td>
<td>N (%)</td>
<td>$X^2$</td>
</tr>
<tr>
<td>Professional</td>
<td>29 (90.6%)</td>
<td>3 (9.4%)</td>
<td>32 (100%)</td>
<td>$0.571$</td>
</tr>
<tr>
<td>Homemade</td>
<td>27 (84.4%)</td>
<td>5 (15.6%)</td>
<td>32 (100%)</td>
<td>$0.450$</td>
</tr>
<tr>
<td>Total</td>
<td>56 (87.5%)</td>
<td>8 (12.5%)</td>
<td>64 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

$X^2=chisquare; *p<0.05$

3.2.4 Implant Position in the Arch (Anterior Vs. Posterior) and Screw Retrieval Success

Twenty-nine implant abutment screws out of the 32 that were placed in the anterior part of the dental arches (lower and upper) were retrieved, represented a 90.6% success rate. Twenty-seven abutment screws out of the 32 that were placed in the posterior part of the dental arches (lower and upper) were retrieved (84.4%). No significant association was observed (Table 3.5).
Table 3.5: Association between Implant Position in the Arch (Anterior Vs. Posterior) and Screw Retrieval Success

<table>
<thead>
<tr>
<th>Retrieval success</th>
<th>Total</th>
<th>Chi-square $X^2$</th>
<th>Fisher’s Exact $p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes N (%)</td>
<td>No N (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>29 (90.6%)</td>
<td>3 (9.4%)</td>
<td>32 (100%)</td>
</tr>
<tr>
<td>Posterior</td>
<td>27 (84.4%)</td>
<td>5 (15.6%)</td>
<td>32 (100%)</td>
</tr>
<tr>
<td>Total</td>
<td>56 (87.5%)</td>
<td>8 (12.5%)</td>
<td>64 (100%)</td>
</tr>
</tbody>
</table>

$X^2$=chi-square; *$p<0.05$

3.2.5 Implant Location in the Mouth (Maxilla Vs. Mandible) and Screw Retrieval Success

Twenty-seven implant abutment screws out of the 32 that were placed in the upper arch (anterior and posterior) were retrieved representing a success rate of 84.4%. Twenty-nine abutment screws out of the 32 that were placed in the lower arch (anterior and posterior) were retrieved representing a success rate of 90.6%. No significant association was observed. (Table 3.6)
Table 3.6: Association between Implant Location in the Arch (Upper Vs. Lower) and Screw Retrieval Success

<table>
<thead>
<tr>
<th></th>
<th>Retrieval success</th>
<th>Total</th>
<th>Chi-square X²</th>
<th>Fisher’s Exact p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes N (%)</td>
<td>No N (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implant location in the arch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>27 (84.4%)</td>
<td>5 (15.6%)</td>
<td>32 (100%)</td>
<td>X²= 0.571</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p= 0.450</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p= 0.708</td>
</tr>
<tr>
<td>Lower</td>
<td>29 (90.6%)</td>
<td>3 (9.4%)</td>
<td>32 (100%)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>56 (87.5%)</td>
<td>8 (12.5%)</td>
<td>64 (100%)</td>
<td></td>
</tr>
</tbody>
</table>

X²=chi-square; *p<0.05

3.2.6 Torque Force at Which Screw Fracture Occurred and Screw Retrieval Success

Successfully retrieved abutment screws and screws that failed to be retrieved, were identified to have significantly different mean values of torque at which screw fracture occurred (t=2.202; p=0.016), (Table 3.7). Interestingly, the screws that fractured at lower torque were more difficult to retrieve. The distribution of the torque force values at which screw fracture occurred for all screws can be seen in Figure 3.1.
Table 3.7: Differences in Retrieval Success Depending on the Mean Values of Screw Fracture

<table>
<thead>
<tr>
<th></th>
<th>Retrieval success</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t-test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Torque</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td>56</td>
<td>24.21</td>
<td>(8.93)</td>
<td>2.202</td>
<td>p = 0.016*</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td>8</td>
<td>17.00</td>
<td>(6.16)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Kolmogorov-Smirnov p-value>0.05; t= t-test; *p<0.05

**Figure 3.1:** Distribution of torque force values at which screw fracture occurred.

**3.2.7 Fracture Morphology and Screw Retrieval Success**

No significant association was observed between different fracture morphologies and the success rate of fractured abutment screw retrieval ($\chi^2 = 5.092; p=0.165$). (Table 3.8)
Table 3.8: Association between Fracture Morphology and Screw Retrieval Success

<table>
<thead>
<tr>
<th>Fracture Morphology</th>
<th>Retrieval success Yes N (%)</th>
<th>Retrieval success No N (%)</th>
<th>Total N (%)</th>
<th>Chi-square $X^2$</th>
<th>Fisher’s Exact $p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>16 (76.2%)</td>
<td>5 (23.8%)</td>
<td>21 (100%)</td>
<td>$X^2= 5.092$</td>
<td>$p= 0.165$</td>
</tr>
<tr>
<td>II</td>
<td>13 (100%)</td>
<td>0 (0)</td>
<td>13 (100%)</td>
<td>$X^2= 4.477$</td>
<td>$p= 0.184$</td>
</tr>
<tr>
<td>III</td>
<td>11 (84.6%)</td>
<td>2 (15.4%)</td>
<td>13 (100%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>16 (94.1%)</td>
<td>1 (5.9%)</td>
<td>17 (100%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>56 (87.5%)</td>
<td>8 (12.5%)</td>
<td>64 (100%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$X^2$=chi-square; *p<0.05

3.3 Retrieval Time

3.3.1 Implant System and Time Taken for Screw Retrieval

To successfully retrieve (<15 minutes) the abutment screws, it took a mean time of 2.84 ± 2.66 minutes for all implants. (Internal connection 4.16 ± 3.13 min; External connection 1.85 ± 1.72). The difference in time taken for successful screw retrieval between the two implant systems was statistically significant ($p<0.001$). (Table 3.9)
Table 3.9: Differences in Mean Time Taken for Screw Retrieval between the Two Implant Systems Used

<table>
<thead>
<tr>
<th>Implant system</th>
<th>N</th>
<th>Time spent-Retrieval success</th>
<th>Mann-Whitney U test</th>
<th>p- value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± (SD) - Min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Osseotite® Certain, dental Implants (n= 24)</td>
<td>(n=24)</td>
<td>4.16 ± (3.13)</td>
<td>U= 3.386</td>
<td>p &lt;0.001 =0.0005</td>
</tr>
<tr>
<td>Osseotite®, Micromini External Hex connection dental implants (n=32)</td>
<td>(n=32)</td>
<td>1.85 ± (1.72)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (n=56)</td>
<td>(n=56)</td>
<td>2.84 ± (2.66)</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

Kolmogorov-Smirnov p-value<0.05 - Mann-Whitney test

The highest number of screws (n=20) were retrieved in less than 1 minute, with the majority retrieved in less than 2 minutes (Figure 3.2).
Figure 3.2: The graph represents the histogram for the time taken for screw retrieval (total) (Kolmogorov-Smirnov \( p < 0.001 \)).

Box plot of the distribution of fractured screws from each implant system (internal connection vs. external hexagonal connection) based on retrieval time in minutes is presented in Figure 3.3.

Figure 3.3: Box plot distribution of screws retrieval time (min) for the two implant systems used
### 3.3.2 Operator’s Experience and Time Taken for Screw Retrieval

The experienced operators retrieved 26 fractured implant abutment screws in a mean time of $2.88 \pm (3.16)$ minutes, while the less experienced operators retrieved 30 fractured screws in a mean time of $2.80 \pm (2.21)$ minutes. There was no statistically significant difference between the two groups $p= 0.455$. (Table 3.10).

#### Table 3.10: Differences in Mean Time Taken to Retrieve the Fractured Abutment Screws between Operators with Different Levels of Experience

<table>
<thead>
<tr>
<th>Operator’s experience</th>
<th>N</th>
<th>Time spent-Retrieval success Mean ± (SD) - Min</th>
<th>Mann-Whitney U test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experienced operator</td>
<td>(n= 26)</td>
<td>$2.88 \pm (3.16)$</td>
<td>U = - 0.756</td>
<td>$p=0.455$</td>
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<tr>
<td>Inexperienced operator</td>
<td>(n=30)</td>
<td>$2.80 \pm (2.21)$</td>
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<td>Total</td>
<td>(n=56)</td>
<td>$2.84 \pm (2.66)$</td>
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</table>

Kolmogorov-Smirnov $p$-value<0.05 - Mann-Whitney test
3.3.3 Retrieval Kit (Homemade + Professional) and Time Taken for Screw Retrieval

The mean screw retrieval time when the home-made kit was used was 

\[(2.36 \pm 1.87)\] minutes, while the mean screw retrieval time when the professional kit was used was \[(3.29 \pm 3.21)\] minutes. The difference between the two groups was not statistically significant \((p=0.422)\)

Table 3.11: Differences in Time Taken to Retrieve the Fractured Abutment Screws between the Two Retrieval Kits Used

<table>
<thead>
<tr>
<th>Retrieval kit</th>
<th>N</th>
<th>Time spent- Retrieval success</th>
<th>Mann-Whitney U test</th>
<th>p- value</th>
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</thead>
<tbody>
<tr>
<td>Professional</td>
<td>(n= 29)</td>
<td>3.29 ± (3.21)</td>
<td>U= 0.812</td>
<td>p=0.422</td>
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<tr>
<td>Homemade</td>
<td>(n=27)</td>
<td>2.36 ± (1.87)</td>
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<tr>
<td>Total</td>
<td>(n=56)</td>
<td>2.84 ± (2.66)</td>
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Kolmogorov-Smirnov \(p\)-value<0.05 - Mann-Whitney test

3.3.4 Implant Position in the Arch (Anterior Vs. Posterior) and Time Taken for Screw Retrieval

Implants located in the arch's anterior segment (1.2, 2.2, 4.2, and 3.2 sites) registered a mean screw retrieval time of \[(3.27 \pm 2.94)\] minutes. Implants embedded in the posterior segment of the arch (1.6, 2.6, 4.6, and 3.6 sites)
registered a mean screw retrieval time of \((2.38 \pm 2.30)\) minutes. The difference between the two groups was not statistically significant \(p=0.359\).

Table 3.12: Differences in Time Taken to Retrieve the Fractured Abutment Screws from Implants Placed in two Different Positions within a Dental Arch (Anterior – Posterior)

<table>
<thead>
<tr>
<th>Implant position in the arch</th>
<th>N</th>
<th>Time spent-Retrieval success Mean ± (SD) - Min</th>
<th>Mann-Whitney U test</th>
<th>(p)- value</th>
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<tr>
<td>Anterior (n= 29)</td>
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<td>3.27 ± (2.94)</td>
<td>U= 0.927</td>
<td>(p=0.359)</td>
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<tr>
<td>Posterior (n=27)</td>
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<td>2.38 ± (2.30)</td>
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<tr>
<td>Total (n=56)</td>
<td></td>
<td>2.84 ± (2.66)</td>
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</table>

\(p\)-value<0.05 - Mann-Whitney test

3.3.5 Implant Location in the Mouth (Maxilla/Mandible) and Time Taken for Screw Retrieval

The mean screw retrieval time for implants located in the maxilla was \((2.94 \pm 2.59)\) minutes, and the mean screw retrieval time for implants located in the mandible was \((2.74 \pm 2.78)\) minutes. The difference between the two groups was not statically significant \(p=0.385\). (Table 3.13).
Table 3.13: Differences in Time Taken to Retrieve the Fractured Abutment Screws from Implants Placed in two Different Areas of the Mouth (Maxilla – Mandible)

<table>
<thead>
<tr>
<th>Implant location in the arch</th>
<th>N</th>
<th>Time spent-Retrieval success</th>
<th>Mann-Whitney U test</th>
<th>p-value</th>
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<tr>
<td></td>
<td></td>
<td>Mean ± (SD)</td>
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<td>- Min</td>
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<tr>
<td>Maxilla</td>
<td>(n= 27)</td>
<td>2.94 ± (2.59)</td>
<td>U=0.877</td>
<td>p=0.385</td>
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<tr>
<td>Mandible</td>
<td>(n=29)</td>
<td>2.74 ± (2.78)</td>
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<tr>
<td>Total</td>
<td>(n=56)</td>
<td>2.84 ± (2.66)</td>
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Kolmogorov-Smirnov p-value<0.05 - Mann-Whitney test

3.3.6 Screw Fracture Morphology and Time Taken for Screw Retrieval

The mean time taken to retrieve the 16 screws with fracture morphology type I was (3.00 ± 2.09) minutes, (1.89 ± 1.32) minutes for the 13 screws with morphology type II, (2.53 ± 3.25) for the 11 screws with morphology type III, and finally (3.67 ± 3.41) minutes for the remaining 16 screws with morphology type IV. The differences in the mean values between these four groups were not statistically significant p=0.268. (Table 3.14). A box plot demonstrating the distribution of retrieval time (minutes) for screws with different fracture morphologies can be seen in Figure 3.4.
### Table 3.14: Differences in Time Taken to Retrieve the Fractured Abutment Screws with Different Fracture Morphologies

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<th>p-value</th>
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<td>I</td>
<td>(n=16)</td>
<td>3.00 ± (2.09)</td>
<td>H= 3.936</td>
<td>p=0.268</td>
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<td>II</td>
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<td>IV</td>
<td>(n=16)</td>
<td>3.67 ± (3.41)</td>
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<td>Total</td>
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<td>2.84 ± (2.66)</td>
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Kolmogorov-Smirnov p-value<0.05 – Kruskal Wallis test
**Figure 3.4:** Distribution of retrieval time (minutes) for screws with different fracture morphologies (I-IV)

### 3.3.7 Torque Force at Which Screw Fracture Occurred and Time Spent for Screw Retrieval Success

A Pearson correlation plot was used to investigate a possible correlation between the two continuous variables (time and torque). The outcome shows a negative weak correlation between torque force (N.cm) and time spent for the retrieval of the fractured abutment screws correlation coefficient $(r) = -0.274$ ($p=0.041*$).
Figure 3.5: Pearson correlation plot between Torque force and time taken for screw retrieval success
CHAPTER 4
DISCUSSION AND CONCLUSION
4.1 Discussion

The main aim of the *in-vitro* study herein was to compare the efficacy of a commercially available abutment screw retrieval kit with this of a homemade kit. There was an attempt to remove 64 screw fragments, 32 internal connection and 32 external connection Zimmer Biomet dental implants. The possible effect of a number of confounding factors on the retrieval of these fragments was also analysed. Based on the results the standard dental instruments (homemade screw retrieval kit) were equally efficacious with the commercially available screw fragment retrieval kit in removing abutment screw fragments from these two types of implants.

When an implant abutment screw fractures within the well of the dental implant and no damage occurs to the internal threads, it loses preload and is usually retained passively within the screw channel. Although not evidenced in our results, it is possible that when the fracture occurs, the morphology of the coronal aspect of the screw will dictate the ease by which dental instruments can engage and ultimately rotate the fragment in an anticlockwise direction (Mizumoto et al., 2018). As reported by a number of earlier publications, abutment screw fracture usually occurs within the screw body at the level of the first/second thread. Therefore, the abutment screws in this study were weakened at this level using a diamond disk (Quek et al., 2006, Katsavochristou and Koumoulis, 2019). After weakening the screws, a static load was applied using a calibrated torque wrench with the intention to fracture the screws but without causing any deformation to the internal threads of the screw channel. In order to achieve this, the values at which the screw fractured were recorded in order to make sure that they fractured within a range that didn’t exceed the yield strength of the titanium (Sprenger et al., 2018). Occasionally debris from the fractured screw can be displaced to the periphery of the well and impede the free rotation of the fragment and this could explain how the screws that fractured at lower torque were more difficult to retrieve.
Over the years, a number of clinical reports have been published, presenting a plethora of different techniques for the management of fractured abutment screws. Despite this abundance of case reports, these very common complications are still managed empirically and no consensus on a standardized management protocol exists.

Previous in-vitro studies investigating the relative efficacy of standard dental instruments and professional retrieval kits have provided conflicting results (Agustín-Panadero et al., 2017, Agustín-Panadero et al., 2020). In both the above-mentioned studies, the dental implants specimens used pristine abutment screws which underwent cyclic loading prior to fracturing the screw by applying a static load of 5000 N. Because of the high static load applied, this technique has the potential to result in the deformation of the threads of the dental implants and the abutment screws. Additionally, weakening of the screws using cyclic loading results in screws fracturing at varying levels. Although, this pattern of loading might represent the clinical situation in a more accurate way, it is not possible to standardize the damage caused and the depth at which it happens. This variability makes comparisons between different retrieval methods difficult.

The design of the two screw types used in this study was different. The Osseotite® Certain Gold-Tite Screw, internal connection, has a long-polished screw shank, and its apical portion has only six threads. The Osseotite® external hexagon screw, on the other hand, has threads all the way to the screw head, so following fracture, the depth of the fragments differed between the two implants groups. Agustín-Panadero et al. (2017) reported that the depth of screw fragments within the implants did not have an effect on the efficacy of screw fragment retrieval.

The internal connection abutment screw had a narrower diameter of 1.5 mm compared to the external connection abutment screw of 1.95 mm. The professional kit used in our study was selected because the claws and drills
included in the kit were dimensionally suitable to access the screw fragments within both dental implant systems investigated. With a diameter of 1.05 mm, the claw was the most suitable commercially available tool for engaging the Certain® Gold-Tite Screw. In a recent study by Agustín-Panadero et al. (2020), it was reported that successful retrieval of screw fragments was not dependent on screw morphology which is not in agreement with our study. This could be explained by the fact that in their study, although the morphology was different, the diameter of the screws used was similar. This was not the case in our study where both the morphology and diameter were different.

The study herein also highlighted that the level of the experience of the operators, had no effect on their ability to successfully retrieve the fractured abutment screws and neither had an effect on the time that took for them to be retrieved. This result is in agreement with the Agustín-Panadero et al. (2020) study.

One could speculate that successful retrieval of abutment screw fragments is also dependent on visibility and access. Our results failed to confirm the above speculation as the location of the dental implant specimens within the upper and lower arches, or the anterior vs. posterior position was shown not to have an effect on the success of retrieval or the time taken to retrieve the screw fragments. The majority of similar in-vitro studies were conducted on a lab bench surface which does not effectively replicate the clinical scenario (Agustín-Panadero et al., 2017, Agustín-Panadero et al., 2020).

Although efforts were made to simulate the clinical situation, the lack of the peri-implant mucosa, saliva, and neighbouring teeth made the conditions less challenging during retrieval attempts. Another limitation of this study is that it wasn’t possible to blind the operators regarding the retrieval kits that they were using during the removal exercise.
For any abutment screw with a diameter smaller than 1.6 mm, there is a limited amount of instruments which can predictably remove the broken fragments without damaging the internal threads of the implant. Additionally, existing universal kits do not often have drills suitable for use with small diameter abutment screws. When routinely using an implant system which uses small diameter screws it might be prudent for the clinician involved to select (if available) retrieval kits designed specifically for the implant system in question. In the majority of cases though these “specially designed kits” only include a very thin claw.

4.2 Conclusions

No differences were observed in the efficacy between the universal screw retrieval kit and the homemade screw retrieval kit. When there is no significant deformation of the screw/implant threads, the vast majority of fractured abutment screws can be removed even by relatively inexperienced clinicians using instruments already present in their dental practice.

There seems to be an association between the type of implant/abutment screw and the ability of the operators to successfully remove the broken screw fragments. Additionally, a statistically significant association was observed between the type of implant/abutment screw and the time it took the operators to successfully remove the broken screw fragments.

When trying to retrieve screw fragments from the internal well of dental implants, it is important to have good access and be able to see clearly the anatomy of the broken fragment. This way, the operator can select the most appropriate instrument for the task at hand. If no movement can be observed within the first 15-30 minutes, the chance of removing the broken fragment decreases exponentially.
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the incidence of biological, technical, and aesthetic complications
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single-tooth external-hexagon implant system: clinical and


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APPENDICES
Appendix I: Certificate of Calibration

Certificate of Calibration

Issued to: Dublin Dental University Hospital
Lincoln Place
Dublin 2

Attention of: Advan Moorthy

Certificate Number: 190925
Item Calibrated: Torque Meter
Serial Number: 0398171
Client ID Number: N/A
Manufacturer: Treharne
Model: 6BTCN
Range: 0-60 cN.m
Resolution: 1 cN.m
Units: cN.m
Order Number: Advan Moorthy
Date Received: 13 Mar 2019
NM Procedure Number: DAP-NM-34

Calibration Standards: Transducer & Display, ID No.: 0708, Due Date: 21 Jul 2019

Calibrated by: Graham Thomas
Approved by: Paul Hetherington
Date of Calibration: 20 Mar 2019
Date of Issue: 12 Mar 2019
Appendix II: Sample Flow Chart (page 1 of 3)
### Appendix II: Sample Flow Chart (page 2 of 3)

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