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Prosthetic and dental complications of hybrid double-crown retained removable partial dentures in severely reduced dentition

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To my beloved family

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List of abbreviations

CAD/CAM	Computer-aided designing /Computer-aided manufacturing
CRF	Case Report Form
DMS	Deutsche Mundgesundheitsstudie
DC-RPDs	Double Crown retained Removable Partial Dentures
FDI	Federation Dentaire Internationale
FDPs	Fixed Dental Prostheses
HDC-RPDs	Hybrid Double Crown retained Removable Partial Dentures
OHIP	Oral Health Impact Profile
PEEK	Polyether Ether Ketone
PBI	Papilla Bleeding Index
PI	Plaque Index
RPDs	Removable Partial Dentures
SD	Standard deviation
TTE	Time-to-event

1 Introduction

1.1 Preface

Population aging is a reality. Worldwide, one ninth of the population is more than 60 years old. This fraction is predicted to be one fifth by 2050 (Guzman, 2012). By that date, 30% of the German population will be at least 65 years old (Eisenmenger et al., 2006, Müller-Koelbl, 2019). Depending on the extent of the assumed net immigration, the population of Germany, estimated at 80.8 million people in 2013, was expected to increase for another 5 to 7 years and then decrease. It is not expected to drop below the level of 2013 until 2023 at the earliest. Depending on the immigration rate, the population will be between 67.6 million and 73.1 million in 2060 (Grünheid and Sulak, 2016). Accordingly, the number of people aged 65 or over will continue to rise. This age group will grow particularly rapidly in the next 20 years as baby boomers reach the age of 65. In 2060, the number of people in Germany aged 65 or over is projected to be 22 to 23 million. While approximately one in five people in Germany currently belongs to this age group (21% in 2013), approximately one in three people (33%) is expected to do so in 2060 (Grünheid and Sulak, 2016).

According to the DMS V (Jordan et al., 2014), a population can be divided age-wise into the following four groups:

- Children (up to 12 years old)
- Young adults (35–44 years old)
- Young seniors (65–74 years old)
- Old seniors (75–100 years old).

Because of the continuous improvement in dental prophylaxis and oral health education, the number of patients with remaining natural teeth in old age is increasing. Younger seniors are keeping their teeth longer, and there are greater opportunities for the fabrication of fixed dental prostheses (FDPs). Nevertheless, because removable partial dentures (RPDs) are still essential and are frequently used as a therapeutic option, they are expected to continue to play a role in patients' care in the future. More and more younger seniors (65 to 74 years old) are keeping their teeth. In 1997 (DMS III), one in four younger seniors was edentulous (24.8%); today, only one in eight is (12.4%) (Jordan AR et al., 2016).

Tooth loss influences the function of the stomatognathic system. It is crucial to restore the ability to chew with good dentures to prevent functional disorders. Therefore, dentures represent a form of tertiary prevention to maintain oral health (Hegde, 2021). Approximately 50% of adults in Western societies have had some type of prosthetic dental restoration, and between 13% and 29% of adults have removable dental prostheses (Jordan et al., 2014). Despite the success of prophylactic measures and therapy with dental implants, RPDs are still a treatment option, especially for older patients (Rehmann et al., 2006). The rate of edentulism in the elderly population has decreased, but the actual number of edentulous individuals has increased because of population growth (Hummel S, 2002). The goal of prosthetic rehabilitation is to maintain and restore the masticatory system, and the remaining teeth have to meet the increasing demands of patients from both functional and esthetic points of view (Jüde et al., 2002).

Many therapeutic alternatives for the treatment of edentulous situations exist that differ in terms of comfort, aesthetics, invasiveness, and associated costs (Kern et al., 2011). The number, situation, and distribution of abutments, as well as the patient's compliance and financial ability, dictate the means of restoration to be used, i.e., fixed, removable, or combined fixed–removable restoration. The inserted dentures should not have any negative impact on the stomatognathic system (Bergman et al., 1977). Studies have shown that new telescopic dentures achieve significant improvements in appearance, comfort, and the quality of food intake (Kothe et al., 2003). In cases of severe ridge defects in esthetic areas, RPDs offer some hygienic and esthetic advantages over FDPs. In addition, abutments that are compromised in terms of prognosis can be implemented in the fabrication of RDPs (Kern et al., 2011).

RPDs serve three functions, namely, support, retention, and stability. Support is defined as resistance to forces directed toward the basal tissue or underlying structures. Retention is defined as resistance to forces that would dislodge prostheses along the path of placement. Stability is defined as resistance to horizontal displacement of prostheses (Driscoll et al., 2017). RPDs can be affixed to dentition in various ways, the simplest of which employs either wrought or cast wire clasps. More complex retentive elements involve precision attachment or double crown systems (Freesmeyer, 1987). The use of double crowns in the construction of removable prostheses reduces destructive horizontal and rotational forces against abutment teeth by directing the forces more axially, which reduces trauma to periodontal tissues (Langer, 1980). They have also been approved for clinical treatment of reduced residual dentition because they combine the advantages of fixed and removable partial dentures (Zahn et al., 2016). In Germany, there was no decline in the choice of hybrid double crown removable partial dentures (HD-RPDs) as a treatment option between 2006 and 2020. According to an analysis by the Federal Association of Dental Health Insurers, the proportion of charged cases in 2019 was 7 per 100, which represents a 6.1% increase over the proportion (6.6 per 100) in 2006 (KZBV, 2020).

Dentition with fewer than four teeth per jaw is defined as severely reduced dentition(Szentpétery and Setz, 2015). RPDs or overdentures retained by double crowns are a well-accepted treatment option for prosthetic rehabilitation of patients with severely compromised dentition (Rinke et al., 2015). RPDs are an acceptable and economical treatment modality for patients with reduced dentition (Wagner and Kern, 2000). It has also been reported that frictional telescopic crowns can be a favorable treatment option in cases of severely reduced dentition with regard to the distribution of abutment teeth, sex, age, and jaw and tooth vitality (Szentpetery et al., 2012).

1.2 Severely reduced dentition

Niedermeier defined severely reduced dentition as dentition with less than or maximally four teeth in the jaw (Niedermeier, 1988). Such dentitions are characterized by compromised periodontal status, massive carious lesions, worn teeth, and/or unfavorable positions in the jaw, all of which adversely affect the biomechanical principles of prosthesis planning (Öwall et al., 1995). Furthermore, the distribution of the teeth in the jaw is often unfavorable from a static perspective; consequently, the support polygon is usually missing, and the support line runs across the base of the prostheses (Körper, 1980). Inadequate prosthetic rehabilitation leads to increased bone loss, which leads to changes in the ratio of the lever arms in relation to the crown/root ratio. The lever arm at the crown level becomes longer than the radicular resistance arm; therefore, the load-bearing capacity of the tooth in the horizontal direction becomes more critical. As a result, tooth mobility is higher because of the increased probability of pocket formation, alveolar bone loss, and inflammation of the marginal gingiva (Dolder and Wirz, 1982).

From a prosthetic point of view, preserving teeth in the remaining dentition is crucial and essential. Therefore, the functional load on the roots plays a vital role in hindering the resorption of the alveolar bone (Jung, 1989). For long-term treatment success, the prostheses must have little or no impact on the prosthesis-bearing tissues (Ludwig, 1983).

1.3 Classification of partial edentulism

Several classifications of partial edentulism are presented in the literature. One of the most critical and practical classifications, which can be used to classify severely reduced dentitions, was proposed by Steffel in 1962 (Steffel, 1962). This system classifies edentulous situations according to their support options. It is based on the number of remaining teeth in the jaw, the prosthesis's support, and the stability of the dentures, according to the prosthesis's kinematics. This classification system is illustrated in Figure 1.

1. Class A describes punctual support on a single remaining tooth. When chewing, load is applied on several sides, leading to rotation of the prosthesis.
2. Class B describes two remaining teeth with linear sagittal support. When chewing, these teeth are loaded against the opposite side.
3. Class C describes linear–transversal support on two teeth.
4. Class D describes linear–diagonal support on two teeth.
5. Class E describes triangular support on three teeth. The distribution of the three teeth in the jaw results in trigonal support. When the load is placed outside the support field, there are rotations about the resulting axes of rotation of the prostheses.
6. Class F describes quadrangular support on four teeth, which results in a more stable support polygon.

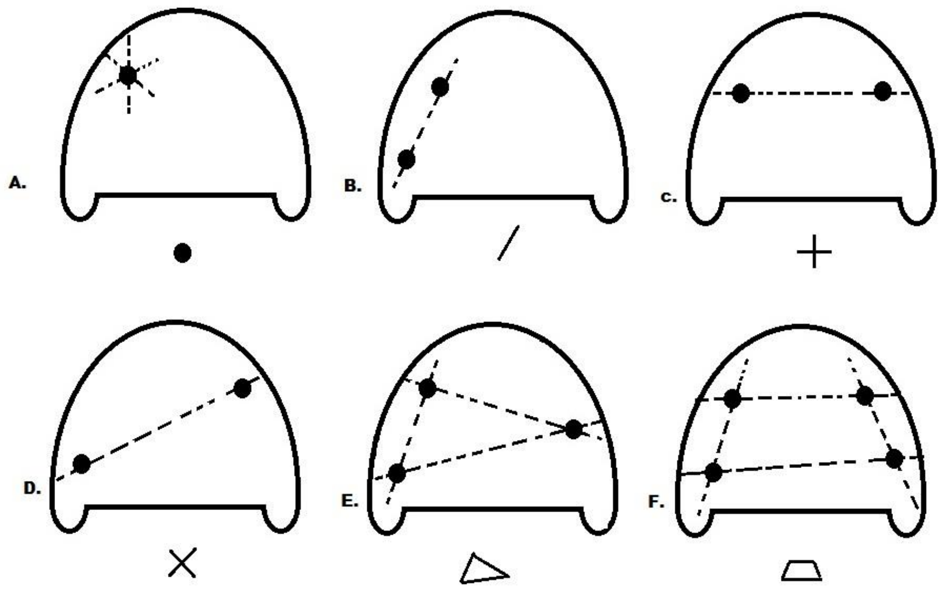

Figure 1 Illustration of Steffel's classification system. There are six categories used for reduced dentition, starting with one remaining tooth (upper left), designated as "single anchorage with punctual support." Support over two abutments sagittally (upper middle) represents a linear and sagittal support line, whereas two points of horizontal support represent transversal support lines (upper right). Two points of non-parallel support lines on each side of the jaw represent diagonal support (lower left). Three points of support distributed over the opposite sides of the jaw illustrate the triangular form of support (lower middle). Support over four well-distributed points on both jaw sides is called quadrangular support (lower right).

This illustration was drawn by the author to represent the original description by Steffel (Steffel, 1962).

1.4 Double crown systems

The concept of double crowns retained with removable partial dentures is not new in dentistry; it has been known for over a century. This concept is based on the accurate fit of two crowns over each other. The first crown is called the primary crown, inner crown, or patrix, which is cemented to the abutment. The second crown, which is attached to the framework, is called the secondary crown, outer crown, or matrix, and is seated over the primary one. Since the 1950s, there has been a steady increase in the development and implementation of double crown-retained removable partial dentures with various types of retentive elements in the construction of RPDs (Wenz and Kern, 2007).

In the literature, double crown-retained RPDs are usually described as telescopic dentures or telescopic prostheses. They are a standard therapeutic option in German-speaking countries (Schwindling, 2015) as well as in others, such as Sweden, Japan, and India (Hulten et al., 1993) (Saito et al., 2003) (Verma et al., 2019).

Double crowns are divided into the following main groups in terms of the form of construction: cylindrical telescopes, conical and resilient telescopes, ovoid telescopes, and undefined telescopes. Double crowns also differ in the type of retentive mechanism created between the primary and secondary crowns. The types of adhesion include friction with parallel-walled cylinder telescopes, wedging with conical telescopes, and additional retentive elements such as friction pins or TK-Snap®. Depending on the type of coverage, double crowns are also classified as either full or partial telescopes, as illustrated in Figure 2 (Strub JR et al., 2011).

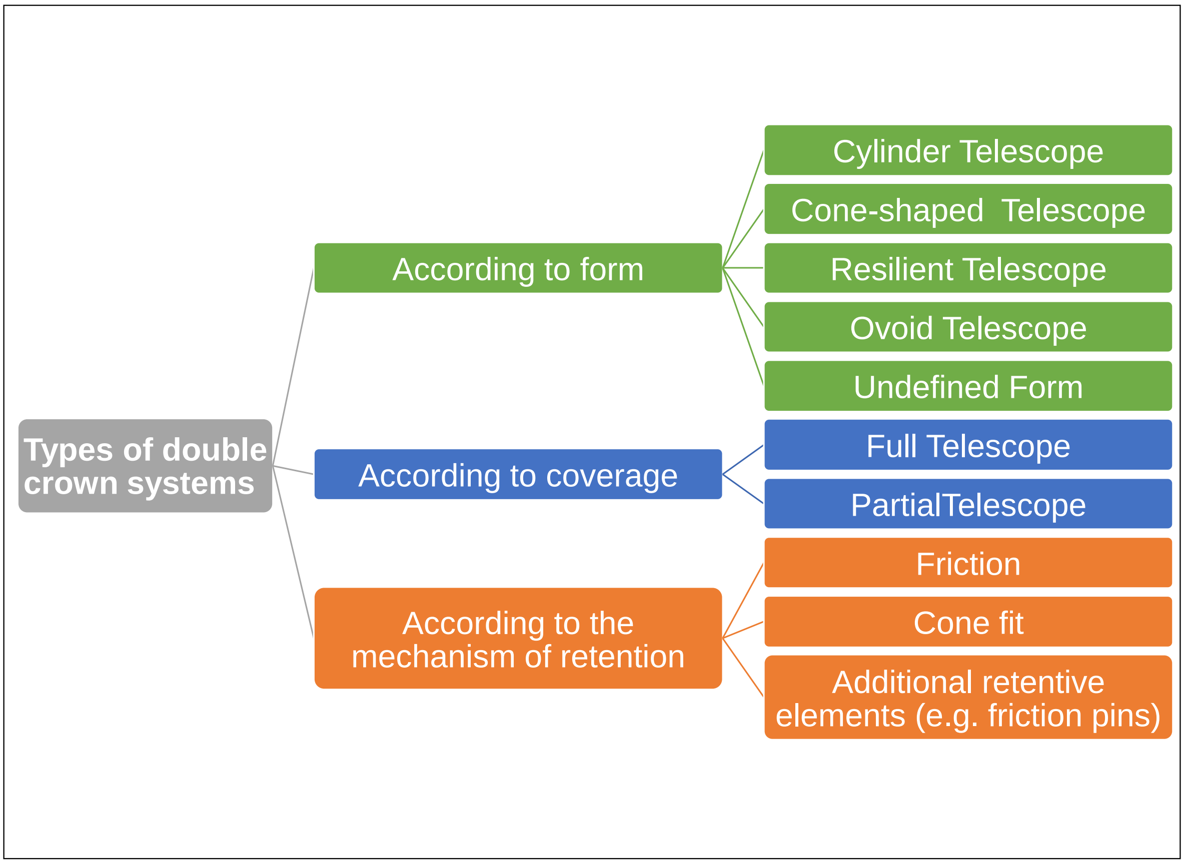

Figure 2 Systematic classification of double crown systems (Strub JR et al., 2011). Double crowns can be classified according to their form of fabrication (upper part), their type of coverage (middle part), or the mechanisms of retention used (lower part).

1.5 Development of double crown systems in prosthodontics

Double crown systems were invented in the US, and the technology was developed further in Europe. In 1886, R. Walter Starr, a dentist from Philadelphia, was the first to describe a cylindrical ring band coping that was cemented onto a prepared tooth, with a secondary part serving as an anchor to support and retain a removable bridge (Wenz and Kern, 2007). Gaslee and Peeso described this in 1924 and used it as a telescopic system for supporting removable and fixed dental prostheses (Peeso, 1924). In 1929, the term “telescopic crown” came into use in Europe, especially in German-speaking countries (Häupl et al., 1929). At that time, gold was specified as the material of choice for the inner crowns, which were to be fabricated in as close to parallel an alignment as possible. Häupl’s students Rehm and Böttger conducted numerous clinical applications of the double crown technique in developing it as an alternative to conventional clasp-retained RPDs (Häupl et al., 1929). Parallel-walled cylindrical telescopic crowns, named after Böttger (Böttger, 1973), are still in use.

In 1966, Hofmann presented resilience telescopes and recommended their use in place of cylinder telescopes, especially in severely reduced dentition cases (Hofmann, 1966). Körber developed and described conical crowns in 1968. The principle underlying their use is that tapered crowns in place of parallel ones compensate for the disadvantages of cylindrical telescopes (Körber, 1968). The main disadvantage of those techniques was the high cost of gold alloys. This led to the introduction and development of new generations of double crowns, which can be made using base metal alloys with additional retentive elements. Since 1980, Lehmann has been working on the further development of this double crown type. In 1988, the “Marburg double crown” was first described (Lehmann KM and Gente, 1988). At this time, a spring bolt system (Iposclip®) was still used as a retaining element. This system later became the TK-Snap® insert (Lehmann, 1999). The spark erosion technique was introduced to dentistry by Rübeling and Kreylos. This technology allows the use of friction pins as additional retentive elements to retain double crowns made with base metal alloys (Weber, 1989 , Weber H and Frank, 1993, Weber and Frank, 1993).

With the tremendous development of technologies and dental material research, new materials and technologies have been introduced into the dental world. Thanks to computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies, a new range of materials can be implemented to fabricate double crown systems. Specifically, precision milling of primary and secondary crowns can be easily applied using materials such as high-strength resins, e.g., polyether ether ketone (PEEK), zirconia (ZrO_2), and titanium (Stock et al., 2016, Wagner et al., 2018, Schimmel et al., 2021)

1.6 Indications for double crown systems

Double crown-retained RPDs can be implemented in various cases of partial edentulism. They are mainly indicated in cases of severely reduced dentition and can even be used with unfavorable abutment distribution (Szentpétery and Setz, 2015, Szentpetery et al., 2012, Pospiech, 2001). Their support can be either purely dental or dental–gingival partial dentures (Mack, 1983). Their implementation is highly dependent on the nature of the marginal periodontium, the relationship of the clinical crown to the root, the opposing dentition, the vitality, and the topographical distribution of the abutment tooth (Frank, 1968).

1.7 Advantages of double crown systems

In addition to being a universal treatment option, double crown-retained RPDs serve the following functions of removable partial dentures: support, retention, stability, and guidance (Szentpétery and Setz, 2015). Because of their good physical structure and axial load on the abutment teeth; they can be physiologically loaded and simultaneously maintain an excellent tight fit (Pospiech 2015). Most periodontal fibers are subjected to tensile stress, which can cause consolidation of loosened abutment teeth (Gernet W et al., 2017).

They also have an esthetic advantage in that no clasps are visible. Their physical shape and the resulting physiological stress on the abutment teeth can be considered advantageous over other types of removable partial dentures (Szentpétery and Setz, 2015).

Daily oral and prosthetic hygiene are more manageable, thanks to the removability of the prostheses. No special cleaning aids, such as interdental brushes, are necessary to clean the primary crowns; a regular toothbrush is sufficient to clean the abutment and the removable part of the prosthesis. Another significant advantage is the expandability of the prosthesis in the event that one of the abutment teeth has to be extracted. This is considered to be an economic advantage for the patient (Kern et al., 2011, Szentpétery and Setz, 2015).

1.8 Disadvantages of double crown systems

Despite the numerous advantages mentioned, there are also some disadvantages to telescopic prostheses.

One of the main disadvantages of this treatment modality is invasiveness during abutment preparation, wherein so much dental hard structure is lost. In addition, this complex treatment approach necessitates multiple treatment visits, which results in both higher fee costs and higher laboratory costs. Another major disadvantage of double crowns is the unavoidable over-contouring of the abutment teeth and associated unsatisfactory esthetic results. Additionally, the metallic edge of the primary crowns is visible on the cervical abutment teeth, which can lead to esthetic restrictions, especially in the anterior region with a cervical smile. Furthermore, the fact that the entire denture can be removed can cause psychological stress for the patient, as the metallic view of the primary crowns can be uncomfortable for others (Strub JR et al., 2011, Gernet W et al., 2017). For older patients in particular, age-related handicaps must be included in the planning. For example, decreasing mental abilities and manual dexterity and increasingly restricted vision and mobility have negative effects on oral hygiene and follow-up treatments (Weigl et al., 2000).

1.9 Survival rate evaluation

Numerous retrospective and prospective studies have been carried out on the various types of double crown-retained removable partial dentures. Such studies have typically examined the survival rates of both the prostheses and the abutment teeth, as well as associated complications and required repair measures. The rational need for such studies can be viewed from different perspectives. On the one hand, the patient needs to understand the treatment consequences and the related costs and time involved. On the other hand, the dentist needs to predict failures and complications that might arise during or after the treatment, as well as the medicolegal issues associated with the offering and selection of what is seen as the best treatment option.

1.9.1 Survival rates of double crown-retained removable partial dentures

Some studies have been conducted to compare the survival rates of different double crown systems. Behr et al. (2009) examined 200 telescopic prostheses, 62 conical prostheses, and 315 resilient double crowns and calculated 10-year survival probabilities of 98.8% for telescopic prostheses, 92.9% for conical crowns, and 86.6% for resilient ones (Behr et al., 2009).

Another clinical study evaluated the survival rates of 117 double crown-retained RPDs, including 32 telescopic prostheses, 51 conical prostheses, and 34 resilient prostheses. The overall survival rate was 93.8% after seven years. Interestingly, there was a significant difference in survival between the different types of double crown prostheses. The parallel-walled telescopic prostheses had a 90% survival rate after seven years, whereas the cone and resilient prostheses had a survival rate of 78.5%. (Schwindling et al., 2014). A pilot study published by Szentpétery in 2005 on the long-term effectiveness of double crowns in cases of severely reduced residual dentition was later continued as a prospective study. The results were published in 2015. A total of 74 patients were treated with 82 partial dentures anchored via friction telescopes. The probability of survival was determined using the Kaplan–Meier method and was 90.9 ± 7.2% after five years and 82.6 ± 17% after ten years for the prostheses. Hinz, in his doctoral dissertation, reported an 88% survival rate after five years for hybrid double crown prostheses made with base metal alloys (Hinz, 2018).

According to Rinke et al. (2019), the survival rate of conical crown-retained removable partial dentures was approximately two thirds of that for delivered prostheses after five years and just 38% after eight years (Rinke et al., 2019). A newer publication addressed the long-term survival rates of the abutments and the Marburg hybrid double system. They assessed 559 patients treated with 759 double crown-retained removable partial dentures over 2,145 abutment teeth. They reported a long-term survival rate of the prostheses of 88% after five years. This rate dropped to 64% after 10 years and just 15% after 20 years (Weber et al., 2021).

1.9.2 Survival rates of the abutment teeth

Mock et al. carried out one of the few prospective studies of parallel-walled telescopic prostheses (Mock FR et al., 2005). As part of their investigation, they examined 92 patients who were provided with 105 prostheses supported on 299 abutment teeth. The mean observation time was 7.4 years, and the probability of survival for abutment teeth was 86.3% after five years and 72.4% after ten years.

An overall survival rate of 91.2% for abutment teeth was calculated in a retrospective study of 117 double crown prostheses over 385 abutment teeth (Dittmann and Rammelsberg, 2008). Of the prostheses examined, 44% were conical, 27% were telescopic, and 29% were resilient. Posterior abutment teeth showed a higher risk of loss (13.6%) than anterior teeth (5.3%). Another significant factor in the survival rate is the endodontic condition of the abutment teeth. Vital abutments had a 90% probability of survival after 7.3 years, while endodontically treated abutments had a 90% probability of survival after 4.7 years. Based on an examination of 74 patients with 82 prostheses and 173 abutments in severely reduced dentition, the survival rate after five years was 80.6% (Szentpetery et al., 2012). In an assessment of the survival rate of 2,145 abutment teeth supporting 759 double crown-retained prostheses in 559 patients, the abutment survival probability was found to be 92% after five years and 80% after ten years (Weber et al., 2021). The probability of survival of the abutment teeth was 90.4 ± 5.2% after five years and 79.3 ± 10.2% after ten years. A Cox regression was calculated for the abutment teeth and prostheses (Hinz, 2018).

1.10 Complications

To better evaluate the success and survival of prosthetic restorations, the frequency and timing of the occurrence of possible biological and prosthetic complications must be considered as they play a significant role in the planning of any oral rehabilitation measures. Numerous researchers have examined the types of complications and the frequency of repair measures carried out on such prostheses and/or the abutment teeth. Complications may be classified as minor or major, depending on their nature (Rammelsberg et al., 2014)

1.10.1 Dental complications

In a study conducted in Sweden (Bergman et al., 1996), 18 conical crown-retained RPDs over 71 abutment teeth and 18 dentures were studied over a period of 73 to 93 months. A yearly increase of 2.3–2.9% in dental caries was recorded, with 87.5% of this occurring marginally. In addition, 25 re-cementation measures for 13 abutment teeth took place for eight patients. Stark and Schrenker (1998) examined 68 patients who received telescopic prostheses over a period of six years and found that the re-cementation rate for abutment teeth was 13%.

(Widbom et al., 2004) retrospectively examined hybrid double crown-retained RPDs over a period of 9 years with a mean of 3.8 years. They investigated 72 patients wearing 75 hybrid double crown-retained RPDs over 368 abutments. During the examination period, the loss of retention of the primary crowns was the most frequent dental complication, followed by abutment fracture. Additionally, 20% of the abutments showed periodontal complications with a pocket depth > 4 mm and 10% of marginal caries, whereas 7% were extracted.
In a prospective study, 92 patients provided with 105 telescopic prostheses were investigated. Re-cementation measures were required for 37% of the patients, making it the most frequent follow-up measure recorded (Mock FR et al., 2005).

Another interesting finding regarding the complications of endodontically treated abutments was documented in a three-year prospective clinical study. This examination sought to determine whether patients with endodontically treated abutment teeth provided with post and core experienced more complications than those with vital abutment teeth. Fifty-eight patients received 73 hybrid double crown-retained RPDs over 280 abutment teeth. One fourth of the abutments had periodontal complications, while 4.3% of the abutments fractured, 3.6% were extracted, 6% suffered from secondary caries, and 5% were re-cemented (Gehring K et al., 2006).

Another retrospective study compared three types of double crown systems, namely, friction parallel telescopic RPDs, conical crown-retained RPDs, and resilience telescopic RPDs. The need for re-cementation was the highest for the conical crowns at 53.2%, followed by 32% for the parallel-sided telescopic RPDs, and 21.3% for the resilience telescopic RPDS. In total, 75% of the patient had to undergo re-cementation measures after 15 years. Between 10.9% and 13.9% of the abutments required endodontic intervention, while the occurrence of secondary caries ranged between 8.5% and 9.8%, depending on the type of luting agent used (Behr et al., 2009).

(Jacoby et al., 2014) investigated the biological complications of different types of removable dental prostheses, including 54 double crown-retained RPDs over 152 abutments. They found that after ten years, secondary caries occurred in 8% of the abutments, 12% of the abutments fractured, and 11% of the abutments were extracted due to periodontal complications. Of 385 abutments, 12.2% required re-cementation procedures (Schwindling et al., 2014). In a recent retrospective study evaluating resilient double crown-retained overdentures in severely reduced dentition, the risk of loss of retention was found to increase with decreasing number of abutments. The incidence of re-cementation measures doubled in the case of just one or two abutments in situ in comparison to three abutments (Rinke et al., 2019).

1.10.2 Prosthetic complications

The technical performance of two types of partial dentures was tested by (Eisenburger and Tschernitschek, 1998). They examined 152 clasp-retained RPDs and 123 parallel-sided telescopic RPDs. A higher repair rate was observed for telescopic prostheses (60%) than for clasp-retained RPDs (45%). Interestingly, relining and fracture repairs were required almost three times more often on telescopic prostheses. Igarashi and Goto (1997) investigated 152 conical crown-retained RPDs over a period of 10 years. They stated that relining measures took place for one third of the prostheses during the observation period and that 92% of those relining measures were performed in patients with severely reduced dentition. Additionally, the retentive forces were reduced significantly for more than half of the subjects in the group. They also found that the fracture rate was approximately 1.5 times higher for each prosthesis type in patients with severely reduced dentition patients during the period of observation. However, they did not specify the type and nature of the fractures (Igarashi and Goto, 1997).

A unique study investigated the technical complications of various double crown systems (Behr et al., 2000). The technical complication rates of 74 parallel-sided telescopic RPDs supported by 251 abutments were compared to 43 conical crown-retained double crown systems over 160 abutments. During the observation period, approximately half of the patients in the conical crowns group had technical complications, while just 34.2% of the patients with parallel-sided telescopic RPDs had technical complications. Over the observation period, the following complications occurred: 7% loss of artificial teeth, 4.7% metal framework fracture, and 4.7% fracture of the acrylic denture base, independent of the type of double crown system.

In a retrospective study conducted over ten years, approximately one third of prostheses were free of complications. Partial or complete loss of the composite veneer was the main observed technical complication, with a 22.2% incidence rate. Additionally, 16.7% of the prostheses experienced fractures of the acrylic part of the base, while metal fractures occurred in 11.1% of the prostheses (Wagner and Kern, 2000). In another investigation with an average observation period of 4.2 ± 1.7 years, 120 RPDs of various types were randomly examined to assess the frequency of technical complications and their costs. During the observation period, 20% of the clasp-retained RPDs, 32.5% of the parallel-sided telescopic prostheses, and 50% of the conical crown-retained prostheses needed repair, with 10% of the conical crowns exhibiting a fracture of the veneer and 7.5% exhibiting a fracture of the metal framework (Hofmann et al., 2002).

In another study, the most frequent prosthetic follow-up measure was found to be the need for relining, at 57%. Veneer repairs accounted for 34% of all complications, whereas crack and fracture repairs accounting for less than 5% (Gehring K et al., 2006). (Wöstmann et al., 2007) examined 554 telescopic RPDs retained on 1758 abutments over an observation period of 5.3 ± 2.9 years. They identified at least one repair measure for 64.8% of all prostheses, with a total of 1626 measures documented. The most common complication was fracture of the composite facing resulting in needed veneering repairs (28.7%), followed by relining (21.3%). The repair measure needed least often was repair of the metal framework (1.2%). Hinz et al. (2020) examined 182 hybrid double crown-retained RPDs in severely reduced dentition with a median observation period of 40 months. During the investigation, the retention of the prostheses decreased. Therefore, friction pins were activated in 12.1% of the RPDs and deactivated in 3.8%.

1.11 Aim and objectives of the study

The aim of this study was to evaluate and describe the longitudinal dental and prosthetic complications of hybrid double crown-retained removable partial dentures in severely reduced dentition. The specific objectives were as follows.

1. To identify dental complications associated with double crown-retained removable partial denture in severely reduced dentition.
2. To identify prosthetic complications associated with double crown-retained removable partial dentures in severely reduced dentition.
3. To assess the distribution of abutment teeth and their sensitivity before and after insertion of double crown-retained removable partial dentures and the status of the opposing jaws.

1.12 Hypotheses

Due to its exploratory character, the study does not follow any hypothesis to be controlled or tested.

2 Materials and Methods

2.1 Overview of the study

The present study is an analysis of a clinical longitudinal database. The purpose of the study is to evaluate dental and prosthetic complications and the long-term survival of hybrid double crown removable partial dentures of severely reduced dentition (with four or fewer abutment teeth in one jaw). The prostheses under evaluation were made and delivered by students in their eighth and ninth semesters under the supervision of qualified assistant dentists and associate professors of the Department of Prosthodontics with Propaedeutic, Center of Dentistry, Oral Medicine and Maxillofacial Surgery at the University of Tübingen, between 2000 and 2018. The clinical data were collected prospectively following recall visits after obtaining the patients' informed consent. The clinical data were extracted, checked for plausibility and completeness, and then statistically evaluated.

All patients were informed about the aims of the study, and they were invited to appear for regular follow-up appointments. It was clarified that their participation would be voluntary and would place no further obligations on them. All patients were assured that their data would be managed confidentially. Information declaration and informed consent forms were signed and obtained.

One week after the delivery of the prostheses, baseline appointments were given by the attending student and his supervisor. All findings were documented using case report forms (CRFs) developed for the longitudinal register study.

The nurse in charge of the students scheduled appointments with the patients and called them for follow-up appointments. Another student evaluated the patient, and the data were noted on the CRF as follows:

2.2 Data acquisition at clinical recalls

2.2.1 Recall visits and clinical assessment

At the beginning of the investigation, general information about the prostheses and the opposite jaw was recorded.

2.2.2 Dental assessment

A dental assessment was documented per FDI code: The patients were asked about their chief complaints, pain, and their last dental checkup or treatments.

2.2.2.1 Percussion

A percussion test was performed by tapping the occlusal tooth surface with the handle of a dental mirror.

2.2.2.2 Sensitivity

A sensitivity test of the teeth was conducted using carbonic acid snow (-70°C), which was held on the teeth using a snow tube with a stamp. After 10 seconds, patients answered yes or no to whether they felt a sensitive reaction to the cold. The reaction was noted per FDI.

2.2.2.3 Tooth mobility

The degree of tooth mobility was assessed with the help of a Periotest device placed in a horizontal position 0.6 to 2 mm from the tooth surface, as proposed by Schulte (Lukas and Schulte, 1990). If the Periotest device was not available, then the tooth mobility test is carried out clinically with the metallic handles of two dental instruments, and the tooth was moved in a buccolingual/buccopalatal direction, as illustrated by Miller (Miller, 1950). The degree of tooth mobility was recorded per FDI.

2.2.3 Probing depth

Periodontal pockets were measured at each of two measuring points per tooth at the mesial and distal surfaces (the mesial and distal values were measured as close as possible to the point of contact) with the University of North Carolina-15 probe, which was introduced into the pocket parallel to the tooth. Both values were noted per FDI.

2.2.3.1 Papilla bleeding index (PBI)

Mühlemann’s procedure was followed to assess the intensity of the bleeding provoked by gentle probing with a blunt periodontal probe inserted into the gingival sulcus at the base of the papilla on the mesial aspect of the tooth and then moved first coronally to the papilla tip and then distally (Engelberger et al., 1983). The two measurements were documented per FDI code.

2.3 Documentation of the dental assessment

The data acquired from the clinical recalls were documented manually in each patient’s record and in the CRF as follows.

2.3.1 Dental Status

Teeth were categorized as missing teeth or abutment teeth. Missing teeth were recorded per FDI code as follows:

(f) For missing and not replaced teeth.

(e) For an acrylic replacement of a tooth

(b) For a pontic tooth

(a) For a cantilever bridge

(i) For an implanted tooth replacement

Abutment teeth were categorized in the CRFs as follows:

(g) When the abutment tooth was sound or filled

(t) If the abutment was restored with a sufficient telescopic crown

(k) If the abutment was restored with a crown

In the case of defective restoration, the findings were recorded as follows:

(ww) When there is a need to overcrown the abutment

(tw) In the case of a defective telescopic crown

(kw) If the crown restoration was not sufficient

The endodontic situation of each tooth was then assessed. If the tooth was endodontically filled, then the tooth as checked to see whether there was any post available, and the material was noted to determine whether the posts were casted or prefabricated, as illustrated in Figure 3.

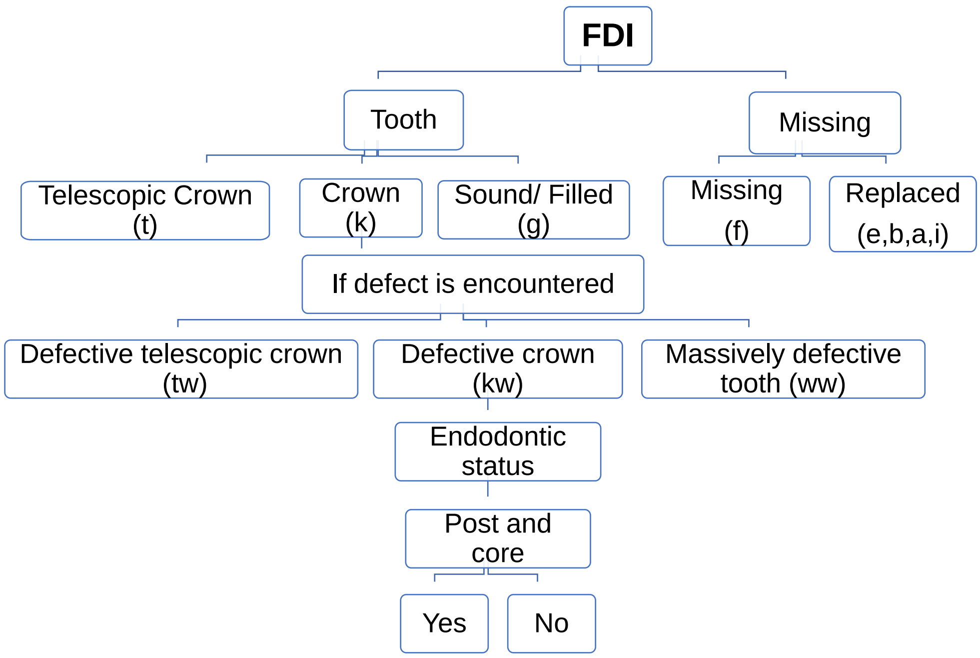

Figure 3 Description of the dental status during the documentation process. In the presence of non-defective abutment teeth, (t,k,g) abbreviations were used and (x) was added in the case of defects encountered. In the case of replaced teeth, (e,b,a,i) were used, and (f) was used in the case of the missing teeth not being replaced. The endodontic status was documented in the presence or absence of post and core.

2.3.2 Percussion

The response to percussion on the abutments was noted as (+) when the tooth was sensitive to percussion and as (-) when the tooth was not.

2.3.3 Sensitivity

The sensitivity was noted as (+) when a subjective feeling of cold was reported and as (-) when it was not.

2.3.4 Tooth mobility

The degree of tooth mobility was classified as follows (see Table 1):

Periotest value(PTV)	Features	Mobility grade
-8 to +9	No mobility	0
+10 to +19	Perceptible	I
+20 to +29	Visible	II
+30 to +50	Movement in all directions	III

Table 1 Degree of tooth mobility. Ranges of Periotest values (PTV) are shown in the left column. Mobility grades determined using the tips of two dental instruments are shown in the right column. Corresponding tooth mobility grade descriptions are provided in the center column (Lukas & Schulte, 1990; Miller, 1950)

2.3.5 Probing depth

The depth of each periodontal pocket was measured in millimeters (mm). Readings of more than 3 mm were recorded with a red pencil, and readings of 3 mm or less were noted with a blue pencil.

2.3.6 Papilla bleeding index (PBI)

The intensity of any provoked papillary bleeding upon gentle probing was recorded on a scale from 0-4 as follows (see Table 2):

Score	Bleeding on gentle probing
0	No bleeding.
1	Only one bleeding point appearing.
2	Several isolated bleeding points or a small blood area appearing.
3	Interdental triangle filled with blood soon after probing.
4	Profuse bleeding when probing, blood spreads towards the marginal gingiva.

Table 2 Papilla bleeding index (PBI) according to Mühlemann 1981 (Engelberger et al., 1983)

2.4 Subjective assessment of prostheses

The perception of the examining person of the hygienic status of the prostheses and the patients' feedback about their feeling about the prostheses was recorded subjectively and added to the CRF.

2.4.1 Hygiene of prostheses

The amount of plaque accumulation was assessed as follows by the examining person to evaluate the hygiene status of the prostheses:

(Kb) when there was no observable plaque accumulation

(Wb) when light plaque accumulation was observed

(Hb) when hard plaque accumulation was observed.

2.4.2 Patients' feedback

The patients' level of comfort with wearing their prostheses during chewing and how well they like their prostheses were recorded. The following questions were asked, and their responses were noted in the CRF. (see Table 3)

Questions	Rating in the database /CRF		
	1	2	3
How do you like your prosthesis?	Very good	Good	Bad
Do you feel comfortable while wearing your prosthesis?	Very good	Good	Bad
Do you feel comfortable while chewing with your prosthesis?	Very good	Good	Bad

Table 3 Patients' feedback. Shown are questions about the patients' perceptions of their prostheses and their answers.

2.5 Definition of complications

After recording all dental findings, the occurrence of complications was recorded, and all information was recorded by date. Prosthetic complications were those related to the prosthetic reconstruction, and dental complications were those related to the abutment teeth.

2.5.1 Complications of the removable part (Prosthetic complications)

Clinical inspection of all removable parts of the prosthesis was executed thoroughly, and the monitored complications were categorized as follows:

- Fracture of the denture base
- Loss of acrylic veneering over the secondary crowns
- Loss of retention of the prosthesis

The measures taken to address these complications differed depending on the nature of the complication. Specifically, in the case of a fracture of the denture base, if the crack was repositionable, then a fast crack repair was carried out in the dental laboratory. If the fracture was extensive and not repositionable, then a remontage of the prosthesis was implied, based on clinical impression taking. In the case of the loss of acrylic veneering of secondary crowns, a quick repair was performed in the dental laboratory. In the case of loss of retention, if the cause was a loss of friction between the primary and secondary crown, then an activation procedure of the frictional pins was conducted. If the cause was alveolar bone loss, then a relining procedure was conducted. Extension of the prosthesis was conducted after the loss of abutment teeth.

2.5.2 Complications of abutment teeth (dental complications)

All abutment teeth were meticulously evaluated individually, and the following complications were identified and noted:

- Secondary caries, either at the margin or root caries
- Loss of retention (de-cementation) of the primary crowns
- Endodontic complications:
    - Clinically or radiographically apical findings
    - Positive (+) response to percussion
- Tooth fracture
- Periodontal complications:
    - Increased tooth mobility
    - Increased probing depth (≥ 4 mm)

The complications were addressed with specific approaches and measures suitable for each individual case.

Secondary caries was inspected, and if the tooth had not lost its vitality, either the lesion was excavated immediately and filler material was applied or the patients were given further appointments. In the event of de-cementation of the primary crown, a direct re-cementation procedure was done. With respect to endodontic complications, if the abutment had lost its vitality, then endodontic therapy was conducted, followed by post and core reinforcement of the abutment. The selection of the post material was dependent on the degree of destruction of the tooth substance. The prefabricated posts were typically made out of titanium, and individualized casted posts were rarely used. In contrast, if the tooth was already endodontically treated and an endodontic complication arose, an apicoectomy procedure or extraction was performed. In the case of tooth fracture, if the fracture was in a favorable position and the abutment tooth was seen to be restorable, then an endodontic treatment was carried out, followed by post and core insertion. Otherwise, the tooth was extracted if it was judged to be non-restorable. Finally, periodontal complications were identified by increased mobility of the abutment, increased probing depth of the periodontal pocket, or both. For this particular type of complication, either periodontal treatment was carried out or extraction was indicated. Any measures taken were first explained the patients, and their agreement was obtained.

2.6 Identification of complications

The complications were identified in two ways:

- Retrospectively from the patients’ records or direct patient questioning
- Clinical assessment of the patients’ current dental status

2.6.1 Documentation of the complications and measures

The complications explained above were documented based on how they were identified. Therefore, the CRF describes the measures taken rather than the complications themselves.

2.6.2 Documentation of the retrospectively identified complications

After reviewing the patients' records and/or questioning, all the identified complications were documented with respect to the date of their occurrence and the date of the measures taken to address them.

2.6.3 Documentation of clinically assessed complications

On the day of recall, all the observed complications were documented in the patients' records and the CRFs. The date of recall was considered the date of the complication. However, if an immediate reaction to complications took place, the needed measures were performed. If the complications were not solvable immediately, then another appointment was offered, or the patient was referred to another department.

2.7 Database design and questioning

A database was created using Microsoft Office Access 2010 (Microsoft Corp., USA) to simplify the data acquisition and facilitate data transfer to statistical software.

2.7.1 Database entry of patients' data

After completion of treatment, a Case Report Form (CRF) was initiated, which included the consent form. The signature on the consent form was checked, and then the data on the dental status before the treatment, after the treatment, and the design of the prosthesis were noted. This permitted the generation of numerical symbols to facilitate analysis of the data.

2.8 Data management

To select the patients and observations relevant to the aim of the study and to perform quality assurance on the database, several measures, such as a plausibility check, inconsistency detection, and subsequent validation and correction, were performed using spreadsheets (JMP Version 14, SAS-Institute, USA) transferred from the database and reentered to the database. Two iterations of data cleaning were performed based on the following principles.

2.8.1 Database extraction and filter

The database information was transferred into tables (see section 2.8.2) using a SAS-based Script (JMP Version 14) provided by the register and authored by Dr. Detlef Axmann. The complete dataset of the databank "KombiZE-Register" was read out and distributed to tables based on a relational connection (key) that allows concatenation of data points between tables due to the bijective character of the key.

The subset of patients with at least one hybrid double crown-retained RPD in a jaw with reduced dentition was filtered by the number of abutment teeth (≤ 4 marked [t | g | k] (see section 2.3.1, Dental Status, page 26) in one jaw AND at the minimum observation time [calculated as the last observation date minus the date of insertion] of 36 (±1) months.

2.8.2 Description of the tables

To simplify the data process, the following tables were created from the main database:

- The key table (Schlusseltabelle) was constructed from the base and study table to contain relevant patient data.
    - The bijective database ID, constructed from the following information:
        - The treated jaws (upper, lower, both)
        - The date of the first database entry (yymmdd)
        - The database patient number (integer count)
    - The date of delivery of the prosthesis (date of insertion)
    - The sex of the patient (male or female)
    - The age on delivery (years)

    - The last observation date (dd.mm.yy) and the calculated maximum observation time.
- The base data table (Stammdatentabelle) contains the following:
    - The bijective database ID
    - The patient’s gender and age at the start of treatment
    - The date of the first visit
    - The treated jaws
- The study table (Studientabelle) includes the following:
    - The bijective database ID
    - The type of reconstruction
    - Existence of a major connector
    - The classification of the tooth topography
    - The situation of the opposing jaw
    - Formal annotations by the team inf the Kombi-ZE register

- The dental status table (all Beunde) contains the following:
    - The bijective database ID
    - The presence of major connectors in the upper and lower jaws
    - The occurrence of any dental complication
    - The occurrence of any prosthetic complication
    - The cases of fabrication of new prostheses
    - The FDI coding of the retainers and teeth
    - Responses to the percussion test
    - Sensibility situation of all abutments
    - Periotest values of all abutments

- Table of insertion (Eingliederungstabelle). This table includes the following:
    - The bijective database ID
    - The date of insertion
    - A description of the constructions
    - The situation of the opposing jaws

Because of the lack of an algorithm, the Steffel classification was selected based on the FDI coding of all abutment teeth in the upper and lower jaws, as illustrated in Figure 4 and based on the following two factors:

- The number of abutments used for each restoration
- The distribution of the abutments, according to the Steffel classification

A column labeled "Steffel class" was manually entered in the insertion table to describe the edentulous situation and compare HDC-RPDs for reduced dentition according to a specific protocol to determine the supporting lines, as explained in section 2.8.3.

- The resulting table is called the table of insertion with the Steffel classification (Eingeliederungsbefund_Steffel_Klasse). It contains the following items:
  - The bijective database ID
  - Date of insertion
  - Description of the delivered prostheses
  - The situation of the opposing jaw
  - The Steffel classification, expressed in Arabic numerals
- A table of periodontal findings (parodontaler Befund) contained the following:
  - Date of insertion
  - Sequence of appointment (U_0 indicates the baseline appointment, U_{05} indicates the six-month follow-up, U_1 indicates the yearly follow-up, etc.)
  - Date of registration of the hygienic status
  - The hygienic status of the denture as evaluated by the examiner (kb,wb, or hb); see section 2.4.1.
  - The patients` feedback about the prostheses (1, 2, or 3), as explained in section 2.4.2
  - Periodontal status (papilla bleeding index (PBI), plaque index (PI), and pocket depth, abbreviated as ST in German, measured in mm) of the abutment teeth, recorded at two points, one on the mesial aspect and the other on the distal one

- A table was created for dental complications (Tabelle der denatlen Komplikationen), containing the following items:
    - The bijective database ID
    - The sequence of appointments addressing the complication
    - The numbering of the abutments, according to FDI
    - The reported dental complications
    - The dates of their occurrence
    - The treating student and supervisor
    - Notes, if there was more information about the complication

A separate table was created for prosthetic complications (Tabelle der prothetischen Komplikationen). This table contained the following items:

- The bijective database ID
- The sequence of appointments addressing the complication took place
- The numeration of abutments according to FDI
- All relevant complications associated with the removable part of the prosthesis (need for activation, expandability, repair of fracture, and relining)
- Dates of occurrence of complications
- The treating student and supervisor
- Notes, if there was more information about the complication

○

2.8.3 Explanation of Steffel's classification system

The distribution of the abutments was evaluated in accordance with the location of the abutments in the jaw and the supporting lines and rotational axis of the prosthesis. The classification was carried out as shown in Figure 4 and as follows:

- Cases with just one isolated abutment or two central incisors were classified as class A
- Cases with sagittal linear support unilaterally were considered class B, regardless of the number of the abutments
- Cases with transversal linear support were classified as class C, regardless of the number of abutments, as follows:
- Cases with just two corresponding abutments
- Cases with three abutments; the strategic value of the abutment is considered
- Cases with four abutments but for which quadrangular support was not possiblewere considered as class D
- Cases with triangular support with either three or four abutments were considered as class E
- Cases with quadrangular support were considered class F

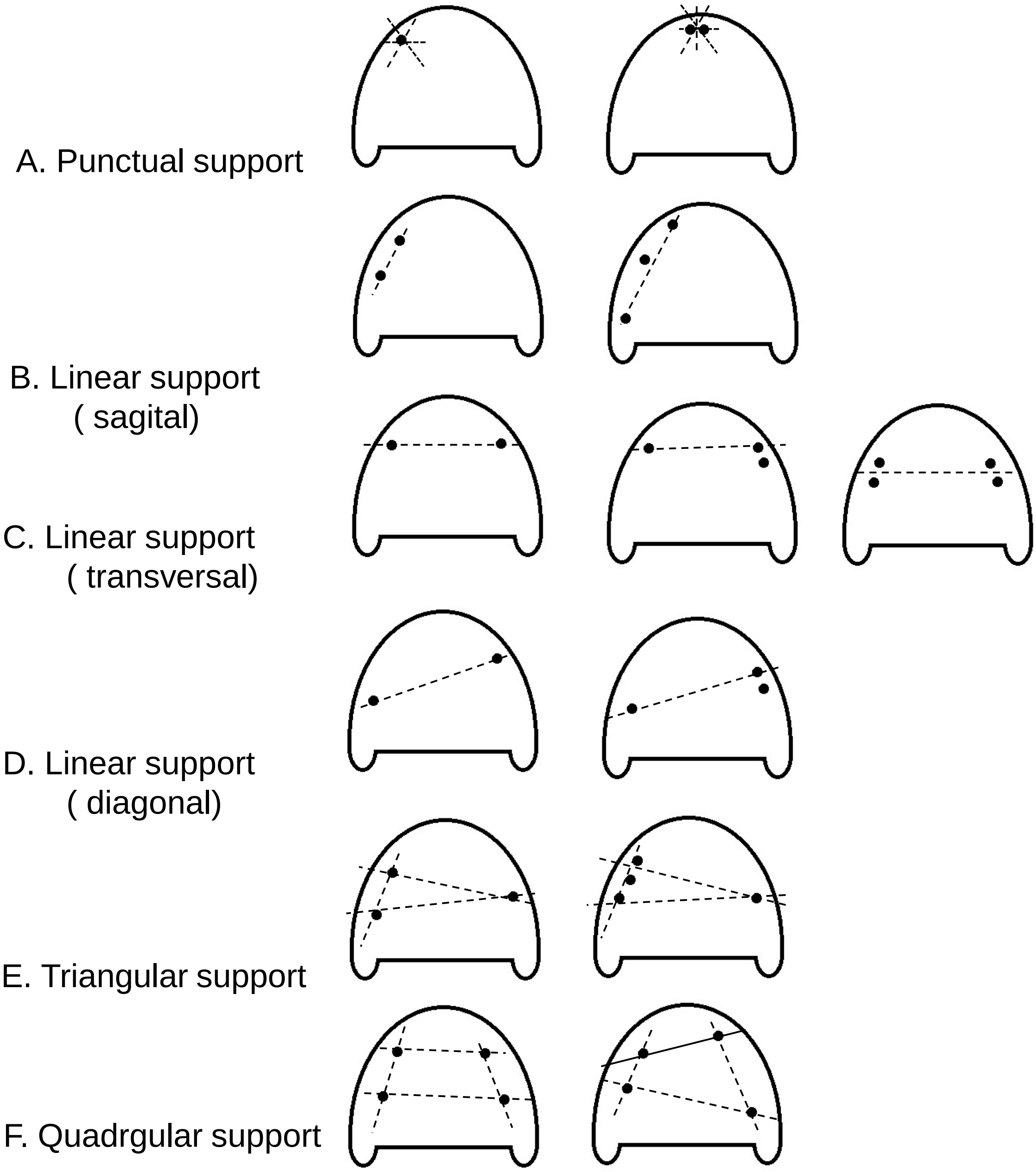

Figure 4 Illustration of Steffel's classification system used in this study, according to the supporting lines, regardless of the number of abutments. Class A represents any punctual denture support on either one abutment or two abutments in the midline. Class B represents linear horizontal support even in the presence of more than two abutments. Class C serves as linear transverse support even in the presence of more than two abutments, considering the more substantial abutment. Class D represents linear diagonal support even in the presence of more than two abutments, considering the more substantial abutment. Class E represents triangular, polygonal support even in the presence of more than three abutments. Class F represents quadrangular polygonal support.

2.8.4 Check for plausibility and completeness of the database

After the selection of eligible patients, hard copies of the tables were printed from the database. These hard copies included the patients' generated IDs and a list of all teeth FDI-wise from 18–48 with the findings noted for them, as explained in section 2.3.1. The data were then checked item by item. First, the patients' signatures on the consent forms were verified. When there was no signature, the patient was excluded. Second, a quick synchronization of the printed data and CRF was carried out.

2.8.5 Check of correctness of database after recalls

After harmonization of the data, a strict review of the data was implemented. When a mistake was encountered, the case report form CRF was used to check the data. If the error was made at the moment of data entry from the CRF to the database, the correct information was entered into the database immediately. Nevertheless, when the recognized error was in both the database and CRF, a review of the patient's file at the medical registration department was conducted, and the information was corrected in the database.

2.8.6 Check of correctness of entry of complications into database

When a complication, either dental or prosthetic, is encountered, it is registered in the database during recall appointments, as explained in section 2.6.3. To avoid mistakes, the date of entry of complications was taken as the date of occurrence rather than the date of recall. For this reason, a review of patients' records was performed, and the correct information was checked and adjusted when any mistake was encountered.

2.9 Statistical analysis

To permit an analysis and description of the cohort and their restorations and clinical situation over time and to identify complications of RPDs and dentition, the tables mentioned above (see section 2.8.2, page 34) have to be joined based on the bijective keys and variables (such as FDI), stacked or split bivariables of interest, as well as subsets of the tables to be generated.

The following data are needed:

- Patients' information, including their number of teeth, the topographic situation of their jaws (retainers), the status of their RPD, and an assessment of the RPD (at each point in time of observation, starting with the date of insertion)
- Information about each dental complication of each FDI and its periodontal and endodontic status under observation (for each point in time of observation).
- Information about each prosthetic complication of each RPD and its design under observation (for each point in time of observation).

The data from the tables are described as follows:

- Frequency distributions of their entities: FDIs, RPD design, age, and observation time.
- Grouped by variables of interest (complications, sex) as well as their derivates (number of data points).

The data are interpreted using the prevalence (number of relevant observations within the main unit) and given as a percentage, grouped by entities or variables of interest.

3 Results

3.1 Characterization of patients

3.1.1 Distribution of patients according to gender and age

Out of 102 included patients in this study, 63 were men versus 39 women. The youngest patient at the date of delivery of the partial denture was 37 years old, and the oldest was 81 years old. The mean age of the patients was 61 years (standard deviation: 10). Figure 5 illustrates the distribution of patients according to their age.

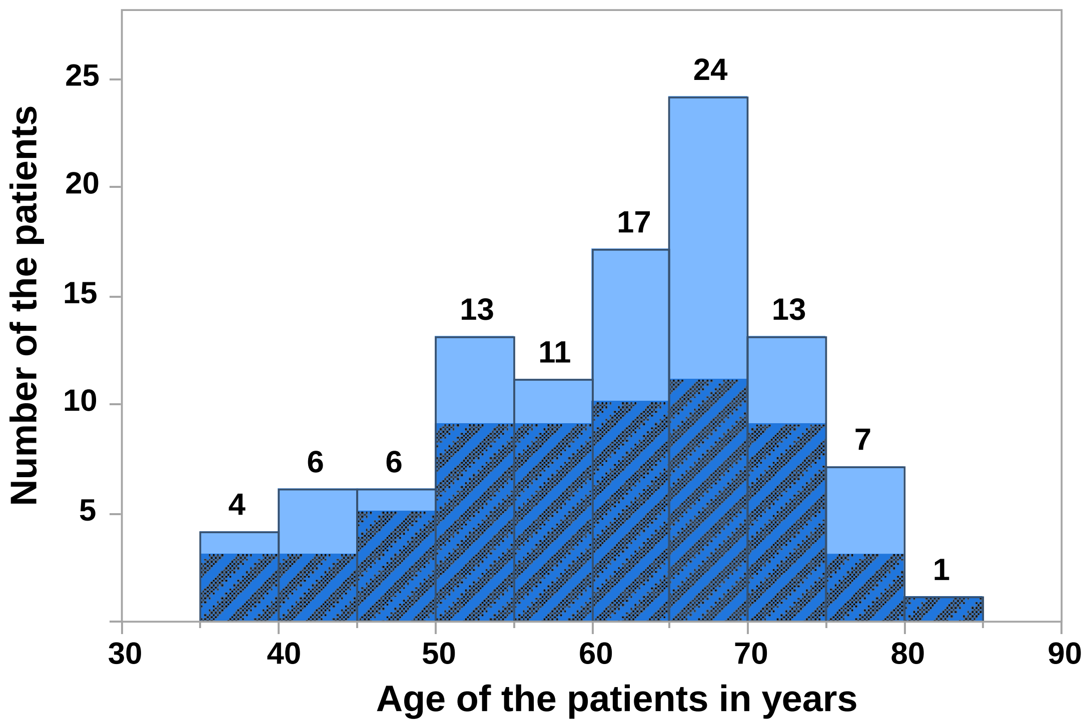

Figure 5 Distribution of the patients by age. Shown are the distribution of the patients according to their age in years (x-axis) and in relation to their number (Y-axis). The majority of the patients were aged between 60 and 70 years. The shaded part represents the male sample

3.1.2 Observation period

The mean observation period of the prosthesis in the study was 6.5 years (standard deviation: 3). The minimum observation period was 2.9 years, and the maximum was 17.75 years. Most of the participants presented in the period of 3–4 years post delivery of their prostheses, as shown in Figure 6.

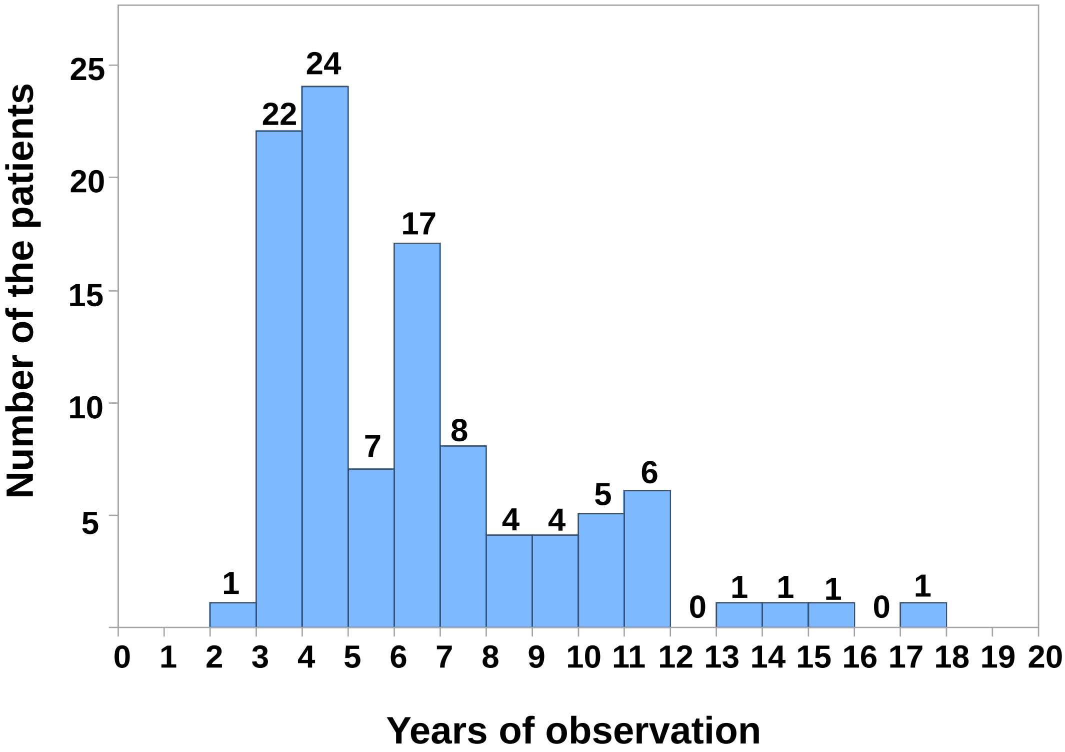

Figure 6 Distribution of the participants according to the observation period. Shown are the observation period in years (X-axis) and the number of patients (Y-axis). The maximum observation period was 17.75 years.

3.2 Prosthetic restorations

3.2.1 Number and distribution of prostheses

Overall, 102 patients with a total of 122 hybrid double-crown removable partial dentures (HDC-RPDs) were recorded. These were divided as follows:

• 69 maxillary HDC-RPDs and • 53 mandibular HDC-RPDs.

Out of the upper 69 HDC-RPDs, 46 prostheses were provided with a maxillary major connecter, whereas 23 prostheses were without. On the other hand, most of the lower dentures (48 prostheses) were provided with sublingual bars, and just four prostheses were provided without this.

3.2.2 Restoration of the opposite jaw

As shown in Figure 7, most of the examined prostheses in both upper and lower jaws were opposed by hybrid double-crown removable partial prosthesis. Conversely, lower prostheses were opposed by upper complete dentures, and 20 upper HDC-RPDs were opposed by either lower FDP or natural dentition.

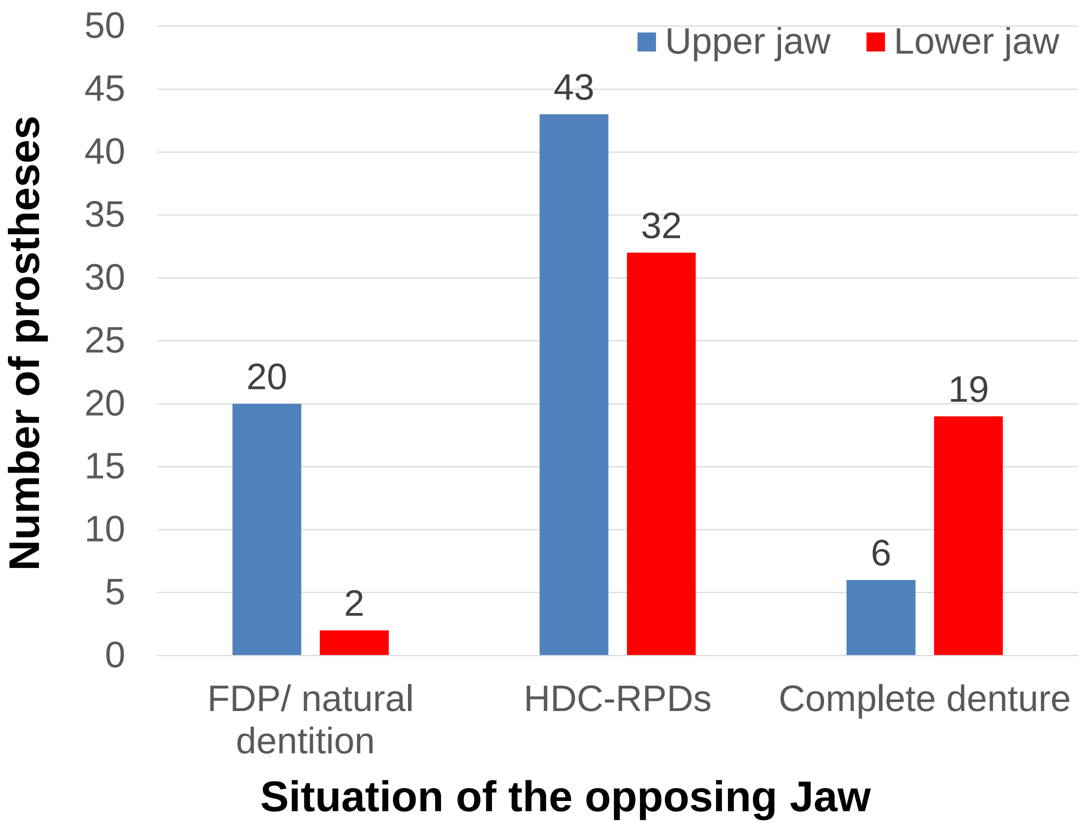

Figure 7 Description of the restorations of the opposing jaws. The blue bars represent the upper jaw situation, and the red bars represent the lower jaw. FDP = fixed dental prostheses; HDC-RPDs = hybrid double-crown removable partial dentures.

3.2.3 Number and distribution of the abutment teeth

A total of 357 abutment teeth were implemented to support the HDC-RPDs. Of these, 201 abutments were used in the upper jaw, and 156 abutments were implemented for the lower prosthesis. In the upper jaw, the majority of the abutments were the canines, with around 41% (n=84) of the abutments, followed by incisors (24%; n=55). The least implemented abutments were the first molars, at 3% of the implemented abutments. The upper third molars were not used in any of the prostheses, as shown in Figure 8.

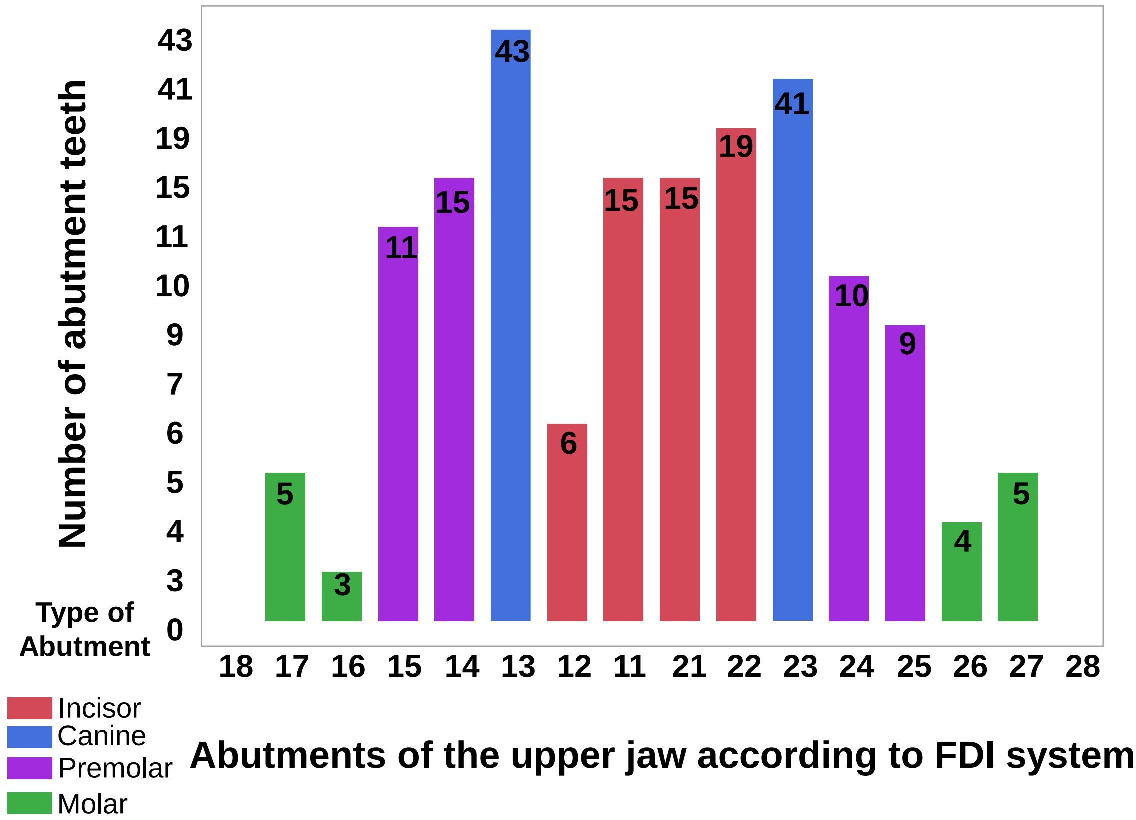

Figure 8 Distribution of the abutment teeth and their numbers in the upper jaw. Shown are the codes of the abutments according to the FDI notation system (X-axis) and the number of the implemented abutments (Y-axis). The majority of the prostheses were supported over canine abutments.

On the other hand, the lower canines were used as a support for half of the lower prostheses, followed by first premolars, comprising 28% of all implemented abutments. Interestingly, the lower molars were the least used abutments, at 7% of the implemented abutments, as illustrated in Figure 9.

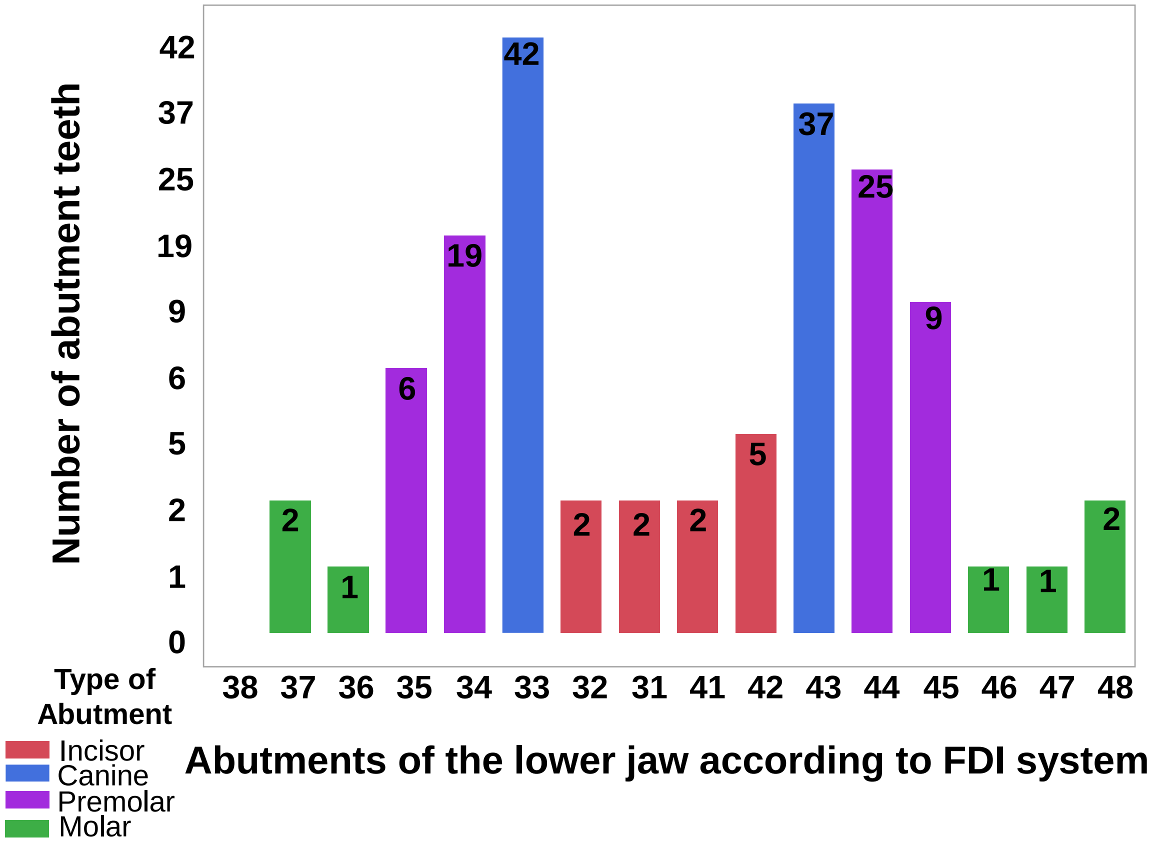

Figure 9 Distribution of the abutment teeth and their numbers in the upper jaw. Shown are the codes of the abutments according to the FDI notation system (X-axis) and the number of the implemented abutments (Y-axis). The majority of the prostheses were supported over canine abutments.

According to the number of implemented abutments for the support of each prosthesis, 40% of upper HDC-RPDs were supported on four remaining abutments compared to just 24% of the lower prosthesis. On the other hand, the lower prostheses were mainly supported over three abutments, with a sum of 24 prostheses in contrast to 19 prostheses in the upper jaw. Consequently, just eight upper prostheses and six lower prostheses were supported punctually over only one remaining abutment, as shown in Figure 10.

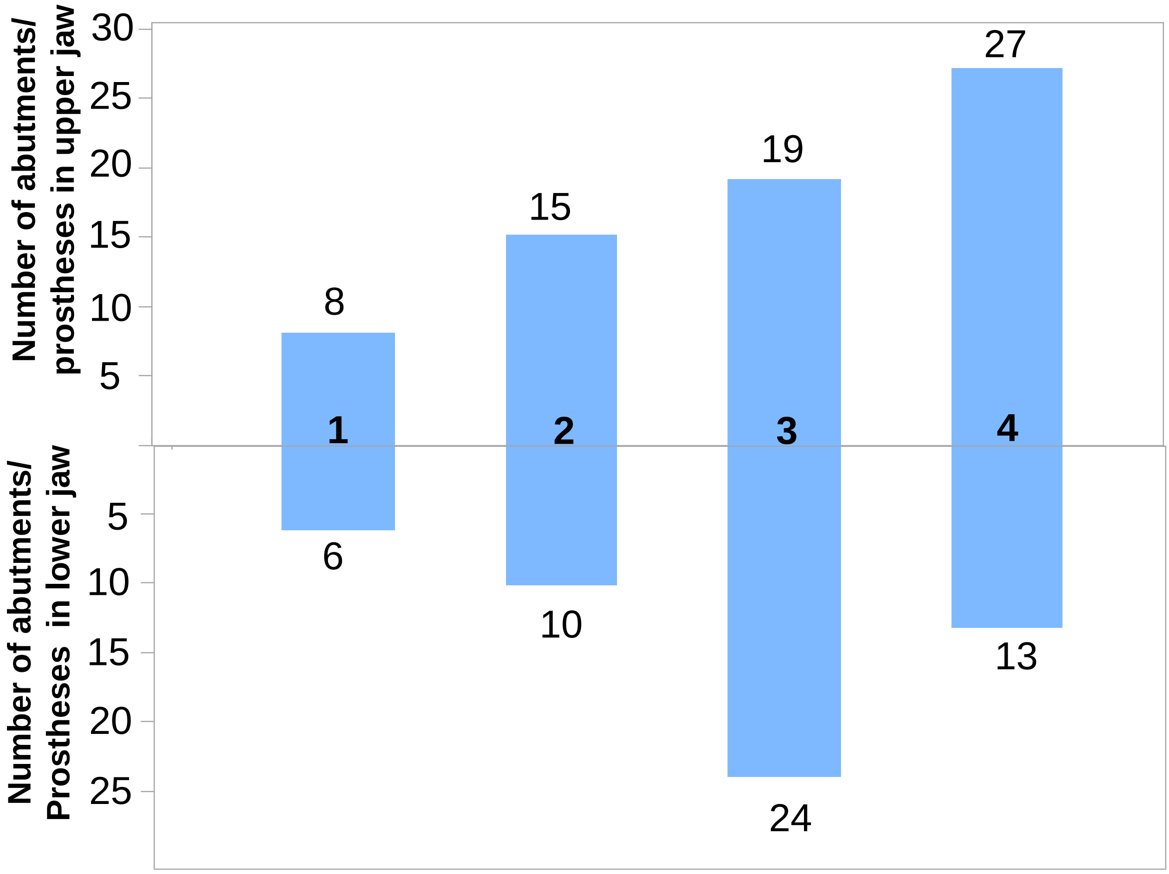

Figure 10 Distribution of the prostheses according to the number of abutments. Upper jaw prostheses were mainly supported over four abutments, whereas the lower prostheses were supported mainly over three remaining abutments.

3.2.4 Means of retention and cementation of the abutments

Of the 357 included abutments, 338 were cemented with zinc phosphate cement, and just three were cemented with glass ionomer cement. The adhesive bonding procedure took place on 10 abutments, and seven abutments were retained with casted clasps.

3.2.5 Analysis according to Steffel classification

In accordance with the Steffel classification as explained in 2.8.3, Figure 11 illustrates that the majority of the examined prosthesis were assigned to class C, with a sum of 40 prostheses: 24 HDC-RPDs in the lower jaw and 16 upper prostheses. Interestingly, 22 upper HDC-RPDs compared to only eight lower prostheses were allocated to class E, whereas just five prostheses belonged to class F. Concerning class A with punctual support, 15 upper and lower cases were recorded: 14 were prosthesis supported over only one abutment, and only one case was supported over two upper central incisors. However, 11 upper prostheses compared to eight lower prostheses were allocated to class B. Furthermore, the same distribution was found of class D cases, with six cases in each jaw.

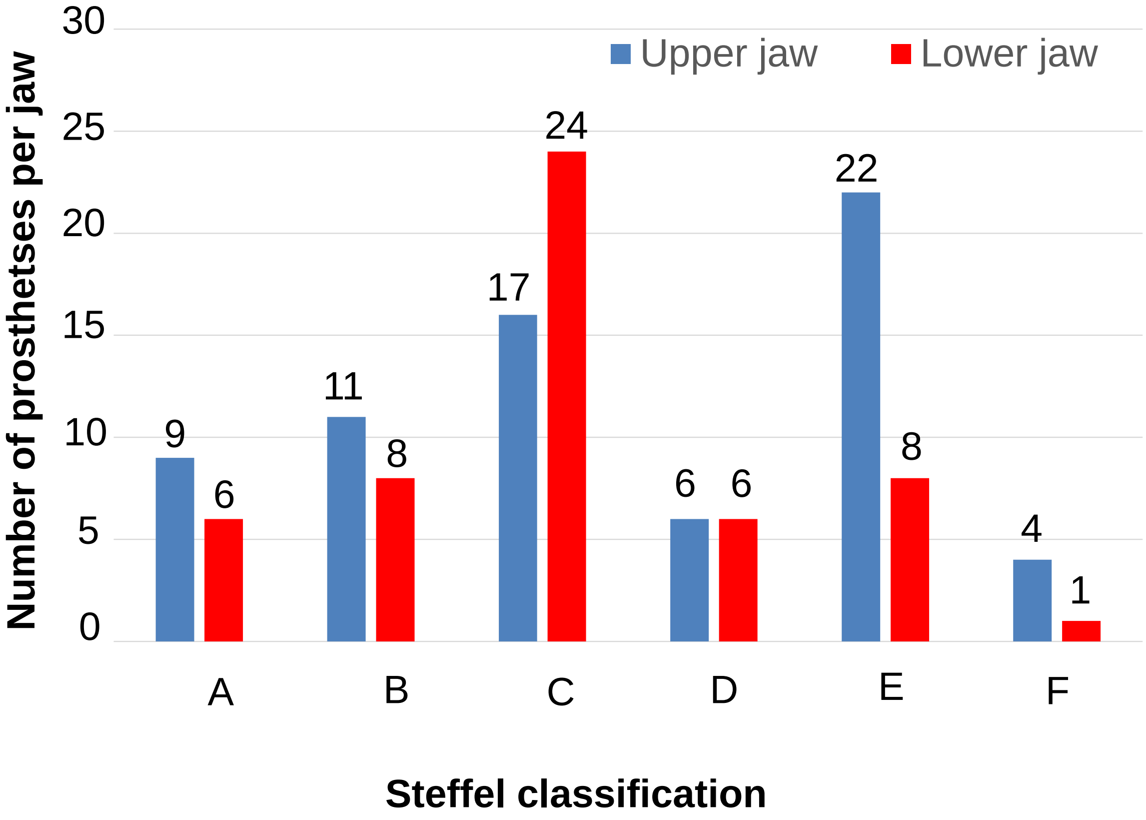

Figure 11 Distribution of the prostheses according to Steffel classification. Most of the examined prostheses were under Steffel classification C, and the least encountered cases were class F. The blue bars represent the upper jaw situation, and the red bars reflect the lower jaw.

3.3 Subjective assessment of the prostheses by the examiner

The hygiene of the prostheses was evaluated by the examiner in the follow-up appointments. The hygiene practice with the upper prostheses showed a gradual drop within the years of this investigation. Within the first year, the hygiene of the upper HDC-RPDs was observed to be good: around 70% of the prostheses had no plaque accumulation, compared to just one third of the prosthesis after five years. Regarding soft plaque accumulation, a gradual increase within the years was noticed, with a 50% increase in soft plaque accumulation from the first year and after five years. The percentage of prostheses with hard plaque was doubled when comparing the situation within the first year and after five years of follow-up. The highest peak of plaque was accumulated until the third year after insertion, as shown in Figure 12.

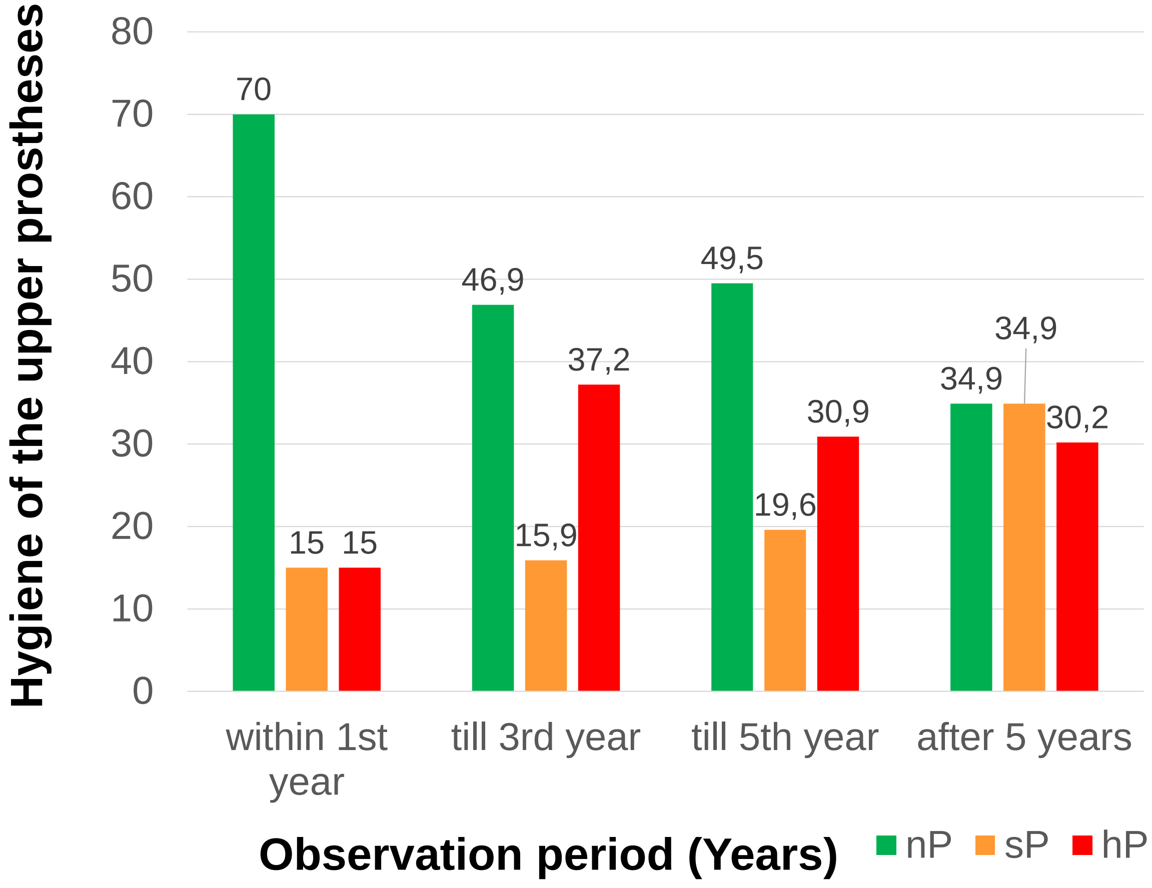

Figure 12 Distribution of the percentage of the hygiene status of the upper prostheses over the years of follow-up. nP: no plaque; sP: soft plaque; hP: hard plaque.

Around two thirds of the lower prostheses showed no plaque accumulation within the first year. This dropped gradually to just 29% of the prostheses after five years. Interestingly, a dramatic increase occurred in hard plaque accumulation in comparison to the soft plaque within the years of observation. The percentage of prostheses with hard plaque increased from 19% within the first year to around 45% of the prostheses under examination after five years, whereas the percentage of soft plaque did not show a considerable increase, as shown in Figure 13.

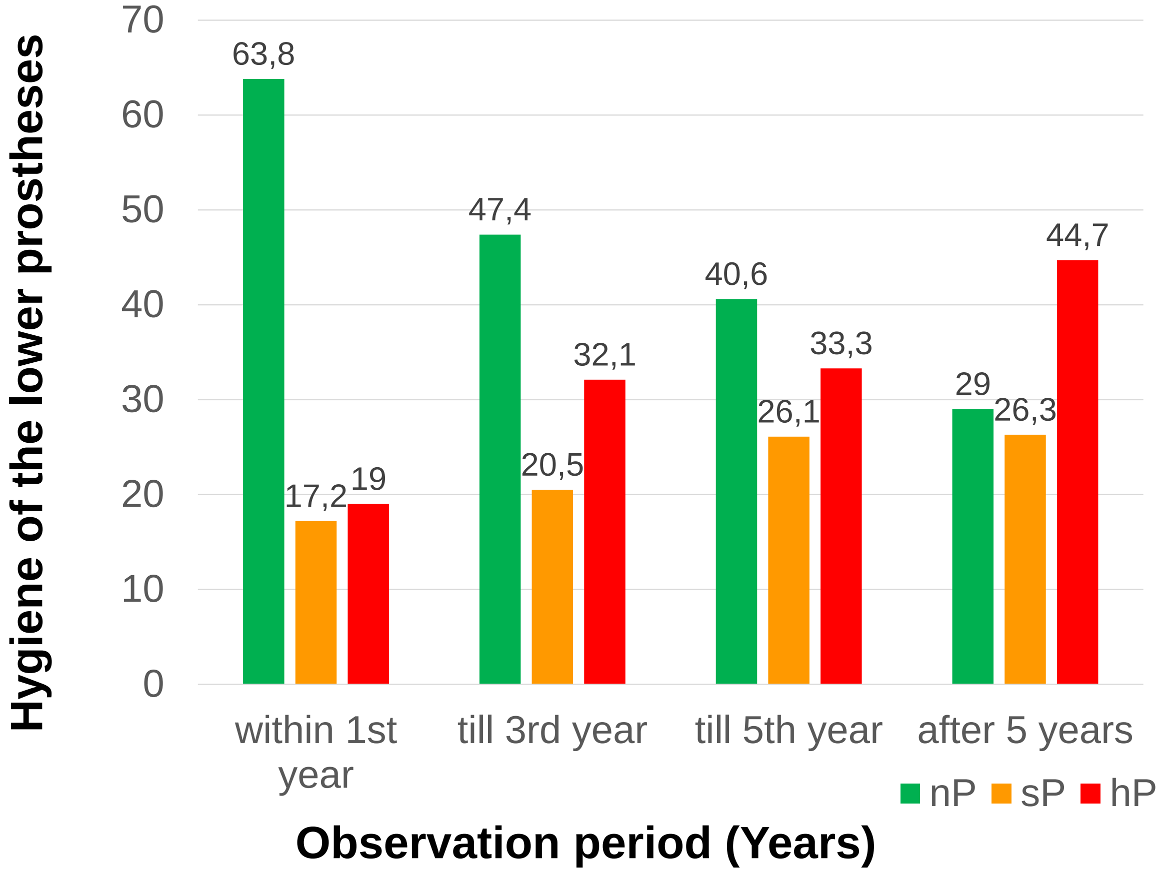

Figure 13 Distribution of the percentage of the hygiene status of the lower prostheses over the years of follow-up. nP: no plaque; sP: soft plaque; hP: hard plaque.

3.4 Subjective assessment of the prostheses by the patients

3.4.1 Overall satisfaction with the prostheses

The values for the overall satisfaction with the upper prostheses showed a gradual decrease over the years: 70% of very satisfied responses within the first year dropped to half in the fifth year and just one third of the samples after five years. On the other hand, the percentage of patients just satisfied with their prostheses incrementally increased within the years of the investigation. Specifically, 27.6% satisfaction within the first years became 59% after five years. The degree of dissatisfaction increased from the first year to the third year from 1.5% to 2.7%, then it was finally 1.7% after five years, as illustrated in Figure 14.

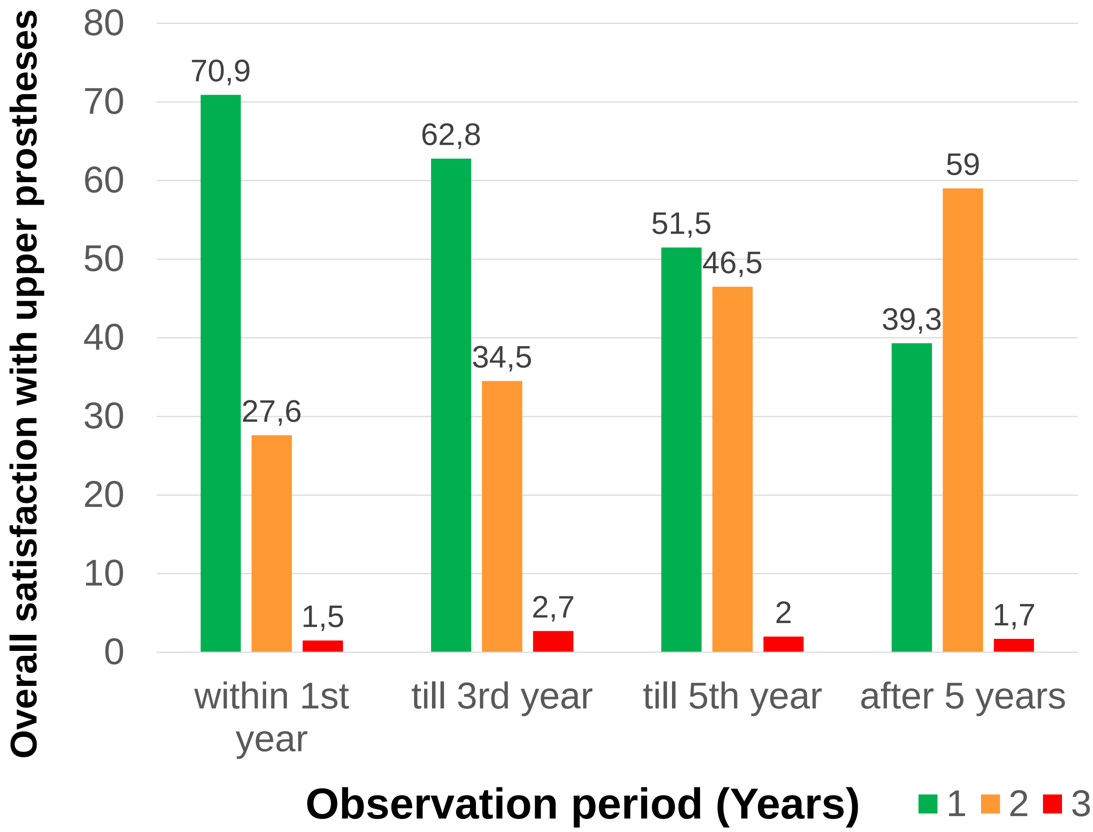

Figure 14 Distribution of the overall satisfaction of the patients with their upper prostheses over the observation period in years. 1: very satisfied; 2: satisfied; 3: not satisfied.

Figure 15 shows the overall satisfaction with the lower prostheses over the years. These patients showed better acceptance in comparison to upper prostheses, with just 2% of the sample dissatisfied with their prostheses in the first year. This dissatisfaction vanished after five years. However, the absolute satisfaction was inversely proportional to the satisfaction with the prostheses over the years. In particular, the degree of absolute satisfaction dropped from around 70% to only a third of the samples after five years. In comparison, the just satisfied responses increased gradually from 28.8% in the first year to around two thirds of the participants after five years of follow-up.

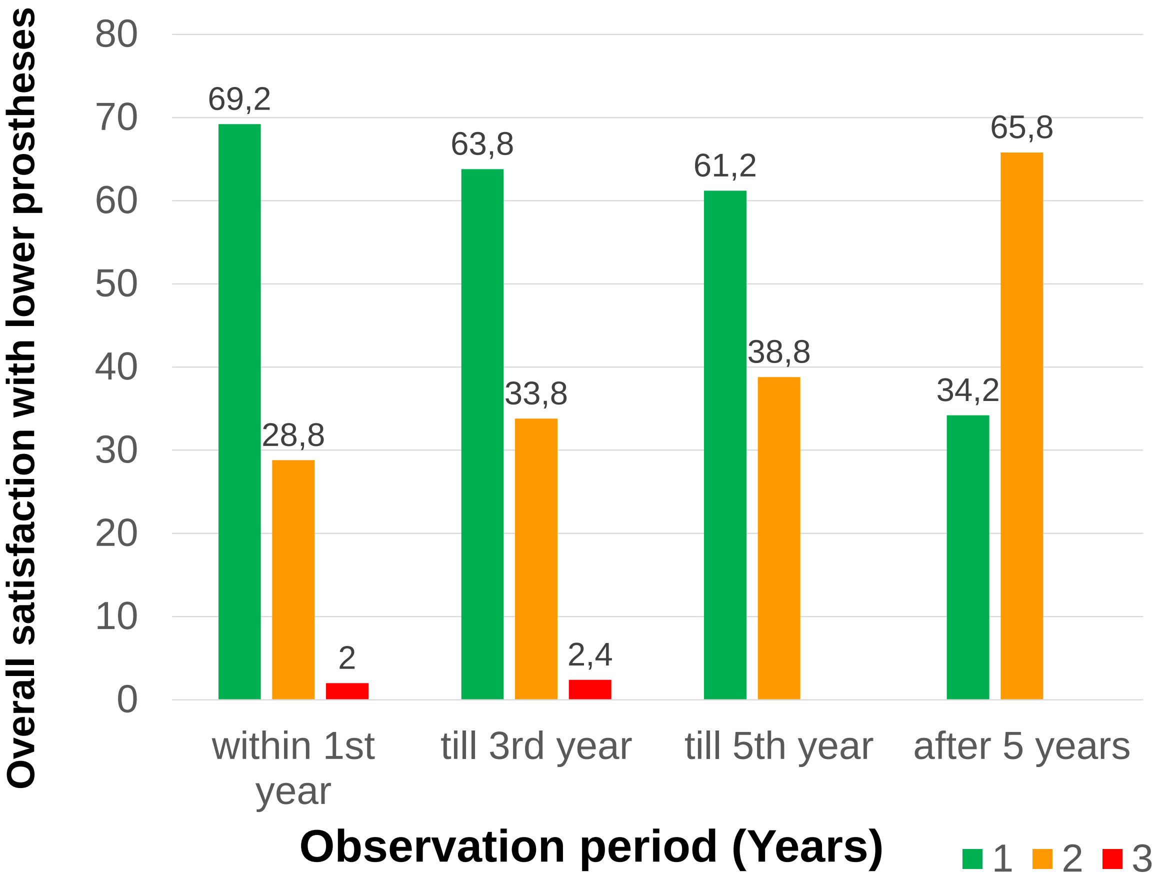

Figure 15 Distribution of the overall satisfaction of the patients with their lower prostheses over the observation period in years. 1: very satisfied; 2: satisfied; 3: not satisfied.

3.4.2 Comfort with the denture

The distribution of the patients' comfort with their upper prostheses is shown in Figure 16. Most patients perceived deterioration of their absolute comfort over the years. Specifically, a drop occurred in the percentage of absolute comfort from around 60% within the first year to 50% until the fifth year, which decreased to around 40% after five years. The just comfortable feeling with the prostheses gradually increased from 35% in the first year to around 55% after the fifth year. The dissatisfaction percentage doubled from the first year to the follow-up after five years of the delivery.

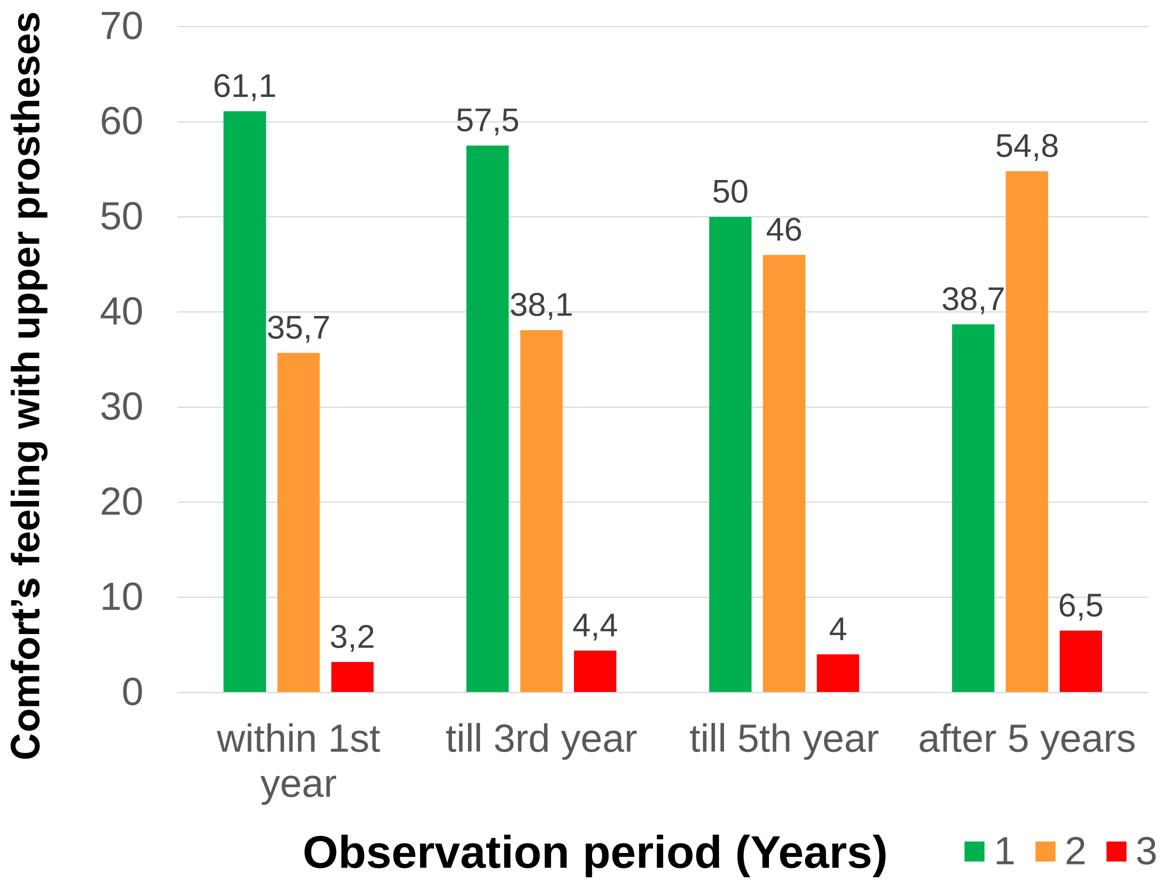

Figure 16 Distribution of the comfort of the patients with their upper prostheses over the observation period in years.1: very satisfied; 2: satisfied; 3: not satisfied.

Contrary to the upper jaw, the degree of dissatisfaction remained the same without any major changes over the years. The absolute satisfaction fluctuated mildly until the third year, then it dropped to around one third of the sample after five years. Regarding the just comfortable group, their percentage constantly increased from around one third of the cases in the first year to slightly more than after five years, as shown in Figure 17.

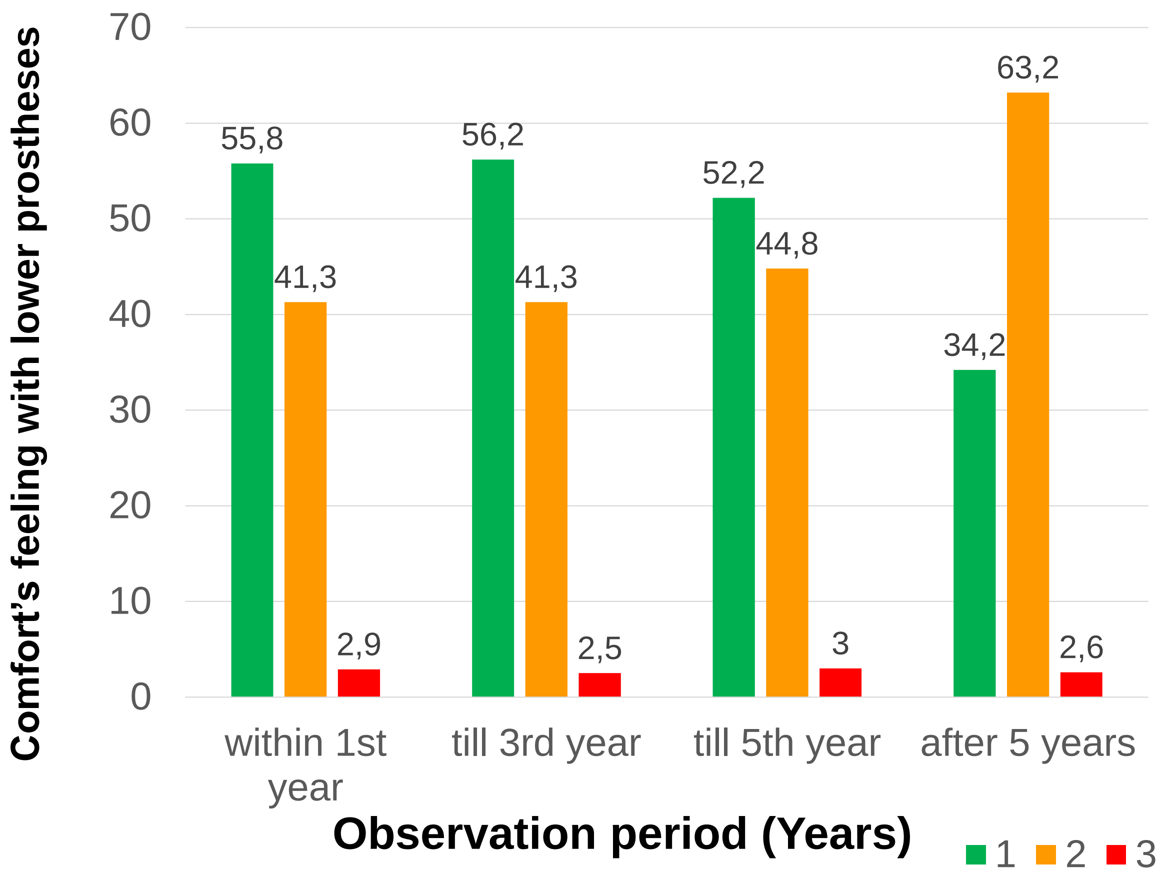

Figure 17 Distribution of the comfort of the patients with their lower prostheses over the observation period in years.1: very satisfied; 2: satisfied; 3: not satisfied.

3.4.3 Satisfaction with chewing with the denture

Figure 18 illustrates the percentage of the reported satisfaction by the patients about chewing with their HDC-RPDs during the investigation period. As with the previous parameters, the percentage of absolute satisfaction with chewing decreased from around 60% to 35.5% after five years. The just satisfied participants showed a regular increase from one third of the participants in the first years to half until the fifth year, then around 60% after five years. Regarding the degree of dissatisfaction, the percentage increased until the fifth year to 7% of the sample, which dropped to around 5% after the fifth year.

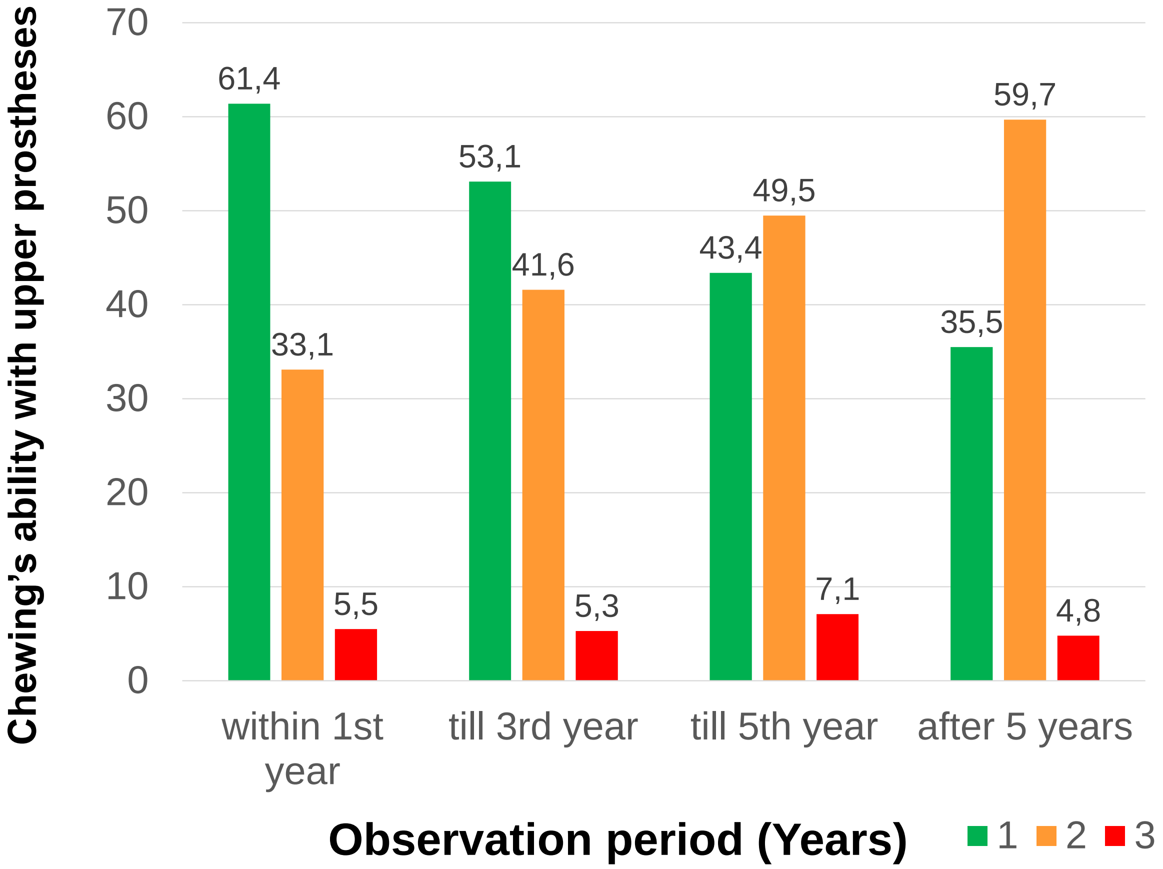

Figure 18 Distribution of the chewing ability of the patients with their upper prostheses over the observation period in years.1: very satisfied; 2: satisfied; 3: not satisfied.

For the lower prostheses, the chewing ability of the patients decreased with time, and dissatisfaction was not encountered in the first year. On the other hand, a gradual increase occurred in the percentage of response of patients who were just satisfied with their chewing with the prostheses: around 70% of the sample after five years compared to just 44% within the first year, as shown in Figure 19.

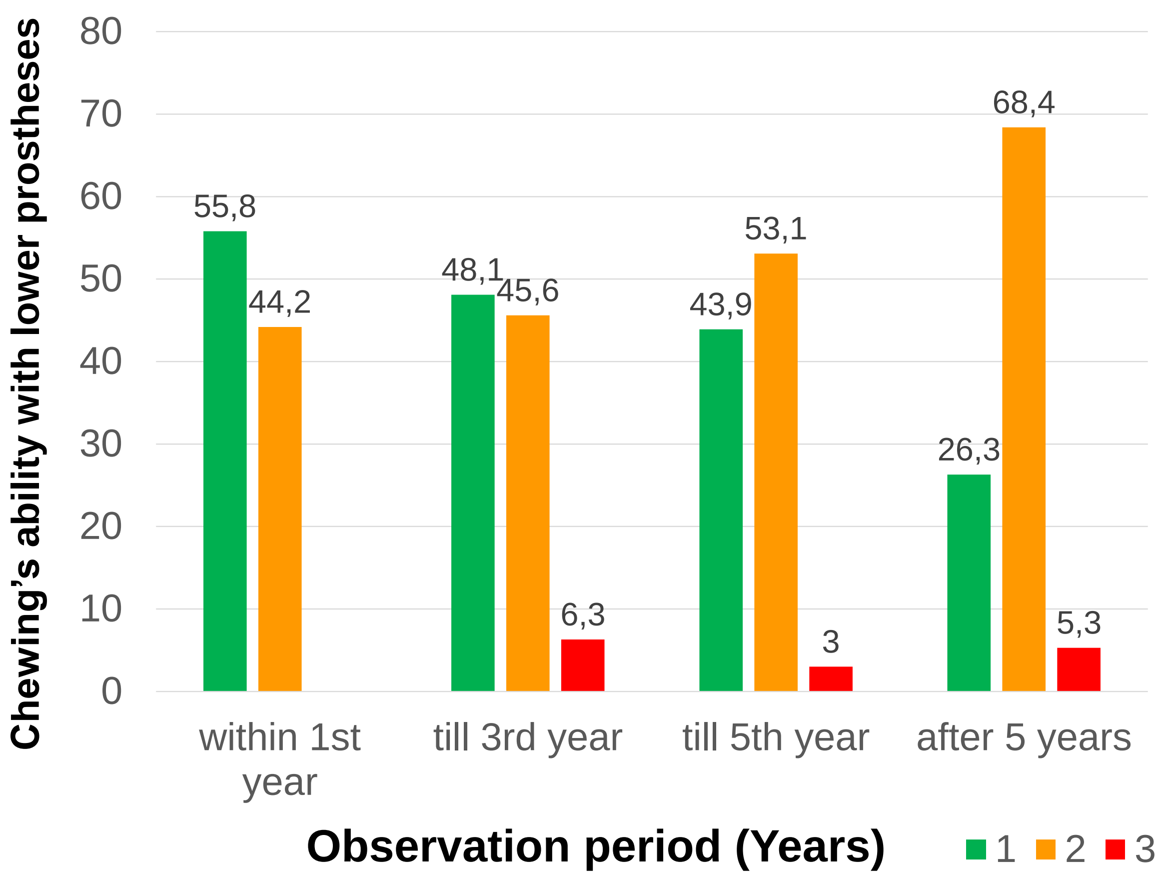

Figure 19 Distribution of the chewing ability of the patients with their lower prostheses over the observation period in years.1: very satisfied; 2: satisfied; 3: not satisfied.

3.5 Dental complications

The encountered complications were distributed to 325 visits, comprising 177 visits for the upper jaw and 148 visits for the lower jaw. Out of 357 abutments included in this study, around half (52%, n=188) of the abutments experienced dental complications. The affected abutments were 109 (58%) in the upper jaw and 79 (42%) lower abutments. Some abutments experienced complications more than once during the observation period. Out of 102 patients included in the study, 68 (66.6%) experienced dental complications. Two thirds (n=44) were men and the other third (n=24) were women. The mean observation period of these complications was 4.7 years, as illustrated in Figure 20.

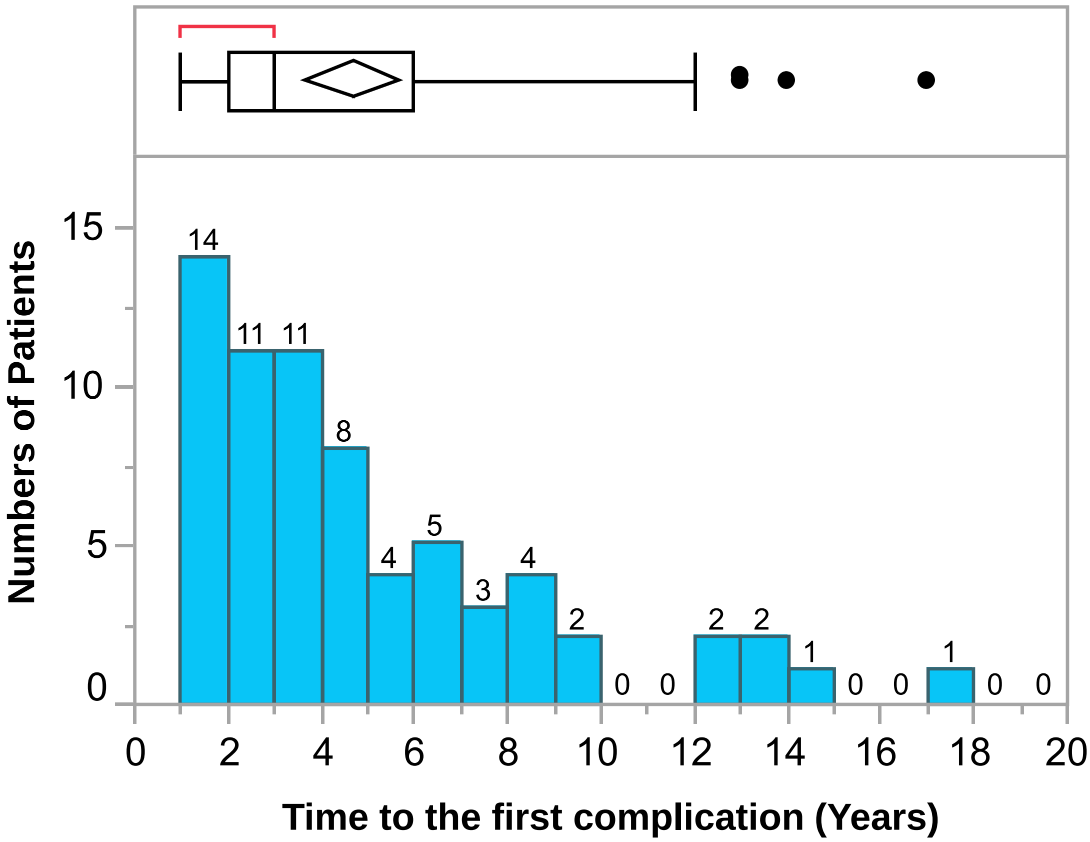

Figure 20 Distribution of the patients who encountered dental complications. The observation period is in years. The mean observation period was 4.7 years as illustrated in the boxplot in the upper part of the diagram.

3.5.1 Description of the dental complications

The most encountered dental complications were periodontal complications, with 170 abutments affected. This represents almost half (47.6%) of the included abutments in this investigation. The mean observation time for this complication to take place was 40.8 months. Dental caries, either cervical or secondary, was the second encountered complication, occurring in 55 abutments and representing around 15% of the total abutments. Although it was the second most presented complication, it was the latest to happen, with an average observation time of 61.7 months. Interestingly, 50 (14%) of the abutments were fractured, with a mean observation period of 39.8 months. Loss of retention took place in 43 abutment teeth (12% of the total abutments). This complication was the fastest to occur, with a mean observation time of 38.3 months.

Finally, endodontic complications occurred in 37 (10%) of the total abutments, with an average observation period of 45.1 months, as presented in Figure 21.

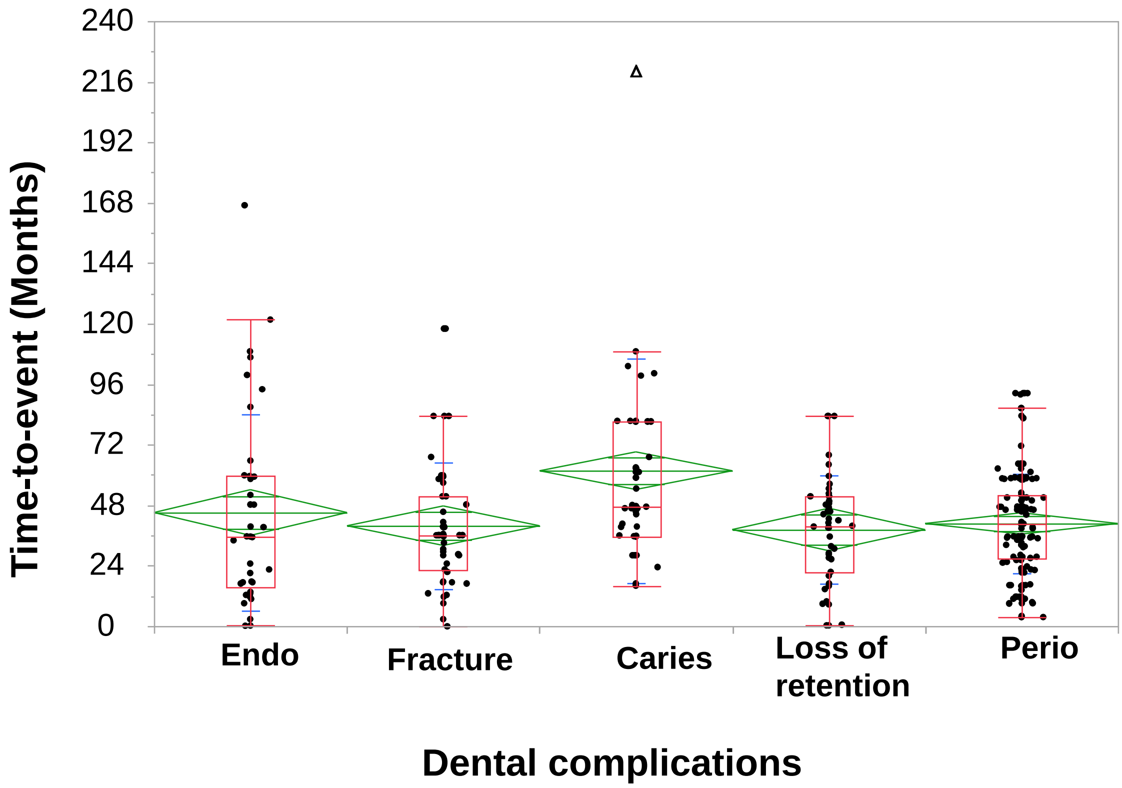

Figure 21 Description of the dental complications and their timing in months. The most common were periodontal complications, and the least common were endodontic. Loss of retention was the earliest complication, and dental caries was the latest to occur.

The extraction of abutments is considered an irreversible complication. This affected 53 abutments, which represents around 15% of the total. Most of the extracted abutments were in the maxillary jaw, with a sum of 30 abutments, and 23 mandibular abutments were extracted. This kind of complication occurred in 29 patients. The mean observation period for this complication to take place was 54.5 months, as illustrated in Figure 22.

The main predisposing factor to extraction was periodontal problems, with a total of 22 abutments; followed by fracture, with 18 abutment teeth. Seven teeth were extracted due to dental caries and five abutments because of loss of retention. Interestingly, just one abutment was extracted due to endodontic complications, as shown in the matrix in Figure 23.

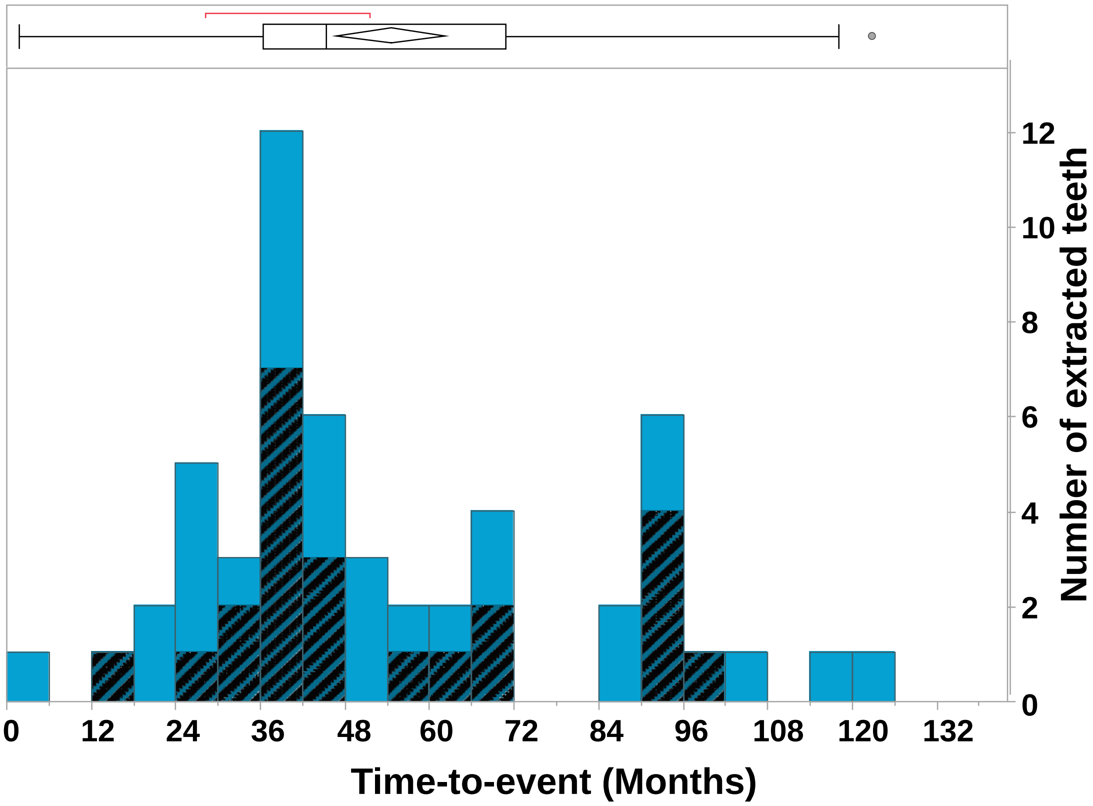

Figure 22 Distribution of the extracted teeth with the timing of their occurrence. Time-to-event (TTE) is monthly. The mean time of occurrence of this complication was 54.5 months, as illustrated by the boxplot in the upper part of this diagram. The shaded bar areas represent the lower jaw.

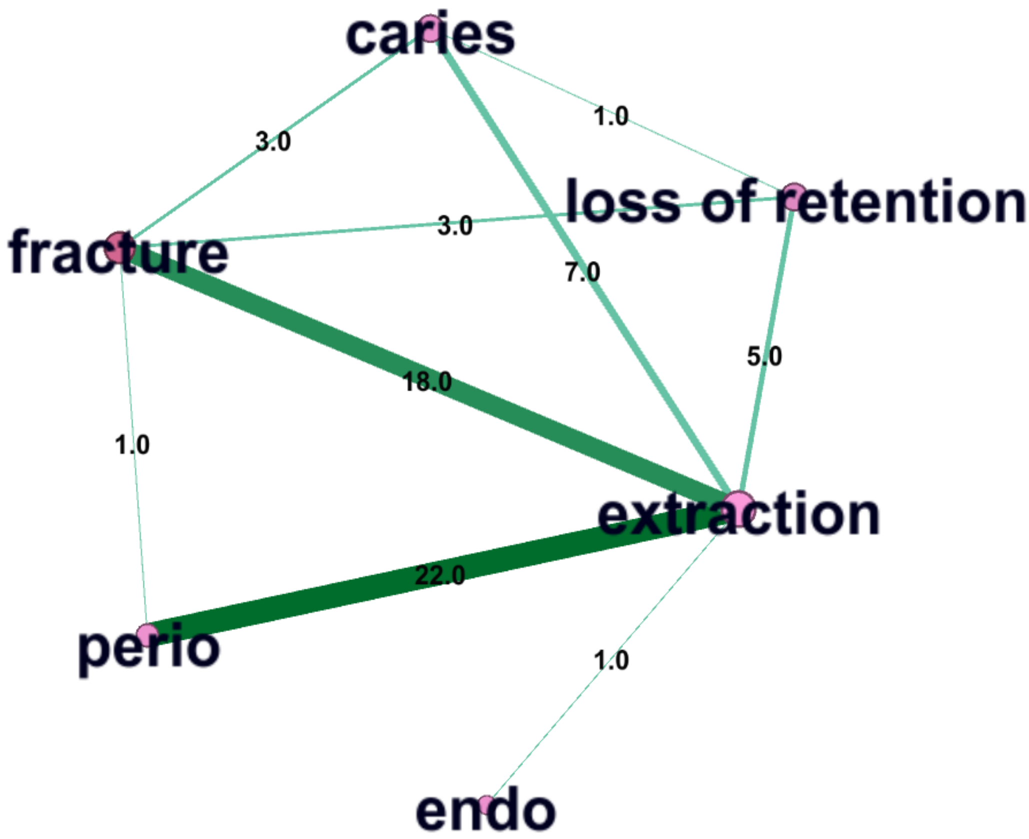

Figure 23 Description of the predisposing factors to dental extraction. Loss of retention led to five extractions and caused three fractures and one dental caries. Dental caries caused seven extractions and led to three fractures. Eighteen fractures led to extraction, and one fracture caused a periodontal complication. Periodontal diseases caused the most extractions, with a sum of 22 abutments, whereas just one abutment was extracted because of an endodontic complication.

3.5.2 Description of the affected abutment teeth

Generally, the most affected abutments (n=82) were canine teeth, representing 23% of the whole number of included abutments (n=357). The molars were the least affected at 4.7% (n=17). In the upper jaw, the second most affected abutments were the incisors (8.6%, n=31). In the lower jaw, the second most affected abutments were the premolars, at 8.4 % (n=30), as illustrated in Table 4 and Figure 24.

	Upper jaw		Lower jaw	
	N	%	N	%
Incisors	31	9%	6	2%
Canines	46	13%	36	10%
Premolars	22	6%	30	8%
Molars	10	3%	7	2%

Table 4 Distribution and percentage of the abutment teeth affected with dental complications. Canine teeth were the most affected, and the molars were the least affected. The percentages presented here are in relation to the whole number of included abutments (n=357). These percentages were rounded either up or down.

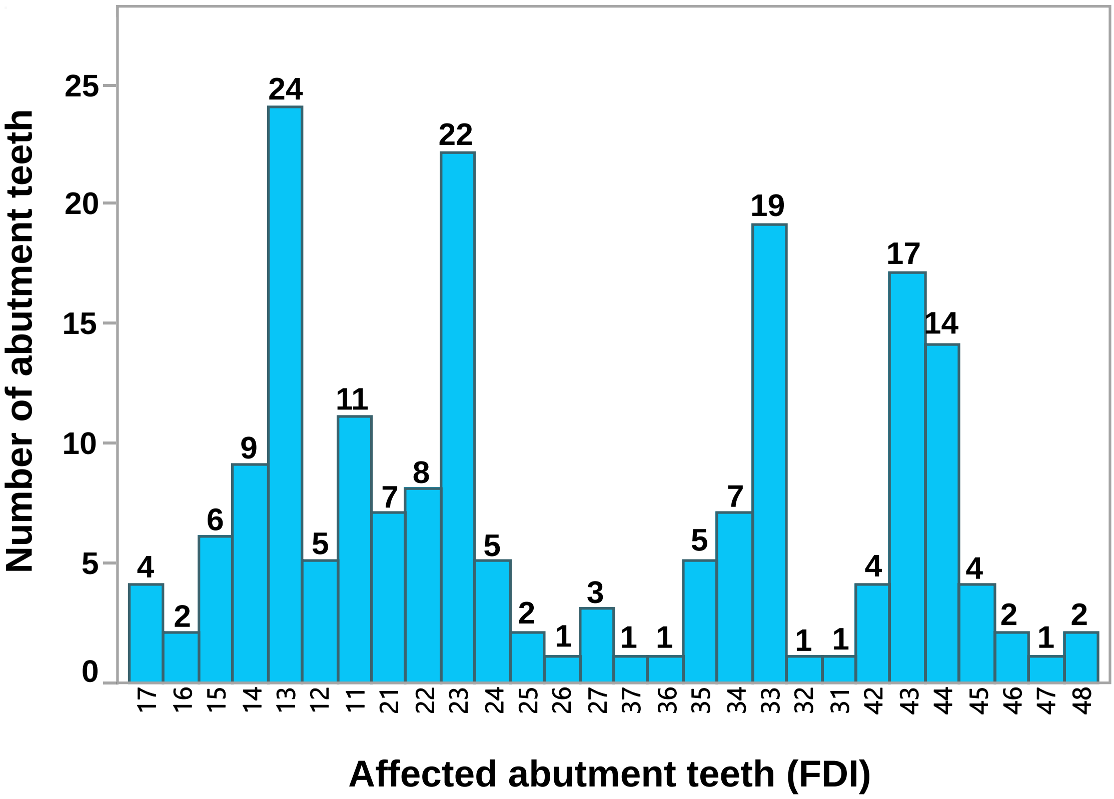

Figure 24 Distribution of the abutment teeth affected with dental complications. Canine teeth were the most affected, and molars were the least affected.

Most of the extracted abutments of the upper jaw were canine teeth, with the highest number of extractions (n=14) under Steffel class A. The incisors were the second most frequently extracted abutments, with a sum of nine, and the highest in class B with a total of three teeth. Ten premolars and molars were extracted, with five abutments under each category, as shown in Figure 25.

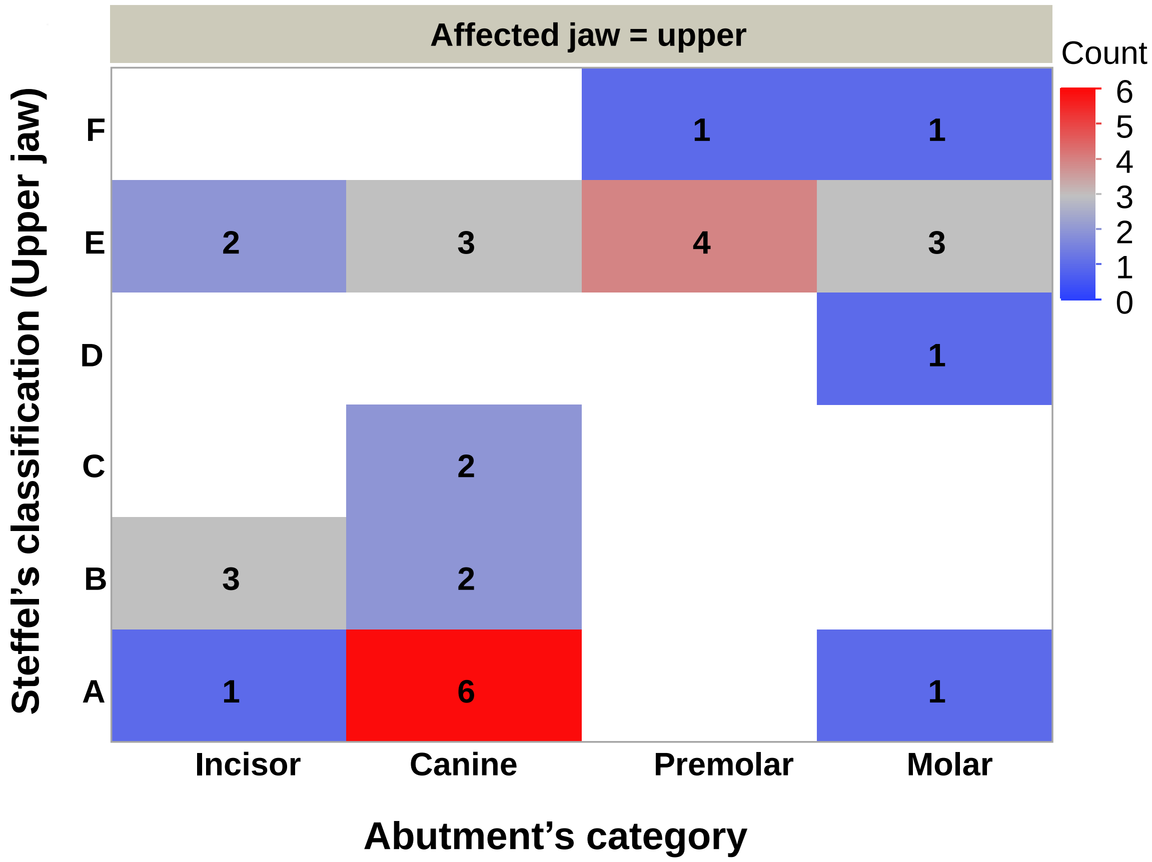

Figure 25 Distribution of the extracted abutments in the upper jaw according to their category and Steffel classification. Most of the affected abutments were canines, with the highest peak of six abutments in class A as illustrated in red.

Figure 26 illustrates the distribution of the extracted abutment according to their anatomical categories. Sixteen abutments under canines and premolars were extracted, with eight abutments to each category. The highest number of extracted canines was seven in Steffel class B, and four was the highest number of premolars in class C. Just three incisors and four molars were extracted.

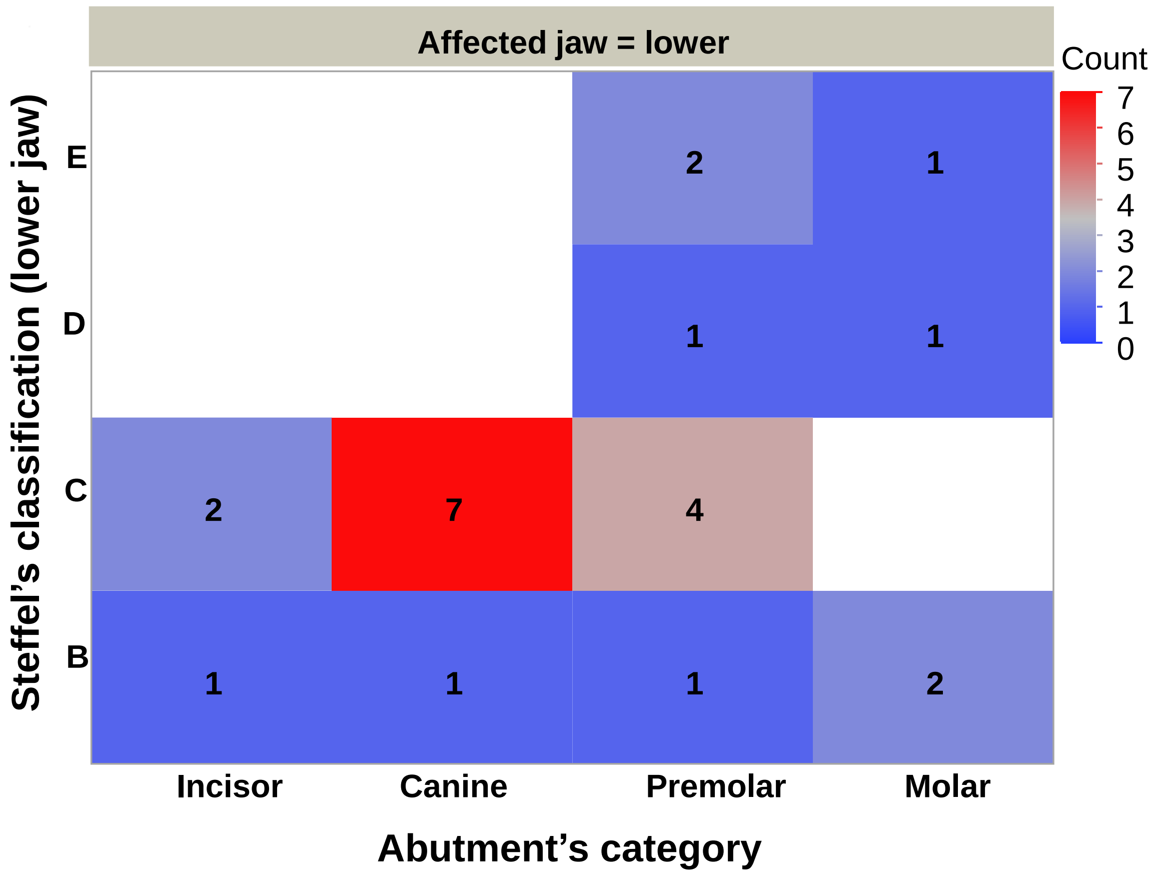

Figure 26 Distribution of the extracted abutments in the lower jaw according to their category and Steffel classification. Most of the affected abutments were canines, with the highest peak of seven abutments in class C as illustrated in red.

3.5.3 Description of the affected abutments according to Steffel classification and timing

Of the 188 affected abutment teeth, 109 were upper abutments, and 79 were in the lower jaw. In the upper jaw, most of the affected abutments were included in Steffel class E (n=47), followed by class C (n=25). The fewest abutments were found in class D (n=4). The other affected abutments were distributed to the other classes as shown in Figure 27.

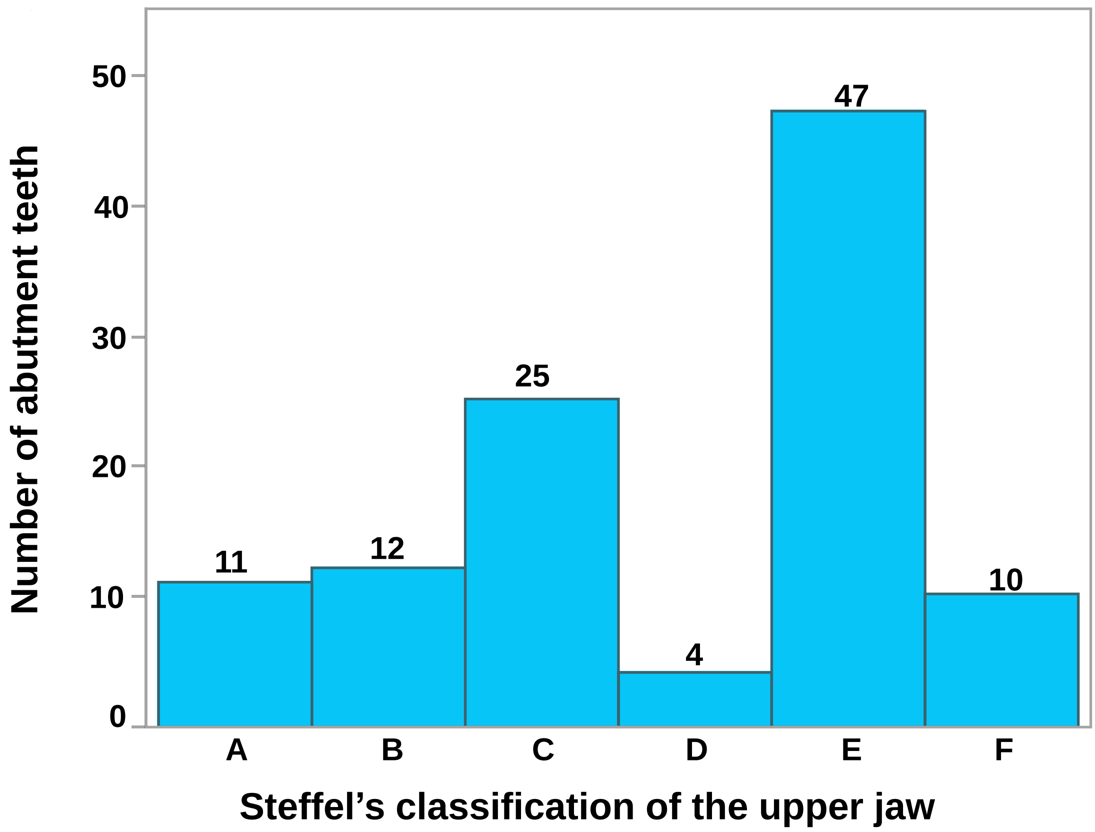

Figure 27 Distribution of the abutment teeth affected with dental complications according to Steffel classification in the upper jaw. The majority of the affected abutments were in class E, and the least affected were in class D.

On the other hand, just 79 abutment teeth were affected in the lower jaw. The majority of the affected abutments belonged to Steffel class C (n=34), and the second most affected abutments were under class E (n=21). The fewest affected abutments were in class A, and the other abutments were distributed to the other classifications as illustrated in Figure 28.

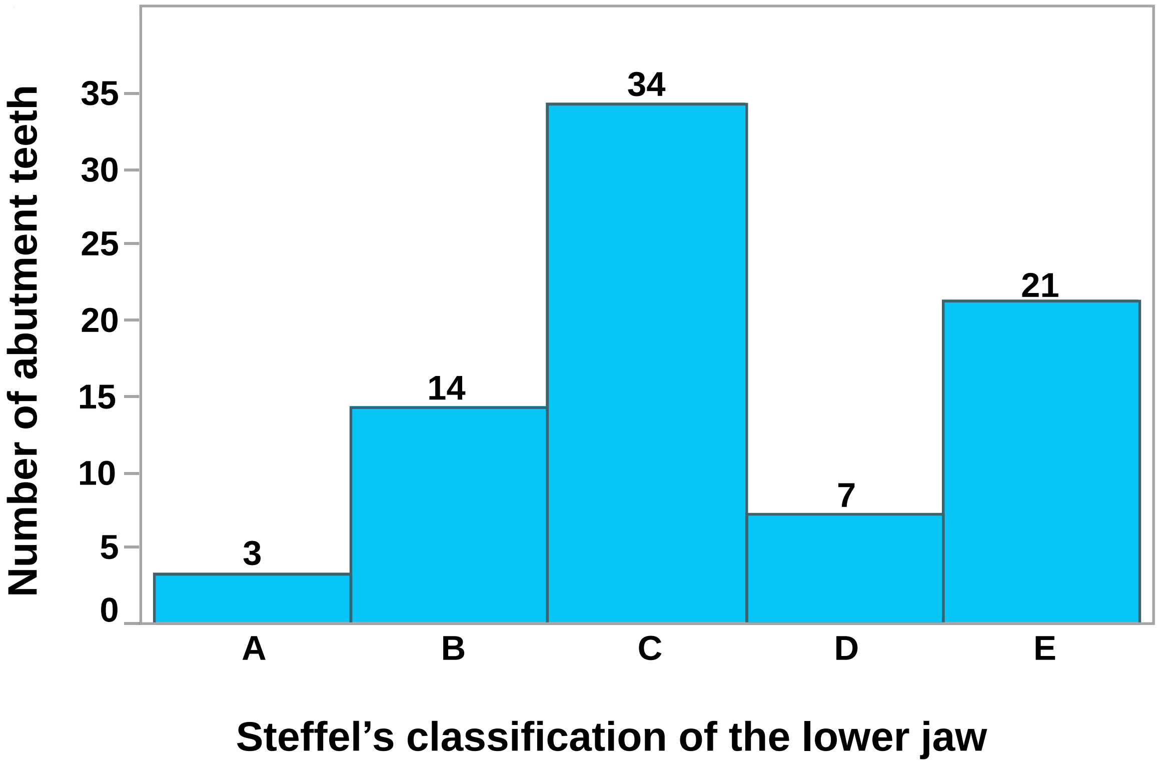

Figure 28 Distribution of the abutment teeth affected with dental complications according to Steffel classification in the lower jaw. The majority of the affected abutments were in class C, and the least affected were in class A.

The occurrence of these complications by observation time and Steffel classification is illustrated in Figure 29. This significantly shows the slowest complications to occur with an average observation time of 57.7 months in class E in the upper jaw. In contrast, the fastest complications took place in class A, with a mean time to event of 31.5 months. Classes D and F showed an average time to event of 52 months, and classes B and C showed a mean of time to occurrence of complications of 36.4 and 37.2 months respectively.

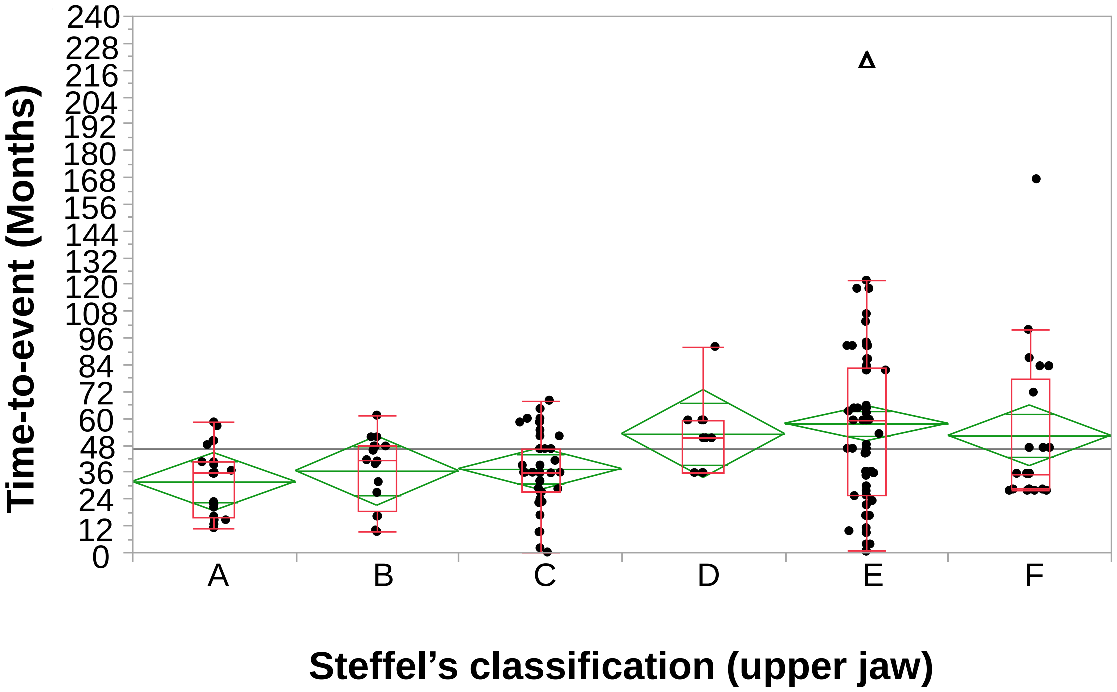

Figure 29 Distribution and timing of dental complications in the upper jaw according to Steffel classification. Class E was significantly the earliest in dental complications, whereas class A was the latestt.

In the lower jaw, the results show a different picture of distribution. Class A showed the significantly slowest detection of complications at 89.7 months, followed by class D with a mean time to event of 57.3 months. Class C showed the fastest mean time to event of 39 months. Classes B and E showed mean times to event of 45 and 41.9 months, respectively, as shown in Figure 30.

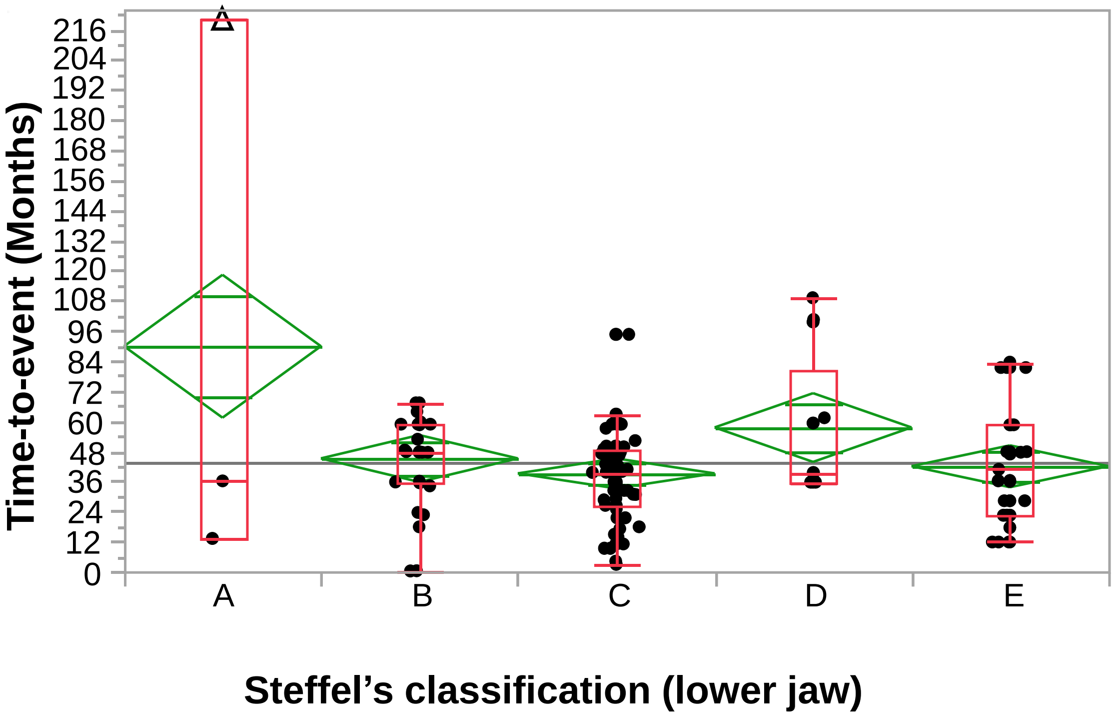

Figure 30 Distribution and timing of dental complications in the lower jaw according to Steffel classification. Class was significantly the earliest in the occurrence of dental complications, and class C was the latest.

According to the time-to-event (TTE) in the upper extracted abutments, the canines showed the fastest extractions with a mean time of 43 months, whereas the incisors and molars showed an average of 64 months and molars 60 months. Regarding the lower abutments, the incisors were the fastest to be extracted, with an average time of 35.9 months. The canines and premolars were extracted in an average time of 57 months and the molars in 58 months, as shown in Figure 31.

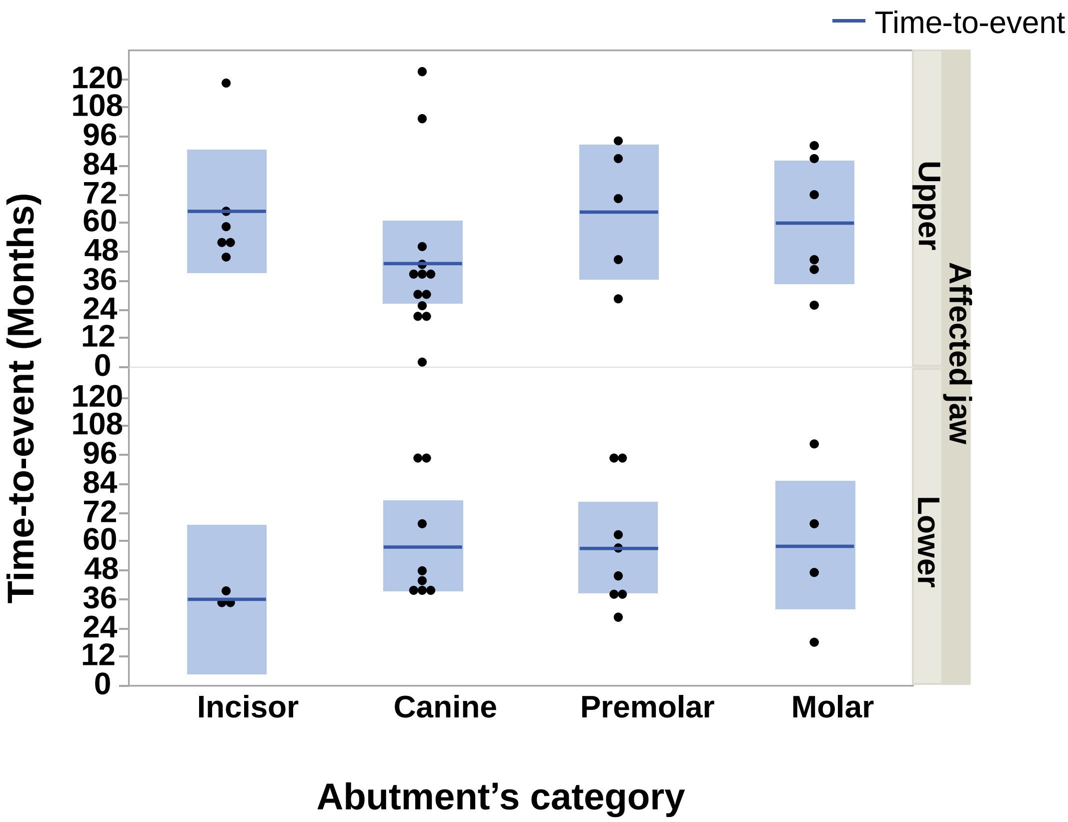

Figure 31 Distribution and timing of the extracted teeth according to their categories. Time-to-event (TTE) is calculated in months.

3.6 Prosthetic complications

3.6.1 Loss of retention and need for relining

The most frequent complication was the loss of retention of the prostheses and the need for relining. In total, 78 relining procedures were required in 49 prostheses in 44 patients. Of these, 14 prostheses were relined twice, seven prostheses trice, and one prosthesis four times. These were distributed as 51 in the upper jaw and 27 in the lower jaw.

This represents 40% of the total number of investigated prostheses and 43.1% of the total number of patients. On average, the need for relining occurred 30 months post insertion of the prostheses. Figure 32 illustrates the first incidence of the relining procedures of the 49 prostheses and their timing in months. Thirtytwo relining procedures took place in the upper jaw and only 17 in the lower jaw. This represents two third (65%) of the prostheses of the upper jaw that underwent relining procedures, and one third (35%) of the lower ones underwent the same procedure. The mean time of the onset of the relining was 30 months (SD: 26.1 months), and the median was 24 months.

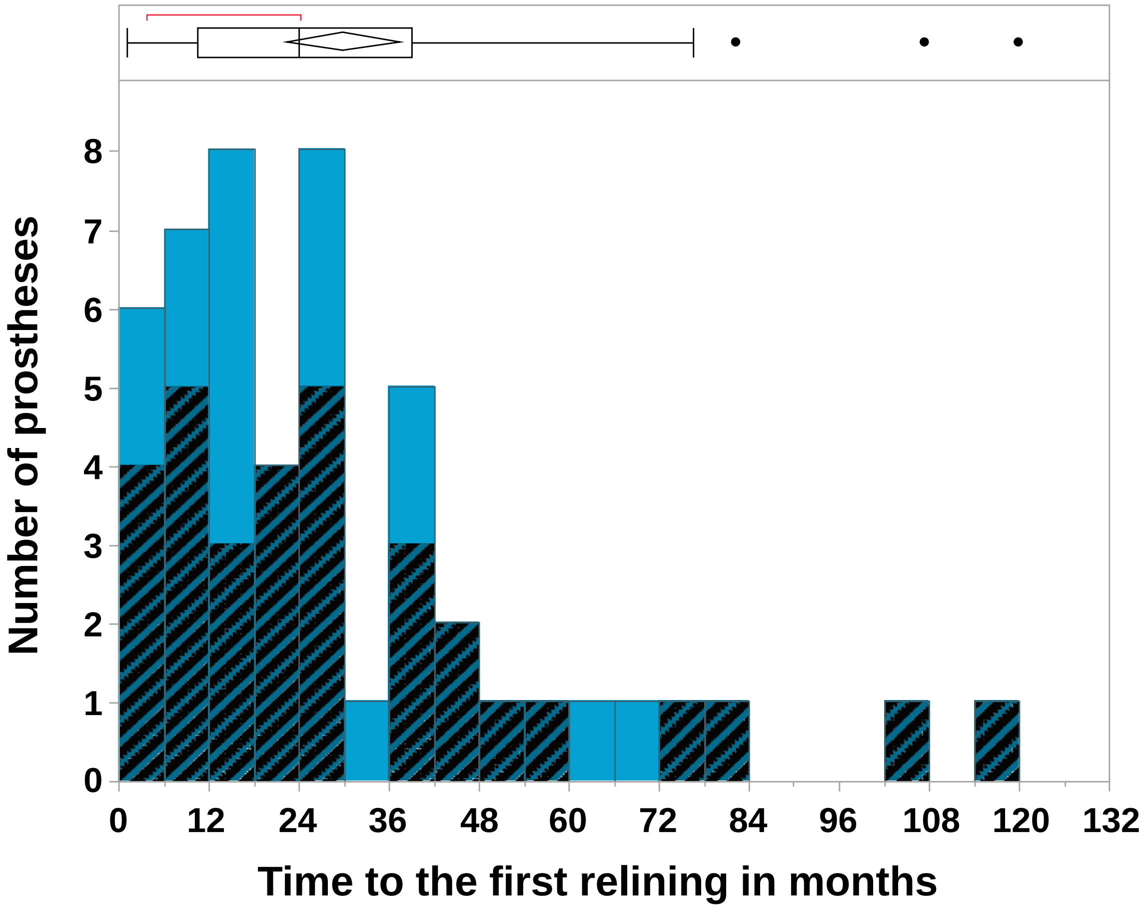

Figure 32 Distribution of the first relining procedures in months. The shaded parts represent the upper jaw. In the upper part of the diagram, the boxplot represents the mean time of occurrence of this complication.

Figure 33 shows the difference between the successive relining procedures. Nineteen upper prostheses were relined many times, and 10 lower ones underwent successive relining. The mean time difference between the first and second relining was 25.87 months, but the median time was 12 months. During this period, 14 upper prostheses were relined.

However, the mean time difference between the second and third relining visits was 30.2 months, with a median of 20 months. This took place in four prostheses. Just one case needed to be relined for a fourth time, with a mean time of 26 months and a median of around three months.

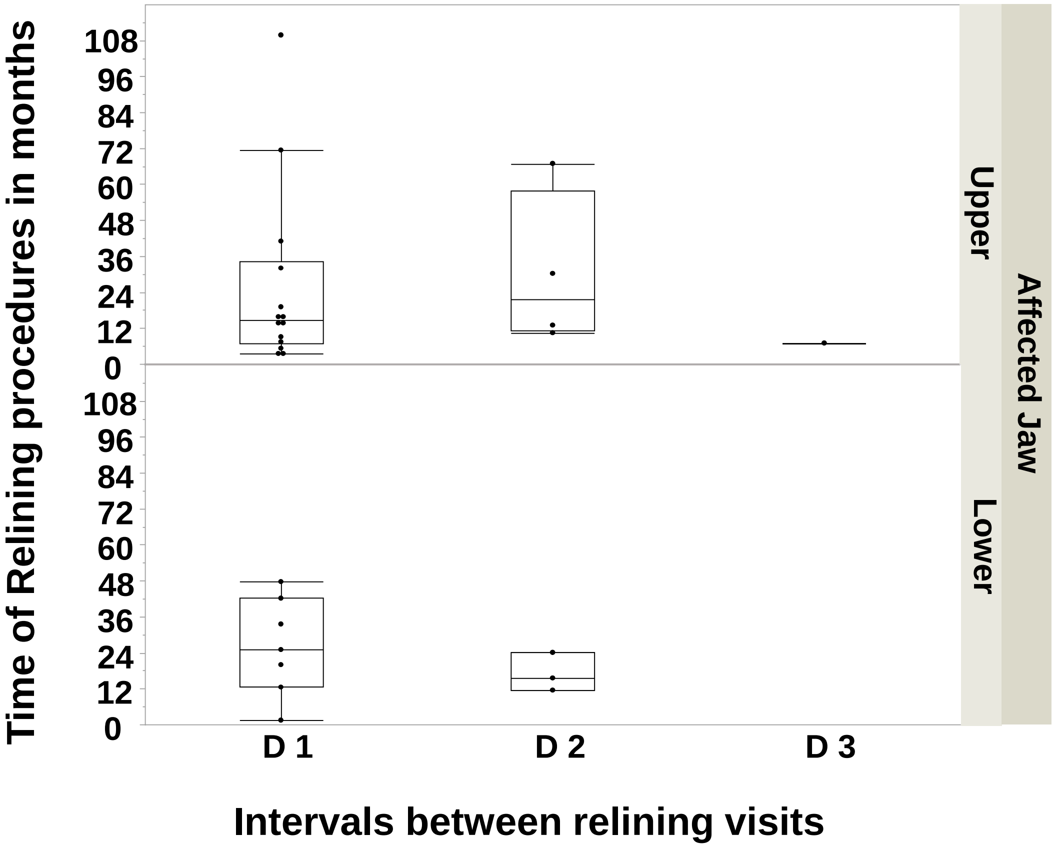

Figure 33 Distribution and timing of the successive relining appointments in months. D1: the difference between the first and second relining appointments; D2: the difference between the second and third relining appointments; D3: the difference between the third and fourth relining appointments.

On the lower jaw, the picture was different, with a mean time difference between the first and second relining visits of 26.1 months and a median of 24 months. This took place in seven cases. Interestingly, this timing dropped to a mean of 17.1 months and a median of 12 months during the third relining procedure.

Figure 34 andFigure 35 show the relevant data about the relining procedures and their median timing according to Steffel classification.

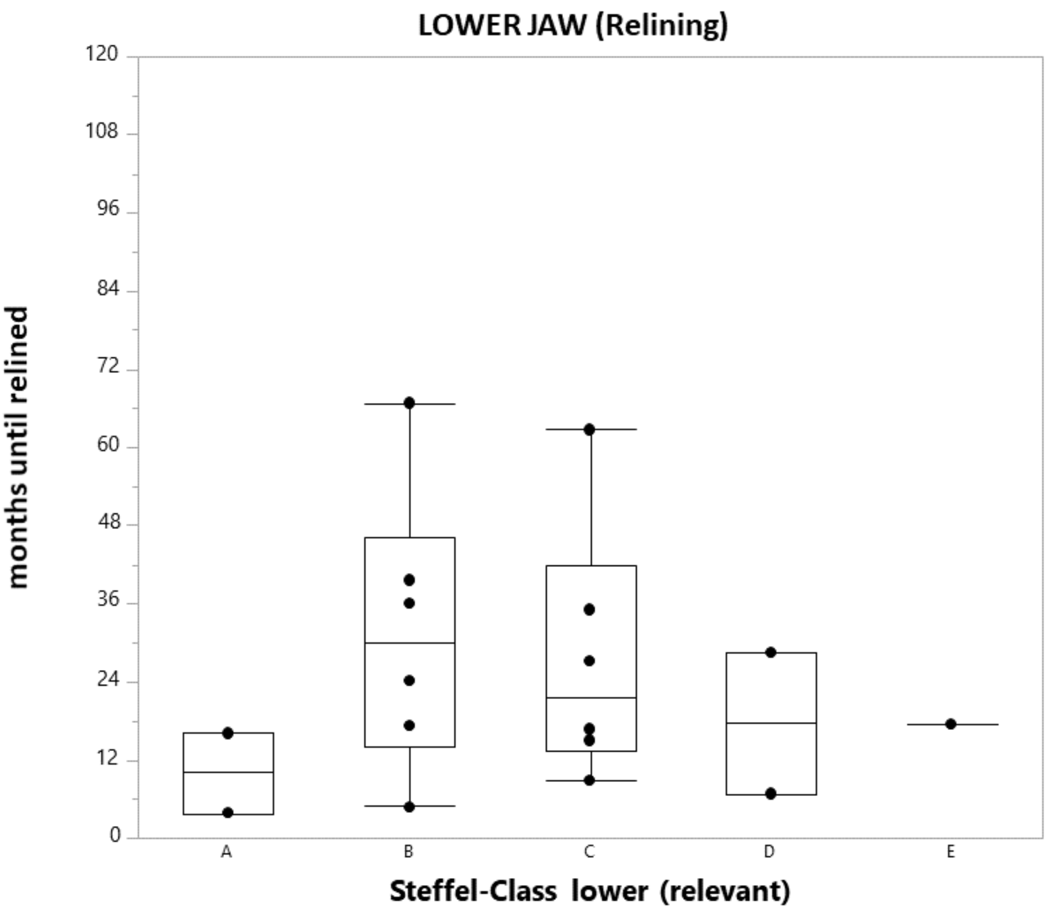

Figure 34 Distribution of the relevant data of the relining measures according to Steffel classification in the lower jaw.

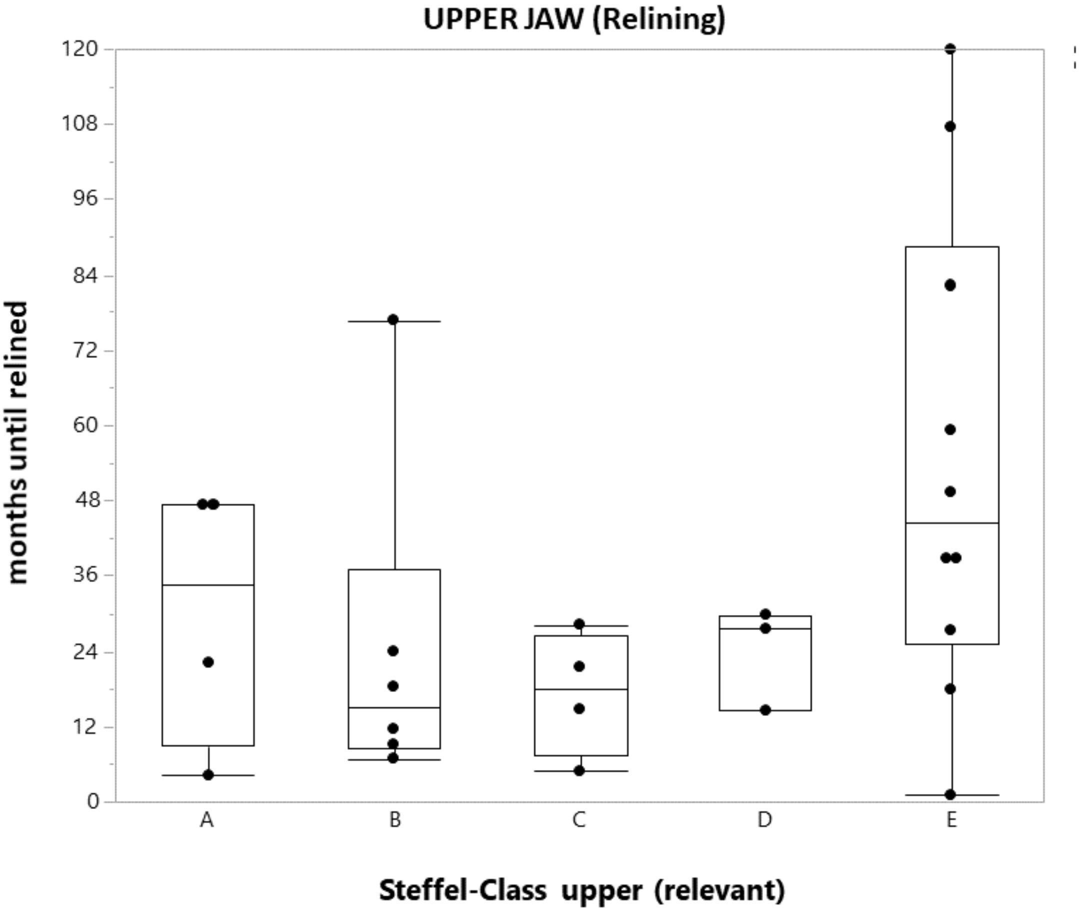

Figure 35 Distribution of the relevant data of the relining measures according to Steffel classification in the upper jaw.

The data showed a mean time of relining of Steffel class A in the upper jaw of 30.3 months and in the lower jaw of 10 months. Interestingly, class B showed a mean time of 18.9 months in the upper jaw, compared to 31.4 months in the lower jaw. For class C, the average time of relining in the lower jaw was 19.4 months in comparison to 27.6 months in the lower jaw. The relining measures took place in a mean time of 24 months in class D cases in the upper jaw and 17.7 months in the lower jaw. Class E in the upper jaw showed the highest mean time of relining procedures, at 54.3 months, compared to 17.5 months in the lower jaw. No cases were found in the lower jaw with class F. The mean time of relining in the upper jaw for class F was 38.9 months.

3.6.2 Loss (chipping) of acrylic veneering

51 veneer repairs had to be carried out in 24 prostheses of 21 patients. On average, these events occurred after 49 months on average, with the shortest time for veneer chipping being 2 weeks and the longest 10 years, mostly affecting the upper anteriors (n=40, see Figure 36). This means that in 456 regions (FDI=13-23 in 76 prostheses) barely every 10th vennering was affected by a visible fracture which has to be repaired.

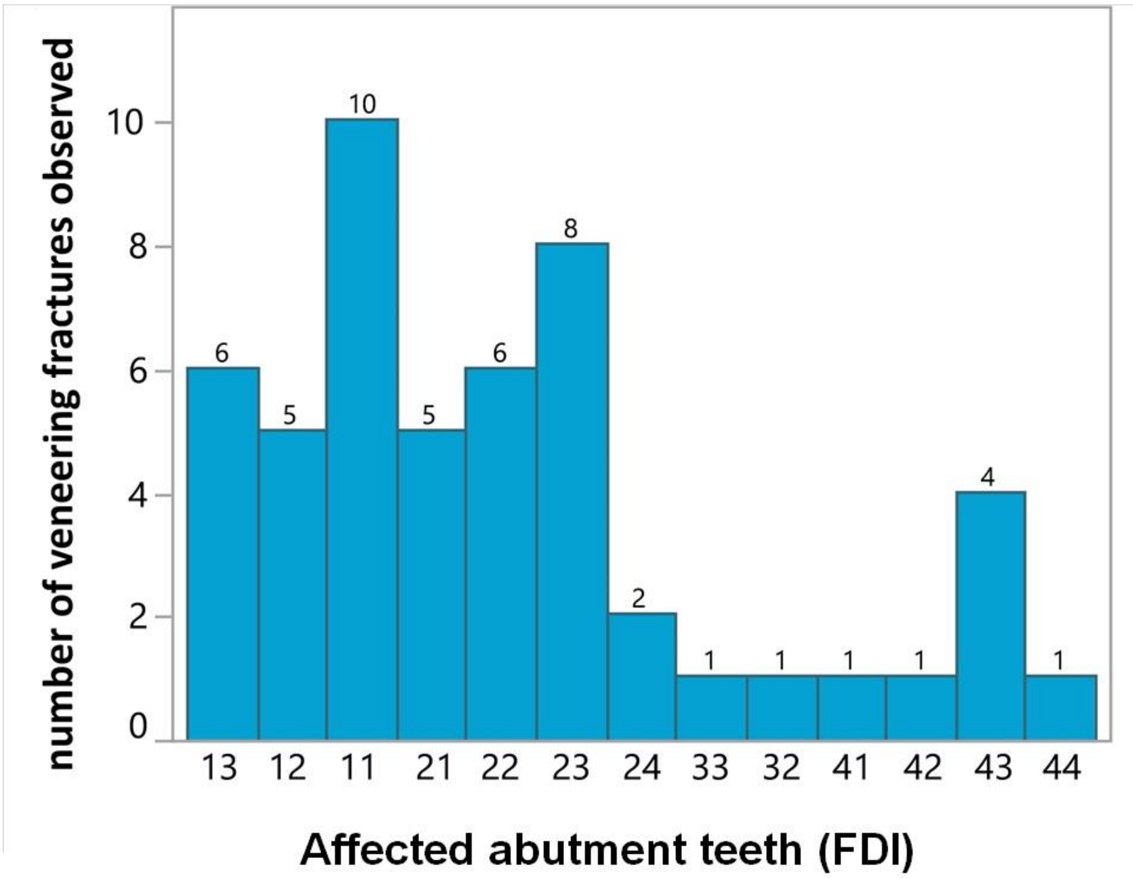

Figure 36 Number of veneering fractures distributed to the FDI-regions of the prostheses observed within the cohort.

4 Discussion

4.1 Discussion of the methodology

Reconstructive dental measures in patients with severely reduced dentition show significant challenges. This is mainly due to the medical and dental morbidities in older patients. Therefore, the therapeutic measures can vary significantly, from the extraction of remaining teeth and fabrication of complete dentures to implant-supported prosthetic options. In general, HDC-RPDs are considered a reliable treatment modality for patients with severely reduced dentition situations in Germany.

This study evaluated the prosthetic and dental complications associated with HDC-RPDs in severely reduced dentition.

4.1.1 Study design

Observational epidemiological and clinical studies are divided into longitudinal studies, case-control studies, and cross-sectional studies (Jones, 1992). This was a longitudinal clinical study to assess the dental and prosthetic complications of severely reduced dentition patients who were treated with HDC-RPDs. The data were collected retrospectively but analyzed prospectively; therefore, the direction of the design remained forward.

Such studies can be time-consuming. However, they can be carried out at low cost. The results of the present study could, on the one hand, be influenced by various factors such as the decisions of the observing dentists, the treatment skills of the students, the quality of the dental laboratory, or the individual initial situation of the patients themselves. On the other hand, all study participants were treated by students as part of the clinical courses in the department of prosthodontics, whereby the treatment processes were specified and the individual steps were checked by assistant dentists and senior doctors. Accordingly, a certain homogeneity existed in the acquired data. Of course, work experience may plausibly impact the survival of prostheses (Bishti et al., 2018).

Consequently, a comparatively inexperienced student could remove more of the hard tooth substance when preparing the abutment teeth than an experienced dentist who has been practicing for a long time. This could have a negative effect on the degree of convergence of the preparation or the susceptibility to fractures, as well as loss of retention. This may jeopardize the survival rate of the abutment teeth and eventually the prostheses.

The obtained data were extracted from the patients' medical records and the specially designed CRFs (as explained in 2.1) to acquire a complete overview of the restorations and the documented changes over time. Due to the sometimes irregular attendance of the patients to the scheduled recall appointments, the detailed documentation and traceability of the complications that occurred were sometimes incomplete and difficult. Furthermore, the detailed documentation of the treatments was very much dependent on the documentation of the student or the treating dentist in the emergency department. Consequently, the incompleteness of the documentation may reduce the validity of the study.

Notably, the data collection in retrospective studies depends on the quality of the file entries. These are often not comparable with each other due to changing practitioners, spelling mistakes, and incomplete documentation. Therefore, to maintain a high quality of data and avoid the chances of failed documentation, a structured clinical follow-up examination took place during this study. This might have increased the validity of the data but with a much higher effort and unpredictable recall rate in the sense of patient availability and presence at the follow-up appointments. Moreover, the data were analyzed carefully, and their correctness and plausibility were checked to gain and extract trustable data from the database.

Generally, most of the studies published about the complications of double-crown removable partial dentures were retrospective. However, prospective longitudinal studies exist, such as the study conducted by (Mock FR et al., 2005) in their investigation of the long-term survival probabilities and success rates of parallel-walled telescope-supported prostheses. A similar design to our study was the investigation carried out by (Müller-Koelbl, 2019), which evaluated telescopic dentures over 20 years.

In such studies, the patients were regularly clinically examined. Regular clinical follow-up examinations allow the complications that have arisen, the relationships, and the condition of the prostheses to be better evaluated. For example, a tooth may have been extracted for a variety of reasons, such as apical periodontitis as a result of unsuccessful endodontic treatment, loosening of periodontal ligaments due to unfavorable loading by supporting elements, or caries.

This study did not record the patient's general health status and corresponding medications. Including general health conditions would allow for determining the factors that further influence the prognosis of the denture. One example is the loss of salivary flow caused by xerostomia due to drug or radiation therapy, which can affect oral hygiene procedures.

In the present study, the statistical evaluation was carried out with the JMP statistics program (JMP, SAS-Institute, USA).

4.1.2 Study population and restorations

Overall, 102 patients provided with 122 with HDC-RPDs supported on 357 abutment teeth were included for data analysis. These numbers are relatively high compared to another study (Szentpétery and Setz, 2015) that examined 74 patients with 82 prostheses supported over 173 abutment teeth. Additionally, Müller-Koelbl examined the same number of patients with 82 prostheses over abutment teeth(Müller-Koelbl, 2019). Other studies have evaluated more patients and abutments, e.g., a group at Göttingen University evaluated 221 patients with 263 prostheses supported over 538 abutment teeth (Rinke et al., 2019), and (Reinhold, 2021) examined 329 patients with 464 prostheses and 1566 abutment teeth.

4.1.2.1 Age distribution

In the present study, the average age of the patients included in the evaluation at inclusion was 61 ±10 years (age range 37 to 81 years). This is similar to the age data from a study by a group at Halle University (Hinz et al., 2020), where the mean age was 62 ± 12 years. In other studies, similar data on mean age can be found (Behr et al., 2000, Rinke et al., 2019).

One possible explanation for this age group may be that most patients with severely reduced dentition are elderly and perhaps more flexible in terms of time, so they have chosen treatment in a student course at a university hospital.

4.1.2.2 Observation period

The maximum recorded observation duration was 17.75 years, and (due to inclusion criteria) the minimum was 2.9 years, with an average observation period of 6.5 ±3 years. This corresponds to the study of (Werdecker, 2003), which had a mean of 6.33 years of observation time. Similarly, (Stark, 1996) showed an average of 6 years of observation. This duration is considered high compared to other studies, such as (Hinz et al., 2020), who had a mean of 3.3 years of observation, and (Hofmann et al., 2002), who had a mean of 4.2 ±1.7 years of observation. It has to be highlighted that the obervational period is limited to ~15 years with regard to age of the patients on prostheses delivery and their life exspectation. Therewith, about 7 years of mean observation time gives an insight of complications to expect on have of the service time; but denies a prediction of complication and failure rates at the end of patients life.

4.1.2.3 Gender distribution

In this study, the proportion of men (63; 64.25%) exceeded that of women (39; 35.75%). The same can be found in the literature on double crown technology, such as (Rinke et al., 2019), who included 122 men compared to 100 women. Other studies have shown more women in comparison to men (Wöstmann et al., 2007, Dittmann and Rammelsberg, 2008)

4.1.2.4 Distribution of prostheses

The distribution of maxillary and mandibular prostheses was 56.5% (n=69) to 43.5% (n=39), respectively. This distribution is compatible with the data in Germany (Schwendicke et al., 2020), and the ratio corresponds to the values in the literature. Maxillary prostheses predominated, and the percentages varied between 54.45% and 76% (Widbom et al., 2004, Mock FR et al., 2005). An explanation could be the bone quality and progress of periodontal diseases in the maxillary arch (Bertl et al., 2020).

4.1.2.5 Distribution of abutments

The choice of a maximum of four abutments in each jaw was based on the definition of Niedermeier of severely reduced dentition situations (Niedermeier, 1988). He defined it as dentition with maximally four teeth in the jaw. The reason for this selection was to increase the number of participants in the study and determine the effect of the distribution of the supporting polygon on the complication rate.

Of 375 abutments, more abutment teeth were used for anchoring the upper HDC-RPDs, with a sum of 201 compared to 156 in the lower jaw prostheses. This contrasts with other studies where more lower abutments were included; (Werdecker, 2003) showed 276 abutments in the upper jaw and 290 in the lower jaw, and 376 upper abutments and 397 mandibular abutments were shown in another investigation (Hinz et al., 2020). This distribution agrees with the upper mentioned data about the number of maxillary prostheses, which exceeds the mandibular ones. Of the included abutments, 45% were canine teeth, with a total of 163 out of all 357 abutments, whereas just 24 molar abutments were included. An explanation for this distribution is that more posterior teeth are affected by dental caries and periodontal diseases; therefore, they are extracted more frequently than anterior teeth (Reich and Hiller, 1993, Alesia and Khalil, 2013).

4.1.2.6 Restoration of the opposing jaw

Opposing dentitions were also included in the assessment to allow us to investigate possible associations with the encountered complications. This was subsequently subdivided into three groups of antagonistic prostheses or teeth. Approximately two thirds (62.2%) of patients had double-crown prostheses on both jaws. Complete dentures were the second most frequently seen on the contralateral jaw (20.5%), followed by natural teeth and/or FDPs (17.3%). These results contrast with those of (Molin et al., 1993, Hupprich, 2015), where more FDPs and natural opposing dentition were reported.

The opposing dentition also conceivably may have affected the survival of the HDC-RPDs. However, this correlation was not considered in this study because the restoration of the opposing jaw could have changed several times during the observation period.

4.1.3 Selection of classification system of partial edentulism

The Steffel classification is considered the most appropriate classification system in cases with severely reduced dentition because it explains the supporting lines and kinematic of the prostheses (Steffel, 1962). Accordingly, in our study, one third of the total number of prosthesis cases were classified as Steffel class C, one quarter were class E, 12% were supported punctually (class A), and the rest belonged to the other classes. The minority (5%) of prostheses belonged to class F. In the literature, more than 40% of the prostheses were reported to belong to class E (Szentpétery and Setz, 2015, Hinz, 2018), and the least used punctual support (class A). Another investigation showed that half of the prostheses used polygonal support, either triangular or quadrangular (Hupprich, 2015).

However, certain inaccuracies may occur because the classification was strictly according to the tooth location according to the FDI scheme. To solve this problem, a new and detailed explanation scheme is proposed in chapter 2.8.3. Another issue could be the migration of the abutment teeth, which could be misdocumented. This problem may lead to inaccuracies in estimating the survival probability of the abutment teeth when analyzed.

4.2 Discussion of the results

The advantage of this study was that various comprehensive parameters related to patient characteristics, abutment tooth condition, and restorations were recorded. We individually investigated the correlation between the events that occurred and the various parameters.

4.3 Objective assessment of the prostheses by the examiner

The hygiene of the prostheses showed a gradual drop within the years of observation. Within the first year, around two thirds of the upper and lower prostheses showed good hygiene in the context of no plaque accumulation detected. This positive hygiene practice dropped after five years to just one third; in between, 40–50% of prostheses exhibited no plaque accumulation. A logical interpretation of these results could be that the older the patients, the more difficult it is to maintain good hygiene practices. Additionally, the loss of retention and need for relining measures plays a major role (Lauritano et al., 2019).

While interpreting these results, some critical points should be noted. Firstly, the overall dental and oral hygiene of the patients and their practices were not planned in this study and therefore not documented. Secondly, the wearing time and frequency were not documented. These points may have influenced the interpretation of the data.

4.4 Subjective assessment of the prostheses by the patients

Studies frequently address patient satisfaction with dental prostheses among other questions. In some cases, authors use a specially developed comprehensive questionnaire (Molin et al., 1993, Wostmann et al., 2008, Kothe et al., 2003), whereas others only ask about individual parameters(Bergman et al., 1996, Wagner and Kern, 2000). Some inconsistency already exists here, which makes comparisons difficult in this respect. Some studies have evaluated the satisfaction of patients treated with double-crown prostheses, but they have not usually used standardized questionnaires.

One of the negative aspects of this study is the design of the questions and their responses. This could have been planned better because the response options of (1) very good, (2) good, and (3) bad may have led to bias during the interpretation of the results as well as confusion among the patients during their answers. Therefore, the interpretation of these results should be read with caution. The use of evaluated questionnaires such as the Oral Health Impact Profile (OHIP) also makes it possible to draw comparisons between individual studies (Slade and Spencer, 1994).

4.5 Dental complications

Generally, most of the encountered dental complications are described in the literature as follows:

1. Secondary caries
2. Loss of sensibility (endodontic complications)
3. Periodontal complications
4. Fracture of the abutment teeth
5. Extraction of the abutment teeth.

In our study, we documented the loss of retention as a dental complication because it is related directly to the tooth and can thus influence the different paraments and the survival of the abutments. However, this has been considered a prosthetic complication in numerous studies. Another characteristic of our study is that we considered the extraction of the abutment as an irreversible complication, but some prostheses were still in situ and in function.

Generally, the overall dental complication rate was 52% (n=188 abutments) of the included abutments after a mean observation period of 4.7 years.

4.5.1 Periodontal complications

The most frequent dental complications were periodontal, with a total of affected abutments of 122 teeth representing 34% of the total included abutments. (Nickenig and Kerschbaum, 1995) reported that after five years, one quarter of the abutments underwent periodontal therapy, and after eight years, almost half of all abutments had undergone periodontal treatment.

The periodontal situation of the abutments influences the long-term survival of abutment teeth rather than the selection of the abutment type (Wenz and Kern, 2007). Another study concluded that after 10 years of observation, all the average values (probing depth and Periotest value for abutment and non-abutment teeth) had increased (Wagner and Kern, 2000). In another investigation, the prognosis of abutment teeth with reduced periodontium in removable dentures showed that periodontally reduced teeth had an increased risk of extraction, but the majority could be successfully used as abutments (Walther and Heners, 1988). In our investigation, no radiological findings were evaluated, but the periodontal pocket value ≥4 mm and increased mobility grade were considered, as also reported by (Widbom et al., 2004).

4.5.2 Secondary caries

In our research, the type of caries was not specifically documented. It could be one of the following types: root caries, recurrent caries, or caries at the margins of the abutments. This lack of documentation could lead to bias in the interpretation of the data. Moreover, notably, root caries is frequently seen in elderly people (Gregory and Hyde, 2015).

When considering the incidence of secondary caries, the overall caries incidence in all abutment teeth was 55 abutments (15%). This was the second most reported complication, with a mean time of incidence of 61.7 months. This was the latest complication to take place in terms of timing. (Hupprich, 2015) showed similar results, with an incidence rate of 11%, in 47 out of 236 abutments. Another study investigated 368 abutments and concluded an incidence rate of 10%

(Widbom et al., 2004). This result supports the statement that crowned teeth have a lower caries risk than non-crowned teeth (Jacoby et al., 2014).

Concerning these results, no statement could be concluded without differentiating the type of carious lesions and their localization.

4.5.3 Fracture of abutments

In the present study with a mean observation time of 39.8 months, fractures occurred in 50 abutments at least once during the observation period, representing 14% of all abutment teeth. The probability of an abutment fracture was similar at 11% in a three-year prospective study conducted by (Szentpetery et al., 2010).
On the other hand, in the investigation of (Weber et al., 2021), 6.3% of 2,145 abutments were fractured. Most of the fractured abutments were endodontically treated teeth.

The preparation of double crowns requires an excessive removal of tooth hard substance. Nevertheless, care should be taken not to weaken the remaining tooth structure too much by excessive preparation because this may promote a later fracture of the abutment. Another reason for an abutment fracture may be advanced root caries. This should thus be diagnosed promptly and treated by conservative means or by fabricating a new primary crown.

4.5.4 Loss of retention

Loss of retention of the primary crowns took place in 12% (n=43) of the total number of abutments. This complication showed the fastest onset, with a mean time of 38.3 months. This rate is within the range of the data in the literature, where 8–26% has been found (Nickenig and Kerschbaum, 1995, Bergman et al., 1996, Schwindling et al., 2014, Behr et al., 2000).

Various factors play a role in the loss of retention. For example, the abutment tooth must be prepared so that extra-axial forces do not lead to a loss of retention of the restoration. The retention of the crown increases with increasing die circumference and a lower preparation angle. The resistance form is influenced by the height of the abutment. The higher the prepared tooth, the greater the form of resistance shape. In addition, the mechanical properties, the mixing ratio of the luting materials, and the process of cementation play a role (Strub JR et al., 2011).

Since the treatment took place in the student course, the lack of clinical experience of the students in the preparation or even incorrect drying of the abutment tooth during impression-taking and cementation and insertion of the restoration could be the reason for the high number of retention losses.

4.5.5 Endodontic complications

Regarding endodontic complications, 10% (n=37) of the abutment teeth were affected, with a mean time of 45.1 months. One of these abutments had to be extracted during the observation period. (Wenz et al., 2001) reported the risk of endodontic treatment as 7% after five years and 9% after 10 years for rigid double-crown RPDs compared to 3% and 7% for resilient anchorage, respectively. The risk of failure for endodontically treated abutments of removable prosthetics was thus higher than for abutments of fixed restorations (Wegner et al., 2006). The survival rates for non-vital teeth were also lower than for vital abutments of removable prostheses (Wegner et al., 2006). Access cavity preparation through the primary crown involves a high risk of abutment fracture. In addition, the root canals are more difficult to locate, so the risk of perforations is higher (Szentpétery and Setz, 2015). Therefore, thorough clinical and radiographic diagnostics are recommended before starting a new prosthetic restoration to clarify the apical conditions of the abutment teeth. In addition, caution should be taken when preparing the abutments, avoiding the removal of tooth structure as well as using sufficient cooling to avoid traumatizing the pulpal tissues.

4.5.6 Extractions

Fifty-three abutments (15%) of the total had to be extracted during the observation period, with a mean period of 54.5 months. More than half (n=30) were in the upper jaw and around 45% (n=23) in the lower jaw. In 22 cases (42%), the abutments had to be extracted because of periodontal disease, and tooth fracture was the cause of 18 (34%) abutment extractions. Seven (13%) of the extracted teeth were due to caries, and five (9%) of the extracted teeth were due to loss of retention. Interestingly, just one (2%) abutment was extracted due to endodontic complications.

Periodontal disease represented the most common cause of extractions, followed by abutment fractures and caries (Eisenburger et al., 2000). Similarly, in another study, periodontal complications were also reported as the main reason for extractions (Coca et al., 2000). Other studies have reported tooth fracture as the main cause of abutment extractions (Widbom et al., 2004, Hinz et al., 2020).

The fact that periodontitis was the most common reason for extraction in this study raises the question of whether the abutments were already periodontally compromised or mis-design of the denture base led to the development of the periodontal disease. Since no thorough periodontal screening was recorded in this study, no conclusion can be drawn, and further research is required.

4.6 Dental complications in context of extracted abutment teeth

The extraction rate of molars was the highest in relation to the original number of abutments. Ten molars were extracted, which represents 41.6% of the total included molars in the study. However, canines were the most extracted teeth during this investigation period, with a sum of 21 teeth, followed by 13 premolars and nine incisors. Their percentage in relation to the whole number of the included abutments ranged between 12.5% and 13.6 %. A further aspect is the distribution of the extracted teeth in the upper and lower jaws. This showed a similar distribution of the extracted teeth to the sum of the included abutments in this study, with 14.9 % in the upper jaw and 14.7% in the lower jaw.

Although the type of recruited abutments in the support of the HDC-RPDs may influence the complication rate, the results of this investigation did not show a statistically significant difference in complication rates of the different abutment types. Despite the non–statistically significant results, molars showed a tendency of poor prognosis when compared with other abutments. It could be assumed that teeth with a larger root surface are more stable and that this is reflected in lower complication rates. However, this was not confirmed. The reason for this could be that molars more frequently exhibit periodontal problems; therefore, they are more likely to be lost. Additionally, the canines are the longest teeth and often have to compensate for the large chewing forces, so they are also more prone to be lost.

The results of this investigation agree with the conclusion of Michaelis and Schiffner (2005), who proved that anterior teeth are generally lost later and less frequently than posterior teeth. Dittmann and Rammelsberg (2008) reported that the abutment teeth located further posterior in the dental arch had a higher risk of loss than anterior teeth. Another study found that the anterior teeth show the best survival rate (Stober et al. 2012). One reason that could be considered is the favorable morphology of anterior teeth making them more accessible for the patient during oral hygiene (Rehmann et al. 2004).

4.7 Extracted abutment teeth in context to the Steffel classification

According to Steffel classification, the most unfavorable classes with respect to the number of extracted abutments were classes C and E, with 15 extracted abutments under each class. This was a considerable decrease in the number of this complication in relation to classes F and D, with two and three affected abutments, respectively. This can be explained on the one hand by the presence of a better support polygon in class F and on the other hand by the higher number of abutments, which shows a more favorable distribution of the abutment. However, the number of abutments in relation to class F was considerably fewer than in the other classes. Regarding the tooth type, almost half of the upper canines (n=13), out of 30 abutments, were extracted in different Steffel classifications, with the majority of cases in class A. One third of the extracted abutments were lower canines, and another third were premolars, with eight cases under each tooth category. An explanation could be the higher number of canine abutments included in the study.

4.8 Prosthetic complications

4.8.1 Loss of retention and need for relining

In this research, 40% of the included prostheses were relined at least once, with a total of 78 relining procedures. This took place in an average time of 30 months. Specifically, relining procedures were required in (65%) of the upper prostheses compared to (35%) of the lower ones. This distribution agrees with the findings of (Eisenburger and Tschernitschek, 1998), in which relining measures were required in 42% of the telescopic prostheses. In another study evaluating telescopic dentures, 45% required relining (Stark and Schrenker, 1998). Another point is the timing of the occurrence of relining. The results of this investigation agree with the conclusion reported by(Eisenburger and Tschernitschek, 1998): most of the relinings were performed within the first two years of the functional period. Regarding the distribution of the relining measures between the upper and lower jaws, our results disagree with the findings of (Pöggeler, 1995), who reported poor retention and an increased need for relining in 25% of the mandibular dentures, compared to just 11% in maxillary dentures. Explanations for this are biological and hormonal factors as well as the individuality of each human being. Additionally, masticatory forces play a role in bone resorption.

Relining is not an avoidable technical complication in comparison to the other measures. Therefore, relining measures promptly is crucial to the longevity of the prostheses and prevention of other complications such as fracture or extraction of abutments, especially in free-end situations (Gehrt and Wolfart, 2011). The need for relining was identified in this study as the most frequent prosthetic complication. However, this is a measure that is usually familiar to the patient, is generally well tolerated, and takes little time.

4.8.2 Loss (Chipping) of acrylic veneering

The second most common prosthetic complication was the chipping of the acrylic veneering of the abutment teeth. This took place in 24 prostheses which means that ever fifth prosthesis was affected. The average period of this complication to happen was almost 4 years. These results corresponds to the findings of a 10 years follow-up study, where they found out 22.2% of the prostheses were affected by either partial or complete loss of veneering (Wagner and Kern, 2000). About one fourth of the affected prostheses was reported by (Wöstmann et al., 2007), whereas another investigation reported only one veneer fracture in 132 prostheses (Saito et al., 2003).

Chipping defects can occur due to many reasons e.g., Material specific factors, technical factors or patients related factors like Bruxism. These factors were not considered during the planning of the study; therefore no specific explanation can be stated.

5 Summary

This evaluation of a longitudinal study aimed to investigate the dental and prosthetic complications associated with HDC-RPDs in severely reduced dentition. Variables of the dentition and restorations were evaluated and categorized for this purpose. This study evaluated not only the complications, but also patients perception of their dentures. The data analysis included a total of 102 patients with 122 HDC-RPDs supported on 357 abutment teeth. The HDC-PRDs were made and delivered by eighth- and ninth-semester students under the supervision of certified dentists and associate professors of the Department of Prosthodontics at the University Hospital of Dentistry, Oral Medicine, and Maxillofacial Surgery in Tübingen between year 2000 and 2018. Patients mean age was 61 ±11 years, observed over a mean period of 6.5 ±3 years. During the observation period, over half of the abutments (188; 52%) experienced dental complications; of these, 53 abutment teeth were extracted. These complications took place in an average time of 4.7 years. Periodontal complications were the most frequent, affecting a sum of 170 abutments. This represents 47.6% of the total number of abutments. Endodontic complications affected 37 abutments (10%). Secondary caries was the latest complication to take place, with a mean time of 61.7 months. Loss of retention was the first to take place, with an average period of 38.3 months. The most affected abutment teeth were canines (23%), and the least affected were molars (4.7%). According to prosthetic complications, the mostly encountered complication was the loss of retention and the need for relining in 40% of the prostheses after a a mean service time of 30 months (SD= 26 months). The chipping of acrylic veneering took place in one fifth of the total number of prsoetheses with an avrage period of 49 months. The data go in hand with reports about telescopic dentures and show that encountered complications are easy to handle in clinical setting whereas 3 out of 4 patients report to be satified with their prosthetic rehabilitation throughout the (evaluatated) time of service.

Zusammenfassung

Ziel der Auswertung der Längsschnittstudie zu Kombinationszahnersatz war es, die dentalen und prothetischen Komplikationen bei Prothesen mit Hybriddoppelkronen im stark reduzierten Restgebiss zu untersuchen. Zu diesem Zweck wurden Variablen der Dentition und Restaurationen strukturiert ausgewertet und nicht nur Komplikationen, sondern auch das subjektive Empfinden der Patienten über ihren Zahnersatz berücksichtigt. Die Datenanalyse umfasste 102 Patienten mit 122 Hybriddoppelkronenprothesen, die auf 357 Pfeilerzähnen getragen wurden. Die Prothesen wurden von Studenten des achten und neunten Semesters unter der Aufsicht von Assistenzzahnärzten und Oberärzten der Poliklinik für Zahnärztliche Prothetik mit Propädeutik am Zentrum für Zahn-, Mund- und Kieferheilkunde der Universität Tübingen in den Jahren 2000-2018 hergestellt und versorgt. Das Durchschnittsalter der Patienten betrug 61 ±11 Jahre, und deren mittlere Beobachtungszeit 6,5 ±3 Jahren. Während des Beobachtungszeitraums traten bei über der Hälfte der Ankerzähne (188; 52 %) dentale Komplikationen auf; davon wurden 53 extrahiert nach durchschnittlich 4,7 Jahren. Parodontale Komplikationen waren am häufigsten und betrafen insgesamt 170 (47,6 % aller Ankerzähne). Endodontische Komplikationen betrafen 37 (10 % aller Ankerzähne). Sekundärkaries war nach im Mittel 61,7 Monaten die am spätesten auftretende Komplikation. Die Dezementierung von Teleskopkronen war nach durchschnittlich 38 Monaten die frühste Komplikationsart. In Summer waren die Eckzähne am häufigsten und (23 %) und die Molaren selten (4,7 %) von Komplikationen betroffen. Bei den prothetischen Komplikationen waren Dezementierung und Unterfütterungsbedarf bei 40 % der Prothesen die häufigsten Komplikationen. Bei einem Fünftel aller Prothesen kam es nach etwa 49 Monaten zu Abplatzungen der Kunststoffverblendung. Die Ergebnisse ordnen sich in die Datenlage zu Kombinationszahnersatz ein und zeigen, dass die Komplikationen klinisch gut beherrschbar sind sowie drei von vier Patienten mit Ihrem Zahnersatz über die hier untersuchte Tragezeit zufrieden sind.

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7 Declaration

I hereby declare that I have written this thesis independently without the unauthorized assistance of third parties and that I have not used any aids other than those indicated.

The dissertation was carried out at the Eberhard-Karls-University of Tübingen under the initial supervision of PD Dr. Eva Engel and further on by the supervision of PD Dr. Fabian Hüttig.

The rawdata were loaded from the database by a script formerly authored by Dr. Detlef Axmann. Thereafter, I organised in the necessary subset for the research question in order to allow the anaylsis all by myself. This includes the validation of data within the patients records and an update of the original database in order to reach data correctness in both, this study and the original database. The statistical analysis was carried out by myself according to the recommendations of PD Dr. Fabian Hüttig regarding the table design and the analysis strategy, including the preparation and finalization of the figures and tables by myself.

The present work has not yet been submitted to any other examination authority in the same or similar form, either in Germany or abroad.

I certify that I have written this manuscript completely independently and that I have not used any sources other than those indicated by me herein or cited in the references.

Tübingen, 16.09.2022

Abdulmajeed Okshah, BDS, MDSc.

8 Acknowledgments

9 Curriculum Vitae