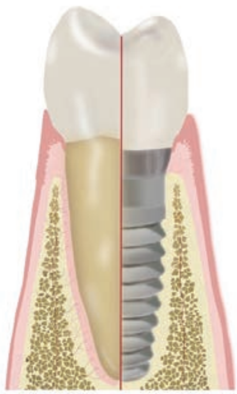
From The Department of Dental Medicine
Karolinska Institutet, Stockholm, Sweden

SINGLE IMPLANTS IN THE ANTERIOR MAXILLA IN YOUNG ADULTS

Nicole Winitsky



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Single implant treatment in the anterior maxilla in young adults

Thesis for Doctoral Degree, Ph.D.

By

Nicole Winitsky

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To my lifelong love and best friend, Peter

To my children Jacob, Isaac and Dinah

In memory of my mother Renée and my great role model and grandmother, Ruth

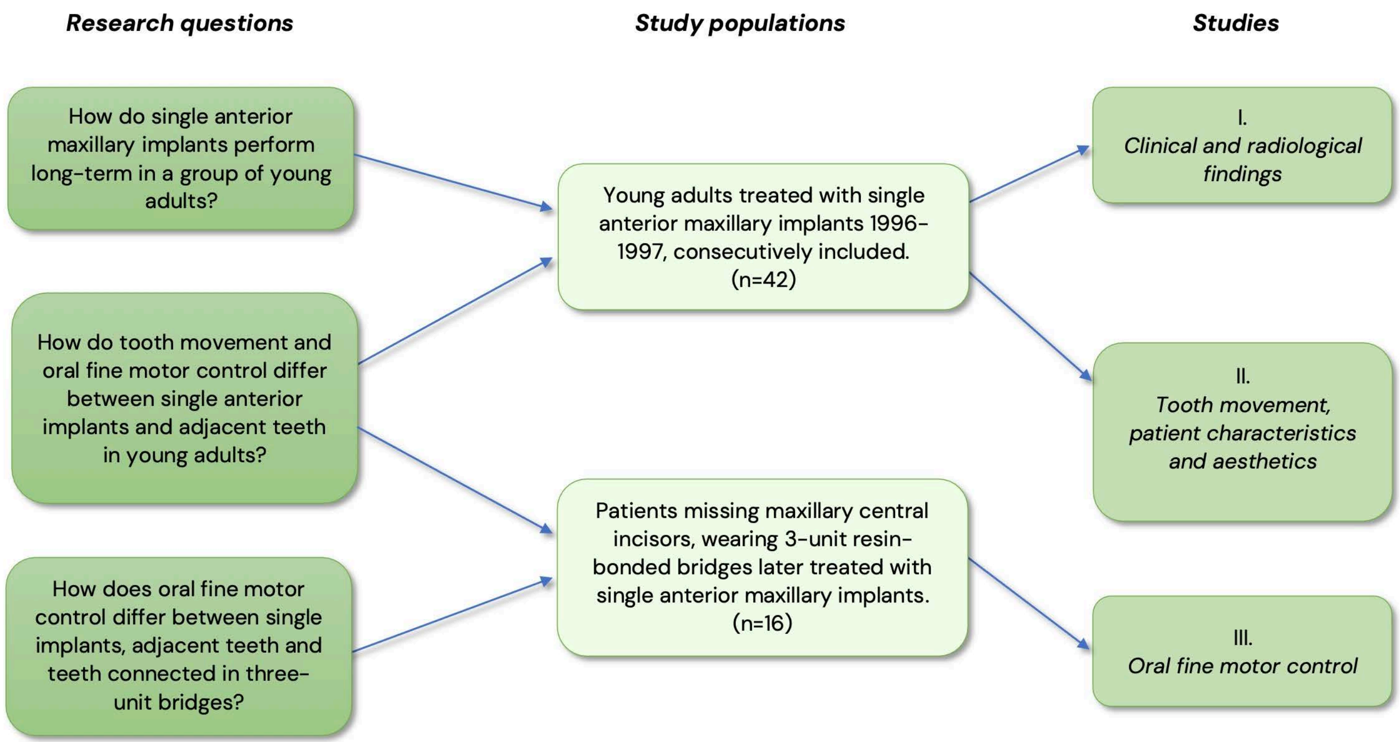
“Det blir alltid som man tänkt sig - Things always turn out the way you plan”

Olof Röhlander

Storyline of the thesis

Single implants in the anterior maxilla in young adults

Long-term performance, oral fine motor control, and esthetics.



POPULAR SCIENCE SUMMARY OF THE THESIS

Background and aims: A single dental implant is a common treatment for a missing front tooth in the upper jaw that is commonly performed in young adult patients. Only a few scientific studies exist on how well these implants functions in the long term and no studies have been performed previously to explore hold and split forces in single implants. The aims of this thesis were to increase the knowledge about the long-term success of single implants in young adults and to compare the forces used by the implant's on the actions holding and splitting food, with those a natural tooth when connected in a dental bridge or not.

Materials and methods: The thesis include three studies. In **Studies I** and **II**, 42 patients received implants in 1996 and 1997 and were examined after 14 to 20 years of follow-up. In **Study I**, the gums and bones surrounding the implants were examined. Radiographs of the implants were taken to compare the bone levels at the implants, at the time the implant crowns placement, with the bone levels at the 14 to 20-year follow-up. Analyses were performed to investigate the associations between bone levels and the probing depth at the implants, contact between the implant and the opposing tooth, and nicotine use. **Study II** involved the analysis of scanned models using a 3-D software to compare the positions of the teeth next to the implants at the time of crown placement with the position after 14 to 20-years. The associations between patient and implant characteristics were examined to identify the potential risk factors for more severe tooth movements over time. Both the patients and the dentist rated the satisfaction with the appearance of the crowns. In **Study III**, 16 patients wearing a 3-unit bridge, connected with wings to the adjacent teeth (resin-bonded bridge), were compared before and after treatment with single implants with regards to hold and split forces. The patients performed a hold-and-split task to measure the forces twice, first wearing a resin-bonded bridge and later a single implant.

Results: The results of **Study I** showed that single implants in the front of the upper jaw show good long-term survival and success. The bone levels surrounding the implants did not show any significant associations with probing depth, whether the implant was in contact with the opposing tooth, or with the usage of nicotine. Complications occurred, but in most cases, only minor adjustments were needed to address them. In **Study II**

findings showed that the adjacent teeth changed position in relation to the implants, causing the implant to appear shorter than the surrounding teeth (implant infraposition). The degree of positional change was found to be more severe in patients with a lower anterior facial height of more than 70 mm, when the implant had no contact with the opposing tooth, when the implant was placed in positions two and three, or when tooth loss was caused by other reasons than trauma. Despite the positional changes, most of the patients were satisfied with the appearance of their implant crowns, and they reported higher levels of satisfaction than the dentists. In **Study III**, the results revealed that the hold and split forces differed between a single implant and a freestanding tooth, in a similar way as the hold forces between a pontic and a tooth connected in a bridge. No statistical differences were found between a tooth freestanding next to an implant or connected in a bridge.

Conclusions: The thesis concludes that single implants in the frontal part of the upper jaw perform well overtime in young adults. Over time the implant crowns tend to end up in an infraposition, which seem to occur especially in patients with a lower anterior facial height of more than 70 mm, when the implant crown is not biting against the tooth in the opposing jaw, when the implant is placed in position two and three or when the reason for tooth loss is other than trauma. Despite the infraposition of the implants, patients are generally satisfied with the appearance of their implant crowns and report a higher grade of satisfaction than the dentist. The sensitive control mechanisms needed for holding and splitting food appear to be impaired on implants compared to teeth. This impairment is similar to that of the pontic in a small 3-unit bridge in the front part of the upper jaw. However, the differences in hold and split forces between a freestanding tooth and a tooth connected in a bridge were too small to conclude that they are of practical relevance. It should be noted that these conclusions are limited by the constraints of the studies including the relatively small groups of patients must. In addition, further research is needed to determine the predictors of infraposition of implants.

Clinical relevance: The findings of this research can be useful in treatment planning of patients in need of single implants in the front of the upper jaw. The patients should be informed that the implant is expected to function well overtime but there is a possibility that the crown of the implant may become shorter than the adjacent teeth in the long term. This will not cause an esthetic problem for most patients but for young adults with a long remaining lifetime, the need to change or repair the implant crown may occur once or a few times during a lifetime. To minimize the risk of infraposition, it is advisable to delay single implant treatment in the front area of the upper jaw for as long as possible. In addition, patients with a lower anterior facial height of more than 70 mm and with implants in positions two and three may have a higher risk for implant infraposition.

ABSTRACT

Background: Single anterior implants are frequently used in the treatment of patients with single anterior tooth loss. Compared with other types of implant treatments, single implants are commonly performed in younger patients where the cause of tooth loss often is non-inflammatory. However, there is a scarcity of long-term follow-up studies, especially in the cohort representing the younger segment of the adult population. Lack of periodontal mechanoreceptors (PMRs) around implants and reduced function of PMRs around teeth connected in full-arch bridges have been shown to affect the oral fine motor control. However, there is no study on the comparison of oral fine motor control between single anterior implants and the alternative treatment, a 3-unit bridge.

Aims: The objective of this thesis was to investigate the performance of single anterior maxillary single implants in young adults. The specific aims of **Studies I** and **II** was primarily to report long-term survival, success, complications, radiological findings and movement of adjacent teeth after 14–20 years follow-up. The secondary aims were to explore correlations between changes in marginal bone levels in relation to probing depth (PD), occlusal contact, and nicotine use, and to investigate the associations between the movement of adjacent teeth, patient and implant characteristics, and the aesthetic assessment of the implant crown. **Study III** aimed to compare oral fine motor control of patients with single anterior tooth loss treated with 3-unit resin-bonded bridges (RBBs) or single implants.

Materials and methods: In **Studies I** and **II,** 40 out of 42 patients who received single anterior implants were re-examined after a period of 14–20 years. Data were collected to assess the long-term survival, success, biological findings and complications of the implants. After 14-20 years, radiological findings were compared with baseline data. A 3-D analysis and calculations were used to investigate the movements of teeth adjacent to the single implants and their associations with patient and implant characteristics. Additionally, an assessment of perceived aesthetics was performed. In **Study III**, a behavioral hold-and-split test was conducted on 16 patients with missing maxillary central incisors. The test was performed twice, once with a 3-unit resin-bonded bridge (RBB) and once with a single implant. The conditions connected tooth (CT), pontic (P), freestanding tooth (T) and single implant (SI) were tested for differences regarding the variables hold force, variability of hold force, split force and duration of split.

Results: In **Study I**, the cumulative survival rate for implants (CSRi) was 96.1% whereas that for crowns was of 80.4% (CSRc). All the remaining implants were considered successful. The mean marginal bone loss was 0.1 ± 1.1 (range, -5.1–1.6) mm and the mean PD was 4.0 ± 1.8 (range, 0–9) mm after 14–20 years follow-up. There was no significant correlation found between marginal bone levels and PD, implant occlusion, or nicotine use ($p > 0.05$). Technical and/or biological complications were found in 50% of the patients, but only 22% required substantial further treatment. In **Study II**, the 3-D movements of teeth adjacent to the single implant showed a mean movement of 1.0 ± 0.5 mm in the incisal direction (vertical; Y-axis), 0.5 ± 0.8 mm in the bucco-lingual direction (sagittal; Z-axis) and -0.0 ± 0.1 mm in the mesio-distal direction (horizontal; X-axis). No patient showed a completely stable vertical relationship (Y-axis). Lower anterior facial height (LAFH) ≥70 mm was significant correlated with more severe vertical tooth movement (>1 mm) ($p < 0.05$). Furthermore, implants in occlusion, implants in central incisor position and in patients when trauma was the reason for tooth loss were significantly correlated with less movement of teeth adjacent the single implants ($p < 0.05$). Despite the infraposition the patients rated the esthetic of the implant crown to a VAS score of 85% ± 19% (range, 20%–100%). Significantly lower VAS scores ($p < 0.05$) were correlated with increased tooth movement in patients with central incisor implants. The dentist ratings of 67% ± 23% (range, 10%–100%) were significantly lower that the patients ($p < 0.05$). In **Study III**, significantly higher ($p < 0.05$) hold force, variability of hold force and split force was found for the single implants compared to the adjacent teeth. Further, the pontic of the RBB showed higher hold forces ($p < 0.05$) than the adjacent connected tooth in a similar manner as the implant. However, no significant differences ($p > 0.05$) were found between the tooth connected in the RBB and the freestanding tooth.

Conclusion: Within the limitations of the studies this thesis highlights that single anterior maxillary implants in young adults show good long-term performance with high success and survival rates and only small changes in marginal bone levels. Complications occur over time; however, they do not seem to be of great concern to the patients. Positional changes of adjacent teeth in relation to the single implants occur over time in all patients but to different degrees. However, the changes seem to be more extensive in patients with LAFH ≥70mm, patients without implant occlusion, patients with implants in the lateral

and canine positions, and patients with tooth loss caused by reasons other than trauma. Only few patients (10%) found the differences in tooth position esthetically disturbing while the dentist was more critical. Furthermore, single implants show impaired oral fine motor control in relation to freestanding adjacent teeth which was also observed for pontics in relation to connected teeth. However, teeth connected in 3-unit anterior bridges appear to maintain sensitivity in oral fine motor control.

Clinical implications: This thesis suggests that patients planned for single anterior maxillary implants should be provided with information that the implant is expected to perform well overtime. However, the implant crown will most likely end up in infraposition in relation to the adjacent tooth. In most patients this will not cause an esthetic problem but in young adults with a long remaining lifetime, the need to change or repair the implant crown may occur once or a few times. To minimize the risk of infraposition, it is advisable to delay anterior maxillary single implant treatment for as long as possible. Patients with a lower anterior facial height of more than 70 mm or implants in lateral or canine position might be in higher risk of more severe infraposition

LIST OF SCIENTIFIC PAPERS

This thesis is based on the following publications and manuscripts, which will be referred to in the text by their Roman numerals as indicated below and appended at the end of the thesis.

I. A retro-prospective long-term follow-up of Brånemark single implants in the anterior maxilla in young adults. Part 1: Clinical and radiographic parameters.
Winitsky N, Olgart K, Jemt T, Smedberg JI
Clin Implant Dent Relat Res. 2018 Dec;20(6):937-944

II. 3-D tooth movement adjacent to single anterior implants and esthetic outcome. A 14- to 20-year follow-up study.
Winitsky N, Naimi-Akbar A, Nedelcu R, Jemt T, Smedberg JI.
Clin Oral Implants Res. 2021 Nov;32(11):1328-1340

III. Oral fine motor control in anterior maxillary single implants, freestanding teeth and teeth connected in 3-unit bridges.
Winitsky N, Smedberg JI, Grigoriadis A
In manuscript

Scientific paper not included in the thesis

The risk for infraposition of dental implants and ankylosed teeth in the anterior maxilla related to craniofacial growth, a systematic review.
Klinge A, Tranaeus S, Becktor J, **Winitsky N**, Naimi-Akbar A.
Acta Odontol Scand. 2021 Jan;79(1):59-68.

CONTENTS

LIST OF ABBREVIATIONS

AL	Ann Lindunger
AA	Anna Andlin, DDS, PhD, Associate Professor of Orthodontics
AF	Anders Frykholm, DDS, Oral radiologist (Studies I and II)
BoP	Bleeding on probing (Study I)
CDA	California Dental Association (Study II)
CT	Connected tooth (Study III)
FDP	Fixed dental prosthesis
JIS	Jan-Ivan Smedberg, DDS, Prosthodontist
KO	Kerstin Olgart, DDS, Prosthodontist, originator of Studies I and II.
LAFH	Lower anterior facial height
LW	Laila Wiklander, DDS, Oral Radiologist (Studies I and II)
Me	Soft tissue menton, facial structure used in linear photogrammetric analysis
MK III	Parallel walled implant
MIP	Maximal intercuspal position
MV	Maud Vereby
N	Soft tissue nasion, facial structure used in linear photogrammetric analysis (Study II)
N	Newton, force (Study III)
NW	Nicole Winitsky, DDS, Prosthodontist
PD	Probing depth
RBB	Resin-bonded bridge
S	Single implant (Study III)
Sn	Subnasal, facial structure used in linear photogrammetric analysis
T	Freestanding tooth (Study III)

UT	Ulf Tegsjö, DDS, Oral and Maxillofacial Surgeon (Studies I and II)
UAFH	Upper anterior facial height
VAS	Visual analogue scale
TAFH	Total anterior facial height

Statistical abbreviations

κ	Kappa index
CSR	Estimated cumulative survival rate
CSRi	Estimated cumulative survival rates for implants (Study I)
CSRc	Estimated cumulative survival rates for crowns (Study I)
IQR	Interquartile ranges
OR	Odds ratio
SEM	Standard error of measurement
SD	Standard deviation

Definitions

Anterior maxilla	The area between canine to canine in the upper jaw
Young adult	A person in the early years of adulthood, aged between 18 to 30 years old

1 BACKGROUND AND LITERATURE REVIEW

1.1 SINGLE ANTERIOR IMPLANTS

1.1.1 History of single implants

The field of implantology has undergone significant development since the first patient was treated in 1965.[1] In the 1960s and 1970s, the majority of implant treatments involved full-arch bridges for edentulous jaws and only later single and partial implant treatments became available. Since it was first described by Jemt in 1986,[2] single implant treatment has become more frequent over the years. The number of implants placed per patient at a major Swedish implant clinic decreased from a mean of 5.7% to 2.2% between 1986 and 2013.[3] Currently, reports from a Swedish hospital indicate an even lower rate of 1.9 implant per patient.[4] In a public dental health organization in Sweden (Folktandvården Stockholm AB), the mean number of implants per patient has decreased from 2.3 to 1.6 over the last 11 years (Figure 1), and the total number of single implants has increased by 3.5 times (Figure 2). This trend reflects the widespread adoption of single-implant treatment, which is now a recognized treatment option regularly used in dental practices worldwide.

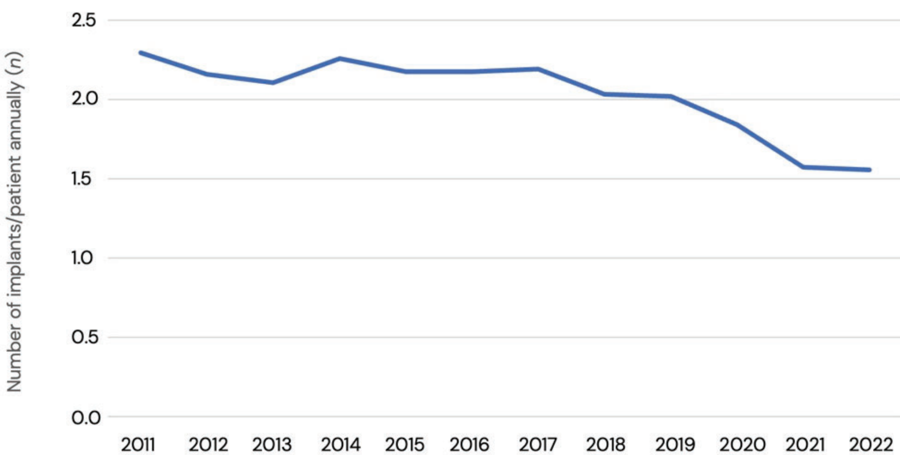


FIGURE 1 Number of implants per patient and year at Folktandvården Stockholm between 2011 and 2022.

Source: Folktandvården Stockholm AB, 2023

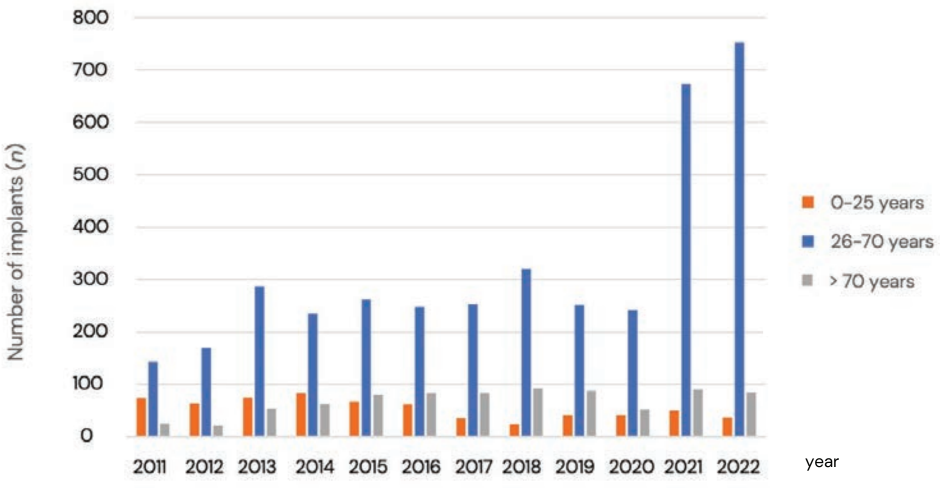


FIGURE 2 Total number of single implants installed in three different age groups between 2011 and 2022. Total number of patients treated 5310.

Source: Folktandvården Stockholm AB, 2023

1.1.2 Long-term follow-up

Single implants in the anterior maxilla are fairly well documented in the literature.[5–8] However, publications of long-term follow-up studies of single implants are scarce. A review revealed that only 367 patients were monitored for a period of more than 10 years.[9] Among the published long-term studies of single implants[10–19] eight show observation periods exceeding 15 years.[10–14,20–22] These scientific papers are based on three Swedish patient materials. The Dierens group[12,20,21] conducted a research that was based on a retrospective material with single implants in different locations in both the upper and lower jaws including patients with a mean age of 24 (range, 14–57) years. The Andersson group[10,11] conducted a study with a prospectively collected material including 57 patients with a mean age of 32 (range, 15–57) years at implant placement (51 patients premolar to premolar in the maxilla). The Jemt group conducted a study of 27 patients with a mean age of 25 (range, 13–62) years with implants placed in the anterior maxilla.[13,14,22] Furthermore, Jemt et al. followed another 344 patients between 15 and 30 years of follow-up retrospectively.[23] The total single implant population in this study consisted of 2417 patients with a mean age at implant placement of 36 ± 19 (range, 13–89) years. In this group, 51% were <30 years with 33% between the ages of 19 and 23 years and 49%

between the ages of 30 and 90 years. Hence, a large part of the patients historically treated with single implants belong to the young adult group.

1.1.3 Implant treatment in younger groups of patients

When comparing younger and older patients an important clinical consideration is that in the younger groups, the implants are expected to remain in function for a significantly longer period. At least another 60 years. All throughout the patient's life, we can expect physiological changes due to, additional facial development,[24] changes of the dental arches,[25] gingival recession,[14,25,26] changes in the marginal bone levels,[27,28] and changes in shade, shape, and position[25,29,30] of the adjacent teeth.

Few implant studies have been performed including patients in very young ages (<18 years). These studies include patients from 3 years of age[31] that have been followed for up to 24 years.[31] The studies are mainly case reports,[32] or consists of small sample sizes [33,34]. The patients are most commonly suffering from congenital oligodontia, including patients diagnosed with the genetic syndrome of ectodermal dysplasia,[35] while a few studies involve patients with dental trauma.[31] Single implants in the anterior maxilla of young patients with a longer follow-up periods were reported in four studies[18,23,36,37]. In one study, with a mean patient age of 15 ± 2 years, 38 single implants were included and followed for 5–79 months,[36] one group with a mean age of 15 (range, 14–19) years, provided with 15 single implants, was followed for 8 years,[18] and one a group of 18 patients between 13 and 18 years were followed for 10 years.[37] In the 30-year follow-up by Jemt[23] 586 patients (55% of 1066 patients) between 13 and 25 years at the time of inclusion were followed up retrospectively for up to 15 years.

1.1.4 Etiology of tooth loss in younger populations

Studies on single implants have indicated that the primary causes of tooth loss are dental trauma and congenital absence of tooth germs (agenesis). The prevalence of dental trauma as an etiological factor ranged from 56% to 62% in a Swedish population and 32% in a Western world population from seven different centers. Agenesis was the primary cause of tooth loss in 16% and 18% of the cases in the aforementioned studies, respectively.[38-40] Moberg and coworkers reported that the reason for tooth loss in the maxillary central and lateral incisors was trauma in 97% of the patients receiving single anterior maxillary implants.[41]

The prevalence of agenesis varies among the ethnic groups. Australia and Europe have a higher prevalence than North America with females showing a slightly higher prevalence than males.[42] Epidemiological studies performed in different parts of Sweden have shown the prevalence of agenesis to range between 6.1% and 7.4%.[43-45] The highest frequency is observed in the mandibular second premolar followed by the maxillary lateral incisor.[42] Swedish studies have reported a prevalence of 2.2–3.1% for agenesis of the maxillary lateral incisor,[44,45] whereas a worldwide meta-analysis showed a lower prevalence of 1.6–1.8% (95% CI).[42] The prevalence of agenesis is believed to be increasing over time in Caucasian populations.[46] The prevalence of frontal tooth loss due to trauma have been reported to range from 0.3%–0.4% in epidemiological Scandinavian studies[44,47] and 97% of dental injuries affects maxillary central incisors.[47] Although dental trauma is the etiology in only a small proportion of patients with tooth loss, these patients comprise a substantial part of patients with single implants.

1.1.5 Outcome of implant treatments

Implant treatment outcomes depend on several variables. Patient selection is important in addition to clinical conditions and proper treatment plans. Additionally, achieving a favorable outcome may also depend on the skill and experience of the practitioner performing the treatment and the facility where the treatment is performed.[48,49] Single anterior maxillary implant treatment is regarded as one of the most challenging implant procedures,[50] and the treatment should be performed in the best possible manner.

The number of implant companies and systems have increased over the years from only a few to several hundred, maybe thousands of different implants to choose from. The inclusion criteria for patients receiving implant treatment were strict in early studies on single implants,[51,52] and treatment was performed by a limited number of clinicians, predominantly specialists.[1] Currently, the inclusion criteria are moderate, and treatments are being performed by a larger number of dentists, many of whom are not specialists and may have less experience than their predecessors. In 2014, the average number of implants placed per dentist annually worldwide was estimated to be less than 50,[53] and is perhaps even lower today.

The number of implants placed can be used as a measure of a surgeon's experience with implant surgery. To have placed less than 50 implants in total has been regarded as a threshold indicating relatively low experience.[48,54] Some studies have shown that the results of implant treatments improve with the increased experience of implant surgeons,[49,54–59] while opposing results reported also have been in the literature.[3,60] The results in the dental literature are contradictory when it comes to differences in failure rates whether the surgeon is a specialist or a general dentist.[3] Early studies have shown that well-trained GPs accomplished the same results as specialists when treating selected cases with single implants.[38,61] Additionally as a group, female surgeons have been shown to present lower failure rates.[3] Implant treatments require the expertise of experienced practitioners[49] who have acquired the necessary skills and knowledge to achieve predictable results. However, not all dentists may possess the right attitudes or capacities to achieve consistently high success rates.[3,53] The skills and communication within the treatment team are also important for a good outcome.[62] Early implant failures have been found to vary from 0% to 10.2% among different treatment centers.[48,54] This can be attributed to the skills and experience of the clinicians and team as well as the treatment center's facilities and environment.

1.1.5.1 Survival, success, and complications

Survival, the most definitive measure of implant treatment, reflects the implant remaining in place over time.[6] However, the success of the treatment cannot be solely based on survival; it must also encompass good health of the surrounding implant tissue and proper functionality. Albrektsson et al.[63,64] described the importance of specific radiological and clinical criteria in evaluating the success of implant treatment. Parameters, such as marginal bone levels, plaque, bleeding on probing (BoP), and technical and biological complications, should be evaluated in both scientific studies and daily clinical work.

Many studies report on probing depth (PD) around implants.[65–68] This parameter is contradictive in the literature. While some researchers believe that probing around implants is crucial for diagnosis and prognosis,[65,68] others believe that PD around implants is a less important predictor of implant health and that probing might even be harmful to the implants.[69,70] Failures and complications may occur in both implants and implant-supported single crowns. Complications occurring at the implant level are more catastrophic, complicated, and expensive to treat than those at the abutment or crown level.

Meta analyses have reported survival rates of single implants of 97% after 5 years and 95% after 10 years and of implant-supported single crowns of 96%–98% after 5 years and

89% after 10 years.[7,71,72] The most frequent technical complications after 5 years were screw loosening, loss of retention of the crown, and fracture of the veneering material.[7,71] Biological outcomes vary between different studies; however, marginal bone loss, mucositis, suppuration, and soft tissue changes have been frequently reported.[7] When treating patients with single anterior implants, aesthetics becomes an important outcome. Thereby, the aesthetic parameters, such as mucosal recession and changes in color and position of adjacent teeth, need to be evaluated to assess the success of these treatments.

Agenesis and trauma, the most frequent causes of tooth loss in younger patients, are non-inflammatory, whereas tooth loss that occurs later in life is often caused by inflammation. Patients with non-inflammatory etiologies show higher 10-year implant survival rates and lower complication rates than patients with periodontal origin to their tooth loss.[73] A retrospective study of 1017 patients revealed that the highest risk for obvious bleeding on probing and/or suppuration in combination with bone loss >1 tread, during the first year was found in the group of middle-aged patients (50–55 years). Younger (and older) patients showed significantly lower risks. The risk of early mucosal inflammation and bone loss increases significantly by 8% per year from 17 to 53 years of age.[49]

1.2 FACIAL TYPE, VERTICAL FACIAL AND DENTAL CHANGES

In the dental discipline of orthodontics, patients are often categorized according to facial type. Facial type as well as malocclusion influence the orthodontic treatments results[74,75] and determine the long-term treatment success.[76,77] Craniofacial growth potential varies across different developmental stages[78] (Figure 3). Childhood growth is largely influenced by genetics, physical health, and environmental factors. Puberty is marked by temporary growth acceleration, followed by a plateau during adolescence also including differences between the sexes. In young adulthood, subtle changes continue to occur in the craniofacial structure, which persist into adulthood[78-84] (Figure 3). During growth of the facial skeleton from birth to young adulthood different growth patterns of have been observed between individuals and between different facial types[84]. The continuous development of the face throughout life, particularly the vertical changes of the anterior maxillary skeleton, differs depending on the individuals' facial type and sex.[78,79,85-89] Historically, the facial shape of a patient has not played a significant role in prosthodontics. However, when replacing teeth in the anterior zone of the maxilla, the facial shape and growth pattern may be relevant factors to consider for optimal treatment outcome and long-term prognosis.

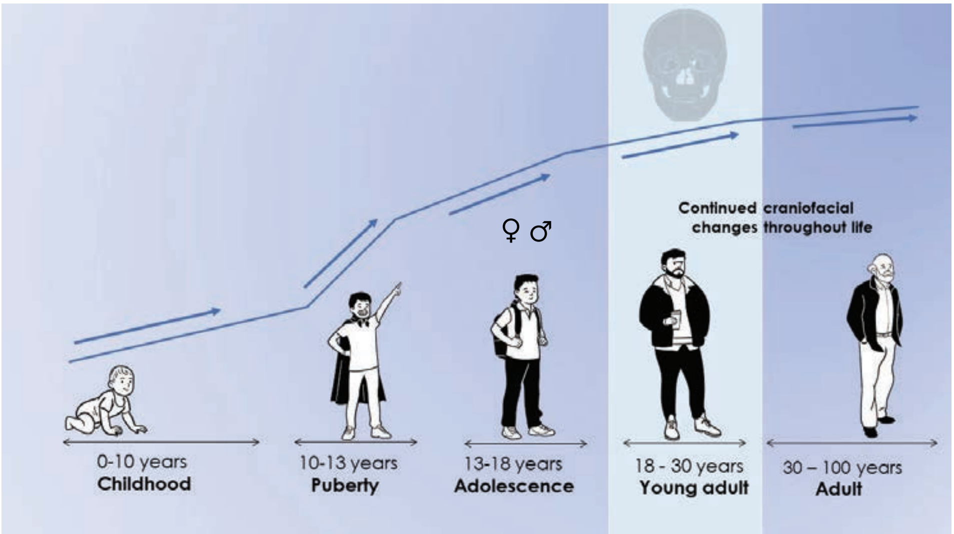


FIGURE 3 Craniofacial growth potential throughout life
Inspiration from Behrents, 1985.[78] Illustration Gabriel Issa.

1.2.1 Classification of facial types

Facial types are categorized into three groups based on their vertical dimensions: long (dolichocephalic), neutral (mesocephalic), and short (brachycephalic) types[82,90] (Figure 4). Individuals with the long facial type have an increased total anterior facial height (TAFH) due to a vertical excess of the lower anterior facial height (LAFH), whereas patients with the short facial type show a decrease in TAFH due to small vertical dimensions of LAFH[82] (Figure 4). The *long face* pattern can be further categorized into three subtypes: mild, moderate, and severe.[76] *Long face* individuals can present with and without an open bite. Patients with an open bite presented short ramus mandibulae, while those without an open bite presented long ramus.[91] Patients with long facial shapes have also been shown to exhibit a more open gonial angle (the angle between the posterior and inferiors borders of ramus and basis mandibulae).[92,93] The growth characteristics for *long*- and *short face* patients are so specific that they override sexual dimorphism.[81-83] However, growth patterns have been shown to differ both within facial groups and between sexes. [89,94-96]

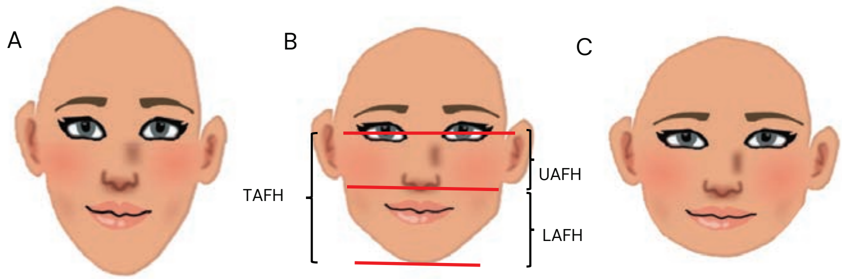


FIGURE 4 Schematic sketch of the three craniofacial types. (A) Long facial type, (B) neutral facial type, and (C) short facial type. TAFH = total anterior facial height, UAFH = upper anterior facial height, LAFH = lower anterior facial height.

The methods for diagnosis of facial type is difficult to standardize, which leads to controversy regarding the incidence of individuals with different vertical facial growth patterns.[94,96-99] The prevalence of different facial types varies between ethnic groups and is difficult to identify from the literature. Brazilian and American studies involving a mix of ethnic groups show prevalence of the long facial type ranging from 6% to 35%. Individuals of Brazilian and African descent have been shown to exhibit the long facial type more often than Caucasian individuals.[76] The developmental patterns of individuals with *long face* differ[74-77,100] from the other groups, and it has been suggested that patients in this group have a higher degree of vertical tooth movements over time.[10,22] The facial type has been shown to be fairly constant from childhood to young adulthood and is believed to stay that way throughout life.[89,101] However, the *long face* pattern may have been reported to deteriorate during adolescence and is sometimes only diagnosed post-adolescence.[102]

1.2.2 Methods of measurements

Cephalometric tracings and measurements[86,92,103,104] and photogrammetric analysis[76] are techniques used to measure craniofacial growth and tooth movements during eruption. Multiple cephalometric, dental, and soft tissue variables can describe the morphology of a face classified as *long face*.[76,80,97] Cephalometric tracing, in which a *long face* is characterized by increased TAFH due to increased LAFH, is a commonly used method to identify *long-*, *neutral-*, and *short face* patients.[97] Another cephalometric method is to classify the groups by a quota of the LAFH/TAFH where ≥58% classifies patients as *long face* and ≤56% as *short face*.[105]

Photogrammetric analysis, another method used by orthodontists to classify different facial types by using clinical landmarks on the soft tissue on photographs, has been previously described.[76,80,94,106] Linear and angular photogrammetry can be used to measure and analyze soft tissue facial profiles by examining reference lines and angles in frontal and lateral photographs.[106] Photogrammetry has been used to establish normal values,[107] facial proportions and growth[106,108,109] as well as in daily use for clinical diagnosis and treatment planning.[94] Methodological variables, such as accurate head position, standardized camera position, and distance from the patient are important to achieve reliable results .[110,111] Both linear and angular photogrammetry methods were found to be reliable when comparing standardized facial lateral photography with cephalometric radiography to characterize craniofacial morphology. A significant correlation between both angular and linear measurements with the highest correlation for estimates of vertical facial height have been found.[112] Clinical facial assessments has also been employed to diagnose facial patterns on standardized extra- and intraoral photographs. It was shown to be effective, reproducible, and suitable for patients >18 years.[102]

1.2.3 Vertical facial changes through life

From childhood, the growth of the maxilla follows a strict chronology, where it first grows in the transverse plane, followed by the sagittal plane, and finally in the vertical plane.[84] Sagittal growth of the maxilla is strongly linked to the growth of skeletal body height. Vertical growth occurs via the displacement and remodeling of the orbits, maxillary sinuses, and nasal cavity.[84] Facial growth patterns are established in childhood, even before the eruption of permanent teeth and long before the adolescent growth spurt (Figure 3). It has been indicated that in children, a fast growth rate for the upper anterior face is associated with a slow growth rate for the lower anterior face and *vice versa*. These different growth patterns may lead to the development of different facial types.[81]

During adolescence, events may occur that magnify or maintain differences between the facial types.[80-82] Both sexes develop based on their adolescent growth patterns (horizontal or vertical) until their 20s; however, in young adulthood (Figure 3), everyone starts to grow vertically. Females complete their facial growth at around 17–18 years, whereas males continue to grow until approximately 25 years. Further, females may experience later growth owing to post-fertilization stimulation.[79,84] Studies on young adults (mean age of 21–26 years at inclusion) followed for 5–20 years have shown that most patients present a slow continued increase in anterior facial dimensions with the most significant changes occurring in the LAFH.[86,91,92,104,113] TAFH increases in both sexes over time, whereas LAFH increases more in females.[22,85,86] Consequently, older individuals and females tend to have more vertical growth patterns.[114,115]

Individuals with a mean age of 22 years in two different studies showed a mean increase in anterior facial height ranging from 1.6 to 2 mm during a period of 20 years.[104,116] The changes have been shown to be larger in young adulthood than mid adulthood (Figure 3) and to decrease in rate with age.[91,117,118] As a result of changes in body posture, soft tissue, muscle function, and bone remodeling, vertical facial development in the anterior maxilla may occur in the fourth and fifth decade of life and possibly even later.[79,85-87,114,117] Continuous vertical development is believed to be limited to individuals with healthy and complete dentitions. However, patients with single tooth loss exhibit minimal differences in growth compared with those suffering from multiple tooth loss, which show less vertical growth.[79,104]

1.2.4 Continuous eruption and up-righting of maxillary incisors

To maintain teeth in balanced occlusion and to compensate for dental attrition throughout life, changes in the surrounding tissues, including the alveolar bone, occur as vertical facial changes takes place. This results in compensatory tilting and eruption of the maxillary incisors into the created space.[79,85,95,104] The upper incisors become more upright (anterior displacement of the apex and posterior movement of the crown) with age in both sexes, well into late adulthood.[79,114,116,117] Individuals with a *long face*, shown to have a thinner and longer alveolar bone in the anterior maxilla, show a more prominent growth pattern with continuous vertical eruption of the maxillary incisors persisting for a longer period throughout their lifespan.[95]

In female patients aged 9–25 years, a continuous vertical eruption of the central incisor of 6 mm during a period of 9–16 years has been observed.[119] In older groups with mean ages of 25 and 30 years at inclusion, vertical movement of maxillary incisors of 1.0 mm after 20 years follow-up and 0.2 mm after 2–8 years was observed[85,104]. The retroclination of the maxillary incisors ranges from 1.4° to 3°.[116,120] Some authors have suggested that the increase in the lower anterior face during adulthood is a result of the eruption/tilting of the teeth and not vice versa.[91,104] Theytaz and Kiliaridis[121] have shown the post eruptive movements of the maxillary incisors to be accompanied by a small gingival recessions after 2–10 years in adult patients (20–50 years) which is hypothesized to be associated with increase of the LAFH.[121] However, Huanca Ghislanzoni and colleagues[122] did not provide evidence that gingival recession accompanies the continuous eruption of incisors, despite findings of such a correlation in premolars and molars.[122]

1.3 MOVEMENT OF TEETH ADJACENT TO SINGLE IMPLANTS

In the situation with single implants, the adaptation of adjacent natural teeth due to continuous vertical changes of the face throughout life has been reported to cause dramatic positional changes of the adjacent teeth in relation to the implant.[79] This causes the implant to end up in infraposition. Both the implant itself and the surrounding bone and mucosa are affected by the changes that have been reported to vary among individuals, ranging from no observed differences to 2–3 mm.[79,123] The incidence of infraposition of a single anterior maxillary implant has been reported to be higher in female than in male patients after 15 years in function.[10,22]

It was early observed that the risk of infraposition was higher in very young patients, and therefore stated that patients should not be provided with implants before the age of 17 to 18 years, when they have reached their growth maxima.[124] However, in a study of 15 young patients, aged 13–19 years, patients of the same age at implant insertion were reported to show different degrees of infraposition (0.8–1.6 mm) after 3 years of follow-up.[123] Other studies, including patients with a mean age of 25 and 32 years at the time of implant placement, also showed different degrees of infraposition (0–>1 mm) after 16–19 years with the implants in function.[10,22] Therefore, as opposed to age, skeletal maturation and changes have been stated to be important factors to consider in predicting the risk of implants ending up in infraposition.[18,123]Additionally, similar patterns of infraposition as with single implants have been reported in ankylotic teeth after trauma.[125]

Movement of adjacent teeth in relation to single anterior implants has been shown to occur in vertical, sagittal, and horizontal directions. A systematic review and meta-analysis, including 27 studies and 1572 patients with a mean age of 42 years followed up for a mean time of 19 years, reported a prevalence of infraposition >1 mm in 21% of the placed implants (five studies). Additionally, it has been found that there is a risk of almost every second implant[126] of opening of approximal contacts in combination with infrapositon.[127,128]

1.3.1 Digital measurements of tooth movement

Throughout the years, two-dimensional (2-D) techniques have been used to measure infraposition (Table 1). Since the early 1990s, three-dimensional (3-D) CAD software has been used to analyze photographed or scanned study models through superimposition.[129-132] The 3-D technique have been shown to be as accurate as using a digital caliper on study models[133] and have been used in two articles to study tooth movement in relation to single implants[127,128] (Table 2). For reliable superimposition and 3-D measurement, choosing a correct point of reference is critical.[122] Different parts of the palate have been used with less successful results. When the curvature of the central part of the hard palate was used as a reference area, comparatively small vertical tooth movements were difficult to detect.[128] Furthermore, the palatal rugae were found to be too unstable in vertical dimensions to be used as references.[134] When the single implant crown together with the third rugae was used as the point of reference[127] relatively small tooth movements was shown in relation to studies using 2-D methods.

Table 1 Overview of scientific articles with 2-D methods to measure maxillary single implant infraposition. Numbers presented as mean ± SD (range) according to presentation in the studies.
*Cohorts divided into two groups
**Two different methods used

Scientific papers with 2-D methods to measure single implant infraposition								
Study	**Year of publication**	**Method**	**Number of patients**	**Mean follow-up time (years)**	**Age at inclusion**	**Implant position**	**Results mean infraposition (mm)**	**Significant risk factors**
Bernard et al.*	2004	Radiographs	1) 14 2) 14	4 (2–9)	1) 18 (15.5–21) 2) 44 (40–55)	Canine-canine	1) 0.7 (0.1-1.7) 2) 0.7 (0.1-1.9) 1+2) 18% >1	None
Jemt et al.	2007	Clinical Photographs	25	16	25	Canine-canine	14 % >1	Female
Chang and Wennström	2012	Radiographs	22	8	40 (19–71)	2nd premolar-2nd premolar	0.4 (95% CI; 0.2/0.6) Incisor position: 0.5 (95% CI; 0.2/0.9)	Central and lateral incisor position
Andersson et al.**	2013	Clinical photographs (1), Radiographs (2)	34	18 (17–19)	31.4 (18–56)	Canine-canine	1) 35% >1 2) Mean 0.2 ± 0.3	Female
Vilhjalmsson et al.	2013	Radiographs	23	3	35 (20–56)	Canine-canine	0.67 (0.13–1.8)	Lower age
Schwartz-Arad and Bichacho *	2015	Clinical Photographs	1) 22 2) 13	8 ± 5 (3–16)	1) 23±4 2) 40±6	Central incisors	Rate %/y 1) 1.0% ± 0.46% 2) 0.3% ± 0.2%	Lower age
Nilsson et al.	2019	Clinical Photographs	22	5 (3.3-6.6)	23 (18-53)	Canine-canine	3%>1	None
Cocchetto et al.	2019	Clinical Photographs	60	11± 4 (5–20)	35 ± 10 (20-65)	Canine -Canine (11 cases splinted)	10% >1	None
Polymeri et al.	2020	Radiographs	76	(1–15)	45 (21–78)	Canine-canine	Max value of 1.7 Rate mm/year 0.08	Delayed placement, lower age
Sauvin et al.	2022	Radiographs	23	13 (8-17)	48 (19-66)	Lateral and central incisors	0.6±0.35 (0.2–1.6)	None
Wittneben et al.	2022	Photographed models, radiographs	28	3	48 (23–79)	1st premolar- 1st premolar	0.25	Crown length of implant crown and adjcent teeth

Table 2 Overview of scientific articles with 3-D methods to measure tooth movement.
Note: The article by Jemt 2005 is a case study

Scientific papers with 3-D methods to measure infraposition								
Study	**Year of publication**	**Reference**	**Number of patients analyzed**	**Mean follow-up time (years)**	**Mean age at inclusion (range)**	**Implant position**	**Results vertical infraposition (mm)**	**Identified risk factors**
Jemt	2005	Palate	1	16	25	Premolar and central incisor	No obvious tooth movements detected	None
Brahem et al.	2017	Implant and 3rd rugae	57	5	30 ± 10	2nd premolar-2nd premolar	4% <1	None

1.4 OBJECTIVE AND SUBJECTIVE AESTHETIC EVALUATION

In the early years of implant treatment, a successful treatment outcome was based primarily on receiving and maintaining osseointegration. High predictability in achieving osseointegration as well as high survival and success rates have been reported.[7,11,13,135,136] However, new technical possibilities for producing single implant crowns in combination with patient demand have added aesthetic outcomes an important parameter of success.[137]

Aesthetics is particularly important when treatment is performed in the anterior maxilla and in patients with a high smile line.[138] The perceptions of what is important to achieve aesthetic satisfaction differ between dentists and patients. Variables, such as the size and form of papillae, deviant peri-implant soft tissue appearance, visibility of metal, emergence profile, size, shape, and shade of single implant crowns compared with adjacent teeth, were considered significant by dentists but have been shown to be less important for the patient.[5,136,138-143]

The importance of reproducible aesthetic evaluations for the comparison of odontological treatment results was reported by Gotfredsen 2004.[137] A vast number of different indices have been developed since then. Methods used to measure the dentists' objective clinical assessments of the aesthetic result in single anterior implant studies include California Dental Association (CDA) quality evaluation index,[41,144-146] Jemt's papilla index,[143,147-150] pink aesthetic score/white aesthetic score (PES/WES),[141,142,151-159] Copenhagen index score (CIS),[160] complex aesthetic index (CEI),[161] implant crown aesthetic index (ICAI),[136,145,156,158,159,162,163] prosthetic aesthetic index (PEI),[164] dental aesthetic index (DAI),[165] implant aesthetic score (IES),[166] and peri-implant and crown index (PICI).[158]

The visual analogue scale (VAS) is a commonly used method that can and have been used for both objective and subjective assessments of the aesthetic result in single anterior implants.[5,135-143,146,152,154,155,157,158,162,167-171] Alternative methods used for subjective evaluation of patients include the use of oral health impact profile (OHIP) in its various forms,[141,160,164,165,172-175] orofacial aesthetic scale (OAS),[165,174,176] and questionnaires that incorporate different types of scales for responses.[41,149,156,157,170,175,177-180] Patient-reported outcome measures (PROMs), have been used in implant dentistry to evaluate the influence of oral health status, care, and other non-clinical values on a patient's quality of life.[181-185] The main characteristics of concern for the patients, regarding aesthetic evaluation of anterior teeth, are the shape and color of the crowns.[186] High aesthetic satisfaction has been shown to be more positively associated with the patients willingness to undergo implant treatment again compared to functional aspects such as chewing ability and phonetics.[170]

1.4.1 Visual analogue scale

Research using the VAS to evaluate the aesthetic outcomes of single anterior maxillary implants generally shows relatively high, although varying, results. Patients with mean ages ranging from 33 to 50 years assessed the aesthetics between 91% and 96%, after mean follow-up times of 3–8 years,[137,140,155,187] whereas another group of patients with a mean age of 32 years showed only 85% (range, 38%–98%) satisfaction after <4 years.[138] The satisfaction has been shown to decrease from 93% to 76% between 3 and 10 years of follow-up.[135]

Several studies show weak correlation between patient and observer satisfaction regarding aesthetics.[10,137,139] In a study comparing the assessment of patients (mean age 32 years) to that of prosthodontists after a mean follow-up time of 3 years, it was found that VAS results differed between 94% and 74% respectively.[139] After a considerably longer mean follow-up time of 18 years, patient (mean age 31 years) and operator assessments differed between 91% and 57%, respectively.[10] Patients with single maxillary implants from premolar to premolar (mean age 33–40 years) valued the aesthetic of their implant crowns at 90%–92% on the VAS scale after 2–10 years.[137,152,154]

1.4.2 California Dental Association evaluation index

The CDA quality evaluation index was originally developed and has mainly been used for evaluation of tooth-supported restorative prosthodontic reconstructions[188-193] but has also been used for evaluation of implant-supported prosthodontics.[41,145,146,194,195]

1.4.3 Smile line

The smile line of patients can be classified into three different groups defined by the amount of gingival display at the maximum smile. The first is the high smile line, with an uninterrupted full display of the anterior teeth in combination with the gingiva cervical to the teeth. The second is the average smile line, displaying 75%–100% of the teeth as well as interproximal papillae, and third, the low smile line that displays less than 75% of the teeth.[196] However, this classification is not intended for use in patients with implants. Therefore, a modified criterion has been used to classify smile lines particularly in patients with anterior implants.[197] These criteria stipulate that if the gingiva of the teeth adjacent to the implant restorations is visible, it would define a high smile line, even if the full-length implant crown is not visible. If the papillae of the adjacent teeth are visible, this indicates a medium smile line, even if the papillae approximal to the implant are not visible.

The etiology of a high smile line does not correlate with lip length. However, a correlation has been found with a high smile line and the efficiency of the lip elevation musculature [198] and with patients belonging to the *long face* group.[95] Females have been reported to have significantly higher smile line than males,[196,199,200] and younger patients to commonly show a higher smile line than older patients. In a group of patients ranging from 23 to 52 years, the patients with a high smile line were approximately seven years younger than those with a low smile line. All men with a high smile line were younger than 32 years.[199]

1.5 ORAL FINE MOTOR CONTROL IN TOOTH AND IMPLANT-SUPPORTED RESTORATIONS

Single dental implants or tooth-supported fixed dental prostheses (FDP) are commonly used prosthetic treatment options in patients with single anterior tooth loss. The periodontal membrane surrounding natural teeth contains periodontal mechanoreceptors (PMRs) that provide sensory feedback essential for holding, biting, and chewing food. Implants, lack the periodontal membrane and the associated sensory feedback (Figure 5).

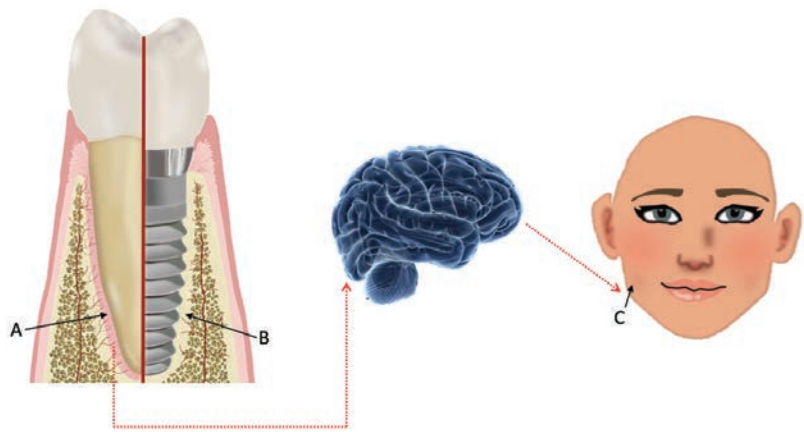


FIGURE 5 Illustration of the different biology around a tooth and an implant as well as the sensorimotor signaling from the PMRs located in the periodontal membrane to the CNS providing feedback to the jaw muscles. (A) Periodontal membrane, (B) Bone-to-implant contact (BIC) with lack of periodontal membrane. (C) Jaw muscles.
Illustrations tooth/implant and face by Nicole Winitsky, brain from Shutterstock.

1.5.1 Proprioception

Proprioception or kinesthesia enables the awareness of body parts, such as muscles, limbs, and joints, without relying on audio-visual input.[201] Another phenomena worth mentioning in the context of oral motor control is stereognosis, which refers to "the ability to recognize shape, structure and texture of food and objects placed in the oral cavity".[202] Proprioception involves sensory nerve endings, known as proprioceptive receptors. These receptors are located in various parts of the body, including the periosteum and the periodontal ligament.[203] Innervation of the periodontal ligament has been histologically examined in humans since 1913 (Dependorf, 1913) and neurophysiologically since 1976.[204]

1.5.2 Periodontal mechanoreceptors and sensorimotor regulation

Various sensory organs send signals to the central nervous system to regulate biting force and speed. The ability to hold and split food depends on these mechanisms. The periodontal membrane surrounding the roots of the teeth represents one of these sensory organs and consists of both organized and "free" nerve endings. Some of these are periodontal mechanoreceptors (PMRs), a specialized group of receptors that controls the jaw muscles during biting and chewing.[205-210] The PMRs are sensitive to mechanical stimuli. The loading of a tooth causes the periodontal membrane to stretch and activates the PMRs to send input about forces acting on the tooth to the central nervous system (CNS).[208,211-213] The CNS then uses the sensory information to adjust and refine the masticatory movements. By providing feedback to the jaw muscles, delicate adjustments of intensity, direction, and rate of occlusal load are enabled[214-216] (Figure 5). These mechanisms are particularly important for positioning and holding food between the teeth, adjusting the bite force to the firmness of the food, and enabling chewing.[211,217,218]

The highest sensitivity to changes is in most PMRs exhibited at very low force levels, which have been shown to be below 1 N for anterior and 3–4 N for posterior teeth.[217,219] Anterior teeth exhibit a greater number of periodontal receptors resulting in the higher sensitivity to low force than posterior teeth.[206,220,221] Owing to their ability to detect low forces (below 1 N) with high sensitivity, periodontal receptors in the anterior teeth have been suggested to be well suited for detecting information regarding initial tooth contact as well as holding of food.[209] When the process of splitting food occurs and the forces of tooth loading increase, the sensitivity of the PMRs decreases. Only a small number of PMRs remain sensitive and can change their firing rate when fast and forceful loads are applied.[217]

For instance, the lack of PMRs in patients with dental implants impairs the fine motor control of the jaws.[220] The effect of this is a lower ability to control the positioning of food, and to adjust the intensity and direction of force in relation to the consistency of food.[222] Implants have been reported to have an approximately 10- to 50-fold higher passive threshold for detecting loads than natural teeth.[217,223] The interocclusal active tactile threshold is twice as high for an implant occluding against a tooth and three times as high for an implant occluding against another implant compared with natural occluding teeth.[224]

1.5.3 Osseoperception

Osseoperception acts on dental implants lacking periodontal membranes and is an expression coined by PI Brånemark. It can be described as a perception originating from the bone [225] through external stimuli such as a bone-anchored prosthesis. The exact mechanism behind this phenomenon is still unknown. However, it appears to involve activation and sensory input from mechanoreceptors in adjacent tissues such as the periosteum, mucosa, skin, muscles, temporomandibular joint, and bone. The sensory input from these mechanoreceptors results in the perception of the transmitted stimuli but has shown to be limited and not fully replace the function of the PMRs.[211,220,223,226,227]

1.5.4 Oral fine motor control

The absence (dental implants) or alteration (dental anesthesia) of sensory inputs from PMRs leads to an inability to properly control forces and regulate spatial positioning [209,211,222,226,228]. Dental anesthesia has been shown to affect hold and split actions by creating a higher and more variable hold force. The absence of effect on the splitting behavior indicates that this action is not influenced by PMRs.[209] Instead, the forces involved in splitting are believed to be mostly influenced by mechanical characteristics such as the shape of the splitting tooth's incisal edge.[209,229]

Studies on edentulous patients with bimaxillary full-arch implant prostheses have revealed that they exhibit impaired force control during initial tooth–food contact and mastication compared with those with natural dentition.[215,230-233] This is most likely because of the absence of PMRs in patients with implants. Interestingly, patients treated with bimaxillary tooth-supported bridges also exhibited impairments.[226] The variability and levels of holding forces were intermediate between individuals with natural teeth and implant-supported bridges. This indicates that the ability to control the magnitude of holding forces are somewhat remained but weakened.[211] Thus, it has been proposed that, owing to the inhibition of rich sensory information from the PMRs, it might be advisable to refrain from splinting separate teeth together in rigid constructions.[211]

Single implants lack support from neighboring implants and cannot be compared with implants connected to bridges in terms of occlusal loads. Unlike bridges, single implants require protection of surrounding natural teeth.[177] The maximum bite force exerted by a natural single anterior incisor is approximately 42% to 48% of the maximum bite force displayed by the first molar. In individuals in early adulthood (19–29 years), bite force has been shown to differ between males and females. The central incisors differ in mean bite force between 94 N and 146 N for females and males, respectively,[234] and the maximum bite forces have been shown to vary from 90 N to 370 N.[235] Despite the ability to generate high maximum bite forces, such forces are seldom used. For example, the mean force required to split a peanut (Estrella, roasted and salted) and a biscuit (McVities Digestive) have been shown to be 18 N and 9 N, respectively.[209]

The holding and biting forces differ between age groups, and children with primary or mixed dentition show higher and more variable hold forces than older children with permanent dentitions (13–18 years) and patients aged between 18 and 35 years.[236] The holding forces in adults have been reported to range from 0.6 to 0.8 N.[209,220,226,229,236,237] The duration of split has been shown to be 50% shorter in children with primary dentition than adults, while no significant differences have been observed in the splitting force.[236]

1.6 TREATMENT OPTIONS AT SINGLE ANTERIOR TOOTH LOSS

The historical options for treatment of young adult patients with single anterior tooth loss have been orthodontic space closure[238,239], 3-unit FDPs, resin-bonded bridges (RBBs)[240], or auto transplantation in the Western world previous to the implant era[241-244]. The selection of treatment method should be determined, after thorough planning based on the specific needs and circumstances of each patient. The best aesthetic and functional outcomes are most likely achieved by the collaboration of a multidisciplinary dental team.[239,245] Since single implant treatment, started to be used also in young adult patients[18,36,37] it has grown to become a frequently used treatment option in this group of patients (Table 2).[23]

Various factors should be considered when considering this treatment modality, such as the time-consuming nature of the procedure, high cost, risks of damage to hard and soft tissues and neighboring teeth, and potential prosthodontic and surgical failures.[3,39,246] Single-implant treatment has previously been stated to be the most popular treatment for replacing a single tooth.[247] However, with new options regarding the minimally invasive treatment with RBBs, with a metal framework or in full ceramics, this may be subject to change.[248]

1.6.1 Tooth-supported fixed dental prostheses

Before 1986, treatment options for single implants were unavailable. The non-removable prosthetic treatments used in patients with single-tooth loss were 3-unit FDPs or RBBs. Both options used metal frameworks with acrylic and, later, porcelain veneering. A review article reporting the estimated survival, success, and complications of FDPs after 5 and 10 years reported survival rates of 94% and 80%, respectively[6]. Caries and devitalization of teeth were found to be the most common biological complications, while fractures of the veneering material and loss of retention the most common technical complications. The same study reported 5- and 10-year survival rates of 95% and 89%, respectively, for single implants. FDPs showed significantly higher annual failure rate than single implants.[6]

1.6.2 Resin-bonded bridges

RBBs are an attractive treatment option to avoid the preparation of adjacent teeth in younger patients. Before single implants became available, Rochette-type resin-bonded bridge (RBB) was routinely performed in patients with single anterior tooth loss at a large prosthodontic clinic in Sweden. However, since the late 1990s, when single implants started to be used also in the younger patient groups, single implant treatment has become a more frequent choice of treatment. In the 1970s, RBBs were considered a long-term temporary solution with survival rates of 1–2 years[249,250] but have more recently been shown to possess survival rates that must be considered acceptable for definitive treatments.[248,251]

In the last two decades, the development of ceramic materials has taken big steps, and RBBs, currently the full ceramic options, are becoming a more commonly used treatment option[252,253]. A systematic review of RBBs[248] followed up for a mean time of 6 (range, 5–13) years found that the most frequent technical complication was debonding, which occurred in 15% of the bridges. Metal–ceramic bridges have shown an estimated 5-year survival rate of 91% and a 10-year survival rate of 83%. The full ceramic RBBs ranged from 93% to 100% with zirconia being the most successful material with 100% survival after 5 years[248]. When comparing the location in the mouth and number of abutment teeth, the highest 5-year survival rates were seen for bridges retained on only one adjacent tooth in the anterior maxilla (94%–96%)[248] although other locations also have been shown to function well[253]. Single implant crowns show survival rates of 96% after 5 years and 89% after 10 years.[7] Although higher survival rates are shown for single implants, considering the low cost, short treatment time, minimally invasive nature, and improved success and survival rates of RBBs, this option should be considered an attractive choice of treatment.

1.7 RATIONALE FOR THE THESIS AND HYPOTHESIS

Study I

The introduction of this thesis highlights that single implant treatment has been performed for almost 40 years; however, a scarcity of long-term studies (>15 years) focusing on this method of treatment remains.[7,9,136] Given the increasing number of patients receiving single implant treatment; long-term survival, success, and complications, particularly in individuals in early adulthood, require further study.[126] The hypothesis of Study I was that treatment with single implants in the anterior maxilla has a good long-term prognosis in early adulthood with a positive correlation between marginal bone loss and PD, implant occlusion, and usage of nicotine.

Study II

The influence of the craniofacial morphology on the movement of teeth adjacent to single implants in young adults remains unclear and requires further assessment using a more robust methodology. Previous studies have suggested that patients with a long facial type have a higher degree of vertical tooth movement over time[10,22,95] and that females possess more pronounced vertical growth[78,115]. Further studies on biological changes related to the teeth and tissues surrounding single implants and to evaluate the subjective assessment of aesthetics in a younger group of patients after a long follow-up are in demand. In Study II, implants in the anterior maxilla in young adults were hypothesized to end up in infraposition after 14–20 years in function and the degree of tooth movement to be positively related to the long facial type. It was further hypothesized that patients asses the aesthetics as good despite infraposition and rate the aesthetics higher than professionals.

Study III

The introduction also further presents that owing to the lack of PMRs, the oral fine motor control is disturbed in patients with full-arch implant-supported bridges, and the ability to hold and split food is inferior to that of natural teeth. Teeth connected in full-arch bridges also perform inferiorly to natural teeth, most likely due to the disturbance of the PMRs when connected in rigid constructions.[226] No previous studies have been conducted on oral fine motor control in treatments with single anterior implants and small bridges. The hypothesis in Study III was that single implants, pontics, and teeth connected with RBB would exhibit inferior oral fine motor control compared with freestanding teeth adjacent to dental implants.

2 RESEARCH AIMS

The overall aim of this thesis was to research the area of single anterior maxillary implants in a group of young adults after an extended period of time and further to examine the sensorimotor-function of the implants in relation adjacent teeth and tooth-supported bridges shortly after implant treatment.

Study I

The primary aim of this study to was report long-term survival, success, biological parameters, complications, and radiological findings of single anterior maxillary implants in young adults. The secondary aim was to evaluate associations between changes in marginal bone levels in relation to probing depth, occlusal contact and usage of nicotine in this relatively young cohort.

Study II

The aims were to analyze the frequency and degree of tooth movement adjacent to single implants in the anterior maxilla in young adults and to clarify whether different patient characteristics can be related to long-term prognosis regarding the position of the implants in relation to the adjacent teeth. It was further, to examine and compare the patients and dentist view of the esthetics after 14–20 years.

Study III

The aim of this study was to compare the oral fine motor control in patients with tooth loss of a single maxillary central incisor treated with resin-bonded bridges and single implant crowns in close proximity to the implant treatment.

3 MATERIALS AND METHODS

Studies I and II were based on the same study group, including 42 consecutively treated single implant patients at the Department of Juvenile Prosthodontics at Folktandvården Eastman Institute in Stockholm between January 1996 and November 1997. A protocol was designed for the treatment procedure and follow-up of the clinical and radiographic parameters. Baseline data were recorded for all patients at the time of crown delivery. The same parameters were assessed again after a lapse of one year. After a mean period of 17 ± 2 (range, 14–20) years a new examination was performed, and biological parameters were added to the protocol. These studies are referred to as the "Long-term follow-up" studies.

In Study III, 16 patients retrieved from the lists of patients scheduled for single anterior implant treatment at the Department of Prosthetic Dentistry, Folktandvården Eastmaninstitutet in Stockholm, the Department of Prosthetic Dentistry, Folktandvården Uppsala, and the Uppsala Surgical Center (Sweden) between November 2020 and January 2022 were included. The first hold-and-split test was performed before the beginning of the implant treatment, with the patients restored with metal-ceramic resin-bonded bridges (RBBs), and the second was performed after a mean time of 31 (range, 8–56) weeks after the first test session, a median time of 28 (range, 12–52) weeks from implant installation and five (range, 2–9) weeks after delivery of the single implant crowns. Results were compared between the two test sessions, with the patients acting as their own controls. This study is referred to as the "oral fine motor control" study.

3.1 PATIENTS

3.1.1 Long-term follow-up (Studies I and II)

At baseline, the cohort was comprised of 24 male and 18 female patients. The mean age was 21 ± 3 (range, 16–30) years at the time of implant treatment. Trauma (*n*=26) and aplasia (*n*=14) were the two main reasons for single anterior tooth loss. In another two patients the tooth loss was attributed to idiopathic root resorption and tooth malformation. Pre-prosthetic orthodontic treatment was performed in 16 patients (38%).

The central (25) and lateral incisors (24) were the primary locations of the implants, and four implants were placed in the canine position. In total, 53 implants were performed, with each patient receiving between one to three single implants. Patients with remaining original single implant crowns (*n*=32) were included in the study on movement of adjacent teeth (Study II).

3.1.2 Oral fine motor control (Study III)

Patients missing one maxillary central incisor, scheduled for single implant treatment, and restored with an intermediate 3-unit, metal-ceramic resin-bonded bridge (RBB) attached to one tooth on each side of the missing tooth were assessed for inclusion. The exclusion criteria included the presence of temporomandibular pathologies, subjective symptoms or malfunction during chewing or biting, allergy to peanuts, and missing or prosthetically treated occluded teeth in the anterior mandible. All patients who met the inclusion criteria were scheduled for examination and treatment planning (Figure 6). The cohort that completed the single implant treatment and followed through with the two hold-and-split examinations consisted of 12 men and 4 women who all had lost their central incisors due to. At the first examination, the mean age of the patients was 24 ± 9 (range, 20–59) years, and they had been restored with RBBs between 0.6 and 9 years (median: 4 years) before. Pre-prosthetic orthodontic treatment had been performed in five patients (31%) prior to the RBB treatment, and two (12%) still had a metal retention cord bonded to the lower anterior teeth. In two patients, the RBB had been dislodged and re-cemented once. Additionally, the RBB had been dislodged more than once in one patient, and more than five times in three patients (19%). Ten of the patients (63%) had never had their RBB re-cemented.

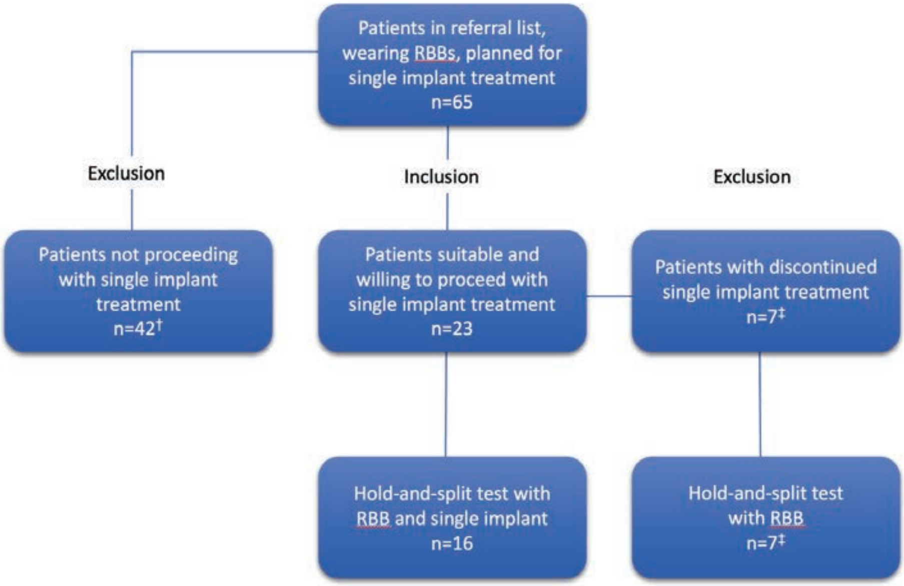


FIGURE 6 Flowchart of patients examined for inclusion or exclusion in Study III.
† Patients considered not suitable or unwilling to go through with implant treatment continued to wear the same resin-bonded bridge (RBB) or received a new RBB.
‡ Patients who later decided to continue wearing the RBB, experienced loss of implant prior to prosthetics, or whose treatment duration was prolonged outside the study timeframe.

3.2 IMPLANT TREATMENT

3.2.1 Long-term follow-up (Studies I and II)

The implants were installed by the same oral surgeon (UT), and the prosthetic treatments were performed by a single prosthodontist (KO). Brånemark implants (MK III; Nobel Biocare AB, Göteborg, Sweden) with a machined surface were installed using a two-stage protocol procedure.[254] The mean healing time from extraction of the primary or permanent tooth to implant placement was 29 ± 37 (range, 3–120) months. Data from two patients was missing. The installed implants were 3.75 mm wide and 15 mm (47%), or 18 mm (53 %) long. Bone quality was classified as grade 2 or 3 according to the Lekholm and Zarb classification.[255] Data from 10 patients/12 implants was missing. After a mean duration of 8 ± 2 (range, 6–16) months, the second stage surgery was performed and abutment cylinders of CeraOne type (Nobelpharma AB, Gothenburg, Sweden) were selected based on mucosal thickness.[2] Abutments of varying lengths –1 mm (23%), 2 mm (28%), 3 mm

(40%), or 4 mm (9%)– were used. Permanent crown placement took place after a mean time of 3 ± 2 (range, 1–8) weeks after the second stage surgery, and the CeraOne abutments were secured to the implants using gold screws[256] tightened to 32 Ncm using a torque driver (Nobel Biocare AB). The 53 aluminum oxide crowns, produced by the same dental technician (MV), were cemented onto the abutments using zinc phosphate cement (Harvard Cement, Harvard Dental Inter. GmbH i.G, Hoppegarten, Germany). In all but four of the crowns, a vent hole[257] was incorporated into the palatal surface approximately 1.5 mm from the cervical border of the crown. This had the objective of preventing excessive submucosal spread of the cement along the abutments.

3.2.2 Oral fine motor control (Study III)

In this study, the implant procedure was conducted by six different prosthodontists and eight implant surgeons. All but one patient underwent treatment at Folktandvården Eastmaninstitutet in Stockholm. The remaining patient was treated at Folktandvården Uppsala and at a private clinic in Uppsala. The width and length of the implants ranged between 2.75–4.3 mm and 11–13 mm, respectively. Implants from five different manufacturers (Straumann Bone Level, Institute Straumann AG, Basel, Switzerland; Nobel Branemark MK III, Nobel Active, Nobel Parallel, Nobel Biocare Zürich, Switzerland; Astra Tech EV, Dentsply Sirona Implants, Mölndal, Sweden) were used. Fifteen patients (data missing in one case) received screw-retained ceramic crowns. All implants with internal implant-abutment connections (81%) had crowns attached to the implants with titanium bases.

3.3 DATA COLLECTION

3.3.1 Long-term follow-up (Studies I and II)

3.3.1.1 Baseline data and one-year examination

At both baseline (42 patients/53 implants) and one-year follow-up (40 patients/50 implants), the clinical examinations were performed by the treating prosthodontist (KO). All radiographs were exposed and assessed by the same oral radiologist (AF). During the baseline (crown delivery) and the one-year examination, the general health status, nicotine use, pain or mobility, and occlusal contacts on the implants were recorded. Marginal bone levels were registered, and impressions for study models were taken.

3.3.1.2 14–20-year examination

After 14–20 years, the patients were contacted and asked to participate in a long-term follow-up of their implant treatments. Clinical examination at the follow-up was performed by a different prosthodontist (NW), and the radiological examination was performed by a different oral radiologist (LW).

Survival and success (Study I)

Single implants and original crowns still in use, including re-cemented crowns, were documented as survivals. Radiological success was calculated according to the criteria delineated by Albrektsson and Isidor[63] according to which implants with less than 1.5 mm of bone loss during the initial year of function and less than 0.2 mm of bone loss per year thereafter, together with the absence of pain, mobility or paresthesia, are considered successful.

Marginal bone levels (Study I)

Radiographic examination at the long-term follow-up was performed in accordance with the original protocol, with standardized periapical radiographs obtained using a film holder and the long-cone paralleling technique. The projection was decided using the baseline radiographs as a guide and aimed to expose the greatest extent of readable screw threads and at the same time include the apical parts of the implant as well as the surrounding bone. To mimic the analogue technique with dental double film packets (Ektaspeed Plus, Eastman Kodak, Rochester, N.Y.) that had been used at baseline and at the one-year follow-up, all implants except three were exposed on digital image phosphor plates (VistaScan SO, 2x3cm Mini/Perio/CombiPlus, Dürr, Germany) in film holders (Skandia Denta, Falun, Sweden) and scanned using a dental imaging scanner (VistaScan Perio Plus IP, Dürr, Germany). The remaining three implants (corresponding to three patients) were exposed using digital sensors. The radiological images from baseline and the one-year follow-up were re-measured with a digital caliper and a magnifying glass on a light table and compared with the images from the long-term follow-up measured using the digital radiography software Romexis (Planmeca Romexis, Planmeca Oy, Helsinki, Finland). Marginal bone levels were measured in a blinded manner according to figure 7, and the mean values of the mesial and distal measurements were calculated for each implant. To evaluate intra-observer variability, the same radiologist measured the radiographs of the first ten patients (13 implants) obtained at baseline, one-year follow-up, and at the 14–20-year follow-up a second time, more than two months after the initial measurements, and with the observer blinded to patient identity and time of exposure.

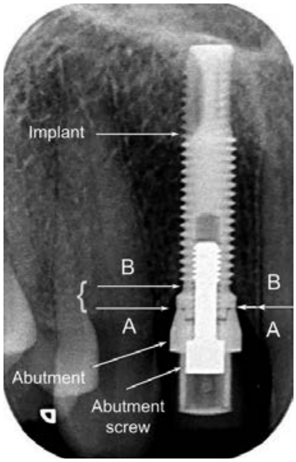


FIGURE 7 Measurements of marginal bone levels (mm) measured mesially and distally from the cervical part of the implant collar (A) to the first visible bone-to-implant contact (BIC) (B).
Note: A and B mesially at the same level.

Biological parameters (Study I)

Observations related to plaque and mucosal health were not registered during the first two examinations. The additional parameters presence of plaque, bleeding on probing (BoP), probing depth (PD), and pus were incorporated to the clinical examination at the long-term follow-up for both implants and for contralateral teeth used as control. In two patients with both upper central incisors replaced by single implants, the adjacent instead of the contralateral teeth were used as control. The parameters were measured on four different surfaces (mesial, buccal, distal, and palatal) on both implants and on the contralateral tooth.[11] PDs were assessed by applying gentle pressure until slight resistance was felt using a metal probe with recordings to the nearest millimeter.[41] The recorded data was divided into two groups based on whether the PD was above or below 6 mm.[67,258] BoP was recorded if it occurred subsequent to the measurement of PD. The mean PD and BoP for the mesial and distal surfaces were calculated and used in the correlation analysis with changes in bone levels.

Complications (Study I)

Biological and technical complications, occurring up until the 14–20-year follow-up, were reported by the patients or retrieved from dental records, and were noted at both implant and patient levels. A recurring complication in the same patient was reported as one event, except in cases in which the crown had initially been chipped and later progressed to a fracture. Subsequently, this was considered a fracture.

Patient and implant characteristics (Study II)

Parameters categorised as patient and implant characteristics included a) facial type (long, neutral, short), b) lower anterior facial height (LAFH), c) sex (m/f), d) age at time of crown placement, e) position of the implant in the maxilla (central incisor, lateral incisor, canine), f) implant occlusion (yes/no), g) cause of tooth loss (trauma or aplasia), h) follow-up period (years) and i) pre-prosthetic orthodontic treatment (yes/no). Data were collected during clinical examinations or from dental records. A 0.8 μm occlusal strip (TrollFoil, Trollhätteplast AB, Trollhättan, Sweden) was used to register occlusal contacts between implant crowns and opposing teeth at the maximal intercuspal position (MIP).

Facial type and lower anterior facial height (Study II)

The facial type of the patient and the LAFH measurements were determined using linear photogrammetry (Figure 8). To ensure a natural posture of the head and a parallel alignment of the occlusal and the horizontal planes, the patient was positioned in a cephalostat during the acquisition of extra-oral photographs (Figure 8).[259]

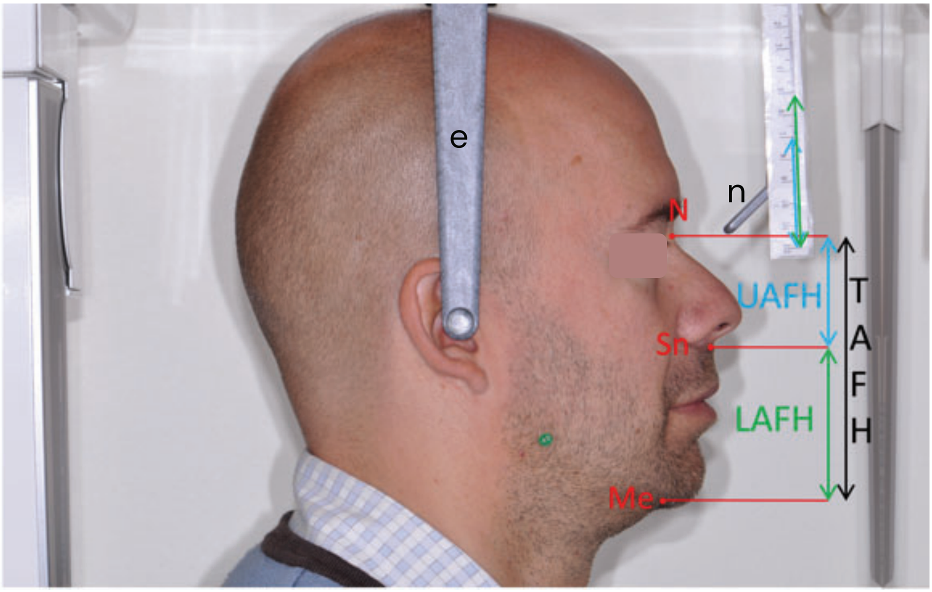


FIGURE 8 Linear and angular photogrammetric analyses with the patient placed in a cephalostat. Landmarks and distances: N=Soft tissue nasion, Sn=Subnasal, Me=Soft tissue menton,[112,259,260] UAFH=Upper anterior facial height (N-Sn), LAFH=lower anterior facial height (Sn-Me), TAFH=total anterior facial height (N-Me). (e) Ear post, (n) Nasal positioner

The patients were instructed to relax their lips, jaws, and face, as well as to maintain a natural head posture during the procedure. Since a cephalostat was not available in six cases, the photographs were obtained without, while adhering to the same protocol. A "reference ruler" was included in all photographs to minimize measurement errors. In the images obtained in the cephalostat, the ruler was placed on the ear post and nasal positioner (Figure 8), otherwise it was attached to the wall next to the patient. The soft tissue landmarks (Figure 8) were identified by (NW) together with an experienced orthodontist (AA)[112,259,260] according to the methodology proposed by Zhang et al.[112] A ruler calibrated to the one depicted in the images was used for the measurements. With a slight amendment, the methodology described by Jamroz et al.[105] in a Caucasian population was used to determine the facial type (Figure 9). LAFH was further dichotomized as above or below 70 mm.

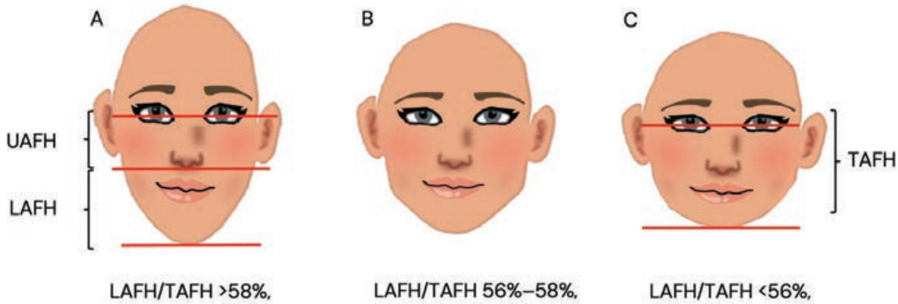


FIGURE 9 Classification of the three facial types, (A) *long face*, (B) *neutral face*, and (C) *short face*. TAFH= total anterior facial height, UAFH = upper anterior facial height, LAFH = lower anterior facial height

Tooth movement adjacent to single implants (Study II)

Plaster casts (Coecal, GC, Tokyo, Japan) produced from the impressions obtained at the long-term follow-up examination were scanned (Trios D900, 3Shape, Copenhagen, Denmark) together with the casts produced at baseline. The scans were converted into stereolithography (STL) files (Dental System 2013, 3Shape, Denmark, Copenhagen) and uploaded to the inspection and metrology software Geomagic Control X (Geomagic Control X, software version 2018.1.1 64-bit; 3-D Systems, South Carolina, United States) to measure differences in the position of the tooth adjacent to the single implant between the two sets of casts in 3-D. To visualize the occlusal plane of each patient, en face photographs were captured during maximal smiling in the cephalostat. These photographs were then used in combination with the follow-up scans of the models. Manual alignment of the occlusal plane of the scanned follow-up models was performed in the 3-D coordinate system of the Geomagic Control X software. The aligned models were then superimposed with a semi-transparent overlay (WindowTop v3.4.5; GitHub) onto the en face photographs, enabling alignment of the models with the horizontal plane of the patient. The models were repositioned using the software based on the angle of inclination of the tooth being measured. This was performed for later measurement of the 3-D movement of the adjacent tooth relative to its own longitudinal axis.

The area of reference, selected as the buccal surface of the implant crown, was marked on the follow-up model in the software to cover an area as extensive as possible. To ensure accurate results during the matching process of the two sets of casts, any regions that had artifacts or alterations in the shape of the implant crown surface, such as crown fractures, were excluded.[127] Additionally, areas located in close proximity to the marginal gingiva and the incisal edge of the buccal surface of the implant crown were omitted from the matching process because of the potential risk of inaccuracy. Using automatic matching in the Geomagic software, the marked area was then aligned with its corresponding buccal region on the implant crown on the scanned baseline model, enabling the two models from each patient to be oriented in the same 3-D coordinate system in the software.

The 3-D movement was compared in the midline at the incisal edge of the tooth positioned mesially to the single implant crown. However, in two sets of casts the adjacent teeth located distal to the implant crown was measured instead. These two situations included one patient with two central incisor implants as well as a veneer that had been placed on the tooth mesial to the implant. If two separate single implants had been placed in different quadrants, the analysis was performed on the implant placed in the right quadrant. Differences in positions were calculated by the software and registered in mm as tooth movements between the two casts. The values calculated on the y-axis represent the tooth's vertical (incisal) movement, those on the z-axis represent its sagittal (bucco-palatal) movement, and those on the x-axis correspond to the lateral (mesio-distal) movement (Figure 10). The rate of displacement was determined by dividing the vertical (Y-axis) movement in mm by the follow-up time (in years).

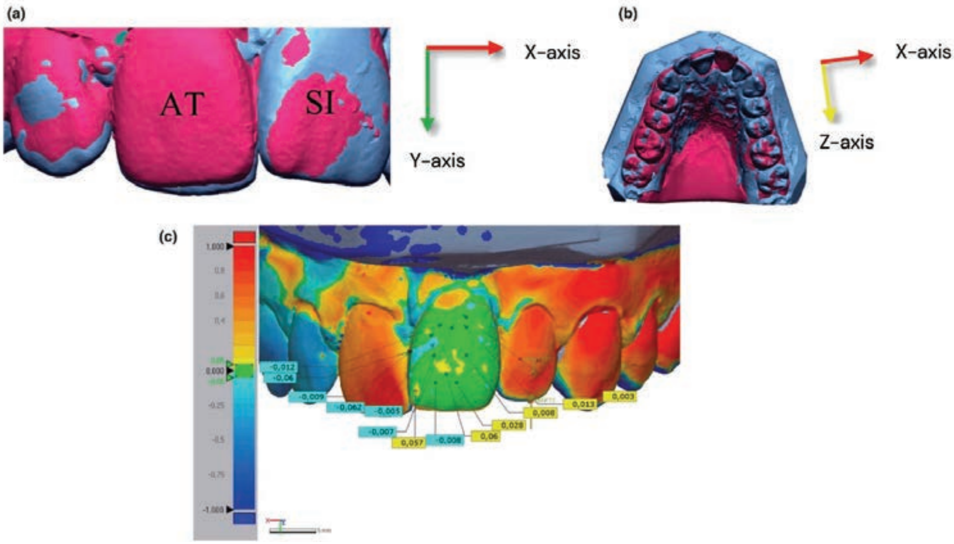


FIGURE 10 Software-assisted 3-D analysis of adjacent tooth movements. (a, b) Showing matching of the models from baseline (pink) and 14–20-year follow-up (blue). (a) Incisal (y-axis, green) and mesio-distal (x-axis, red) movement. (b) Mesio-distal (x-axis, red) and bucco-palatal (z-axis, yellow) movement. Single implant crown (SI) 21 used as reference when movements of adjacent tooth (AT) 11 was measured. (c) Annotations showing deviations on the implant position 21 after best-fit alignment. The color scale indicates magnitude of deviation, ranging from -1 mm to 1 mm, with green color corresponding to alignment with deviations below 0.05 mm.

Objective assessment of esthetics (Study II)

Objective aesthetic assessments were performed using the California Dental Association (CDA) index[144] and the visual analogue scale (VAS).[261] The CDA index was used to rate the clinical quality of the single implant crowns. Two dentists (NW and AL) evaluated the crowns using the following CDA criteria: “color,” “shape,” “surface,” and “marginal integrity.” The rating scale consisted of four categories: “R”(Romeo) for “excellent”, “S” (Sierra) for “acceptable”, “T” (Tango) for “should be replaced”, and “V” (Victor) for “must be replaced” [41,145]. Evaluation of the surface of the implant crown was performed visually as well as with the use of a dental probe. A dental probe was also used to assess marginal integrity, which could not be analyzed in 11 patients due to the presence of deep submucosal margins. In accordance with the CDA guidelines,[144] the rating with the most superior grade was selected as the final rating in case of disagreement between the two observers.

During the clinical examination, the dentist (NW) assessed the aesthetics using the VAS. The answer to the question: "How satisfied are you with the aesthetics of the implant crown?" was graded on a 10 mm scale,[137,139,142,158,168,261] with the endpoints being "not satisfied at all" (0) and "completely satisfied" (10). The responses were recorded in millimeters and presented as percentage of the overall distance.[262]

Subjective assessment of aesthetics (Study II)

Subjective aesthetic evaluations were conducted using the VAS[137,146] following the same protocol used during the assessment conducted by the dentist. To reduce the possibility of bias due to the presence of the examiner, the clinical examination concluded with the VAS question being answered by the patient alone in an isolated room.

Smile line (Study II)

The smile line was categorized by two investigators (NW and JIS) based on photographs of the patient exhibiting a maximum smile. A modified version of a method previously described in a study on anterior implants[197] was used for the assessment (Figure 11).

FIGURE 11 Determination of smile line. The smile line was classified as high if mucosa was visible cervically to the implant crown (A), as medium if only parts of the papilla were visible or if there was an absence of papillae mesially and/or distally to the implant (B), and as low if there was no visible mucosa in the implant region (C).
Note: The numbers indicate the position of the implant in each case.

3.3.2 Measurement of oral fine motor control (Study III)

3.3.2.1 Equipment (Study III)

A custom-built apparatus (DC 200 Hz; Department of Integrative Medical Biology, Umeå University, Umeå, Sweden) was used to measure the hold and split forces.[263] The apparatus consisted of a bar-shaped metal handle covered with plastic, measuring 11 cm in length and 0.7 cm in diameter. The handle was attached to duralumin blocks ending in two parallel rectangular plates with a stiffness of 50 N/mm between them. The upper duralumin block included a strain gauge force transducer that changed resistance when compressed. By converting the applied force into an electrical signal, the hold and split forces applied to the plate were measured and recorded. The equipment was designed to ensure that the force measurement remained unaffected by the position on the plate where the force was applied.[226]

3.3.2.2 Experimental procedure (Study III)

The test consisted of holding and splitting half a peanut and was carried out in a quiet room with the patient seated in a comfortable chair in front of a table. The patients were asked to sit in an upright position and hold the force transducer using one hand. Additionally, to maintain a horizontal alignment between the anterior teeth and the upper plate of the transducer, the patients were advised to rest their elbow on the table.[226,263] After the hilum was removed, the patients placed a peanut half (Estrella salta jordnötter, Estrella AB, Angered, Sweden) on the force transducer. The patient was asked to hold the nut between one upper central incisor and its antagonist with "a force as low as possible" for 3–4 seconds (hold phase), and then to split the peanut when asked to do so (split phase).[209,226,236,263-266] To ensure that the patients were comfortable with the hold-and-split task, they were allowed at least five practice trials before the actual recording of the hold and split forces. Additional practice was provided if required until the patient felt at ease with the procedure. The recording was repeated five times, and the mean value of the five recordings value was used for further analysis. In total, at the two experimental sessions, four conditions were tested. First, with the RBB in place on the connected tooth (CT) and on the pontic (P), and then after the single implant treatment on the same tooth, now freestanding, (T) and on the adjacent single implant (SI).

3.3.2.3 Data analysis (Study III)

The force signals were recorded at a rate of 1000 samples per second (1000 Hz), and the signals were low-pass filtered at 250 Hz. A data acquisition and analysis software system (WinSC/WinZoom v1.52.0.1; Umeå University, Physiology Section, IBM, Umeå, Sweden) with a 12-bit resolution at 800 Hz was used to monitor, measure, collect, and analyze the holding and splitting force data. The collected data were used to analyze various aspects of the force, including its magnitude, duration, and pattern over time. Four outcome variables (hold force, variability of hold force, split force, and duration of split) were extracted and calculated. As in previous studies,[226,263] the force profile of each trial was separated into two distinct phases: the hold phase and split phase (Figure 12). The software automatically identified the demarcations between the phases, which were subsequently verified through manual inspection for accuracy. The point at which the force rate exceeded 5 N/s, the minimum rate of increase previously shown to be reliably detected during an individual trial[226], was selected as the point of onset of the hold and split phases (Figure 12). The outcome variable "variability of the hold force" was calculated by dividing the standard deviation of the hold force by the mean of the hold force within an individual trial. The split force was assessed by identifying the peak of the force profile corresponding to the moment when the peanut was split. The duration of the split was defined as the time elapsed from the onset to the moment when the peak force of the split phase was reached (Figure 12).

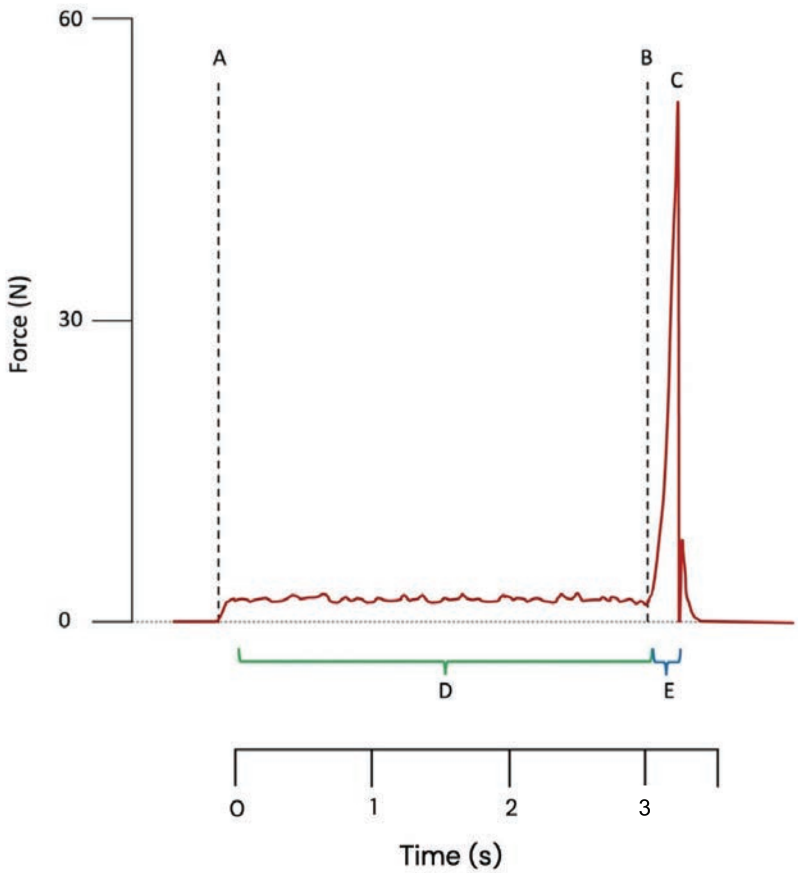


FIGURE 12 Force profile illustration. (A) the point where contact between peanut and tooth/implant/pontic is established. (B) the initiation of the split phase. (C) the peak of the split force. (D) the hold phase, illustrated by the fluctuating force line from 5 N/s after initial contact with the peanut to 5 N/s before the onset of the split phase. (E) the split phase, illustrated by a force profile with a rapid rise until the peak at the breaking of the peanut, followed by a fast decline.

3.4 STATISTICAL ANALYSES

3.4.1 Study I

3.4.1.1 Descriptive statistics

Mean values and standard deviations ($\bar{x} \pm SD$) were computed and reported alongside ranges.

3.4.1.2 Inferential statistics

The estimated cumulative survival rates for implants (CSRi) and implant crowns (CSRc) were calculated using the Kaplan-Meier method.[267] To evaluate the relationship between PD and changes in marginal bone levels the Pearson correlation test was employed. A paired *t*-test was conducted to detect disparities in bone-level changes between nicotine users and non-nicotine users, as well as between implant crowns with or without occlusion at MIP. Intra-observer consistency in the radiological measurements of bone levels was assessed using the intraclass correlation test (ICC), with values <0.4 indicating poor agreement, values between 0.4 and 0.59 indicating moderate agreement, values between 0.6 and 0.74 indicating good agreement, and values >0.75 indicating excellent agreement.[268] The standard error of measurements (SEM) was calculated.

3.4.2 Study II

3.4.2.1 Descriptive statistics

Mean values, standard deviations ($\bar{x} \pm SD$), median values, interquartile ranges (IQR), and ranges were calculated. Mean and median values of tooth movement were rounded to the closest 0.5 mm.

3.4.2.2 Inferential statistics

Associations between tooth movement and the variables a) facial type, b) LAFH (more or less than 70 mm), c) sex, d) age at time of crown delivery, e) position of the implant in the maxilla, f) implant occlusion, g) cause of tooth loss, h) follow-up period and i) pre-prosthetic orthodontic treatment were analyzed with quantile regression analysis of the 50th percentile. A univariate model was used to for each of the exposure variables. Further, a multivariate model was used for the main exposure LAFH that was adjusted for teeth adjacent to implants in central incisor position (yes/no), and implant in occlusion (yes/no). Additionally, a logistic regression model including these same variables but with movement of adjacent teeth as a dichotomous variable of more or less than 1 mm was used.

To analyze the statistical interaction between vertical tooth movement of >1mm, LAFH >70 mm and implants with or without occlusion, a quantile regression model was stratified on implants without occlusal contact, that included trauma as the cause of tooth loss or teeth adjacent to implants in the central incisor position.

The level of agreement between the VAS scores reported by the clinician and the patients was assessed using the Spearman correlation, the kappa test, contingency tables and paired *t*-test. A quantile regression analysis of the VAS score for each patient, which included the smile line, was carried out for all patients, and it was stratified only for those patients with implants in the central incisor position.

Statistical significance for the quantile regression and the odds ratio (OR) (not including 1 in the case of logistic regression) was determined by considering *p*-values <0.05 and 95% confidence intervals of regression coefficients not including the 0 value. All statistical analyses were performed using the Stata 15 SE software (StataCorp LLC, College Station, Texas, United States).

3.4.3 Study III

3.4.3.1 Descriptive statistics

All four outcome variables (hold force, variability of hold force, split force, and duration of split) are presented as means ± standard deviations ($\bar{x} \pm SD$) at the test conditions CT, P, T, and SI. The Shapiro-Wilk test, histograms, and normal Q-Q plots were used to assess the normal distribution of the data.

3.4.3.2 Inferential statistics

The split force variable, which showed a normal distribution, was analyzed using the paired Student's *t*-test, while the hold force, variability of hold force, and duration of split variables, which showed skewed distributions, were analyzed using the Wilcoxon signed-rank test. Statistical significance was assumed at *p*-values of <0.05.

3.5 ETHICAL CONSIDERATIONS

All three studies received approval by the Swedish Ethical Review Authority in Stockholm. Studies I and II, Dnr 2013/1302-31/3 and Study III, Dnr 2018/1677-31/1. In all studies patient data was processed according to applicable confidentiality rules and in accordance with the laws that govern registration and management of databases. Each patient/study subject received a trial subject number as well as a patient number (patient code) that was recorded in all forms. All data and results were recorded in coded form and then entered into the department's database, where the patient identification list is also located. Permission for the database was obtained from the Swedish Authority for Privacy Protection's. As specified in the Helsinki declaration, all included patients signed a written informed consent form before the commencement of the study. Study III was registered in the ISRCTN registry (24104637).

4 RESULTS

4.1 CLINICAL AND RADIOGRAPHIC PARAMETERS (STUDY I)

4.1.1 Patients lost to follow-up

At the 14–20-year (mean 17 ± 2) follow-up examination, two patients from the original cohort of 42 were unable to attend the examination. Both patients were lost after 1-year follow-up. One had the implant crown re-cemented after four months in function and the other had no reported complications before the dropout.

4.1.2 Patients

The remaining 40 patients with 51 implants had a mean age of 38 ± 4 (range, 32–47) years at the 14–20-year follow-up. The mean age of delivery of the crowns was 21 ± 3 (range, 16–30) years. Trauma (25) and aplasia (13) were the main causes of tooth loss. Good general health without any illnesses or medical conditions was reported in 95% of patients at baseline (*n*=42). This percentage decreased to 77% at the 14–20-year examination (*n*=40) with patients starting with medications for asthma, allergy, rheumatism, migraine, epilepsy, ADHD, high Blood pressure. The number of patients using nicotine (smoking or snuff) increased from four at baseline to 16 at the 14–20-year examination.

4.1.3 Implant and crown survival

At the completion of the study (*n*=40), two implants in two patients failed (5% patients/4% implants), reaching a CSRi of 96.1%. The first, removed after 3.5 years, displayed loss of buccal bone, mucositis, and pus and was not reinstated. The second failed implant was initially placed too buccally and showed exposure of threads at baseline. The implant was removed and replaced 11 years later because of esthetic concerns with 6 mm bone loss and soft tissue recession, exposing the implant up to the eighth thread. Of the remaining 38 patients, 10 original single crowns in six different patients were replaced during the follow-up period. In four patients, six crowns were replaced due to accidents, while in two female patients, four crowns were replaced due to infraposition and esthetic concerns. In all patients in whom single implant crowns were replaced due to an accident, the etiology of tooth loss was trauma. A CSRc of 80.4% was found after 14–20 years in function.

4.1.4 Implant success

According to the success criteria of Albrektsson and Isidor (1993), all remaining implants were considered successful (100%). No mobility, pain, and/or paresthesia were found at any of the implants during follow-up. Marginal bone loss was less than 1.5 mm during the first year in function (0.2 mm), and the mean rate of marginal bone per years was less than 0.2 mm (0.01 mm) during the remaining period of follow-up.

4.1.5 Marginal bone levels

In one patient, the baseline radiographs were missing, and this patient was excluded from Study I. From baseline to the 14–20-year follow-up, a mean marginal bone level change of -0.1 ± 1.1 (range, -5.1–1.6) mm was measured. While an increase in marginal bone levels of more than 0.1 mm was measured in 24 (50%) of the implants, bone loss of >1 mm was measured in nine implants (19%) (Figure 13). Marginal bone loss >2 mm was measured in only one implant (Figure 13). The mean bone loss was -0.2 ± 0.9 (range, -2.0–1.1) mm for implants with (n=11) occlusal contact, and -0.1 ± 1.2 (range, -5.1–1.6) mm for implants without (n=37) occlusal contact MIP (p >0.05) (Figure 14). A mean bone loss of -0.2 ± 0.83 (range, -2.0–1.0) mm was measured in nicotine users (n=16) and -0.1 ± 1.3 (range, -5.1–1.6) mm in non-nicotine users (n=32; p >0.05) (Figure 14). Regarding precision of measurements of the marginal bone levels, the intra-observer variability analyzed with intraclass correlation test (ICC) showed a kappa value (with 95% confidence interval) of 0.71 for radiographs exposed at baseline, 0.91 at the 1–year follow-up, and 0.66 at the 14–20-year follow-up. The SEM at the 14–20-year follow-up was 0.46 mm.

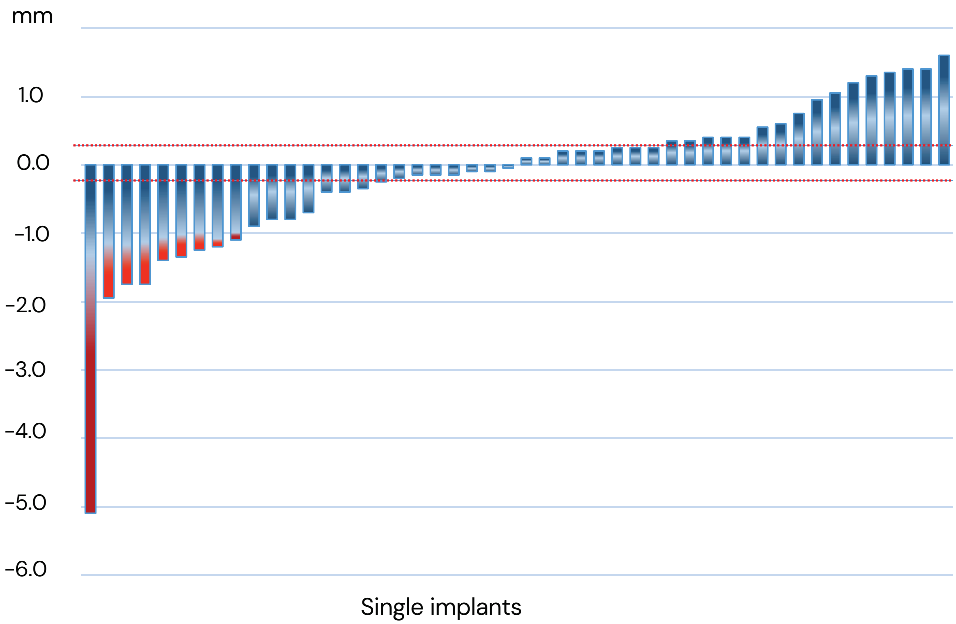


FIGURE 13 Radiological changes in marginal bone levels from baseline to the 14–20-year follow-up. Mean value of mesial and distal measurements calculated. Lines at 0.25 show error of measurement.[269] Bars with parts in red show bone loss above 1 mm. (n=48)

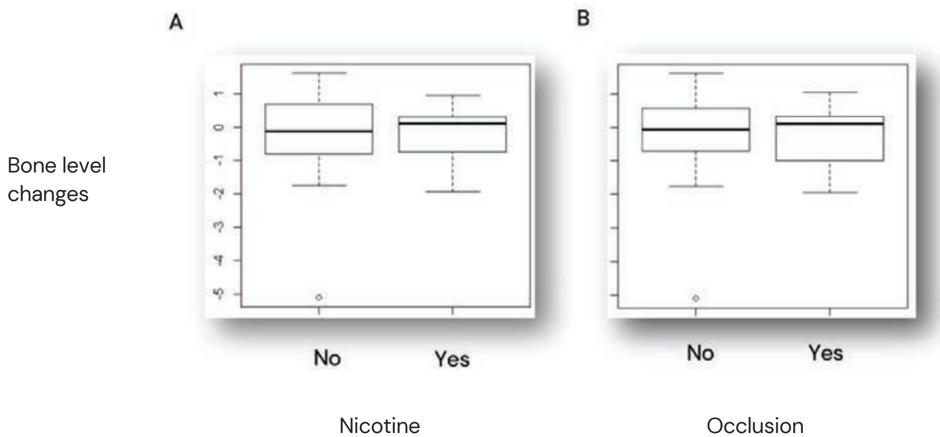


FIGURE 14 Box plot showing the results of bone level changes in relation to usage of nicotine (A) (p=0.77) and to occlusion (B) (p=0.6).

4.1.6 Biological parameters

At the 14–20-year follow-up, the implants (*n*=48) and contralateral natural teeth (*n*=48) were found to have plaque in 31% (*n*= 15) and 59% (*n*=24) of the cases and bleeding on probing (BoP) in 79% (*n*=38) and 58% (*n*=28) of the cases, respectively. The mean PD on implants was 4.0 ± 1.8 (range, 0–9) mm, and PD >6 mm was found in nine implants (19%) (Figure 15).

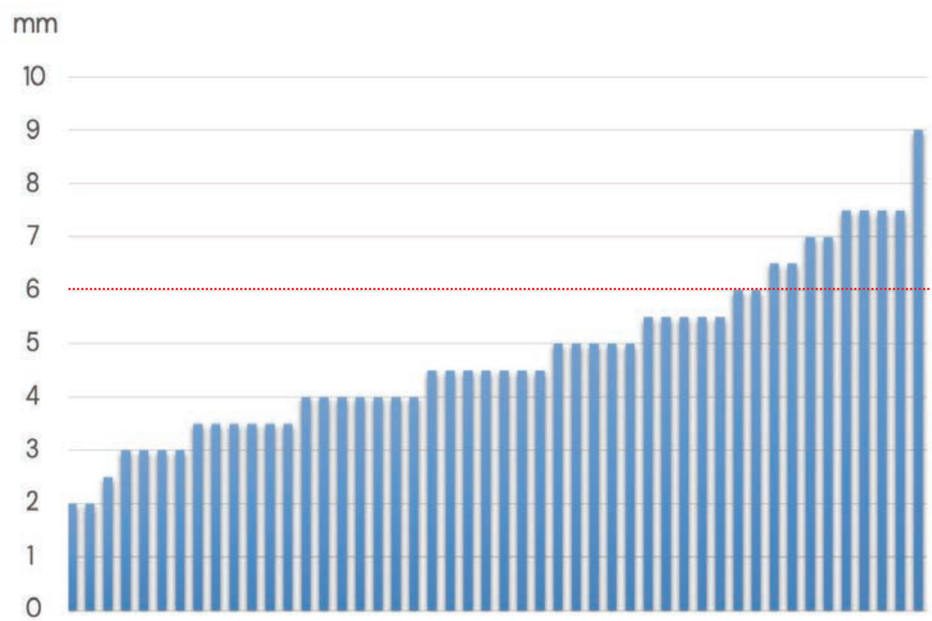


FIGURE 15 Probing depth (PD) of single implants at the 14–20-year follow-up. Mean value of mesial and distal measurements calculated. Bars above the red line show implants with probing dept >6 mm. (*n* = 48)

Plaque was detected at 15 implants. Among the surfaces with a PD >6 mm (*n*=29), BoP was found in 22 (75%), plaque in two (7%), and pus in five surfaces (17%). The five surfaces with pus showed a mean PD of 5.3 ± 1.9 (range, 3–7.5) mm. One patient experienced recurrent pus and swelling over the past ten years without concurrent progressive loss of bone (Figure 16).

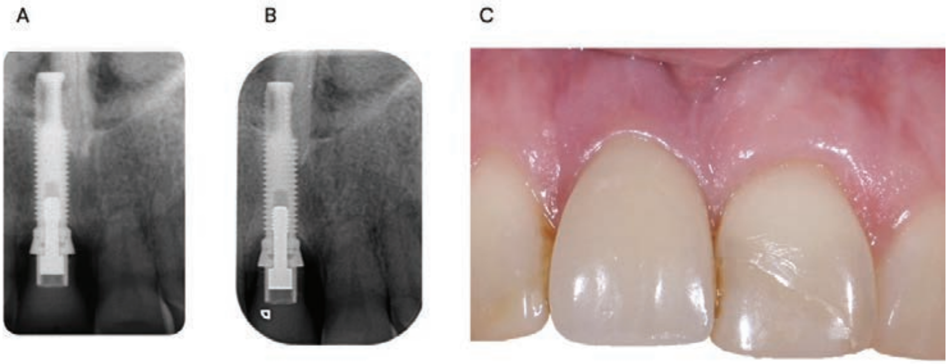


FIGURE 16 Patient reporting recurrent buccal swelling with pus since the last 10 years, at right central incisor implant, at the 15-year follow-up examination. Clinical status showing probing depth (PD) of 8 mm mesially and 7 mm distally with bleeding on probing (BoP) at both sites. Radiological measurements show a mean marginal bone loss after the first year of 0.4 mm and an additional 1.0 mm from year one to 15-year examination. A. Radiograph at the 5-year follow-up before onset of recurrent mucosal swelling and pus. B. Radiograph at the 15-year follow-up with mean marginal bone loss of 1.4 mm. C. Clinical photograph at the 15-year follow-up with implant appearing shorter and buccally tilted in relation to adjacent central incisor. Movements of adjacent tooth: 0.4 mm in incisal direction (Y-axis), 0.5 mm in palatal direction (Z-axis) and 0.03 mm in mesial direction (X-axis).
Note: Level of first bone-to-implant contact (BIC), short roots and deep placement of implant on radiographs.

The only implant that was showing >2 mm bone loss (Figure 17) was presented with a PD of 3 mm and absence of BoP and pus. Out of seven implants showing PD >6 mm and BoP only two showed a men bone loss >1 mm (Figure 17). Additionally, the implants with a mean PD >6 mm (25%) were displayed with a mean bone loss of 0.2 ± 1.1 (range, -2.0–1.4) mm. The results of the Pearson correlation test failed to show any significant correlation (*p* >0.05) between PD and marginal bone level changes (Figure 17).

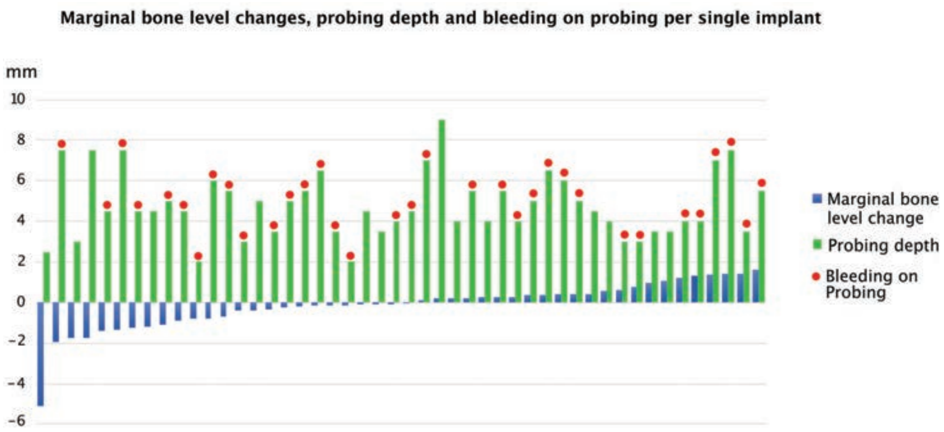


FIGURE 17 Changes in marginal bone level, probing depth (PD) and bleeding on probing (BoP) registered on implant level at the 14–20-year examination. Mean levels of mesial and distal surfaces calculated for PD and marginal bone levels. BoP reported as positive when either mesial or distal site was positive (red dot) (*n*=48).

4.1.7 Complications

Among the 42 patients at baseline, 21 patients experienced complications (50%), 17 had one complication each, while the remaining four patients had 2–4 complications each. In total, nine patients experienced technical complications (21%), and 19 had biological complications (45%). Only one patient experienced both biological and technical complications. Technical complications observed on the implant crowns included chipping of the ceramics (2), fracture of the ceramic (3), abutment screw loosening (3), and re-cementation of the crown (3). Regarding biological complications, 12 implants presented with fistulae with (6) or without pus (6), and seven were presented with soft tissue recession with visible titanium. Substantial treatment due to the complications were performed in 22% of the patients.

4.2 MOVEMENT OF ADJACENT TEETH (STUDY II)

4.2.1 Patients lost to follow-up

Within the study group of 42 patients treated with single anterior implants in 1996–1997, two did not attend the 14–20-year examination. Additionally, one patient experienced implant loss and did not opt for replacement, one had both the implant and crown replaced, and six patients had their crowns changed.

4.2.2 Tooth movement adjacent to single implants

The remaining 32 patients were included in the examination regarding 3-D tooth movement adjacent to the implants. Due to difficulties in 3-D matching, two additional patients were excluded from the measurements. The two paired models of the remaining 30 patients were compared with regards to 3-D tooth positions. The tooth movements calculated by the software (30 adjacent teeth) showed a 3-D displacement ranging from 0.0 to 2.5 mm including mesio-distal (X), bucco-palatal (Z), and incisal (Y) directions. The mean displacements in Y-direction were 1 ± 0.5 (0.1–2.2) mm, in Z-direction 0.5 ± 0.8 (-2.2–2.3) mm, and in X-direction -0.0 ± 0.1 (-0.2–0.1) mm. Moreover, vertical tooth movement along the Y-axis occurred in the incisal direction in all patients, while tooth movement along the Z-axis was predominantly seen in the palatal direction (70%) as opposed to the buccal direction (30%). Along the X-axis, there was an equal occurrence of mesial and distal movements (50%). In 30% of patients with an incisal movement of >1 mm, a mean measure of 1.5 ± 0.4 (range, 1.0–2.2) mm was observed. Additionally, the mean vertical movement of the teeth adjacent to implants in the central incisor position was less (0.5 ± 0.3 mm) than the movement of teeth adjacent to implants in the lateral incisor and canine positions (1.0 ± 0.5 mm). See figure 18 for visualization of adjacent tooth movements.

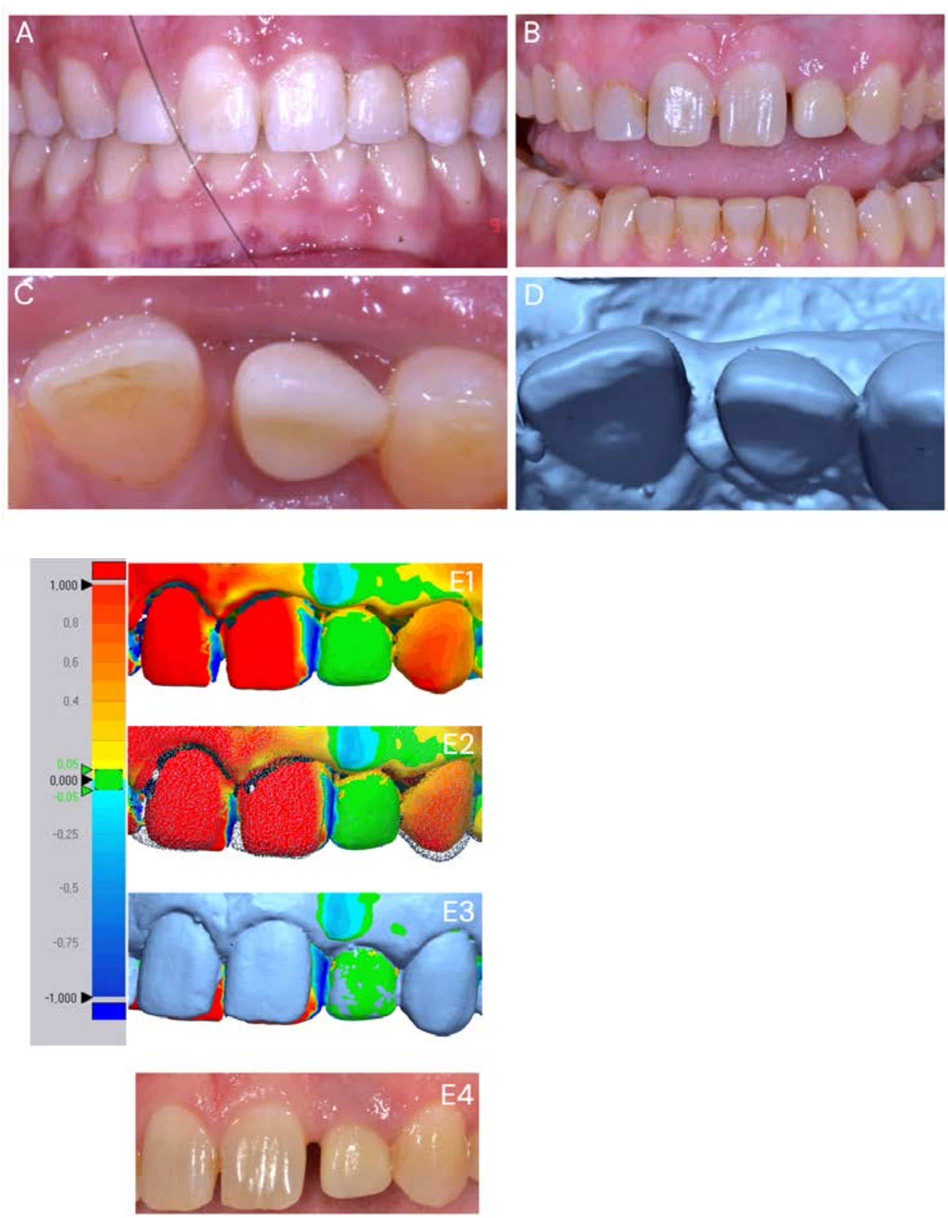


FIGURE 18 Presentation of the patient with the most extensive buccal movement. The adjacent upper left central incisor showed 2.2 mm buccal movement, 0.4 mm incisal movement, and 0.01 mm mesial movement in relation to the implant in upper left lateral position at 17-year follow-up. (A) Frontal photographs of the clinical presentation at baseline and (B) at 17-year follow-up. (C, D) Visualization of the movements in Z- and X-axes from an occlusal view in the 3-D software and in a clinical picture. (E1–3, E4) Visualization of the movements in Y- and X-axes in a buccal view in the software and a clinical picture. (E1) The different colors indicate the magnitude of movement and (E2) the dotted areas illustrate the movement. The overlaying of the models is shown in E3.
Note: Patient received pre-prosthetic orthodontic treatment prior to implant placement, clinical picture showing tongue pressure. Diastema mesial to the implant is not present at baseline.

4.2.3 Patient and implant characteristics

Among the 30 patients measured for tooth movements the mean age at crown delivery was 21 ± 3 (range, 16–30) years and the mean time of follow-up was 17 ± 2 (range, 14–20) years. The main causes of tooth loss were trauma (18) and aplasia (11). Thirteen patients underwent pre-prosthetic orthodontic treatment before implant placement. The implants were placed in the central incisor (14), lateral incisor (13), and canine (3) positions, with six implants in occlusion. A long facial type was found in 15 (50%) patients, a neutral facial type in three (10%), and a short facial type in the remaining 12 (40%) patients. Lower anterior facial height (LAFH) ≥70 mm was reported in 16 (53%) patients, and a LAFH <70 mm in 14 (47%) patients.

The results of the uni- and multivariate quantile regression analyses are presented in Table 3. Univariate quantile regression analysis failed to show any significant correlation between the tooth movement of adjacent teeth (Y-axis) and patient characteristics regarding LAFH ≥70mm, sex, age at crown delivery, follow-up period, pre-prosthetic orthodontic treatment and facial type (Table 3; $p > 0.05$). However, the univariate test showed significant correlations between less tooth movement and implant in occlusion, implant in central incisor position and when trauma was the reason for tooth loss (Table 3; $p < 0.05$). The multivariate quantile regression analysis showed an association between the degree of tooth movement and implants in occlusion ($p < 0.05$), implants in the central incisor position, and LAFH ≥70 mm (Table 3; $p < 0.05$). A statistically significant correlation between LAFH of >70 mm and tooth movement of >1 mm (odds ratio (OR), 13; 95% CI, 1.4–124.3) was observed with logistic regression analysis ($p < 0.05$).

TABLE 3 Uni- and multivariate quantile regression analyses of the association between tooth movement in the incisal direction (Y-axis) and patient and implant characteristics.

Quantile regression	Univariate analysis				Multivariate analysis			
Variables	Coefficient	*p*	95 % CI		Coefficient	*p*	95 % CI	
LAFH ≥70 mm	0.44	0.13	-0.13	1.01	0.46	0.01**	0.11	0.81
Implant in occlusion	-0.53	< 0.01**	-0.88	-0.10	-0.73	0.02*	-1.34	-0.13
Implant in central insicor position	-0.58	< 0.01**	-0.99	-0.18	-0.43	< 0.01**	-0.66	-0.20
Sex	-0.15	0.63	-0.79	0.48				
Age at crown delivery (years)	0.09	0.69	-0.38	0.56				
Follow-up period (years)	0.13	0.20	-0.74	0.03				
Trauma as cause of tooth loss	-0.59	< 0.01**	-1.00	-0.18				
Pre-prosthetic orthodontic treatment	0.33	0.23	-0.22	0.87				
Facial type cathegories†	0.46	0.65	-0.26	0.42				
Long	Reference							
Neutral	0.45	0.20	-0.25	1.15				
Short	0.09	0.78	-0.58	0.76				

Note: Multivariate analysis adjusted for variables trauma as cause of tooth loss, implant in occlusion, and implant in central incisor position in relation to LAFH ≥70 mm is shown with *p*-values and 95% confidence interval (95% CI).
Abbreviation: LAFH, Lower anterior facial height.
†Long facial type=1, neutral facial type=2, short facial type=3
**p* <0.05 statistically significant; ***p* <0.01

4.2.4 Assessment of quality and esthetics

The results of the evaluation according to the California Dental Association (CDA) are shown in table 4. In this evaluation, 27 patients (87%) received R- and S-ratings (excellent and satisfactory), and three (10%) received T-ratings (should be replaced). All T-ratings had issues related to color and shape, and no V-rating (must be replaced) was given.

The aesthetic ratings according to the VAS is shown in table 5. The mean esthetic VAS rating by the dentist was 67% ± 23% (range, 10%–100%), with a lower score for single implant crowns in females of 56% ± 26% (range, 10%–90%) than for males of 76% ± 16% (range, 40%–100%). Regarding the patient's assessment of esthetics, the results were 85% ± 19% (range, 20%–100%), with somewhat lower ratings for females of 80% ± 23% (range, 20%–100%) than males of 89% ± 14% (range, 50%–100%). No significant correlations were found between the patients' VAS scores and the degree of incisal tooth movement, smile line, age, or sex in the overall study population (p >0.05). However, in patients with central incisor implants, a significant correlation was observed (p <0.01) between lower patient VAS scores and increased incisal tooth movement. Regarding patient assessment, when incisal tooth movement exceeded 1 mm, the VAS score was 78% ± 28%, whereas cases with less incisal tooth movement had a corresponding score of 88% ± 14%. Satisfaction with the esthetics of single implant crowns was rated higher by 73% of the patients than the dentist. Additionally, only 10% of the implant crowns were rated as "fully satisfied" by the dentist, while 33% were given the same rating among the patients. The kappa test revealed low agreement (κ index 0.09) and paired *t*-test showed significant differences ($p < 0.05$) between patients and dentist (Figure 19).

TABLE 4 Dentist evaluation of the quality of the implant crown using the California Dental Association (CDA) index [270]. R (Romeo) = excellent, S (Sierra) = acceptable, T (Tango) = should be replaced, V (Victor) = must be replaced. Marginal integrity could only be analyzed in 19 patients due to deep submucosal margins not possible to probe in 11 patients. (*n*=30)

CDA	Rating	Colour	Shape	Surface	Marginal integrity
Satisfactory	R	5	9	18	10
	S	22	18	12	9
Not acceptable	T	3	3	0	0
	V	0	0	0	0
Total		30	30	30	19

TABLE 5 Evaluation according to visual analogue scale (VAS) of the esthetic outcome of the implants by patients and dentist answering the question "How satisfied are you with the aesthetics of your/the patients implant crown." (*n*=30)

VAS	VAS score (mm)	Evaluation by dentist (n=30)	Evaluation by patient (n= 30)
Not satisfied at all	0–20	2	1
	21–40	3	0
	41–60	5	2
	61–80	14	8
Completely satisfied	81–100	6	19

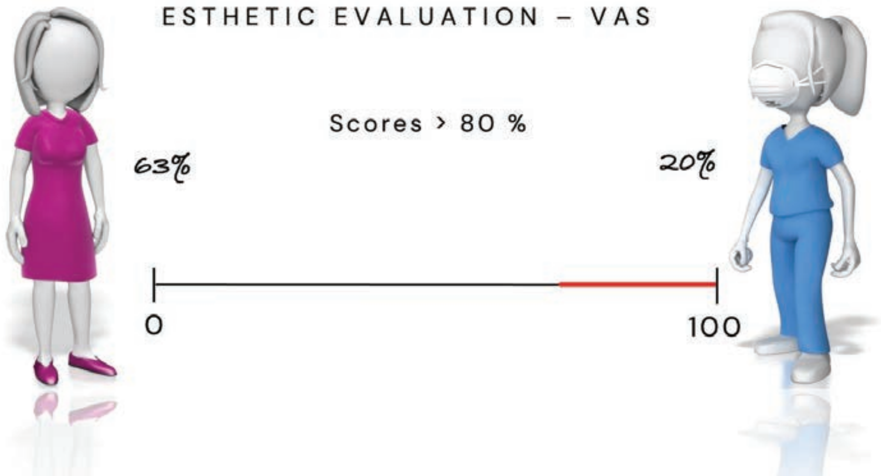


FIGURE 19 Illustration of the percentage of patients rating their esthetics as >80% on the visual analogue scale (VAS) in comparison to the dentist.
Illustrated by Nicole Winitsky. Patient and dentist from Presenter media.

4.2.5 Smile line

Categorization of the smile line resulted in three patients (10%) presenting with a high smile line, 19 with a medium smile line (63%), and eight (27%) with a low smile line.

4.3 ORAL FINE MOTOR CONTROL (STUDY III)

4.3.1 Hold force

The mean hold force values for each of the four different conditions were as follows: 1) 1.32 ± 1.16 N for CT (connected tooth); 2) 1.80 ± 1.87 N for P (pontic); 3) 1.14 ± 0.84 N for T (freestanding tooth); and 4) 1.78 ± 1.28 N for SI (single implant). Statistically significant differences were found between CT and P ($p < 0.05$) and between T and SI ($p < 0.05$), but no statistically significant differences were found between CT and T ($p > 0.05$) or between P and SI ($p > 0.05$) (Figure 20).

4.3.2 Variability of hold force

The results for the mean variability of the hold force were as follows: 1) 0.74 ± 0.71 N for CT; 2) 1.07 ± 1.27 N for P; 3) 0.69 ± 0.47 N for T; and 4) 0.82 ± 0.43 N for SI. There were no significant differences between CT and P ($p > 0.05$); however, there was a significant difference in the hold force variability between T and SI ($p < 0.05$). In addition, no significant differences were found between CT and T ($p > 0.05$) or between P and SI ($p > 0.05$) (Figure 20).

4.3.3 Split force

The analysis of the split force revealed the following mean measurements: 1) 56.35 ± 16.99 N for CT; 2) 55.22 ± 17.60 N for P; 3) 57.17 ± 18.87 N for T; and 4) 51.59 ± 16.11 N for SI. No statistically significant differences were found between CT and P ($p > 0.05$), CT and T ($p > 0.05$), or P and SI ($p > 0.05$). However, a significant difference was observed between T and SI ($p < 0.05$) (Figure 20).

4.3.4 Duration of split

When duration of split force was analyzed, the measurements of 1) 0.16 ± 0.08 s for CT; 2) 0.19 ± 0.12 s for P; 3) 0.18 ± 0.09 s for T; and 4) 0.20 ± 0.14 s for SI were obtained. Furthermore, statistical analysis showed significant differences between CT and P ($p < 0.05$), but not between T and SI ($p > 0.05$), CT and T ($p > 0.05$), or P and SI ($p > 0.05$) (Figure 20).

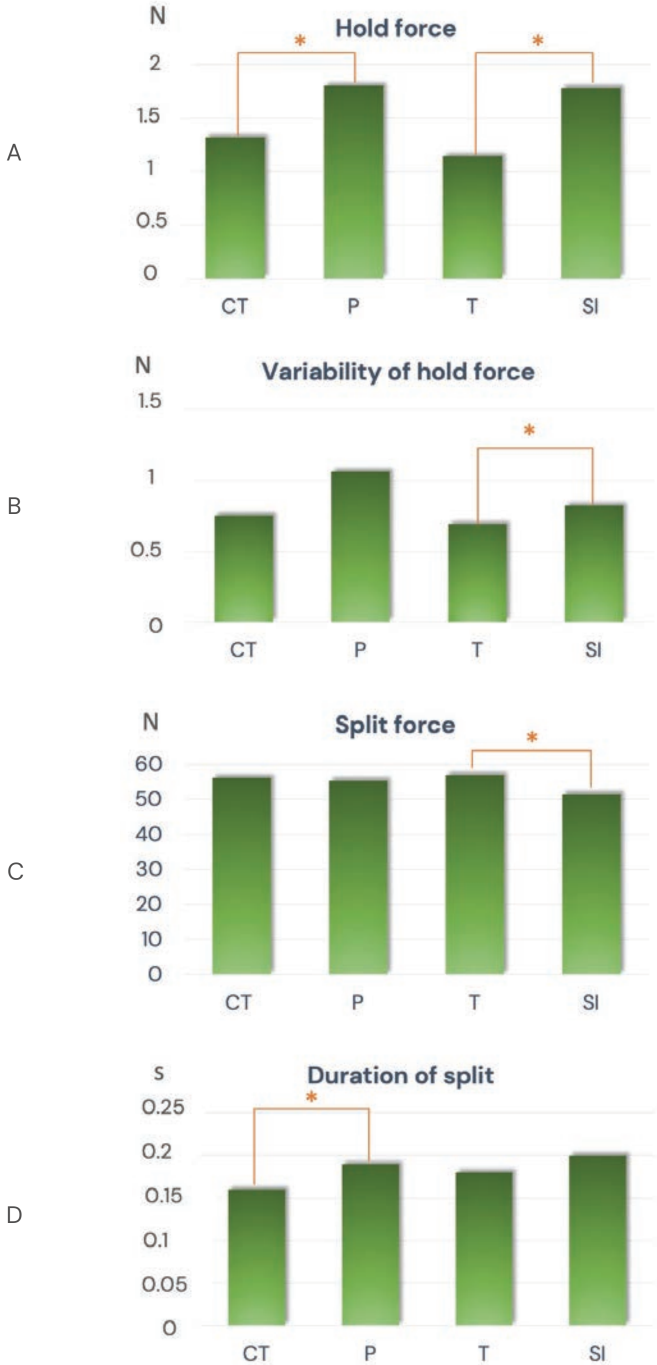


FIGURE 20 Mean values of the measured parameters including hold force (A), variability of hold force (B), split force (C), and duration of split (D) tested in the four conditions: connected tooth (CT), pontic (P), freestanding tooth (T), and single implant (SI). N, Newton. S, time in seconds.
* Statistically significant difference

5 DISCUSSION

5.1 MAIN FINDINGS AND GENERAL DISCUSSION

This thesis consists of three longitudinal studies: two studies involved the long-term follow-up of single implants in the anterior maxilla and one study examined the differences in oral fine motor control between single implants, freestanding teeth and teeth connected in 3-unit anterior RBBs in maxillary central incisor position. The single implant treatment is a treatment modality growing in numbers that is often performed in young adult patients in need of their implants in function for a long remaining lifetime. Therefore, long-term follow-ups to evaluate how the treatments succeed over time and studies regarding sensorimotor regulation in relation to alternative treatments are important areas for investigation.

The results presented within this thesis have contributed to increased knowledge of the changes occurring over time regarding single anterior implants and how patients and dentists perceive long-term single implant esthetics. It has also provided suggestions on how to predict the degree of adjacent tooth movement in individual patients. Furthermore, results have enhanced the understanding of oral fine motor control regarding single implants and teeth connected in 3-unit anterior bridges.

5.2 CLINICAL AND RADIOGRAPHIC PARAMETERS (Study I)

5.2.1 Survival and success

High long-term survival rates have been reported for single implants.[7,11,13,135,136] A systematic review of single implants revealed a cumulative survival rate for single implants (CSRi) of 95% and a cumulative survival rate for single implant crowns (CSRc) of 89% after more than 10 years.[7,9] Furthermore, cohorts with mean ages between 32 and 42 years with the main part of the implants positioned from canine to canine report a 10–18-year CSRi between 96% and 100%[11,135,136,271] and a CSRc of 84%–90%.[11,135] The studies with the longest follow-up times (>15 years)[11,271] reported a CSRi ranging from 97% to 100%, which is in close resemblance with the findings of Study I (96% CSRi, mean follow-up time 17 years). In a younger cohort with a mean age of 25 years followed for 15 years, a CSRi of 100% and a CSRc of 77% were observed.[13]

In correlation with the CSRc of 80% in Study I (mean age of 21 years), a slight tendency towards younger cohorts showing lower CSRc after long-term follow-up can be observed. These differences may be attributed to greater facial development and tooth movement in younger adults than in older adults,[91,116,118,272,273] resulting in a more severe infraposition and desire to change implant crowns for esthetic reasons. Additionally, Study I found that patients who underwent crown replacement due to trauma (accidents) during the follow-up period were the same as those who received their single implants due to tooth loss from trauma. Patient characteristics, such as horizontal overbite >3 mm,[274] incompetent lip closure,[275] participation in high-risk sports or activities,[276] and risk-prone personalities[275] increase the likelihood of repeated trauma to the anterior teeth. The high prevalence of trauma-induced etiology among younger patients requiring single implant treatment in the anterior maxilla[41] may thereby contribute to the higher rate of replacement of the single implant crowns in the younger cohorts.

Implant failures are distinguished as early or late failures based on the inability to establish or maintain osseointegration under functional conditions. Jemt concluded in a follow-up study of 30 years[23] that the failure rate of single implants decreased over time and that early failures (0–1 year) were more frequent, particularly in implants with turned surfaces as was used in the cohort in studies I and II. However, Study I did not report any early implant failures, but two late failures were observed at 3.5 and 11 years. Late implant failures have been described as multifactorial, resulting from factors such as bone quality and volume, overload, bacterial infection and patient health status[277] as well as smoking habits and early inflammatory problems significantly correlated with history of periodontitis.[278] The implant failures in the present study were attributed to a misplaced implant and an early aggressive infection. The implant removed after 3.5 years due to an aggressive early local infection had a 6 mm bone loss at removal and failed to meet the success criteria.[63] The second implant failure occurred due to the improper positioning of the implant, causing severe loss of the buccal bone and soft tissue, which ultimately led to the removal of the implant after 11 years.

All surviving implants in Study I were considered successful (100%) according to the success criteria[63] and in conclusion with a previously performed single implant study,[177] less than 0.2 mm of bone loss per year was observed. An annual rate of bone loss of 0.04–0.07 mm/year has been observed after 5–10 years of follow-up.[67,177,279] An even lower rate of bone loss per year of 0.01 mm annually after the first year was found in Study I.

Considering the cohort of young adults, it may be debatable whether the success criteria of continued bone loss of less than 0.2 mm annually is applicable. A bone loss of 0.2 mm/year for 30 years would result in a 6 mm bone loss. A 6 mm bone loss in an anterior single implant in a 50-year-old may be deemed unsuccessful despite the absence of pain, paresthesia, and mobility issues, according to the criteria for implant success.[64,280-282]

As emphasized in a previous study, the current criteria of success based on edentulous patients could be revised to better relate to single implant treatments.[283] The results from Study I and previous studies of 0.01–0.07 mm mean annual bone loss after the first year show that a limit of less than 0.2 mm/year is reasonable.[67,177,279] Although osseointegration remains the primary factor for successful implant treatment, additional criteria, including biological, prosthetic, and esthetic, as well as complications and subjective factors reported by patients, should be considered and included in future studies[137,284,285].

5.2.2 Marginal bone levels

Marginal bone levels surrounding dental implants are commonly assessed in both clinical and research settings.[269] However, standardized and well-exposed baseline radiographs may not always be obtained, which can hinder the accurate monitoring of bone levels over time. In Study I, radiographs were obtained according to protocol at the time of crown delivery providing credible baseline measurements for future follow-up.

5.2.2.1 Methodology

Intraoral radiographs are reliable to determine marginal bone levels around implants.[286,287] However, studies have demonstrated that radiographic measurements of marginal bone levels in monkeys tend to indicate values that are 0.1–0.5 mm less than the histological marginal bone level.[288] Limitations may arise when measuring changes in radiologic bone levels over time owing to various factors such as variations in the angle of projection, degree of exposure, variation in bone levels over time, and observer variability. To improve precision at the follow-up examinations in Study I, radiographs were taken using the paralleling technique at the same oral radiology department, with previous radiographs serving as a guide and according to the same established protocol. The projection was confirmed by assessing the sharpness of the treads on both sides of the implants. By making sure that sharp implant treads are obtained on all images it has been suggested that individual bite-blocks are not necessary.[289]

In study I radiographs from baseline, 1-year follow-up were remeasured by the same radiologist that measured the radiographs from the final examination (LW). It should be noted that radiographs at baseline and 1-year follow-up were captured on radiological films, whereas the final radiographs were exposed on digital phosphor plates. The mean measurement error for marginal bone levels around Brånemark implants has been reported to be a of 0.25 mm with a standard deviation of 0.7 mm.[269] Furthermore, it has been stated that only with very accurate and reproducible techniques the radiographic measurements of marginal bone levels will be sensitive enough to measure bone loss under 1.0 mm. Most likely the small values reported for loss and gain of bone under 1.0 mm are measurement errors,[290] which should be considered when evaluating the results of such measurements.

5.2.2.2 Bone loss

Study I reported a mean marginal bone loss of 0.1 ± 1.1 mm from baseline to final follow-up (mean, 17 years), with a mean of 0.2 ± 1.0 mm occurring during the first year and a mean of 0.2 ± 1.0 mm from year 1 to the final follow-up. These observations appear to be in line with those of another long-term follow-up study on single implants with a turned surface, in the anterior maxilla in young adults[13]. This study reported the mean marginal bone loss, after 15 years to be 0.7 mm, with 0.6 mm occurring during the first year and 0.1 mm from year 1 to year 15.[13]

Furthermore, two studies that focused on a majority (80% and 87%, respectively) of single anterior maxillary implants with two different surfaces and included cohorts with higher mean ages (32 and 42 years) reported similar marginal bone level changes. After mean follow-up times of 16 and 18 years, respectively these studies reported a total mean bone loss of 0.4 and 0.8 mm, respectively.[11,271] One of the studies reported a mean bone loss of 0.5 mm during the first year and a mean increase in bone of 0.1 mm from year 1 to year 18,[11] whereas the other study reported a mean bone loss of 0.9 mm during the first 6 years, followed by a mean increase of 0.13 mm from year 6 to year 16.[271] Study I and the 18-year follow-up study[11] exhibited comparable outcomes concerning more severe bone loss in individual implants, as both studies revealed that 4% of the implants demonstrated >1.8 mm bone loss during the follow-up period from baseline. However, the 15-year follow-up study by Jemt[13] did not identify any instances of bone loss above this threshold. Study I reported a mean bone level of 1.5 ± 0.7 mm at final examination measured from the most cervical part of the implant to the first bone-to-implant contact (BIC), which coincides with the findings of other studies between 0.9 mm and 1.92 mm after 15–18 years.[11,13,271] Further, in a review article of single implants, a mean marginal bone loss of 1.3 (range, 0.3–2.1) mm were reported from the five included long-term (>10 years) studies.[9] Other studies have reported on bone loss of <0.5 mm at anterior maxillary single implants after 5 years.[137,179,291-293] Additionally, it is intriguing to compare these numbers with the natural reduction in marginal bone levels around teeth that has been found to be 1 mm in all positions of the mouth, when comparing healthy patients with good oral hygiene between the ages of 21-30 years and 41-50 years.[104,294]

Hence, most single anterior maxillary implants seem to yield stable crestal bone levels over time, with no or little bone loss and occasional bone gain. However, as stated by DeBruyn et al.,[295] it should be considered that the mean values may obscure the implants that exhibit the most significant bone-level loss and gain (Figure 13).

5.2.2.3 Bone gain

In Study I, bone loss and gain were observed among implants followed up for 14–20 years. Based on the error of measurement as a limit, ≥0.25 mm of bone loss and bone gain were observed in 33% and 40% of the implants, respectively (Figure 13). Increase in bone levels have observed in previous single implant studies.[11,271,293,296-306] Moreover, implants with mean decrease in bone levels from baseline to year one were found to later show a mean increase in bone levels from year one to the final follow-up.[11,271,307] Study I and a study by Donati et al. found 52% of the single implants to present bone gain with maximum levels of 1.6 and 1.8 mm, respectively.[307]

The factors responsible for the observed increase in bone levels remain unclear, and several hypotheses have been suggested, including actual bone apposition or errors in radiographic measurement.[306,308] In a study where 10.2% of the implants showed positive values of more than 1.8 mm (equivalent to more than 3 threads on Branemark implants), two independent examiners re-analyzed the data and confirmed the positive measurements. It was suggested that the phenomenon of "bone apposition" could occur even without surgical bone augmentation. Furthermore, if bone gain were due to measurement errors, it would likely affect bone loss measurements as well.[306] Considering that bone gain as high as 1.8 mm has been observed, it appears unlikely that measurement error alone can account for the phenomenon.

In the context of this thesis evaluating infraposition, it is expected that with time, as adjacent teeth and also the surrounding bone move in an incisal direction[104] the implant will become positioned even further below the bone crest. Previous studies have shown that dental implant bone levels can be influenced by adjacent teeth,[309] thus it is reasonable to speculate that continued tooth movement causing infraposition may contribute to the observed increase in bone levels over time.

5.2.2.4 Bone loss occlusion and usage of nicotine

Previously reported bone level measurements comparing single implants with and without occlusion or articulation have shown a higher mean annual bone reduction in implants with occlusal contacts than in those without.[177] In contrast, studies in dogs found no induction of marginal bone loss in implants with mucositis upon lateral static loads. Instead, bone remodeling and higher bone density were found in the peri-implant bone surrounding the loaded implants.[310] Smoking have been reported to be a predisposing factor for early (<1 year with prosthesis in function) mucositis with marginal bone loss, and implant failure.[49,278,311-315] In Study I, the parameter usage of nicotine included both patients that was smoking and using snuff. No significant correlation between bone levels and occlusion ($p > 0.05$) or usage of nicotine ($p > 0.05$) was found.

5.2.3 Complications

According to a systematic literature review and meta-analysis, the reporting of complications varies significantly between studies.[7] Frequent categorizations used are soft and hard tissue complications or biological and technical complications. Commonly reported soft tissue complications are fistulae, mucositis, bleeding on probing (BoP), pus and soft tissue recession with visible titanium. Hard tissue complications may include severe bone loss and probing depth (PD) of >5 mm.[316] Other complications mentioned in the literature are mechanical, prosthetic, and esthetic.[7,285,317] In a recent study by Sailer at al., the prosthetic complications for single implants were categorized into fracture/loosening of retaining abutment, loss of crown retention, chipping or fracture of the veneering material, fractures of ceramic abutments, and aesthetic complications.[285]

In Study I, the complications were divided into biological and technical complications. Fistula, pus, and visible titanium were considered biological complications, whereas loosening/fracture of abutment screws, and fracture and re-cementation of crowns were regarded as technical complications. The complication of loosened abutment screws accompanied by soft tissue problems, frequently seen in the 1980s and early 1990s[246] was reduced with the introduction of better screw joint systems.[11,256] However, according to more recent literature, the most frequent technical complications are still screw loosening followed by loss of retention, and fracture of the veneering material, in that order.[7] These complications were also observed in Study I but occurring at the same frequency as one another. Between 21 patients, 19 implants showed biological complications and 11 technical. However, only a minority (22%) of the complications required more advanced treatment than polishing, rinsing, or information. To enable comparison of complication rates across different studies, efforts have been made to establish a standardized categorization of complications for use in clinical trials in the future.[318]

5.2.4 Biological parameters

The implants in Study I had less plaque than the contralateral natural teeth but more BoP and the percentage of implants showing BoP (79%) was more than double the percentage with plaque (31%). One possible explanation could be that the patients may have cleaned the implant especially thoroughly the day before examination. Another could be that the measurements of BoP may not be an entirely reliable parameter for measuring inflammation. In Study I, positive BoP was registered when bleeding occurred after measuring PD. However, some patients with positive BoP exhibited a bright red, thin band of blood along the soft tissue margin instead of profuse bleeding. Although registered as positive BoP, this type of bleeding is suspected to be associated with mucosal trauma rather than mucosal inflammation.[13,319] Some studies have found BoP not to correlate with either PD or rate of bone loss, while other studies found correlation between BoP and bone loss.[12,67,320]

The measurement of PD around implants differs from probing around teeth[321] and is sensitive to technique. The results can be influenced by factors such as the force used and the presence and shape of prosthetic components.[69,322,323] There are probes available to control the light forces of 0.2–0.25 N recommended to use.[66,157,288,324] However, in clinical work on patients these probes are rarely used and the force is thereby hard to control.

A mean PD of 4.0 ± 1.8 mm was found at the single implants in Study I, 14–20 years after implant placement. This corresponds with previous research findings on single implants with a mean of 4.2 ± 0.5 mm PD after 6–7 years under healthy conditions.[325] After 5 years of follow-up, a median PD of 2.8 mm was observed in single anterior maxillary implants,[157] while the mean dimensions of the peri-implant mucosa were reported to be 6 mm one year after implantation in another study.[309] The threshold of 6 mm, previously used to differentiate between shallow and deep PDs,[67,258] was also employed in Study I. The present study revealed that 25% of single anterior maxillary implants had a PD of >6 mm, while a previous cohort with a mean age of 47 years demonstrated this depth in 73% of the implants.[309] Implants in bridges have been shown to present only 15% of PD >6 mm [67]. This could be explained by the fact that single implants in the esthetic zone are often placed deeper in the bone next to a neighboring tooth with a healthy periodontium and thereby naturally show a deeper PD.[70] Moreover, the mucosal thickness varies more in areas adjacent to natural dentition than in edentulous areas, which can also impact differences in PD.[323]

Our findings of PD ranging from 0 mm to 9 mm with as little as 0.1 ± 1.1 mm of bone loss confirms a previous 18-year follow-up study of single implant with the same range of PD and a mean bone loss of 0.4 ± 0.87 mm.[11] Research proposes that to regard of PD of >6 mm as pathological would not be correct and that deep PDs around implants can be a non-pathological finding without clinical correlation with bone loss.[11,13,67,69,70,157] Study I support this, as among the six implants that displayed deep PDs (>6 mm) and bone loss, three exhibited bone loss exceeding 1 mm (Figure 17). This is exemplified through the patient in Study I (Figure 16), that reported recurrent buccal mucosal swelling and pus by the implant during a 10-year period at the 15-year follow-up and revealed unchanged bone levels compared with the 5-year follow-up that the at mesial and distal sites. Moreover, this finding corroborates an earlier study´s failure to establish a correlation between buccal fistulas and mesial and distal bone loss in patients with identical single implants and prosthetic solution as in Study I.[13] The lack of significant correlation found between PD and bone level changes in Study I suggests that PD is likely to be an unreliable predictors for peri-implant bone loss and implant failures.[69,326]

5.3 FACIAL SHAPE (Study II)

Study II classified 50% of patients with long facial type, 40% with short facial type, and 10% with neutral facial type. Comparing facial types across studies can be challenging due to variations in classification methods and ethnic differences.[10,94,96,98] However, a study on a Caucasian population reported the distribution of the facial types tapered, ovoid, and square to 22%, 40% and 18%, respectively and another study long, normal, and short facial types to 23%, 44% and 35%, respectivley.[10,96] Facial types can be categorized by various methods. Linear photogrammetry, used in Study II, has been reported to provide accurate assessments of vertical facial characteristics.[112,259] Moreover, the soft tissue landmarks used in this study were found to be reliable for evaluating facial morphology in Caucasian patients, with the highest reliability found for the estimates of the vertical facial heights.[112]

The ratio between lower anterior facial height (LAFH) and total anterior facial height (TAFH) has been used to classify the different facial types.[105] This method was originally used with measurements on cephalometric radiographs and defined *short face* as <56%, neutral as 57%, and *long face* as ≥58%. In study II, this was slightly modified to widen the range for *neutral face* to 56%–58%. To detect the soft tissue landmarks more easily, some were marked on the patient's face during the photography procedure that was performed in the cephalostat to ensure natural head posture based on the photographic setup described in previous studies.[94,327]

5.4 MOVEMENT OF ADJACENT TEETH (Study II)

5.4.1 Methodology

Several publications on tooth movements adjacent to single implants have used 2-D measurements on radiographs or clinical photographs with or without a standardized procedure (Table 1),[10,146,169,273,328-330] whereas only few have used a 3-D technique (Table 2).[127,128] Study II intended to investigate positional differences between single anterior maxillary implants in relation to adjacent teeth rather than other oral structures. Therefore, the implant was chosen as the reference. Previous studies have used other oral references such as the palatal rugae and the hard palate.[122,128,134] Their findings suggested vertical instability of palatal rugae[134] and identified the challenges of detecting small changes in tooth movement when using the palate as a reference.[122,128]

When performing the 3-D matching and measuring in Study II, the buccal surface of the implant was regarded as the most stable area of the implant crown was thereby chosen as the area of reference. Since gingival coronal migration[14,122] and incisal attrition[331] are known to occur the most cervical and incisal parts of the buccal surface were excluded from the reference area. However, the tooth movements were measured at the incisal edge of the adjacent tooth. In case of attrition over time, this would cause underestimation of tooth movements in Study II.

5.4.2 Characteristics and tooth movement

Studies have reported that the growth patterns connected to the long, neutral, and short facial types, remain relatively stable between the ages of five and 25 years. Moreover, the tendency to maintain the original facial type with age is considered to be strong.[89] In Study II, no significant correlation was found between facial type and the degree of tooth movement. Neither Aarts et al.[332] nor Andersson et al.[10] found any connection between facial type and continuous eruption of teeth and facial growth, whereas Jemt et al. 2007 showed that TAFH together with a backward rotation of the mandible was significantly increased in females in comparison to males.[22] A relevant method for measuring and categorizing facial types with regard to implant treatment is needed to further investigate the association between facial type and infraposition of single implants.

The vertical dimensions of the face have previously been suggested to be associated with vertical tooth movements in younger as well as adult patients.[10,22] A LAFH of more than 70 mm was shown in Study II to be significantly positively correlated with a more pronounced movement (>1 mm) of teeth adjacent to anterior single implants. A longitudinal study followed 27 males and 29 females with normal craniofacial development between the ages of 17 to 48 years, and found a mean increase in LAFH, with of 2.5 ± 2.0 mm for males and 3.2 ± 1.6 mm for females. Between the ages 31 and 48 years (15 patients), both sexes revealed an increase of 1.7 ± 1.2 mm in LAFH.[118] Thereby, the rate of increase in LAFH can be calculated to a mean of 0.06 mm per year, which is comparable with the rate of tooth movement found in the single implants in Study II (mean 0.05 mm/year). This implies that the vertical changes in the LAFH may be positively associated with the infraposition of implants in the anterior maxilla. Further, males are known to generally possess larger faces with larger facial dimensions than females. This was presented in a study of untreated females and males aged 25–46 years with "acceptable occlusion and acceptable facial skeletal features".[333] The cohort displayed a mean LAFH, at 25 and 45 years of for females, of 63 mm and 65 mm, and for males of 68 mm and 70 mm, respectively. Hence, a 70 mm LAFH in a female may mean a greater risk of more severe adjacent tooth movement than if seen in a male, suggesting that the limit should be different for males and females. More studies with larger groups of patients are needed to further evaluate whether the limit of 70 mm can be used as a predictor for more pronounced movement in general and in teeth adjacent to single anterior maxillary implants.

Reports are inconsistent regarding differences in tooth eruption and jaw development between the sexes. Some studies report more significant changes in adult females than in males[10,22,126,334–336] while others show no significant differences.[273,313,328,329] No significant correlation was found in Study II between the degree of vertical (incisal) movement of the adjacent teeth and sex. However, by pooling the measurements with data from Jemt et al.[22] and Anderson et al.[10] a significant correlation (p <0.05) between tooth movement of >1 mm and females was found (Table 6).

Table 6 Number of implants with different amount of vertical infraposition of single implant crowns and gender in the present study and as pooled data with results from Jemt et al[22] and Andersson et al [10].

Implant infraposition (Y-axis)	Number of subjects with regard to degree of infraposition (Y-axis)					
	Present study			Pooled results		
Index	Female	Male	Total	Female	Male	Total
Score A; 0mm	0 (0%)	0 (0%)	0 (0%)	3 (9%)	16 (29%)	19 (21%)
Score B; <0.5 mm	5 (38%)	7 (41%)	12 (40%)	11 (33%)	17 (30%)	28 (31%)
Score C; ≤1.0 mm	2 (15%)	7 (41%)	9 (30%)	5 (15%)	12 (21%)	17 (19%)
Score D; >1.0 mm	6 (46%)	3 (18%)	9 (30%)	14 (42%)	11 (20%)	25 (28%)
Total	13 (100%)	17 (100%)	30 (100%)	33 (100%)	56 (100%)	89 (100%)

Tooth movements in the palatal direction represent the up-righting of the adjacent teeth. In Study II, the mean palatal movement of the crown of the clinical tooth was measured to 0.5 ± 0.8 mm, ranging from 2.2 mm palatally to 2.3 mm buccally. Female patients presented a mean palatal movement of 0.2 ± 0.02 (range, 0.2–0.3) mm and male patients a somewhat larger mean palatal movement of 0.89 ± 0.74 (range, 0.2–2.2) mm (p >0.05). Some studies[78,117] claim that up righting of incisors occurs in both adult males and females during continuous eruption while another[118] suggest that incisor eruption in males occurs without retroclination while in females the crown tip moves towards the palate as eruption takes place. Therefore, the results of Study II do not support the findings from West & McNamara[118] that the movement of the crown of the adjacent tooth in the bucco-palatal direction differs between the sexes.

Maxillary teeth continue to erupt during adulthood.[78,79,85,95,104,118,122,330] Vertical facial growth continues at later ages than somatic growth[84] and varies widely between individuals.[89,94,96,337] Thus, chronological age may not be a good parameter for estimating the cessation of either facial development or eruption of teeth.[84,95,122] Different results have been published regarding the correlation between age and infraposition of single implant crowns in the anterior maxilla in adult patients.[169,272,335,338]

The mean vertical movement of anterior maxillary teeth adjacent to single implants in Study II (mean age at crown delivery at 21 years) was 1.0 ± 0.5 (range, 0.1–2.2) mm after 14–20 years of follow-up. This is somewhat higher than what was found in studies with older cohorts of patients (mean ages 35–48 years) where mean values ranging between 0.4 and 0.7 mm was found after 4–13 years follow-up[169,313,329]. Implant infraposition of >1 mm was found at the rate of 4%–21% in studies with mean ages of 23–31 years[10,20,22,127] after 5–18 years. A systematic review found infraposition of >1 mm in 21% of implants.[126] The finding of 30% of tooth movement of >1 mm in Study II exceeds that in previous studies. The higher degree of tooth movement in Study II may be a result of the younger age of patients and the long follow-up time. The 3-D methodology used with the implant as the reference point probably also plays a role in the difference in degree of tooth movement found in other studies (Table 1, 2).

The results from Study II showed no significant association between age the degree of tooth movement (p=0.69, 95% CI -0.38–0.56) which is in agreement with previous studies.[10,127,146,169,273,328,329,335] Furthermore, tooth movement continues until the fourth[104] and fifth decade[122] of life although both continued development of the jaws and tooth eruption have been stated to occur to a lesser degree after the second decade of life.[336] Infraposition have been found to be more prominent in cohorts of younger adults patients (<30 years) than in older adult patients (≥30 years),[272,335] and the rate of infraposition have to decrease by 0.0013 mm for each additional year of age.[272] However, another study reported that infraposition can occur to the same extent in adults (40–55 years) as in a younger group of patients (15.5–21 years).[273]

In Study II, the vertical displacement of teeth adjacent to single anterior implants showed a mean of 0.5 ± 0.3 mm for central incisors and 1.0 ± 0.5 mm for lateral incisors and canines, with significant differences (p <0.01) between the two categories. Previous studies are inconclusive concerning differences in infraposition depending on the position of the implant in the maxilla. In a study material on young adult and adult patients by Bernard et al.[273] no differences in infraposition between maxillary single implants in the central, lateral, or canine position were reported. In contrast, Thilander et al.[37] found the lateral incisor position, to be extra critical to place implants in regarding infraposition in patients 13–17 years.

The lack of occlusal contact has been suggested to influence the continuous eruption of teeth.[339] In a normal population of 24 dentate women aged 48 years, 25% of the central incisors and 50% of the lateral incisors lacked occlusal contact.[122] In Study II, 80% (*n*=24) of the implants lacked occlusal contact at the 14–20-year follow-up while in another study on anterior maxillary single implants, 62% (*n*=24) of the implants lacked occlusion.[146]

Regarding the pattern for continued eruption in the presence or absence of initial occlusal contacts in the female population without implants, lateral maxillary incisors erupted to a greater extent without contacts and no differences were found between maxillary central incisors with and without occlusal contact.[122] Nilsson et al.[146] did not show any correlation between implant infraposition and occlusion on implants, while Thilander et al.[18] found no or only minor infraposition in patients with incisors in occlusion and more severe changes in patients lacking occlusion. The univariate analysis in Study II revealed less vertical adjacent tooth movement when the implant was in occlusion(p <0.05). Further, the multivariate analysis indicated less incisal tooth movement associated with implants in occlusion, implants in the central incisor position, and implants placed due to tooth loss caused by trauma (p <0.05).

Previous reports have stated that pre-prosthetic orthodontics might give rise to more severe inferior position of a single implant due to the risk of relapse.[18] However, no correlation with tooth movement in anterior maxillary single implants and pre-prosthetic orthodontics were found in Study II, or in supporting observations by Nilsson et al.[146] and Brahem et al.[127]

5.4.3 Esthetic considerations

The esthetic outcome of single anterior implant treatments is important in ensuring patient satisfaction with the treatment.[181] Single anterior implant crowns might be one of the most challenging treatments to perform with a good esthetic result due to the visibility and the immediate comparison of the natural adjacent teeth.[248] A vast number of esthetic indexes have been developed the last two decades to assess the esthetic results of single anterior maxillary implants.[340] With the growing focus of patient related outcome measures (PROMs) in research,[341] evaluation of the patients' perspectives on implant treatments is more frequently used.[136,137,165,171,329] The main characteristics of concern for the patients, regarding the esthetics of anterior teeth have been reported to be the shape and the color of the crowns.[186] Additionally, high patient esthetic satisfaction has been shown to be more positively associated with a greater willingness to undergo implant treatment again, compared with functional satisfaction such as chewing ability and phonetics.[170] However, to enable comparison between different studies, a consensus is needed regarding the tools for assessing esthetics.[341,342]

5.4.3.1 Visual analogue scale (VAS)

The VAS is a frequently used tool for assessing the esthetics of single implants and the esthetics have been rated high by patients (score, 90% to 92%).[157,184] It was recently appointed as one of two recommended tools to use for subjective and objective evaluation of esthetics in clinical trials.[318] In Study II, the female ratings (mean score, 80%) of the esthetics were shown to be lower than the males (mean score, 89%) which was also found in another study[178] and might be explained by females as such being more focused on dental esthetics.[139,186,343] Moreover, in Study II, another observation is that the dentist also rated the esthetics lower for the female patients (mean score, 56%) than for male patients (mean score, 76%) (p >0.05). The mean patient VAS rating of 85% at follow-up after 14–20 years in Study II (37 years mean age), was somewhat lower compared to an older cohort (mean age 50 years) after 17–19 years where a mean VAS rating of 91% was found.[10] However, another study did not find age as a predictor of higher patient satisfaction regarding aesthetics in within an older group of patients (mean age 48 years) after a mean follow-up of 13 years.[329] This finding may be attributed to the mean age already being relatively high. Further, the VAS score has been shown to decrease with time in a comparison of single anterior implants between 3 and 10 years follow-up.[135] The reasons for this are ascribed to the changes in position, color, and shape in relation to adjacent teeth over time.[135]

Assessments by the dentist and patient have been shown to correlate badly, with higher esthetic assessments from the patient.[10,142,149,158,160] A systematic review found that implant crowns in single anterior maxillary implants rate between 81% to 96% on the VAS by the patients and 62% to 90% by the dentist.[340] In Study II, the assessed satisfaction with aesthetics by the patients was higher (mean score 85%) than by the dentist (mean score 67%). Only three patients (10%) rated the esthetics of their crowns as <60% while the dentist rated 10 crowns (33%) at <60%. Professionals tend to be more critical and look at details that are not important to patients.[139]

In Study II, no significant correlation was found between VAS ratings and the overall degree of tooth movement ($p > 0.05$). However, lower VAS ratings were significantly correlated with increased tooth movement in patients with implants in the central incisor position ($p < 0.05$). The VAS rating for patients with a vertical tooth movement of >1 mm was found to be lower (78%) than for those with <1 mm (88%). A previous study on anterior maxillary implants correlated esthetic VAS ratings with observed infraposition after a mean follow-up time of 4.5 years.[146]

A patient with a high smile line shows more of the clinical crowns and gingiva/mucosa, which would be expected to lower the esthetic rating if good esthetics are not achieved. The results from Study II did not, however, show any correlation between smile line and the esthetic VAS rating. This agrees with a previous study where no differences in esthetic assessment according to VAS were found in the different smile types,[187] but is inconclusive with other results showing that patients with a low smile line rate their esthetics higher on the VAS-scale.[138]

In a study by Chang et al differences between single anterior implants in relation to the adjacent natural teeth such as being longer, having a smaller facial lingual width, being surrounded by thicker facial mucosa, and lower papilla height were identified.[140] Despite this a mean of 96% patient satisfaction were presented regarding the appearance of the single implants crowns. In agreement with a Chang et al[139,140], the patients in Study II showed relatively high mean satisfaction of 85% regarding aesthetic, despite infraposition.

5.5 ORAL FINE MOTOR CONTROL (Study III)

It has been shown that the oral fine motor control is disturbed when natural teeth are connected in rigid full-arch bridges and even more so with full-arch implant bridges.[226] It has been suggested that to keep the sensory information from the periodontal mechanoreceptors (PMRs) intact, it may be advisable to refrain from splinting separate teeth together in rigid constructions.[211]

In the hold-and-split test performed in study III, higher hold forces express impaired force control. The findings in Study III showed significantly higher hold forces, variability of hold force, and split force on the single implant (SI) than those observed on the adjacent non-splinted central incisor (T) ($p < 0.05$) (Figure 20). This confirms the lower sensibility shown in another study with higher ($p < 0.05$) mean tactile perception threshold values for single implants than for natural teeth.[344] However, another study by Enkling et al[345] showed that active tactile perception did not differ between single implants and natural teeth when occluding against natural teeth.[345] By anesthetizing the natural antagonistic tooth, the Enkling research group further showed that a single implant may possess sensitivity in itself, and not only in the antagonistic tooth.[346] The higher forces and thresholds found in anesthetized teeth imply that the sensitive functional response present around the tooth is due to the presence of PMR's in the periodontal membrane[203,209,347] whereas implants lacking the periodontal membrane, and thereby PMRs, depend on osseoperception.[223]

The PMRs at the incisors exhibit the highest sensitivity and activity at approximately 1 N[206,209,217] which is in the same order of magnitude as the mean hold forces (1.14 ± 0.84 N) of the freestanding tooth measured in Study III. This implies that the hold forces produced in the hold-and-split test is within the range of load where the incisors perform the best. In accordance with previous studies, this implies an important role of the incisors to act as sensors, signaling to the CNS when, how hard, and in what direction the bolus should be split.[237,348] The less sensitive single implants (hold force 1.78 ± 1.28 N) also exhibited significantly higher split forces ($p < 0.05$) than those of a freestanding tooth (Figure 20). In the resin-bonded bridge (RBB) situation, statistically significant differences were identified between the tooth connected in the bridge (CT) and the pontic (P) in Study III ($p < 0.05$). The similar significant differences between T and SI as those between CT and P may indicate that the oral fine motor control of P in the anterior 3-unit bridge resembles the response from a single anterior implant.

In contrast to the hypothesis in Study III; that teeth connected with RBBs, pontics, and single implants would exhibit inferior oral fine motor control compared with freestanding teeth adjacent to dental implants; no significant differences were found in hold force, variability of hold force, split force, or duration of split between teeth connected in the RBB (CT) and non-splinted teeth (T) adjacent to a single implant ($p > 0.05$). These non-significant results diverge from previous findings regarding teeth connected in full-arch bridges.[226] Non-significant results could be caused by many reasons and should be interpreted with caution. However according to the results in Study III, teeth supporting smaller anterior bridges do not appear to be affected in the same manner as those supporting full-arch bridges. One reason for this could be the greater steadiness provided by larger bridges which involves of the more stable and less sensitive posterior teeth.[206,349] Additionally, the mechanics of the curved shape and the more extensive material dimensions of the larger bridges contribute to enhanced stability.[350-352]

Furthermore, it is known that periodontal mechanoreceptors can respond to the stimulation of more than one tooth, via so-called receptive fields that involve also the adjacent teeth.[204,353-355] It has previously been proposed that in the event of loss of information on occlusal load from a tooth, receptors in healthy adjacent teeth will provide the information.[355] In the case of small anterior bridges, although the sensitivity of the tooth connected to the bridge may be reduced, signaling from adjacent teeth may sufficiently compensate for the holding of food to remain unaffected. Given the documented sensitivity of incisors to loads in all directions,[206] it is plausible that, in teeth connected in anterior 3-unit bridges, the buccolingual sensitivity may also compensate for the decrease in mesial and distal sensitivity.

5.5.1 Choice of prosthetic solution

The choice of an appropriate prosthetic treatment should be based on scientific knowledge, clinical considerations, dentist training and experience as well as patient preferences. It has been proposed, that the sensorimotor response should be considered in the decision-making of a prosthetic solution.[211] Research shows that implant-supported single crowns have lower annual failure rate than conventional tooth-supported bridges.[6] This is further supported by the reported 10-year CSR, in which implant-supported single crowns showed higher survival than those of 3-unit RBBs and conventional bridges (p <0.05).[356] Moreover, another study showed higher survival rates (p <0.05) for teeth adjacent to single implants than for teeth supporting 3-unit conventional tooth-supported bridges, while no differences were found (p <0.05) between the single implant crowns and RBBs (p >0.05)[356]. A study on patient satisfaction revealed that Oral health-related quality of life (OHRQoL) increased significantly and was similar among patients treated with single implants and 3-unit bridges.[173] When considering the effect of oral fine motor control in decision-making regarding treatment of tooth loss of a central incisor, no significant differences between the treatment modalities were found in Study III.

5.6 METHODOLOGICAL CONSIDERATIONS

This thesis comprised three studies based on two patient cohorts. Studies I and II were longitudinal, wherein the results of an intervention were studied long-term in the same patients on different occasions using prospectively collected data. Study III was a longitudinal study with prospectively collected data in which the two different interventions were compared, and the patients served as their own controls.

5.6.1 Limitations

5.6.1.1 Studies I and II

Study I had several limitations, including the potential for incomplete or misinterpreted long-term data from patient records as well as the possibility of patients not recalling events accurately, due of the retrospectively nature of data collection. Moreover, the measurements of marginal bone levels were measured by a single observer. Additionally, no individual film holders and different radiographic films, plates and sensors were used over time which may have influenced the results. The utilization of a non-standardized probe and the prosthetic reconstruction not being removed prior to probing, giving lower retrievability, may have affected the accuracy and reliability of the PD measurements. Furthermore, no baseline PD measurements were available. The evaluation of BoP can be regarded as uncertain because of differences in the characteristics of bleeding.

In Study II, when capturing the photographs in the cephalostate, the possibility of the patients not adopting the correct natural head posture could have led to inconsistences in the photogrammetric analysis. Using only the buccal surface of the implant crown as a reference point and using impression material and plaster to fabricate the models, in conjunction with the continuous attrition of the adjacent teeth, might have further confounded the measurement of displacement of the adjacent tooth. The facial shape and smile line could have been categorized differently, potentially leading to dissimilar outcomes in terms of their association with tooth displacement. The use of the CDA index, which had not been developed for implants, hindered the assessment of marginal discrepancies in the implant crown. Furthermore, the VAS assessment was performed by only one observer. In both studies I and II, the number of patients was relatively small.

5.6.1.2 Study III

The limitations of this study include the hardness of peanuts, which can differ within and between bags. This type of test also depends on the patient's state of mind. Efforts were made to make the environment as calm and relaxed as possible and not to differ between the patients; however, personal factors within the patients could still have affected their behavior during the testing. The outlier age of one patient might have affected the results. Additionally, the four patients who had experienced dislodgement of the RBB more than once prior to the hold-and-split test, could have added uncertainty to their results compared to those of the remaining patients. Furthermore, the length of time spent with the implant crown before the test might have affected the patients' sense of security with the crown and potentially impacted the hold-and-split task.

5.6.2 Strengths

5.6.2.1 Studies I and II

A strength of both studies was the long-term follow-up with a fairly homogeneous patient cohort and the prospective collection of data. Additionally, a small number of dropouts, with 40 of 42 patients having been re-examined after 14–20 years, was a notable strength. Although the choice to measure the buccal surface of the implant crown was a limitation, as stated earlier, it could also have been considered a strength because it provided an opportunity to detect small differences in tooth movement between the implant crown and adjacent teeth. Furthermore, the use of 3-D measurements offers a less invasive alternative to the radiographic methods used in some prior studies.

5.6.2.2 Study III

The strength of this study was that the study design allowed to use of the patients as their own controls while employing a previously standardized method for testing. This approach allowed a direct comparison between the two groups and enhanced the validity of the results.

6 CONCLUSIONS

The main research questions addressed in this thesis are how single anterior maxillary implants perform long-term and how the differences in tooth movement and oral fine motor control differs between single implants, adjacent teeth, and teeth connected in small bridges, all in a group of young adults. Studies on long-term follow-up of young adult patients with single anterior maxillary implants are scarce. Furthermore, no studies have previously conducted to compare the hold-and-split forces between the anterior maxillary treatment modalities of single implants and 3-unit bridges.

The findings of **study I**, suggest that single implants perform well in young adults, with good long-term success and high survival rates. Complications occurred over time but did not seem to be of great concern to the patients. Furthermore, a mean marginal bone loss of 0.1 ± 1.1 (range, -5.1–1.6) mm and a mean PD of 4.0 ± 1.8 (range, 0–9) mm was found with no significant correlation (p >0.05) between the two. A single implant differs from a natural tooth in that it lacks a periodontal membrane. As the continuous facial changes occurs throughout life, an implant cannot adapt in the same way that a natural tooth can and thereby end up in infraposition in relation to the adjacent natural tooth. **Study II** shows that infraposition seems to occur in all patients, but with individual variation. The characteristics LAFH ≥70 mm, implants without occlusion, implants in the lateral and canine positions, and implants placed when the etiology of tooth loss was other than trauma might be used as predictors of more advanced infraposition (>1 mm). Despite infraposition, the patients satisfaction with the esthetics of the single implants after 14–20 years was high. The lack of a periodontal membrane in implants further affects the sensorimotor performance of a single anterior implant. In **Study III**, the oral fine motor control of a single implant was found to be impaired in relation to the adjacent freestanding natural tooth and to resemble the sensorimotor response of the pontic in an anterior 3-unit RBB. Additionally, no significant differences were found between the oral fine motor control of a tooth connected in a 3-unit RBB or a freestanding tooth adjacent to a single implant.

The clinical implications of this thesis would be to inform patients planned for single anterior maxillary implants about the good long-term prognosis of the implant. However, the implant crown is expected to end up in infraposition in relation to the adjacent tooth.

In most patients, this will not cause an esthetic problem but in young adults with a long remaining lifetime, the need to change or repair the implant crown may occur once or a few times. To minimize the risk of infraposition, it is advisable to delay anterior maxillary single implant treatment for as long as possible. In addition, it should be noted that patients with a lower anterior facial height of more than 70 mm and with implants in the lateral and canine positions might be in higher risk of more severe infraposition.

The conclusions drawn from these studies are subject to limitations, as they are based on relatively small patient groups. Further research is needed to confirm the possible predictors of more severe infraposition and the findings regarding oral fine motor control of treatment with single anterior maxillary implants in relation to 3-unit bridges.

7 FUTURE RESEARCH DIRECTIONS

This thesis provides some insights into the treatment of single anterior implants, while also highlighting the need for further exploration of the topic through future research endeavors.

The scanned study models, radiographs and photographs used in **Studies I and II** have potential for application in various new studies. To enhance comprehension of bone level changes surrounding single implants long-term, it would be worthwhile to also assess bone levels at adjacent teeth. Additionally, re-evaluation of the scanned 3-D models for tooth movement by adding two points of reference in the palate would be interesting to compare with the measurements in **Study II**. It would further be intriguing to compare tooth movement measured using 3-D software to radiological and photogrammetric measurements in the same material. Furthermore, measurements of the loss of approximal contacts and the movement of the entire segment of teeth adjacent to the implant could provide additional valuable data.

The findings of **Study II** could be enhanced by conducting a novel regression analysis of the current data on tooth movement in relation to marginal bone levels and implant length. Furthermore, it would be interesting to compare the results of the implant length analysis with those of recent studies in which shorter implants were utilized.

The scanned models used in **Study II** can further be utilized to determine the long-term changes in the volume of the buccal soft tissue and underlying bone. Additionally, analyzing the volumes of buccal hard and soft tissue in relation to the degree of infraposition and mesial and distal radiological bone levels would be beneficial. Furthermore, the scanned models and photographs could be used to analyze the length, height and width ratio of the teeth and their correlation with facial shape. Establishment of a correlation between tooth shape or dimensions and facial shape could be utilized to predict the degree of future infraposition.

A multicenter study in which patients are followed from time of crown delivery to shorter follow-up timepoints than in **Study II** (1, 3, 5, and 10 years), could provide valuable insights into the mechanisms of tooth movement in relation to single implants over time. This approach would enable the study to include a larger patient cohort, thereby increasing the generalizability and reliability of the results. Moreover, conducting another follow-up study of the patients included in **Studies I and II**, after an additional 10-year period would be compelling to provide additional valuable data and insights.

In **Study III**, functional and esthetic patient-reported outcome measures (PROMs) of the 16 patients were compiled. Continued gathering of PROMs in patients with RBBs later receiving single implants would provide valuable data for comparing PROMs between the two treatment modalities. To achieve statistically significant results faster, this could be performed multicentered.

Molars response better to stronger forces (4 N) than the incisors and the bone volume surrounding implants in molar areas is larger, which may affect the sensitivity of the implants to loads through osseoperception. Hence, investigating the variations in hold and split forces in a molar implant compared with a molar 3-unit bridge, would be an interesting approach.

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9 REFERENCES

1. Andersson B, Odman P, Lindvall AM, Branemark PI. Surgical and prosthodontic training of general practitioners for single tooth implants: a study of treatments performed at four general practitioners' offices and at a specialist clinic after 2 years. *J Oral Rehabil* 1995; 22(8): 543-8.
2. Jemt T. Modified single and short-span restorations supported by osseointegrated fixtures in the partially edentulous jaw. *J Prosthet Dent* 1986; 55(2): 243-7.
3. Jemt T, Olsson M, Renouard F, Stenport V, Friberg B. Early Implant Failures Related to Individual Surgeons: An Analysis Covering 11,074 Operations Performed during 28 Years. *Clin Implant Dent Relat Res* 2016; 18(5): 861-72.
4. Dahlin C. Implant placed per patient. In: Winitsky N, editor. Unpublished data; 2022.
5. Belser UC, Schmid B, Higginbottom F, Buser D. Outcome analysis of implant restorations located in the anterior maxilla: a review of the recent literature. *Int J Oral Maxillofac Implants* 2004; 19 Suppl: 30-42.
6. Pjetursson BE, Bragger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). *Clin Oral Implants Res* 2007; 18 Suppl 3: 97-113.
7. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clin Oral Implants Res* 2012; 23 Suppl 6: 2-21.
8. Pjetursson BE, Sailer I, Latyshev A, Rabel K, Kohal RJ, Karasan D. A systematic review and meta-analysis evaluating the survival, the failure, and the complication rates of veneered and monolithic all-ceramic implant-supported single crowns. *Clin Oral Implants Res* 2021; 32 Suppl 21: 254-88.
9. Hjalmarsson L, Gheisarifar M, Jemt T. A systematic review of survival of single implants as presented in longitudinal studies with a follow-up of at least 10 years. *Eur J Oral Implantol* 2016; 9(2): 155-62.
10. Andersson B, Bergenblock S, Fürst B, Jemt T. Long-term function of single-implant restorations: a 17- to 19-year follow-up study on implant infraposition related to the shape of the face and patients' satisfaction. *Clin Implant Dent Relat Res* 2013; 15(4): 471-80.
11. Bergenblock S, Andersson B, Fürst B, Jemt T. Long-term follow-up of CeraOne™ single-implant restorations: an 18-year follow-up study based on a prospective patient cohort. *Clin Implant Dent Relat Res* 2012; 14(4): 471-9.
12. Dierens M, Vandeweghe S, Kisch J, Nilner K, De Bruyn H. Long-term follow-up of turned single implants placed in periodontally healthy patients after 16-22 years: radiographic and peri-implant outcome. *Clin Oral Implants Res* 2012; 23(2): 197-204.
13. Jemt T. Single implants in the anterior maxilla after 15 years of follow-up: comparison with central implants in the edentulous maxilla. *Int J Prosthodont* 2008; 21(5): 400-8.
14. Jemt T, Ahlberg G, Henriksson K, Bondevik O. Changes of anterior clinical crown height in patients provided with single-implant restorations after more than 15 years of follow-up. *Int J Prosthodont* 2006; 19(5): 455-61.
15. Misje K, Bjørnland T, Saxegaard E, Jensen JL. Treatment outcome of dental implants in the esthetic zone: a 12- to 15-year retrospective study. *Int J Prosthodont* 2013; 26(4): 365-9.
16. Mozzati M, Gallesio G, Del Fabbro M. Long-Term (9-12 Years) Outcomes of Titanium Implants With an Oxidized Surface: A Retrospective Investigation on 209 Implants. *J Oral Implantol* 2015; 41(4): 437-43.
17. Ostman PO, Hellman M, Sennerby L. Ten years later. Results from a prospective single-centre clinical study on 121 oxidized (TiUnite) Branemark implants in 46 patients. *Clin Implant Dent Relat Res* 2012; 14(6): 852-60.
18. Thilander B, Odman J, Jemt T. Single implants in the upper incisor region and their relationship to the adjacent teeth. An 8-year follow-up study. *Clin Oral Implants Res* 1999; 10(5): 346-55.
19. Wittneben JG, Buser D, Salvi GE, Bürgin W, Hicklin S, Brägger U. Complication and failure rates with implant-supported fixed dental prostheses and single crowns: a 10-year retrospective study. *Clin Implant Dent Relat Res* 2014; 16(3): 356-64.
20. Dierens M, de Bruecker E, Vandeweghe S, Kisch J, de Bruyn H, Cosyn J. Alterations in soft tissue levels and aesthetics over a 16-22 year period following single implant treatment in periodontally-healthy patients: a retrospective case series. *J Clin Periodontol* 2013; 40(3): 311-8.
21. Dierens M, De Bruyn H, Kisch J, Nilner K, Cosyn J, Vandeweghe S. Prosthetic Survival and Complication Rate of Single Implant Treatment in the Periodontally Healthy Patient after 16 to 22 Years of Follow-Up. *Clin Implant Dent Relat Res* 2016; 18(1): 117-28.
22. Jemt T, Ahlberg G, Henriksson K, Bondevik O. Tooth movements adjacent to single-implant restorations after more than 15 years of follow-up. *Int J Prosthodont* 2007; 20(6): 626-32.
23. Jemt T. Single-Implant Survival: More Than 30 Years of Clinical Experience. *Int J Prosthodont* 2016; 30(6): 551-8.
24. Midori A, Ricanek KJ, Patterson E. A review of the literature on the aging skull and face: Implications for forensic science research and applications. *Forensic Science International* 2007; 172(172): 1-9.
25. Lammie GA, Posselt U. Progressive changes in the dentition of adults. *J Periodontol* 1965; 36(6): 443-54.
26. Theytaz GA, Christou P, Kiliaridis S. Gingival changes and secondary tooth eruption in adolescents and adults: a longitudinal retrospective study. *Am J Orthod Dentofacial Orthop* 2011; 139(4 Suppl): S129-32.

27. Hugoson A, Laurell L. A prospective longitudinal study on periodontal bone height changes in a Swedish population. *J Clin Periodontol* 2000; 27(9): 665-74.
28. Hugoson A, Koch G. Oral health in 1000 individuals aged 3--70 years in the community of Jonkoping, Sweden. A review. *Swed Dent J* 1979; 3(3): 69-87.
29. Gürel G. The science and art of porcelain laminate veneers. London: Quintessence; 2003.
30. Heymann HO. The artistry of conservative esthetic dentistry. *Journal of the American Dental Association (1939)* 1987; Spec No: 14e-23e.
31. Bohner L, Hanisch M, Kleinheinz J, Jung S. Dental implants in growing patients: a systematic review. *Br J Oral Maxillofac Surg* 2019; 57(5): 397-406.
32. Bergendal B, Bjerklin K, Bergendal T, Koch G. Dental Implant Therapy for a Child with X-linked Hypohidrotic Ectodermal Dysplasia--Three Decades of Managed Care. *Int J Prosthodont* 2015; 28(4): 348-56.
33. Guckes AD, Scurria MS, King TS, McCarthy GR, Brahim JS. Prospective clinical trial of dental implants in persons with ectodermal dysplasia. *J Prosthet Dent* 2002; 88(1): 21-5.
34. Kearns G, Sharma A, Perrott D, Schmidt B, Kaban L, Vargervik K. Placement of endosseous implants in children and adolescents with hereditary ectodermal dysplasia. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1999; 88(1): 5-10.
35. Sharma AB, Vargervik K. Using implants for the growing child. *J Calif Dent Assoc* 2006; 34(9): 719-24.
36. Ledermann PD, Hassell TM, Hefti AF. Osseointegrated dental implants as alternative therapy to bridge construction or orthodontics in young patients: seven years of clinical experience. *Pediatr Dent* 1993; 15(5): 327-33.
37. Thilander B, Odman J, Lekholm U. Orthodontic aspects of the use of oral i mplants in adolescents: a 10-year follow-up study. *Eur J Orthod* 2001; 23(6): 715-31.
38. Andersson B. Implants for single-tooth replacement. A clinical and experimental study on the Branemark CeraOne System. *Swed Dent J Suppl* 1995; 108: 1-41.
39. Ekfeldt A, Carlsson GE, Borjesson G. Clinical evaluation of single-tooth restorations supported by osseointegrated implants: a retrospective study. *Int J Oral Maxillofac Implants* 1994; 9(2): 179-83.
40. Jemt T, Laney WR, Harris D, et al. Osseointegrated implants for single tooth replacement: a 1-year report from a multicenter prospective study. *Int J Oral Maxillofac Implants* 1991; 6(1): 29-36.
41. Moberg LE, Kondell PA, Kullman L, Heimdahl A, Gynther GW. Evaluation of single-tooth restorations on ITI dental implants. A prospective study of 29 patients. *Clin Oral Implants Res* 1999; 10(1): 45-53.
42. Polder BJ, Van't Hof MA, Van der Linden FP, Kuijpers-Jagtman AM. A meta-analysis of the prevalence of dental agenesis of permanent teeth. *Community Dent Oral Epidemiol* 2004; 32(3): 217-26.
43. Ingervall B, Seeman L, Thilander B. Frequency of malocclusion and need of orthodontic treatment in 10-year old children in Gothenburg. *Sven Tandlak Tidskr* 1972; 65(1): 7-21.
44. Thilander B, Myrberg N. The prevalence of malocclusion in Swedish schoolchildren. *Scand J Dent Res* 1973; 81(1): 12-21.
45. Bergstrom K. An orthopantomographic study of hypodontia, supernumeraries and other anomalies in school children between the ages of 8-9 years. An epidemiological study. *Swed Dent J* 1977; 1(4): 145-57.
46. Mattheeuws N, Dermaut L, Martens G. Has hypodontia increased in Caucasians during the 20th century? A meta-analysis. *Eur J Orthod* 2004; 26(1): 99-103.
47. Skaare AB, Jacobsen I. Dental injuries in Norwegians aged 7-18 years. *Dent Traumatol* 2003; 19(2): 67-71.
48. Lambert P, Morris HF, Ochi S. RELATIONSHIP BETWEEN IMPLANT SURGICAL EXPERIENCE AND SECOND-STAGE FAILURES: DICRG INTERIM REPORT No. 2. *Implant Dentistry* 1994; 3(2): 97-101.
49. Antoun H, Karouni M, Abitbol J, Zouiten O, Jemt T. A retrospective study on 1592 consecutively performed operations in one private referral clinic. Part I: Early inflammation and early implant failures. *Clin Implant Dent Relat Res* 2017; 19(3): 404-12.
50. Pommer B, Danzinger M, Leite Aiquel L, Pitta J, Haas R. Long-term outcomes of maxillary single-tooth implants in relation to timing protocols of implant placement and loading: Systematic review and meta-analysis. *Clin Oral Implants Res* 2021; 32 Suppl 21: 56-66.
51. Avivi-Arber L, Zarb GA. Clinical effectiveness of implant-supported single-tooth replacement: the Toronto Study. *Int J Oral Maxillofac Implants* 1996; 11(3): 311-21.
52. Schmitt A, Zarb GA. The longitudinal clinical effectiveness of osseointegrated dental implants for single-tooth replacement. *Int J Prosthodont* 1993; 6(2): 197-202.
53. Nisand D, Renouard F. Short implant in limited bone volume. *Periodontol 2000* 2014; 66(1): 72-96.
54. Morris HF, Manz MC, Tarolli JH. Success of multiple endosseous dental implant designs to second-stage surgery across study sites. *J Oral Maxillofac Surg* 1997; 55(12 Suppl 5): 76-82.
55. Lambert PM, Morris HF, Ochi S. Positive effect of surgical experience with implants on second-stage implant survival. *J Oral Maxillofac Surg* 1997; 55(12 Suppl 5): 12-8.
56. Parein AM, Eckert SE, Wollan PC, Keller EE. Implant reconstruction in the posterior mandible: a long-term retrospective study. *J Prosthet Dent* 1997; 78(1): 34-42.
57. Preiskel HW, Tsolka P. Treatment outcomes in implant therapy: the influence of surgical and prosthodontic experience. *Int J Prosthodont* 1995; 8(3): 273-9.
58. Truhlar RS, Farish SE, Scheitler LE, Morris HF, Ochi S. Bone quality and implant design-related outcomes through stage II surgical uncovering of Spectra-System root form implants. *J Oral Maxillofac Surg* 1997; 55(12 Suppl 5): 46-54.
59. Weyant RJ. Characteristics associated with the loss and peri-implant tissue health of endosseous dental implants. *Int J Oral Maxillofac Implants* 1994; 9(1): 95-102.
60. Zupnik J, Kim SW, Ravens D, Karimbux N, Guze K. Factors associated with dental implant survival: a 4-year retrospective analysis. *J Periodontol* 2011; 82(10): 1390-5.

61. Henry PJ, Rosenberg IR, Bills IG, et al. Osseointegrated implants for single tooth replacement in general practice: a 1-year report from a multicentre prospective study. *Aust Dent J* 1995; 40(3): 173-81.
62. Catchpole K, Mishra A, Handa A, McCulloch P. Teamwork and error in the operating room: analysis of skills and roles. *Ann Surg* 2008; 247(4): 699-706.
63. Albrektsson T, Isidor F. Consensus report session IV. In: In: Lang NP KT, eds. , editor. 1st European workshop on periodontology. London: Quintessence; 1993. p. 365–9.
64. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. *Int J Oral Maxillofac Implants* 1986; 1(1): 11-25.
65. Berglundh T, Armitage G, Araujo MG, et al. Peri-implant diseases and conditions: Consensus report of workgroup 4 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *J Periodontol* 2018; 89 Suppl 1: S313-S8.
66. Quirynen M, van Steenberghe D, Jacobs R, Schotte A, Darius P. The reliability of pocket probing around screw-type implants. *Clin Oral Implants Res* 1991; 2(4): 186-92.
67. Lekholm U, Adell R, Lindhe J, et al. Marginal tissue reactions at osseointegrated titanium fixtures. (II) A cross-sectional retrospective study. *Int J Oral Maxillofac Surg* 1986; 15(1): 53-61.
68. Monje A, Amerio E, Farina R, et al. Significance of probing for monitoring peri-implant diseases. *Int J Oral Implantol (Berl)* 2021; 14(4): 385-99.
69. Coli P, Sennerby L. Is Peri-Implant Probing Causing Over-Diagnosis and Over-Treatment of Dental Implants? *J Clin Med* 2019; 8(8).
70. Coli P, Christiaens V, Sennerby L, Bruyn H. Reliability of periodontal diagnostic tools for monitoring peri-implant health and disease. *Periodontol 2000* 2017; 73(1): 203-17.
71. Pjetursson BE, Valente NA, Strasding M, Zwahlen M, Liu S, Sailer I. A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic single crowns. *Clin Oral Implants Res* 2018; 29 Suppl 16: 199-214.
72. Jung RE, Pjetursson BE, Glauser R, Zembic A, Zwahlen M, Lang NP. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. *Clin Oral Implants Res* 2008; 19(2): 119-30.
73. Karoussis IK, Salvi GE, Heitz-Mayfield LJ, Brägger U, Hämmerle CH, Lang NP. Long-term implant prognosis in patients with and without a history of chronic periodontitis: a 10-year prospective cohort study of the ITI Dental Implant System. *Clin Oral Implants Res* 2003; 14(3): 329-39.
74. Benedicto EN, Kairalla SA, Oliveira GMS, Junior LRM, Rosario HD, Paranhos LR. Determination of vertical characteristics with different cephalometric measurements. *Eur J Dent* 2016; 10(1): 116-20.
75. Franchi L, Baccetti T. Prediction of individual mandibular changes induced by functional jaw orthopedics followed by fixed appliances in Class II patients. *Angle Orthod* 2006; 76(6): 950-4.
76. Cardoso Mde A, Castro RC, Li An T, Normando D, Garib DG, Capelozza Filho L. Prevalence of long face pattern in Brazilian individuals of different ethnic backgrounds. *J Appl Oral Sci* 2013; 21(2): 150-6.
77. Kim YH. Overbite depth indicator with particular reference to anterior open-bite. *Am J Orthod* 1974; 65(6): 586-611.
78. Behrents RG. Growth of the aging skeleton. Monograpf 17. Monograph 17, Craniofacial Growth Series, Center for Human Growth and Development, The University of Michigan. 1985.; 1985.
79. Oesterle LJ, Cronin RJ, Jr. Adult growth, aging, and the single-tooth implant. *Int J Oral Maxillofac Implants* 2000; 15(2): 252-60.
80. Fields HW, Proffit WR, Nixon WL, Phillips C, Stanek E. Facial pattern differences in long-faced children and adults. *Am J Orthod* 1984; 85(3): 217-23.
81. Ligthelm-Bakker AS, Wattel E, Uljee IH, Prahl-Andersen B. Vertical growth of the anterior face: a new approach. *Am J Orthod Dentofacial Orthop* 1992; 101(6): 509-13.
82. Nanda SK. Patterns of vertical growth in the face. *Am J Orthod Dentofacial Orthop* 1988; 93(2): 103-16.
83. Nanda SK, Rowe TK. Circumpubertal growth spurt related to vertical dysplasia. *Angle Orthod* 1989; 59(2): 113-22.
84. Heij DG, Opdebeeck H, van Steenberghe D, Kokich VG, Belser U, Quirynen M. Facial development, continuous tooth eruption, and mesial drift as compromising factors for implant placement. *Int J Oral Maxillofac Implants* 2006; 21(6): 867-78.
85. Akgul AA, Toygar TU. Natural craniofacial changes in the third decade of life: a longitudinal study. *Am J Orthod Dentofacial Orthop* 2002; 122(5): 512-22.
86. Forsberg CM. Facial morphology and ageing: a longitudinal cephalometric investigation of young adults. *Eur J Orthod* 1979; 1(1): 15-23.
87. Bishara SE, Treder JE, Jakobsen JR. Facial and dental changes in adulthood. *Am J Orthod Dentofacial Orthop* 1994; 106(2): 175-86.
88. Formby WA, Nanda RS, Currier GF. Longitudinal changes in the adult facial profile. *Am J Orthod Dentofacial Orthop* 1994; 105(5): 464-76.
89. Bishara SE, Jakobsen JR. Longitudinal changes in three normal facial types. *Am J Orthod* 1985; 88(6): 466-502.
90. Collett AR, West VC. Terminology of facial morphology in the vertical dimension. *Aust Dent J* 1993; 38(3): 204-9.
91. Sarnas KV, Solow B. Early adult changes in the skeletal and soft-tissue profile. *Eur J Orthod* 1980; 2(1): 1-12.
92. da Silva Filho O.G CGCPB, Cardoso M., Filho L.C. Study of the cephalometric features of Brazilian long face adolescents. *Dental Press J Orthod* 2010; July-Aug;(15(4):35.): e1-12.
93. Isaacson JR, Isaacson RJ, Speidel TM, Worms FW. Extreme variation in vertical facial growth and associated variation in skeletal and dental relations. *Angle Orthod* 1971; 41(3): 219-29.

94. Malkoc S, Demir A, Uysal T, Canbuldu N. Angular photogrammetric analysis of the soft tissue facial profile of Turkish adults. *Eur J Orthod* 2009; 31(2): 174-9.
95. Klinge A. Craniofacial Height in Relation to Alveolar Bone Morphology [Doctoral thesis, comprehensive summary]. Malmö: Malmö universitet; 2020.
96. Wolfart S, Menzel H, Kern M. Inability to relate tooth forms to face shape and gender. *Eur J Oral Sci* 2004; 112(6): 471-6.
97. da Silva Filho O.G CGCPB, Cardoso M., Filho L.C. Study of the cephalometric features of Brazilian long face adolescents. *Dental Press J Orthod* 2010; July-Aug;(15(4):35.): e1-12.
98. Cabello M, Alvarado S. Relationship between the shape of the upper central incisors and the facial contour in dental students. Lima. Peru. *Journal Of Oral Research* 2015; 4: 189-96.
99. Silva F, Almeida N, Ferreira D, Mesquita M, Negreiros W. Digitized study of the correlation between the face and tooth shapes in young adult individuals. *Brazilian Journal of Oral Sciences (ISSN: 1677-3217) Vol 6 Num 22* 2007; 6.
100. Klinge A, Becktor K, Lindh C, Becktor JP. Craniofacial height in relation to cross-sectional maxillary and mandibular morphology. *Prog Orthod* 2017; 18(1): 32.
101. Chang HP, Kinoshita Z, Kawamoto T. A study of the growth changes in facial configuration. *Eur J Orthod* 1993; 15(6): 493-501.
102. Reis AoJ, Claro C.A.A, Fornazari R.F, Capelozza Filho L. Agreement among orthodontists regarding facial pattern diagnosis. *Dental Press J Orthod* 2011; July-Aug; 16((4):): 60-72.
103. Johnston LE. A simplified approach to prediction. *Am J Orthod* 1975; 67(3): 253-7.
104. Forsberg CM, Eliasson S, Westergren H. Face height and tooth eruption in adults--a 20-year follow-up investigation. *Eur J Orthod* 1991; 13(4): 249-54.
105. Jamroz GM, Kuijpers-Jagtman AM, van't Hof MA, Katsaros C. Dental maturation in short and long facial types. Is there a difference? *Angle Orthod* 2006; 76(5): 768-72.
106. Bishara SE, Jorgensen GJ, Jakobsen JR. Changes in facial dimensions assessed from lateral and frontal photographs. Part I--Methodology. *Am J Orthod Dentofacial Orthop* 1995; 108(4): 389-93.
107. Yeung CY, McGrath CP, Wong RW, Hagg EU, Lo J, Yang Y. Frontal facial proportions of 12-year-old southern Chinese: a photogrammetric study. *Head Face Med* 2015; 11: 26.
108. Bishara SE, Jorgensen GJ, Jakobsen JR. Changes in facial dimensions assessed from lateral and frontal photographs. Part II--Results and conclusions. *Am J Orthod Dentofacial Orthop* 1995; 108(5): 489-99.
109. Ferring V, Pancherz H. Divine proportions in the growing face. *Am J Orthod Dentofacial Orthop* 2008; 134(4): 472-9.
110. Gavan JA, Washburn SL, Lewis PH. Photography: an anthropometric tool. *Am J Phys Anthropol* 1952; 10(3): 331-53.
111. Tanner JM, Weiner JS. The reliability of the photogrammetric method of anthropometry, with a description of a miniature camera technique. *Am J Phys Anthropol* 1949; 7(2): 145-86.
112. Zhang X, Hans MG, Graham G, Kirchner HL, Redline S. Correlations between cephalometric and facial photographic measurements of craniofacial form. *Am J Orthod Dentofacial Orthop* 2007; 131(1): 67-71.
113. Schendel SA, Eisenfeld J, Bell WH, Epker BN, Mishelevich DJ. The long face syndrome: vertical maxillary excess. *Am J Orthod* 1976; 70(4): 398-408.
114. Behrents RG. Growth of the aging skeleton. Monograpf 17. Monograph 17, Craniofacial Growth Series, Center for Human Growth and Development, The University of Michigan. 1985.
115. Tallgren A, Solow B. Age differences in adult dentoalveolar heights. *Eur J Orthod* 1991; 13(2): 149-56.
116. Bondevik O. Growth changes in the cranial base and the face: a longitudinal cephalometric study of linear and angular changes in adult Norwegians. *Eur J Orthod* 1995; 17(6): 525-32.
117. Bondevik O. Dentofacial changes in adults: a longitudinal cephalometric study in 22-33 and 33-43 year olds. *J Orofac Orthop* 2012; 73(4): 277-88.
118. West KS, McNamara JA, Jr. Changes in the craniofacial complex from adolescence to midadulthood: a cephalometric study. *Am J Orthod Dentofacial Orthop* 1999; 115(5): 521-32.
119. Iseri H, Solow B. Continued eruption of maxillary incisors and first molars in girls from 9 to 25 years, studied by the implant method. *Eur J Orthod* 1996; 18(3): 245-56.
120. Behrents RG. The biological basis for understanding craniofacial growth during adulthood. *Prog Clin Biol Res* 1985; 187: 307-19.
121. Theytaz GA, Kiliaridis S. Gingival and dentofacial changes in adolescents and adults 2 to 10 years after orthodontic treatment. *J Clin Periodontol* 2008; 35(9): 825-30.
122. Huanca Ghislanzoni L, Jonasson G, Kiliaridis S. Continuous eruption of maxillary teeth and changes in clinical crown length: A 10-year longitudinal study in adult women. *Clin Implant Dent Relat Res* 2017; 19(6): 1082-9.
123. Thilander B, Odman J, Grondahl K, Friberg B. Osseointegrated implants in adolescents. An alternative in replacing missing teeth? *Eur J Orthod* 1994; 16(2): 84-95.
124. Ödman J. Implants in orthodontics: an experimental and clinical study. *[dissertation] Göteborg:* 1994.
125. Kawanami M, Andreasen JO, Borum MK, Schou S, Hjorting-Hansen E, Kato H. Infraposition of ankylosed permanent maxillary incisors after replantation related to age and sex. *Endod Dent Traumatol* 1999; 15(2): 50-6.
126. Papageorgiou SN, Eliades T, Hammerle CHF. Frequency of infraposition and missing contact points in implant-supported restorations within natural dentitions over time: A systematic review with meta-analysis. *Clin Oral Implants Res* 2018; 29 Suppl 18: 309-25.

127. Brahem EB, Holm B, Sonnesen L, Worsaae N, Gotfredsen K. Positional changes of maxillary central incisors following orthodontic treatment using single-crown implants as fixed reference markers. *Clin Oral Implants Res* 2017; 28(12): 1560-6.
128. Jemt T. Measurements of tooth movements in relation to single-implant restorations during 16 years: a case report. *Clin Implant Dent Relat Res* 2005; 7(4): 200-8.
129. Lie A, Jemt T. Photogrammetric measurements of implant positions. Description of a technique to determine the fit between implants and superstructures. *Clin Oral Implants Res* 1994; 5(1): 30-6.
130. Jemt T, Book K, Lie A, Borjesson T. Mucosal topography around implants in edentulous upper jaws. Photogrammetric three-dimensional measurements of the effect of replacement of a removable prosthesis with a fixed prosthesis. *Clin Oral Implants Res* 1994; 5(4): 220-8.
131. Jemt T, Back T, Petersson A. Photogrammetry--an alternative to conventional impressions in implant dentistry? A clinical pilot study. *Int J Prosthodont* 1999; 12(4): 363-8.
132. Jang I, Tanaka M, Koga Y, et al. A novel method for the assessment of three-dimensional tooth movement during orthodontic treatment. *Angle Orthod* 2009; 79(3): 447-53.
133. Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. *Am J Orthod Dentofacial Orthop* 2012; 142(2): 269-73.
134. Christou P, Kiliaridis S. Vertical growth-related changes in the positions of palatal rugae and maxillary incisors. *Am J Orthod Dentofacial Orthop* 2008; 133(1): 81-6.
135. Gotfredsen K. A 10-year prospective study of single tooth implants placed in the anterior maxilla. *Clin Implant Dent Relat Res* 2012; 14(1): 80-7.
136. Meijndert CM, Raghoebar GM, Meijndert L, Stellingsma K, Vissink A, Meijer HJ. Single implants in the aesthetic region preceded by local ridge augmentation; a 10-year randomized controlled trial. *Clin Oral Implants Res* 2017; 28(4): 388-95.
137. Gotfredsen K. A 5-year prospective study of single-tooth replacements supported by the Astra Tech implant: a pilot study. *Clin Implant Dent Relat Res* 2004; 6(1): 1-8.
138. Altay MA, Sindel A, Tezerisener HA, Yildirimyan N, Ozarslan MM. Esthetic evaluation of implant-supported single crowns: a comparison of objective and patient-reported outcomes. *Int J Implant Dent* 2019; 5(1): 2.
139. Chang M, Odman PA, Wennstrom JL, Andersson B. Esthetic outcome of implant-supported single-tooth replacements assessed by the patient and by prosthodontists. *Int J Prosthodont* 1999; 12(4): 335-41.
140. Chang M, Wennstrom JL, Odman P, Andersson B. Implant supported single-tooth replacements compared to contralateral natural teeth. Crown and soft tissue dimensions. *Clin Oral Implants Res* 1999; 10(3): 185-94.
141. Taylor EJ, Yuan JC, Lee DJ, et al. Are predoctoral students able to provide single tooth implant restorations in the maxillary esthetic zone? *J Dent Educ* 2014; 78(5): 779-88.
142. Hartlev J, Kohberg P, Ahlmann S, Andersen NT, Schou S, Isidor F. Patient satisfaction and esthetic outcome after immediate placement and provisionalization of single-tooth implants involving a definitive individual abutment. *Clin Oral Implants Res* 2014; 25(11): 1245-50.
143. Hof M, Pommer B, Strbac GD, Sütö D, Watzek G, Zechner W. Esthetic evaluation of single-tooth implants in the anterior maxilla following autologous bone augmentation. *Clin Oral Implants Res* 2013; 24 Suppl A100: 88-93.
144. California Dental Association. Quality evaluation for dental care: Guidelines for the assessment of clinical quality and professional performance. 1977: 3-5; 53-5.
145. Vilhjalmsson VH, Klock KS, Storksen K, Bardsen A. Aesthetics of implant-supported single anterior maxillary crowns evaluated by objective indices and participants' perceptions. *Clin Oral Implants Res* 2011; 22(12): 1399-403.
146. Nilsson A, Johansson LA, Stenport VF, Wennerberg A, Ekfeldt A. Infraposition of anterior maxillary implant-supported single-tooth restorations in adolescent and adult patients-A prospective follow-up study up to 6 years. *Clin Implant Dent Relat Res* 2019.
147. Jemt T. Regeneration of gingival papillae after single-implant treatment. *Int J Periodontics Restorative Dent* 1997; 17(4): 326-33.
148. Jemt T. Restoring the gingival contour by means of provisional resin crowns after single-implant treatment. *Int J Periodontics Restorative Dent* 1999; 19(1): 20-9.
149. Palmer RM, Farkondeh N, Palmer PJ, Wilson RF. Astra Tech single-tooth implants: an audit of patient satisfaction and soft tissue form. *J Clin Periodontol* 2007; 34(7): 633-8.
150. Schropp L, Isidor F. Papilla dimension and soft tissue level after early vs. delayed placement of single-tooth implants: 10-year results from a randomized controlled clinical trial. *Clin Oral Implants Res* 2015; 26(3): 278-86.
151. Furhauser R, Florescu D, Benesch T, Haas R, Mailath G, Watzek G. Evaluation of soft tissue around single-tooth implant crowns: the pink esthetic score. *Clin Oral Implants Res* 2005; 16(6): 639-44.
152. Belser UC, Grutter L, Vailati F, Bornstein MM, Weber HP, Buser D. Outcome evaluation of early placed maxillary anterior single-tooth implants using objective esthetic criteria: a cross-sectional, retrospective study in 45 patients with a 2- to 4-year follow-up using pink and white esthetic scores. *J Periodontol* 2009; 80(1): 140-51.
153. Wittneben JG, Gavric J, Sailer I, Buser D, Wismeijer D. Clinical and esthetic outcomes of two different prosthetic workflows for implant-supported all-ceramic single crowns-3 year results of a randomized multicenter clinical trail. *Clin Oral Implants Res* 2020; 31(5): 495-505.
154. Bonde MJ, Stokholm R, Schou S, Isidor F. Patient satisfaction and aesthetic outcome of implant-supported single-tooth replacements performed by dental students: a retrospective evaluation 8 to 12 years after treatment. *Eur J Oral Implantol* 2013; 6(4): 387-95.

155. Cosyn J, Eghbali A, De Bruyn H, Dierens M, De Rouck T. Single implant treatment in healing versus healed sites of the anterior maxilla: an aesthetic evaluation. *Clin Implant Dent Relat Res* 2012; 14(4): 517-26.
156. den Hartog L, Raghoebar GM, Slater JJ, Stellingsma K, Vissink A, Meijer HJ. Single-tooth implants with different neck designs: a randomized clinical trial evaluating the aesthetic outcome. *Clin Implant Dent Relat Res* 2013; 15(3): 311-21.
157. Meijndert CM, Raghoebar GM, Santing HJ, Vissink A, Meijer HJA. Performance of bone-level implants with conical connections in the anterior maxilla: A 5-year prospective cohort study. *Clin Oral Implants Res* 2020; 31(2): 173-80.
158. Tettamanti S, Millen C, Gavric J, et al. Esthetic Evaluation of Implant Crowns and Peri-Implant Soft Tissue in the Anterior Maxilla: Comparison and Reproducibility of Three Different Indices. *Clin Implant Dent Relat Res* 2016; 18(3): 517-26.
159. Vaidya S, Ho YL, Hao J, Lang NP, Mattheos N. Evaluation of the influence exerted by different dental specialty backgrounds and measuring instrument reproducibility on esthetic aspects of maxillary implant-supported single crown. *Clin Oral Implants Res* 2015; 26(3): 250-6.
160. Hosseini M, Gotfredsen K. A feasible, aesthetic quality evaluation of implant-supported single crowns: an analysis of validity and reliability. *Clin Oral Implants Res* 2012; 23(4): 453-8.
161. Juodzbalys G, Wang HL. Esthetic index for anterior maxillary implant-supported restorations. *J Periodontol* 2010; 81(1): 34-42.
162. Meijndert L, Meijer HJ, Stellingsma K, Stegenga B, Raghoebar GM. Evaluation of aesthetics of implant-supported single-tooth replacements using different bone augmentation procedures: a prospective randomized clinical study. *Clin Oral Implants Res* 2007; 18(6): 715-9.
163. Meijer HJ, Stellingsma K, Meijndert L, Raghoebar GM. A new index for rating aesthetics of implant-supported single crowns and adjacent soft tissues--the Implant Crown Aesthetic Index. *Clin Oral Implants Res* 2005; 16(6): 645-9.
164. Ozhayat EB, Gotfredsen K. Patient-reported effect in patients receiving i mplant or tooth-supported fixed prosthesis. *J Oral Rehabil* 2020; 47(2): 229-34.
165. Ozhayat EB. Responsiveness of the Prosthetic Esthetic Scale. *Clin Oral Investig* 2017; 21(3): 907-13.
166. Testori T, Bianchi F, Del Fabbro M, et al. Implant aesthetic score for evaluating the outcome: immediate loading in the aesthetic zone. *Pract Proced Aesthet Dent* 2005; 17(2): 123-30; quiz 32.
167. Huskisson EC. Visual Analogue Scales. In: Pain measurement and assessment. New York: Raven Press; 1983. .
168. Suphanantachat S, Thovanich K, Nisapakultorn K. The influence of peri-implant mucosal level on the satisfaction with anterior maxillary implants. *Clin Oral Implants Res* 2012; 23(9): 1075-81.
169. Chang M, Wennstrom JL. Longitudinal changes in tooth/single-implant relationship and bone topography: an 8-year retrospective analysis. *Clin Implant Dent Relat Res* 2012; 14(3): 388-94.
170. Pjetursson BE, Karoussis I, Burgin W, Bragger U, Lang NP. Patients' satisfaction following implant therapy. A 10-year prospective cohort study. *Clin Oral Implants Res* 2005; 16(2): 185-93.
171. Atef M, El Barbary A, Dahrous MSE, Zahran AF. Comparison of the soft and hard peri-implant tissue dimensional changes around single immediate implants in the esthetic zone with socket shield technique versus using xenograft: A randomized controlled clinical trial. *Clin Implant Dent Relat Res* 2021; 23(3): 456-65.
172. Petricević N, Celebić A, Papić M, Rener-Sitar K. The Croatian version of the Oral Health Impact Profile Questionnaire. *Coll Antropol* 2009; 33(3): 841-7.
173. Park SY, Oh SH, Kim J, et al. Single-Tooth Implant Versus Three-Unit Fixed Partial Denture: A Study of Oral Health-Related Quality of Life. *Int J Oral Maxillofac Implants* 2016; 31(2): 376-81.
174. Peršić S, Čelebić A. Influence of different prosthodontic rehabilitation options on oral health-related quality of life, orofacial esthetics and chewing function based on patient-reported outcomes. *Qual Life Res* 2015; 24(4): 919-26.
175. Swelem AA, Gurevich KG, Fabrikant EG, Hassan MH, Aqou S. Oral health-related quality of life in partially edentulous patients treated with removable, fixed, fixed-removable, and implant-supported prostheses. *Int J Prosthodont* 2014; 27(4): 338-47.
176. Larsson P, John MT, Nilner K, List T. Reliability and validity of the Orofacial Esthetic Scale in prosthodontic patients. *Int J Prosthodont* 2010; 23(3): 257-62.
177. Gibbard LL, Zarb G. A 5-year prospective study of implant-supported single-tooth replacements. *J Can Dent Assoc* 2002; 68(2): 110-6.
178. Derks J, Hakansson J, Wennstrom JL, Klinge B, Berglundh T. Patient-reported outcomes of dental implant therapy in a large randomly selected sample. *Clin Oral Implants Res* 2015; 26(5): 586-91.
179. Pieri F, Aldini NN, Marchetti C, Corinaldesi G. Esthetic outcome and tissue stability of maxillary anterior single-tooth implants following reconstruction with mandibular block grafts: a 5-year prospective study. *Int J Oral Maxillofac Implants* 2013; 28(1): 270-80.
180. Hammerle CHF, Jung RE, Sanz M, et al. Submerged and transmucosal healing yield the same clinical outcomes with two-piece implants in the anterior maxilla and mandible: interim 1-year results of a randomized, controlled clinical trial. *Clin Oral Implants Res* 2012; 23(2): 211-9.
181. Cosyn J, Thoma DS, Hämmerle CH, De Bruyn H. Esthetic assessments in implant dentistry: objective and subjective criteria for clinicians and patients. *Periodontol 2000* 2017; 73(1): 193-202.
182. Lang NP, Zitzmann NU. Clinical research in implant dentistry: evaluation of implant-supported restorations, aesthetic and patient-reported outcomes. *J Clin Periodontol* 2012; 39 Suppl 12: 133-8.
183. McGrath C, Lam O, Lang N. An evidence-based review of patient-reported outcome measures in dental implant research among dentate subjects. *J Clin Periodontol* 2012; 39 Suppl 12: 193-201.

184. Wittneben JG, Wismeijer D, Bragger U, Joda T, Abou-Ayash S. Patient-reported outcome measures focusing on aesthetics of implant- and tooth-supported fixed dental prostheses: A systematic review and meta-analysis. *Clin Oral Implants Res* 2018; 29 Suppl 16: 224-40.
185. Gotfredsen K, Hosseini M, Rimborg S, Ozhayat E. Patient's perception of timing concepts in implant dentistry: A systematic review. *Clin Oral Implants Res* 2021; 32 Suppl 21: 67-84.
186. Burgersdijk R, Truin GJ, Kalsbeek H, van't Hof M, Mulder J. Objective and subjective need for cosmetic dentistry in the Dutch adult population. *Community Dent Oral Epidemiol* 1991; 19(2): 61-3.
187. Chang M, Wennstrom JL. Soft tissue topography and dimensions lateral to single implant-supported restorations. a cross-sectional study. *Clin Oral Implants Res* 2013; 24(5): 556-62.
188. Glantz PO, Ryge G, Jendresen MD, Nilner K. Quality of extensive fixed prosthodontics after five years. *J Prosthet Dent* 1984; 52(4): 475-9.
189. Sjogren G, Bergman M, Molin M, Bessing C. A clinical examination of ceramic (Cerec) inlays. *Acta Odontol Scand* 1992; 50(3): 171-8.
190. Holm C, Tidehag P, Tillberg A, Molin M. Longevity and quality of FPDs: a retrospective study of restorations 30, 20, and 10 years after insertion. *Int J Prosthodont* 2003; 16(3): 283-9.
191. Widbom T, Lofquist L, Widbom C, Soderfeldt B, Kronstrom M. Tooth-supported telescopic crown-retained dentures: an up to 9-year retrospective clinical follow-up study. *Int J Prosthodont* 2004; 17(1): 29-34.
192. Cehreli MC, Kokat AM, Akca K. CAD/CAM Zirconia vs. slip-cast glass-infiltrated Alumina/Zirconia all-ceramic crowns: 2-year results of a randomized controlled clinical trial. *J Appl Oral Sci* 2009; 17(1): 49-55.
193. Cehreli MC, Kokat AM, Ozpay C, Karasoy D, Akca K. A randomized controlled clinical trial of feldspathic versus glass-infiltrated alumina all-ceramic crowns: a 3-year follow-up. *Int J Prosthodont* 2011; 24(1): 77-84.
194. Nejatidanesh F, Moradpoor H, Savabi O. Clinical outcomes of zirconia-based implant- and tooth-supported single crowns. *Clin Oral Investig* 2016; 20(1): 169-78.
195. Ekfeldt A, Zellmer M, Carlsson GE. Treatment with implant-supported fixed dental prostheses in patients with congenital and acquired neurologic disabilities: a prospective study. *Int J Prosthodont* 2013; 26(6): 517-24.
196. Tjan AHL, Miller GD, The JGP. Some esthetic factors in a smile. *The Journal of Prosthetic Dentistry* 1984; 51(1): 24-8.
197. Kourkouta S. Implant therapy in the esthetic zone: smile line assessment. *Int J Periodontics Restorative Dent* 2011; 31(2): 195-201.
198. Peck S, Peck L, Kataja M. The gingival smile line. *Angle Orthod* 1992; 62(2): 91-100; discussion 1-2.
199. Al-Jabrah O, Al-Shammout R, El-Naji W, Al-Ajarmeh M, Al-Quran AH. Gender differences in the amount of gingival display during smiling using two intraoral dental biometric measurements. *J Prosthodont* 2010; 19(4): 286-93.
200. Peck S, Peck L, Kataja M. Some vertical lineaments of lip position. *Am J Orthod Dentofacial Orthop* 1992; 101(6): 519-24.
201. Proske U, Gandevia SC. The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiol Rev* 2012; 92(4): 1651-97.
202. Klineberg I. Introduction: from osseointegration to osseoperception. The functional translation. *Clin Exp Pharmacol Physiol* 2005; 32(1-2): 97-9.
203. Cash RM, Linden RW. The distribution of mechanoreceptors in the periodontal ligament of the mandibular canine tooth of the cat. *J Physiol* 1982; 330: 439-47.
204. Johansson, Olsson KA. Microelectrode recordings from human oral mechanoreceptors. *Brain Res* 1976; 118(2): 307-11.
205. Lund JP. Mastication and its control by the brain stem. *Crit Rev Oral Biol Med* 1991; 2(1): 33-64.
206. Trulsson M. Sensory-motor function of human periodontal mechanoreceptors. *J Oral Rehabil* 2006; 33(4): 262-73.
207. Türker KS. Reflex control of human jaw muscles. *Crit Rev Oral Biol Med* 2002; 13(1): 85-104.
208. Trulsson M, Johansson RS. Human periodontal mechanoreceptors: Encoding of force and role in control of jaw actions. In: Morimoto T, Matsuya T, Takada K, eds. International Congress Series; Brain and oral functions: Oral motor function and dysfunction; 1995: 155-63.
209. Trulsson M, Johansson RS. Forces applied by the incisors and roles of periodontal afferents during food-holding and -biting tasks. *Exp Brain Res* 1996; 107(3): 486-96.
210. Trulsson M, Johansson RS. Encoding of tooth loads by human periodontal afferents and their role in jaw motor control. *Prog Neurobiol* 1996; 49(3): 267-84.
211. Svensson KG. Sensory-motor regulation of human biting behavior. Stockholm, Sweden: Karolinska Institutet; 2010.
212. van Steenberghe D. The structure and function of periodontal innervation. A review of the literature. *J Periodontal Res* 1979; 14(3): 185-203.
213. Lund JP, Kolta A. Generation of the central masticatory pattern and its modification by sensory feedback. *Dysphagia* 2006; 21(3): 167-74.
214. Trulsson M, Johansson RS, Olsson KA. Directional sensitivity of human periodontal mechanoreceptive afferents to forces applied to the teeth. *J Physiol* 1992; 447: 373-89.
215. Grigoriadis A, Johansson RS, Trulsson M. Adaptability of mastication in people with implant-supported bridges. *J Clin Periodontol* 2011; 38(4): 395-404.
216. Grigoriadis A, Trulsson M. Excitatory drive of masseter muscle during mastication with dental implants. *Sci Rep* 2018; 8(1): 8597.

217. Trulsson M. Sensory and motor function of teeth and dental implants: a basis for osseoperception. *Clin Exp Pharmacol Physiol* 2005; 32(1-2): 119-22.
218. Grigoriadis A. Masticatory function in people with dental implants. https://openarchive.ki.se/: Karolinska Institutet; 2014.
219. Johnsen SE, Trulsson M. Encoding of amplitude and rate of tooth loads by human periodontal afferents from premolar and molar teeth. *J Neurophysiol* 2005; 93(4): 1889-97.
220. Trulsson M, Gunne HS. Food-holding and -biting behavior in human subjects lacking periodontal receptors. *J Dent Res* 1998; 77(4): 574-82.
221. Klineberg I, Calford MB, Dreher B, et al. A consensus statement on osseoperception. *Clin Exp Pharmacol Physiol* 2005; 32(1-2): 145-6.
222. Grigoriadis J. Spatial control of biting behavior- To bite and not to slip. Stockholm, Sweden: Karolinska institutet; 2016.
223. Jacobs R, Van Steenberghe D. From osseoperception to implant-mediated sensory-motor interactions and related clinical implications. *J Oral Rehabil* 2006; 33(4): 282-92.
224. Jacobs R, van Steenberghe D. Comparative evaluation of the oral tactile function by means of teeth or implant-supported prostheses. *Clin Oral Implants Res* 1991; 2(2): 75-80.
225. van Steenberghe D. From osseointegration to osseoperception. *J Dent Res* 2000; 79(11): 1833-7.
226. Svensson KG, Trulsson M. Impaired force control during food holding and biting in subjects with tooth- or implant-supported fixed prostheses. *J Clin Periodontol* 2011; 38(12): 1137-46.
227. Song D, Shujaat S, Politis C, Orhan K, Jacobs R. Osseoperception following dental implant treatment: A systematic review. *J Oral Rehabil* 2022; 49(5): 573-85.
228. Johansson AS, Svensson KG, Trulsson M. Impaired masticatory behavior in subjects with reduced periodontal tissue support. *J Periodontol* 2006; 77(9): 1491-7.
229. Svensson KG, Trulsson M. Regulation of bite force increase during splitting of food. *Eur J Oral Sci* 2009; 117(6): 704-10.
230. Homsi G, Karlsson A, Almotairy N, Trulsson M, Kumar A, Grigoriadis A. Subjective and objective evaluation of masticatory function in patients with bimaxillary implant-supported prostheses. *J Oral Rehabil* 2023; 50(2): 140-9.
231. Homsi G, Kumar A, Almotairy N, Wester E, Trulsson M, Grigoriadis A. Assessment of masticatory function in older individuals with bimaxillary implant-supported fixed prostheses or with a natural dentition: A case-control study. *J Prosthet Dent* 2021.
232. Grigoriadis J, Trulsson M, Svensson KG. Motor behavior during the first chewing cycle in subjects with fixed tooth- or implant-supported prostheses. *Clin Oral Implants Res* 2016; 27(4): 473-80.
233. Svensson KG, Grigoriadis J, Trulsson M. Alterations in intraoral manipulation and splitting of food by subjects with tooth- or implant-supported fixed prostheses. *Clin Oral Implants Res* 2013; 24(5): 549-55.
234. Ferrario VF, Sforza C, Serrao G, Dellavia C, Tartaglia GM. Single tooth bite f orces in healthy young adults. *J Oral Rehabil* 2004; 31(1): 18-22.
235. Paphangkorakit J, Osborn JW. The effect of pressure on a maximum incisal bite force in man. *Arch Oral Biol* 1997; 42(1): 11-7.
236. Almotairy N, Kumar A, Noirrit-Esclassan E, Grigoriadis A. Developmental and age-related changes in sensorimotor regulation of biting maneuvers in humans. *Physiol Behav* 2020; 219: 112845.
237. Johnsen SE, Svensson KG, Trulsson M. Forces applied by anterior and posterior teeth and roles of periodontal afferents during hold-and-split tasks in human subjects. *Exp Brain Res* 2007; 178(1): 126-34.
238. Zachrisson BU. Improving orthodontic results in cases with maxillary i ncisors missing. *Am J Orthod* 1978; 73(3): 274-89.
239. Kokich VO, Jr., Kinzer GA. Managing congenitally missing lateral incisors. Part I: Canine substitution. *J Esthet Restor Dent* 2005; 17(1): 5-10.
240. Kinzer GA, Kokich VO, Jr. Managing congenitally missing lateral incisors. Part II: tooth-supported restorations. *J Esthet Restor Dent* 2005; 17(2): 76-84.
241. Slagsvold O, Bjercke B. Applicability of autotransplantation in cases of missing upper anterior teeth. *Am J Orthod* 1978; 74(4): 410-21.
242. Czochrowska EM, Stenvik A, Bjercke B, Zachrisson BU. Outcome of tooth transplantation: survival and success rates 17-41 years posttreatment. *Am J Orthod Dentofacial Orthop* 2002; 121(2): 110-9; quiz 93.
243. Andreasen JO, Paulsen HU, Yu Z, Bayer T, Schwartz O. A long-term study of 370 autotransplanted premolars. Part II. Tooth survival and pulp healing subsequent to transplantation. *Eur J Orthod* 1990; 12(1): 14-24.
244. Akhlef Y, Schwartz O, Andreasen JO, Jensen SS. Autotransplantation of teeth to the anterior maxilla: A systematic review of survival and success, aesthetic presentation and patient-reported outcome. *Dent Traumatol* 2018; 34(1): 20-7.
245. Priest GF. An interdisciplinary approach to aesthetic single implant outcomes for young patients. *Pract Proced Aesthet Dent* 2008; 20(3): 167-75.
246. Jemt T, Pettersson P. A 3-year follow-up study on single implant treatment. *J Dent* 1993; 21(4): 203-8.
247. Kokich VO, Jr., Kinzer GA, Janakievski J. Congenitally missing maxillary lateral incisors: restorative replacement. Counterpoint. *Am J Orthod Dentofacial Orthop* 2011; 139(4): 435, 7, 9 passim.
248. Thoma DS, Sailer I, Ioannidis A, Zwahlen M, Makarov N, Pjetursson BE. A systematic review of the survival and complication rates of resin-bonded fixed dental prostheses after a mean observation period of at least 5 years. *Clin Oral Implants Res* 2017; 28(11): 1421-32.
249. Howe DF, Denehy GE. Anterior fixed partial dentures utilizing the acid-etch technique and a cast metal framework. *J Prosthet Dent* 1977; 37(1): 28-31.

250. Rochette AL. Attachment of a splint to enamel of lower anterior teeth. *J Prosthet Dent* 1973; 30(4 Pt 1): 418-23.
251. Sailer I, Bonani T, Brodbeck U, Hammerle CH. Retrospective clinical study of single-retainer cantilever anterior and posterior glass-ceramic resin-bonded fixed dental prostheses at a mean follow-up of 6 years. *Int J Prosthodont* 2013; 26(5): 443-50.
252. Kern M, Gläser R. Single-retainer all-ceramic resin-bonded fixed dental prostheses: Long-term outcomes in the esthetic zone. *J Esthet Restor Dent* 2023; 35(1): 64-73.
253. Yazigi C, Kern M. Clinical evaluation of zirconia cantilevered single-retainer resin-bonded fixed dental prostheses replacing missing canines and posterior teeth. *J Dent* 2022; 116: 103907.
254. Adell R, Lekholm U, Rockler B, Branemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg* 1981; 10(6): 387-416.
255. Lekholm U, Zarb GA. Patient selection and preparation. In: Brånemark P-I, Zarb GA, Albreksson T, eds. In tissue-integrated prosthesis: Osseointegration in clinical dentistry. Chicago: Quintessence Publ Co.; 1985: 199-209.
256. Jorneus L, Jemt T, Carlsson L. Loads and designs of screw joints for single crowns supported by osseointegrated implants. *Int J Oral Maxillofac Implants* 1992; 7(3): 353-9.
257. Patel D, Invest JC, Tredwin CJ, Setchell DJ, Moles DR. An analysis of the effect of a vent hole on excess cement expressed at the crown-abutment margin for cement-retained implant crowns. *J Prosthodont* 2009; 18(1): 54-9.
258. Mombelli A, van Oosten MA, Schurch E, Jr., Land NP. The microbiota associated with successful or failing osseointegrated titanium implants. *Oral Microbiol Immunol* 1987; 2(4): 145-51.
259. Fernandez-Riveiro P, Suarez-Quintanilla D, Smyth-Chamosa E, Suarez-Cunqueiro M. Linear photogrammetric analysis of the soft tissue facial profile. *Am J Orthod Dentofacial Orthop* 2002; 122(1): 59-66.
260. Jacobsson A. Radiographic Cephalometry: From Basics to videoimaging: Quintessence Publishing Co Inc.,U.S. ; 1995.
261. Huskisson EC. Measurement of pain. *Lancet* 1974; 2(7889): 1127-31.
262. Belser U, Buser D, Higginbottom F. Consensus statements and recommended clinical procedures regarding esthetics in implant dentistry. *Int J Oral Maxillofac Implants* 2004; 19 Suppl: 73-4.
263. Al-Manei, Almotairy, Al-Manei, Kumar, Grigoriadis. Oral Fine Motor Control of Teeth Treated with Endodontic Microsurgery: A Single-Blinded Case-control Study. *J Endod* 2021; 47(2): 226-33.
264. Kumar A, Castrillon E, Trulsson M, Svensson KG, Svensson P. Fine motor control of the jaw following alteration of orofacial afferent inputs. *Clin Oral Investig* 2017; 21(2): 613-26.
265. Kumar A, Svensson KG, Baad-Hansen L, Trulsson M, Isidor F, Svensson P. Optimization of jaw muscle activity and fine motor control during repeated biting tasks. *Arch Oral Biol* 2014; 59(12): 1342-51.
266. Kumar A, Tanaka Y, Takahashi K, et al. Vibratory stimulus to the masseter muscle impairs the oral fine motor control during biting tasks. *J Prosthodont Res* 2019; 63(3): 354-60.
267. Kaplan EL, Meier P. Nonparametric estimation from incomplete observations. *Journal of the American statistical association* 1958; 53(282): 457-81.
268. Cicchetti DV. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. Psychological Assessment. ;. 1994; 6(4): 284–90.
269. Pikner SS. Radiographic follow-up analysis of Brånemark® dental implants [Doctoral thesis, comprehensive summary]. Gothenburg: University of Gothenburg; 2008.
270. CaliforniaDentalAssociation. Quality evaluation for dental care: Guidelines for the assessment of clinical quality and professional performance. Los Angeles.: The California Dental Association,; 1977. p. 53-5.
271. Mijiritsky E, Barone A, Cinar IC, Nagy K, Shacham M. 3D Considerations and Outcomes of Immediate Single Implant Insertion and Provisionalization at the Maxillary Esthetic Zone: A Long-Term Retrospective Follow-Up Study of Up to 18 Years. *J Clin Med* 2021; 10(18).
272. Polymeri A, Li Q, Laine ML, Loos BG, Wang HL. Occlusal Migration of Teeth Adjacent to Implant Prostheses in Adults: A Long-Term Study. *Int J Oral Maxillofac Implants* 2020; 35(2): 342-9.
273. Bernard JP, Schatz JP, Christou P, Belser U, Kiliaridis S. Long-term vertical changes of the anterior maxillary teeth adjacent to single implants in young and mature adults. A retrospective study. *J Clin Periodontol* 2004; 31(11): 1024-8.
274. Shulman JD, Peterson J. The association between incisor trauma and occlusal characteristics in individuals 8-50 years of age. *Dent Traumatol* 2004; 20(2): 67-74.
275. Glendor U. Epidemiology of traumatic dental injuries--a 12 year review of the literature. *Dent Traumatol* 2008; 24(6): 603-11.
276. Järvinen S. On the causes of traumatic dental injuries with special reference to sports accidents in a sample of Finnish children. A study of a clinical patient material. *Acta Odontol Scand* 1980; 38(3): 151-4.
277. Esposito M, Hirsch JM, Lekholm U, Thomsen P. Biological factors contributing to failures of osseointegrated oral implants. (II). Etiopathogenesis. *Eur J Oral Sci* 1998; 106(3): 721-64.
278. Jemt T, Karouni M, Abitbol J, Zouiten O, Antoun H. A retrospective study on 1592 consecutively performed operations in one private referral clinic. Part II: Peri-implantitis and implant failures. *Clin Implant Dent Relat Res* 2017; 19(3): 413-22.
279. Naert I, Koutsikakis G, Duyck J, Quirynen M, Jacobs R, van Steenberghe D. Biologic outcome of single-implant restorations as tooth replacements: a long-term follow-up study. *Clin Implant Dent Relat Res* 2000; 2(4): 209-18.
280. Smith DE, Zarb GA. Criteria for success of osseointegrated endosseous implants. *J Prosthet Dent* 1989; 62(5): 567-72.

281. Roos J, Sennerby L, Lekholm U, Jemt T, Grondahl K, Albrektsson T. A qualitative and quantitative method for evaluating implant success: a 5-year retrospective analysis of the Branemark implant. *Int J Oral Maxillofac Implants* 1997; 12(4): 504-14.
282. Albrektsson T, Zarb GA. Current interpretations of the osseointegrated response: clinical significance. *Int J Prosthodont* 1993; 6(2): 95-105.
283. Scholander S. A retrospective evaluation of 259 single-tooth replacements by the use of Branemark implants. *Int J Prosthodont* 1999; 12(6): 483-91.
284. Papaspyridakos P, Chen CJ, Singh M, Weber HP, Gallucci GO. Success criteria in implant dentistry: a systematic review. *J Dent Res* 2012; 91(3): 242-8.
285. Sailer I, Karasan D, Todorovic A, Ligoutsikou M, Pjetursson BE. Prosthetic failures in dental implant therapy. *Periodontol 2000* 2022; 88(1): 130-44.
286. Corpas Ldos S, Jacobs R, Quirynen M, Huang Y, Naert I, Duyck J. Peri-implant bone tissue assessment by comparing the outcome of intra-oral radiograph and cone beam computed tomography analyses to the histological standard. *Clin Oral Implants Res* 2011; 22(5): 492-9.
287. Hermann JS, Schoolfield JD, Nummikoski PV, Buser D, Schenk RK, Cochran DL. Crestal bone changes around titanium implants: a methodologic study comparing linear radiographic with histometric measurements. *Int J Oral Maxillofac Implants* 2001; 16(4): 475-85.
288. Isidor F. Clinical probing and radiographic assessment in relation to the histologic bone level at oral implants in monkeys. *Clin Oral Implants Res* 1997; 8(4): 255-64.
289. Schropp L, Wenzel A. Timing of single implant placement and long-term observation of marginal bone levels. *Eur J Oral Implantol* 2016; 9 Suppl 1: S107-22.
290. Benn DK. A review of the reliability of radiographic measurements in estimating alveolar bone changes. *J Clin Periodontol* 1990; 17(1): 14-21.
291. Palmer RM, Palmer PJ, Smith BJ. A 5-year prospective study of Astra single tooth implants. *Clin Oral Implants Res* 2000; 11(2): 179-82.
292. Berberi AN, Sabbagh JM, Aboushelib MN, Noujeim ZF, Salameh ZA. A 5-year comparison of marginal bone level following immediate loading of single-tooth implants placed in healed alveolar ridges and extraction sockets in the maxilla. *Front Physiol* 2014; 5: 29.
293. Cooper LF, Reside G, Raes F, et al. Immediate provisionalization of dental implants in grafted alveolar ridges in the esthetic zone: a 5-year evaluation. *Int J Periodontics Restorative Dent* 2014; 34(4): 477-86.
294. Bergström J, Eliasson S. Alveolar bone height in professional musicians. *Acta Odontol Scand* 1986; 44(3): 141-7.
295. De Bruyn H, Christiaens V, Doornewaard R, et al. Implant surface roughness and patient factors on long-term peri-implant bone loss. *Periodontol 2000* 2017; 73(1): 218-27.
296. Henry PJ, Laney WR, Jemt T, et al. Osseointegrated implants for single-tooth replacement: a prospective 5-year multicenter study. *Int J Oral Maxillofac Implants* 1996; 11(4): 450-5.
297. Schropp L, Wenzel A, Stavropoulos A. Early, delayed, or late single implant placement: 10-year results from a randomized controlled clinical trial. *Clin Oral Implants Res* 2014; 25(12): 1359-65.
298. Cooper LF, Raes F, Reside GJ, et al. Comparison of radiographic and clinical outcomes following immediate provisionalization of single-tooth dental implants placed in healed alveolar ridges and extraction sockets. *Int J Oral Maxillofac Implants* 2010; 25(6): 1222-32.
299. Kan JY, Rungcharassaeng K, Liddelow G, Henry P, Goodacre CJ. Periimplant tissue response following immediate provisional restoration of scalloped implants in the esthetic zone: a one-year pilot prospective multicenter study. *J Prosthet Dent* 2007; 97(6 Suppl): S109-18.
300. Atieh MA, Alsabeeha NH, Duncan WJ, et al. Immediate single implant restorations in mandibular molar extraction sockets: a controlled clinical trial. *Clin Oral Implants Res* 2013; 24(5): 484-96.
301. De Bruyn H, Raes F, Cooper LF, et al. Three-years clinical outcome of immediate provisionalization of single Osseospeed(™) implants in extraction sockets and healed ridges. *Clin Oral Implants Res* 2013; 24(2): 217-23.
302. Aguirre-Zorzano LA, Rodríguez-Andrés C, Estefanía-Fresco R, Fernández-Jiménez A. Immediate temporary restoration of single-tooth implants: Prospective clinical study. *Med Oral Patol Oral Cir Bucal* 2011; 16(6): e794-9.
303. Raes F, Cosyn J, De Bruyn H. Clinical, aesthetic, and patient-related outcome of immediately loaded single implants in the anterior maxilla: a prospective study in extraction sockets, healed ridges, and grafted sites. *Clin Implant Dent Relat Res* 2013; 15(6): 819-35.
304. Kolinski ML, Cherry JE, McAllister BS, Parrish KD, Pumphrey DW, Schroering RL. Evaluation of a variable-thread tapered implant in extraction sites with immediate temporization: a 3-year multicenter clinical study. *J Periodontol* 2014; 85(3): 386-94.
305. Shibly O, Patel N, Albandar JM, Kutkut A. Bone regeneration around implants in periodontally compromised patients: a randomized clinical trial of the effect of immediate implant with immediate loading. *J Periodontol* 2010; 81(12): 1743-51.
306. Roos-Jansaker AM, Lindahl C, Renvert H, Renvert S. Nine- to fourteen-year follow-up of implant treatment. Part II: presence of peri-implant lesions. *J Clin Periodontol* 2006; 33(4): 290-5.
307. Donati M, La Scala V, Di Raimondo R, Speroni S, Testi M, Berglundh T. Marginal bone preservation in single-tooth replacement: a 5-year prospective clinical multicenter study. *Clin Implant Dent Relat Res* 2015; 17(3): 425-34.
308. Coli P, Jemt T. On marginal bone level changes around dental implants. *Clin Implant Dent Relat Res* 2021; 23(2): 159-69.

309. Kan JY, Rungcharassaeng K, Umezu K, Kois JC. Dimensions of peri-implant mucosa: an evaluation of maxillary anterior single implants in humans. *J Periodontol* 2003; 74(4): 557-62.
310. Gotfredsen K, Berglundh T, Lindhe J. Bone reactions at implants subjected to experimental peri-implantitis and static load. A study in the dog. *J Clin Periodontol* 2002; 29(2): 144-51.
311. Bain CA, Moy PK. The association between the failure of dental implants and cigarette smoking. *Int J Oral Maxillofac Implants* 1993; 8(6): 609-15.
312. Lindquist LW, Carlsson GE, Jemt T. Association between marginal bone loss around osseointegrated mandibular implants and smoking habits: a 10-year follow-up study. *J Dent Res* 1997; 76(10): 1667-74.
313. Vilhjalmsson VH, Klock KS, Storksen K, Bardsen A. Radiological evaluation of single implants in maxillary anterior sites with special emphasis on their relation to adjacent teeth: a 3-year follow-up study. *Dent Traumatol* 2013; 29(1): 66-72.
314. French D, Ofec R, Levin L. Long term clinical performance of 10 871 dental implants with up to 22 years of follow-up: A cohort study in 4247 patients. *Clin Implant Dent Relat Res* 2021; 23(3): 289-97.
315. Windael S, Vervaeke S, De Buyser S, De Bruyn H, Collaert B. The Long-Term Effect of Smoking on 10 Years' Survival and Success of Dental Implants: A Prospective Analysis of 453 Implants in a Non-University Setting. *J Clin Med* 2020; 9(4).
316. Zembic A, Kim S, Zwahlen M, Kelly JR. Systematic review of the survival rate and incidence of biologic, technical, and esthetic complications of single implant abutments supporting fixed prostheses. *Int J Oral Maxillofac Implants* 2014; 29 Suppl: 99-116.
317. Salvi GE, Bragger U. Mechanical and technical risks in implant therapy. *Int J Oral Maxillofac Implants* 2009; 24 Suppl: 69-85.
318. Tonetti MS, Sanz M, Avila-Ortiz G, et al. Relevant domains, core outcome sets and measurements for implant dentistry clinical trials: The Implant Dentistry Core Outcome Set and Measurement (ID-COSM) international consensus report. *J Clin Periodontol* 2023.
319. Jepsen S, Ruhling A, Jepsen K, Ohlenbusch B, Albers HK. Progressive peri-implantitis. Incidence and prediction of peri-implant attachment loss. *Clin Oral Implants Res* 1996; 7(2): 133-42.
320. Karlsson K, Derks J, Håkansson J, Wennström JL, Petzold M, Berglundh T. Interventions for peri-implantitis and their effects on further bone loss: A retrospective analysis of a registry-based cohort. *J Clin Periodontol* 2019; 46(8): 872-9.
321. Ericsson I, Lindhe J. Probing depth at implants and teeth. An experimental study in the dog. *J Clin Periodontol* 1993; 20(9): 623-7.
322. Lang NP, Berglundh T, Periodontology WGoSEWo. Periimplant diseases: where are we now?--Consensus of the Seventh European Workshop on Periodontology. *J Clin Periodontol* 2011; 38 Suppl 11: 178-81.
323. Serino G, Turri A, Lang NP. Probing at implants with peri-implantitis and its relation to clinical peri-implant bone loss. *Clin Oral Implants Res* 2013; 24(1): 91-5.
324. Lang NP, Wetzel AC, Stich H, Caffesse RG. Histologic probe penetration in healthy and inflamed peri-implant tissues. *Clin Oral Implants Res* 1994; 5(4): 191-201.
325. Buser D, Chappuis V, Kuchler U, et al. Long-term stability of early implant placement with contour augmentation. *J Dent Res* 2013; 92(12 Suppl): 176S-82S.
326. Weber HP, Crohin CC, Fiorellini JP. A 5-year prospective clinical and radiographic study of non-submerged dental implants. *Clin Oral Implants Res* 2000; 11(2): 144-53.
327. Fernandez-Riveiro P, Smyth-Chamosa E, Suarez-Quintanilla D, Suarez-Cunqueiro M. Angular photogrammetric analysis of the soft tissue facial profile. *Eur J Orthod* 2003; 25(4): 393-9.
328. Cocchetto R, Pradies G, Celletti R, Canullo L. Continuous craniofacial growth in adult patients treated with dental implants in the anterior maxilla. *Clin Implant Dent Relat Res* 2019; 21(4): 627-34.
329. Sauvin G, Nurdin N, Bischof M, Kiliaridis S. Assessment and aesthetic impact of a long-term vertical discrepancy between the single anterior maxillary implant-supported crown and adjacent teeth: A retrospective cross-sectional study. *Clin Exp Dent Res* 2022; 8(5): 1109-16.
330. Wittneben JG, Igarashi K, Brägger U, Daniel B, Schimmel M, Wismeijer D. Vertical eruption of anterior maxillary teeth adjacent to single-implant-supported crowns: An assessment after a 3-year follow-up period. *J Prosthet Dent* 2022; 128(4): 605-10.
331. Silness J, Berge M, Johannessen G. Relationship between incisal tooth wear and the increasing number of permanent teeth in children and adolescents. *J Oral Rehabil* 1997; 24(6): 410-3.
332. Aarts BE, Convens J, Bronkhorst EM, Kuijpers-Jagtman AM, Fudalej PS. Cessation of facial growth in subjects with short, average, and long facial types - Implications for the timing of implant placement. *J Craniomaxillofac Surg* 2015; 43(10): 2106-11.
333. Bishara SE, Jakobsen JR, Treder JE, Stasi MJ. Changes in the maxillary and mandibular tooth size-arch length relationship from early adolescence to early adulthood. A longitudinal study. *Am J Orthod Dentofacial Orthop* 1989; 95(1): 46-59.
334. Gjelvold B, Chrcanovic BR, Bagewitz IC, Kisch J, Albrektsson T, Wennerberg A. Esthetic and Patient-Centered Outcomes of Single Implants: A Retrospective Study. *Int J Oral Maxillofac Implants* 2017; 32(5): 1065-73.
335. Schwartz-Arad D, Bichacho N. Effect of age on single implant submersion rate in the central maxillary incisor region: a long-term retrospective study. *Clin Implant Dent Relat Res* 2015; 17(3): 509-14.
336. Fudalej P, Kokich VG, Leroux B. Determining the cessation of vertical growth of the craniofacial structures to facilitate placement of single-tooth implants. *Am J Orthod Dentofacial Orthop* 2007; 131(4 Suppl): S59-67.

337. Klinge A, Tranaeus S, Becktor J, Winitsky N, Naimi-Akbar A. The risk for infraposition of dental implants and ankylosed teeth in the anterior maxilla related to craniofacial growth, a systematic review. *Acta Odontol Scand* 2020: 1-10.
338. Mijiritsky E, Badran M, Kleinman S, Manor Y, Peleg O. Continuous tooth eruption adjacent to single-implant restorations in the anterior maxilla: aetiology, mechanism and outcomes - A review of the literature. *Int Dent J* 2020.
339. Christou P, Kiliaridis S. Three-dimensional changes in the position of unopposed molars in adults. *Eur J Orthod* 2007; 29(6): 543-9.
340. Arunyanak SP, Pollini A, Ntounis A, Morton D. Clinician assessments and patient perspectives of single-tooth implant restorations in the esthetic zone of the maxilla: A systematic review. *J Prosthet Dent* 2017; 118(1): 10-7.
341. De Bruyn H, Raes S, Matthys C, Cosyn J. The current use of patient-centered/reported outcomes in implant dentistry: a systematic review. *Clin Oral Implants Res* 2015; 26 Suppl 11: 45-56.
342. Srivastava G, Panda S, Panda S, Padhiary SK, Das SS, Fabbro MD. Reproducibility and validity of anterior implant esthetic indices: A review. *J Indian Soc Periodontol* 2020; 24(4): 301-8.
343. Vallittu PK, Vallittu AS, Lassila VP. Dental aesthetics--a survey of attitudes in different groups of patients. *J Dent* 1996; 24(5): 335-8.
344. Hammerle CH, Wagner D, Bragger U, et al. Threshold of tactile sensitivity perceived with dental endosseous implants and natural teeth. *Clin Oral Implants Res* 1995; 6(2): 83-90.
345. Enkling N, Nicolay C, Utz KH, Johren P, Wahl G, Mericske-Stern R. Tactile sensibility of single-tooth implants and natural teeth. *Clin Oral Implants Res* 2007; 18(2): 231-6.
346. Enkling N, Heussner S, Nicolay C, Bayer S, Mericske-Stern R, Utz KH. Tactile sensibility of single-tooth implants and natural teeth under local anesthesia of the natural antagonistic teeth. *Clin Implant Dent Relat Res* 2012; 14(2): 273-80.
347. Jacobs R, van Steenberghe D. Role of periodontal ligament receptors in the tactile function of teeth: a review. *J Periodontal Res* 1994; 29(3): 153-67.
348. Johnsen SE, Trulsson M. Receptive field properties of human periodontal afferents responding to loading of premolar and molar teeth. *J Neurophysiol* 2003; 89(3): 1478-87.
349. Byers MR, Dong WK. Comparison of trigeminal receptor location and structure in the periodontal ligament of different types of teeth from the rat, cat, and monkey. *J Comp Neurol* 1989; 279(1): 117-27.
350. Nyman SR, Lang NP. Tooth mobility and the biological rationale for splinting teeth. *Periodontol 2000* 1994; 4: 15-22.
351. Weinberg LA. Force distribution in splinted posterior teeth. *Oral Surg Oral Med Oral Pathol* 1957; 10(12): 1268-76.
352. Weinberg LA. Force distribution in splinted anterior teeth. *Oral Surg Oral Med Oral Pathol* 1957; 10(5): 484-94.
353. Hannam AG. Receptor fields of periodontal mechanosensitive units in the dog. *Arch Oral Biol* 1970; 15(10): 971-8.
354. Sakada S, Kamio E. Receptive fields and directional sensitivity of single sensory units innervating the periodontal ligaments of the cat mandibular teeth. *Bull Tokyo Dent Coll* 1971; 12(1): 25-43.
355. Trulsson M. Multiple-tooth receptive fields of single human periodontal mechanoreceptive afferents. *J Neurophysiol* 1993; 69(2): 474-81.
356. Okuni S, Maekawa K, Mino T, Kurosaki Y, Kuboki T. A retrospective comparison of the survival of vital teeth adjacent to single, bounded edentulous spaces rehabilitated using implant-supported, resin-bonded, and conventional fixed dental prostheses. *J Dent* 2022; 116: 103911.