# A CONTEMPORARY PERSPECTIVE ON TOOTH EXTRACTION IN ORTHODONTICS

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# ABSTRACT

Camille Guez: A contemporary perspective on tooth extraction in orthodontics
(Under the direction of Ching-Chang Ko)

**Introduction:** The decision to extract teeth for orthodontic purposes is one of the most complex and debated topics in the specialty. The profession's understanding of factors affecting the extraction decision (e.g., outcome stability and facial appearance) has evolved over time, and estimated extraction rates have varied from 10% in 1953 to 78% in 1968 to 28% in 1994. A contemporary perspective on the rate of orthodontic extractions is needed to help clinicians understand this treatment choice in light of 21st century philosophies, techniques, and appliances. To this end, we investigated changes in orthodontic extraction rates at the University of North Carolina from 2000 to 2011, as well as factors that may have affected those rates. We hypothesize that extraction rates have changed as a result of evolving diagnostic methodology and appliance selection (e.g., self-ligating brackets). **Methods:** Pre- and post- treatment records were analyzed to determine extraction rates over time, and different factors (Angle classification, skeletal relationship, use of self-ligation, etc.) were investigated to evaluate potential impact on the extraction decision. The sample consisted of 2,184 patients, with 1,263 females (58%). Age at the start of treatment ranged from 7 to 67 years. Third molar extractions were excluded from analyses. Student t-test and chi square were used to evaluate the extraction rate over time. Logistic regression was used to investigate diagnostic and treatment factors that might affect extraction rates over time. **Results:** The extraction rate decreased significantly from 2000 to 2005, from 40% to less than 20%. After 2005, it remained stable around 27%. 8 out of our 13 explanatory variables were found to influence the overall extraction rate but none of them could explain the decrease of the extraction rate over time. **Conclusions:** The extraction rate fluctuated greatly since 2000 and has decreased linearly over the years ($p<0.05$). Several explanatory variables were found to influence the overall extraction decision, but none of them could explain the decreasing trend over time. Irrational cognition with medical concerns about extraction may have an impact on the decreased trend.

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# LITERATURE REVIEW

## Introduction

The first organized data on malocclusion in the United States was reported by the US Public Health Service in the 1960s, which was collectively documented as part of the first National Health and Nutrition Examination Survey (NHANES). According to NHANES, Kelly et al. reported that 24.4% of the children between 6 and 11 years had normal occlusion, 22.4% had a definite malocclusion, 8.7% had severe malocclusion, and 5.5% were classified as having a very severe malocclusion[1]. This was the first epidemiological study showing that at least 35% of American children are candidates for orthodontic treatment. More recently, the American Association of Orthodontists stated that in 2004, there were 5,750,000 patients undergoing orthodontic treatment, and that this statistic had undergone a steady and significant increase since 1989. Depending upon the year of treatment, 28% to 76% of orthodontic patients have undergone tooth extraction, which represents a substantial surgical intervention in orthodontics[2-3-4]. Some patients have concerns about losing teeth and how this will affect their general health. As evidence-based research and new technology advance the field of orthodontics, it is important to understand what factors affect the decision to extract teeth and whether it is possible to limit the extraction rate using modern approaches.

**History**

Pierre Fauchard, widely acknowledged as the father of modern dentistry, published “The Surgeon Dentist” in 1728. His book contained detailed information about all areas of contemporary dentistry and illustrated his invention of one of the first orthodontic appliances called “bandeau” (Figure 1). This “bandeau” consisted of a horseshoe-shaped strip of precious metal to which the teeth were ligated. This appliance became the basis for Angle’s E-arch and its principle is still used today to unravel crowded arches.

Figure 1. Fauchard “bandeau” appliance[30]

Another French dentist, Etienne Bourdet, followed Fauchard’s footsteps and refined the “bandeau” appliance. He published “The Dentist’s Art” in 1757 which contained a chapter dedicated to orthodontics. He is the first dentist known to have recommended serial extractions and extraction of permanent teeth, especially premolars, as a mean to alleviate crowding. He was also the first known dentist to practice “lingual orthodontics”, expanding the arches from the lingual. He emphasized the importance of dental hygiene and described the symptoms of tooth eruption in children. He was the dentist of the King of France, Louis XV then Louis XVI[5].

Extractions have been proven to improve alignment since early times but orthodontics as a science was created in the mid-1800s[5-6]. Norman Kingsley created a technique to avoid the systematic extraction of teeth: he invented the occipital traction, precursor to the Headgear appliance, and used occlusal coverage appliances among many technical innovations. These technics are still widely used today. He also focused on cleft patients and perfected a gold obturator and artificial vellum of soft rubber in 1859[7]. From a biological standpoint, John Farrar introduced the foundation of the scientific approach of orthodontics by studying the limits of tooth movements. He investigated the physiologic and pathologic changes occurring in animals as a result of orthodontic tooth movement. He recommended the bodily movement of teeth as opposed to a simple tipping movement and advised orthodontists to limit the orthodontic force to avoid any pain to the patient[5]. Based on animal studies, he enunciated the theory of intermittent force and developed a screw to deliver this force in controlled increments.

At the beginning of the twentieth century, Edward Angle (1855-1930) founded the first orthodontic school, first orthodontic society and first orthodontic journal.


Figure 2. Angle School of Orthodontia, first postgraduate school for orthodontists[7]

He was the most influential figure in orthodontics and is considered as “the father of modern orthodontics”. He created a dental classification of malocclusion which is still the most widely used classification around the world today. His vision of orthodontic treatment was based on the possibility for any given patient to align the 32 teeth in perfect Class I occlusion: He strongly advocated a non-extraction approach stating that jaws and bones would grow accordingly and the adjacent tissues would adapt to their new position. Ideal occlusion is "nature's intended ideal form"[8-9-10]. His credo was that "the best balance, the best harmony, the best proportions of the mouth in its relation to the other features require that there shall be a full complement of teeth, and that each tooth shall be made to occupy its normal position—i.e., normal occlusion". Calvin Case defended extractions as a treatment to correct facial deformities in one of his articles and instigated the "Great Extraction Debate" in 1911 with Edward Angle[7-8]. One of Angle's disciples, Charles Tweed, followed his teacher's approach and realized later in his career that many of his patients experienced relapse after the end of their non-extraction treatment, especially when the lower incisors were overly proclined. Non-extraction arch-expansion, originally proposed by Edward Angle, was found to be unstable after treatment[11]. Tweed re-treated a number of his patients with the extraction of four premolars and obtained a satisfactory result. Other orthodontists like Raymond Begg followed his footsteps and advocated premolar extraction as a valid way to treat patients. Technological advances also played a major role in that direction. As an example, the possibility to bond to enamel gave the clinician better control over the tooth movements.

William Proffit and James Ackerman added another dimension to the debate in the 1980s with the soft tissue paradigm[12-13]. In opposition to Angle's theory, they developed the idea that the clinician should focus on the soft tissue balance instead of focusing solely on a perfect dental occlusion. Variation is now accepted as a natural form, perfect occlusion is more the exception than the rule. The orthodontist has to plan his treatment based on the soft tissue limitations and contours of his patient. They stressed the importance of the smile arc, defined by the contour of the lower teeth which should match the contour of the lower lip.

As of today, the philosophic evolution in orthodontic treatment lies on three principles: occlusion, stability, and soft tissue balance. Derived from these principles, it has been accepted by the orthodontic community that some patients will need extractions and other will not. However, in practicality, the question remains as to which patients should benefit from these extractions and how the clinician should make that decision.

**The extraction decision, a multi-factorial decision**

Three main aspects have historically guided the practitioner in his treatment plan. First the occlusion with Edward Angle, then the stability and concerns about relapse with Charles Tweed, and finally esthetics, with the soft tissue paradigm. Occlusion, stability and esthetics are the three goals for a successful treatment plan, but no single rule can give the orthodontist a simple way to decide how to reach these three goals: The extraction decision is multi-factorial[3].

The historical and most common extraction pattern is the extraction of four premolars, two on the upper arch and two on the lower arch. However, different extraction patterns can be followed depending on the type of malocclusion and are all successful if used in appropriate patients[12-14-15].

A dilemma exists: some clinicians are more inclined to extract teeth than expand the arches; others would rather conserve the teeth if possible and try to expand the arches to relieve the crowding. In borderline cases, both treatments offer good stability and results[16-17-18-19]. A reliable criterion for extracting teeth remains elusive. Many researchers attempted to find a way to help the decision of the clinician, like Takada who created a mathematical model to guide the treatment plan decision and optimize orthodontic treatment outcome. His model used 25 morphologic traits with four major categories (sagittal dentoskeletal and soft tissue relationship, vertical dentoskeletal relationship, transverse dental relationship and intra-arch conditions). His model had a success rate of 90.4% at its prediction performance, but Takada recognized the importance of the orthodontist's elaborate thinking to make the final decision. The model will be tested on different ethnical groups, at different times and with different groups of orthodontists to be improved in the future[20].

Several factors guide the practitioner in his/her treatment plan, among them are: demographical factors, clinical factors, and treatment factors as well as philosophical and psycho-social variables[12-21-22-23-24-25].

<u>Demographical factors</u>: Age, ethnicity, gender

- Age

The age of the patient plays a role in the decision to extract teeth. One of the reasons is that tooth movement is slower and not as predictable in adults due to the constitution of the bone which is less vascularized than in teenagers[12].

- Ethnicity

Different ethnical groups present with different facial features and different perception of ideal/desired esthetics, which impacts the decision to extract. As an example, 42 Japanese dental students and 42 orthodontists were asked to rank their 3 favorite profiles among 30 constructed profiles with different lip protrusion. The study showed that the Japanese students preferred a retrusive profile, suggesting a reduced orthodontic extraction rate, even though natural Japanese facial features are somewhat convex[26]. The same scenario may be applied to the African American population.

- Gender

Gender could also be important for the treatment plan. Using the same example, Ioi's study showed that the dental students favored a more retrusive lip position in women[26].

Clinical factors: Crowding, Overjet, Overbite, Bolton ratio, Angle classification, skeletal anterior-posterior classification, vertical dimension, transverse dimension, curve of Spee, incisors angulation, impacted teeth, periodontal status, presence of root resorption, previous trauma or heavily restored teeth, agenesis, supernumerary, malformed teeth and soft tissue profile.

This is a non-exhaustive list of the clinical factors which guide the orthodontist in establishing his/her treatment plan.

- Crowding and curve of Spee

Tooth extraction in orthodontics represents one major treatment option to relieve crowding. Proffit established three categories to guide the practitioner in his decision to extract teeth in Class I crowding cases. Extractions are rarely recommended in patients with less than 4mm of arch length discrepancy, both extraction and non-extraction treatments are possible between 5 and 9 mm and finally extractions are almost always required with more than 10mm of crowding[12]. Patients presenting with severe crowding (greater than 6-7mm) in the upper and lower jaws have been treated successfully by extracting four premolars with satisfactory alignment of lower incisors up to and exceeding ten years post-retention[10-17].

Francisconi et al. studied a sample of 84 Class I and Class II patients and found that there was more relapse of maxillary crowding in the non-extraction patients while patients treated with extractions had more overbite relapse[27]. This could be due to the fact that extractions favor a decrease in incisors proclination, potentially increasing the overbite[28]. The curve of Spee also impacts the extraction decision since its leveling will increase the lower incisor proclination. The curve of Spee adds up to the crowding measured on the lower arch.

Nevertheless, the long-term response to mandibular anterior alignment remains unpredictable for extraction cases[29].

- Overjet

An excessive or a negative overjet is one of the major chief complaints for orthodontic patients. Extractions have been used as a mean to improve overjet for decades, even centuries. Recent advocate on differential growth modification using Herbst, headgear, and temporary skeletal anchorage may reduce the numbers of extraction. Once more, the facial profile plays a crucial role on the extraction decision.

- Overbite and vertical dimension

The skeletal vertical dimension and the overbite influence the decision to extract teeth. We know that a non-extraction treatment will likely procline the teeth and consequently decrease the overbite, and the opposite is true with an increase of overbite in extraction cases. Therefore it is important to take into consideration the initial overbite in the decision to extract[28].

- Bolton Ratio

Bolton in 1958 measured mesio-distal width of 12 maxillary teeth, first molar of one side to the first molar of the opposite side, and compared with the sum derived by the same procedure carried out on 12 mandibular teeth. He found anterior and overall ratios for tooth size. Bolton's ratios help in estimating overbite, overjet relationships, and the effects of contemplated extractions on posterior occlusion. In case of a tooth size discrepancy, inter-proximal reduction can be an option to improve the Bolton ratio, and sometimes extraction if the discrepancy is important[30].

- Angle and skeletal anterior-posterior classifications

Extractions have historically been used to correct Class II and Class III patients. They can be used as camouflage or to prepare for a surgical treatment, partially depending upon the soft tissue profile[23]. Sometimes, the adult with compromised periodontal tissues may prefer surgery rather than camouflage with extraction.

- Transverse dimension (midline discrepancy, facial asymmetries)

"Extraction versus expansion", this very contemporary debate is the illustration of the close relationship between the transverse dimension and extractions. A patient with large buccal corridors would probably benefit more from expansion than extraction. Also, extractions can be used as a mean to correct midlines discrepancy and mask facial asymmetries[19-31].

- Incisors angulation

Patients are very sensitive to the incisors proclination. As we stated before, extractions will impact the incisors angulation: a non-extraction approach will favor proclination whereas extractions will cause some retroclination. The evolution of treatment planning has shifted from planned lower incisor position to planned upper incisor position for esthetic consideration[12].

- Periodontal status

The periodontal health of the patient is of major importance for any orthodontic treatment, especially in adults who often require a multi-disciplinary approach. Reduced attached gingiva and bone levels will impact the way teeth will move during treatment and influence the treatment plan including extraction decisions.

- Presence of root resorption

Research shows that extractions can be a risk factor for root resorption, especially when the treatment involves significant retraction of maxillary incisors[33].

- Previous trauma / ankylosis / heavy restoration / impaction / agenesis / supernumerary and malformed teeth

The overall dental situation is to be considered carefully when deciding which teeth if any should be extracted.

- Soft-tissue profile

As stated previously, the treatment plan relies on the soft tissue profile and the smile esthetics. This factor will be studied in greater details in the next paragraph.

All these variables are important and all play a role in the decision to extract. In a sample of 542 Class I patients, Konstantonis found that the most important clinical measurements in the extraction decision were lower crowding, lower lip to E-Plane, upper crowding and overjet[34].

<u>Treatment factors:</u> treatment time, bracket type, growth modification appliances and use of orthognathic surgery

- Treatment length

Research shows that you can treat a patient with a similar outcome and stability with or without extractions, but the treatment length will not be the same. Closing extraction spaces takes a considerable amount of time and impacts the overall treatment length[17-18]. Holman observed an additional 3 months of treatment for the patients treated with extractions, while Vig's findings ranged from 3 to 7.3 months added treatment length for extraction cases[10-24]. In today's consumer mentality and with all the marketing directed at orthodontists and patients this could influence the practitioner's decision.

- Bracket type

Technological advances like the recent improvement of self-ligating brackets can influence the practitioner's treatment plan. Self-ligating brackets have been used for decades[35]. As examples, the Russel Lock was the first one on the market in 1935, followed by the Ormco Edgelock in 1972, the SPEED bracket in 1980, and the Damon SL in 1996. Due to technical improvement in the past decade, their use is becoming more and more frequent. The Damon system in particular presents not only a bracket but a "system" which is believed to help the practitioner expand the arches more than what was previously possible with other modes of treatment. The reason behind this belief is based on the low friction between the bracket and arch wires[36-37-38]. Of course this creates a debate in the orthodontic community since no evidence-based long-term study is available[39]. Fleming could not find any evidence supporting the use of self-ligating brackets over conventional appliance systems[40]. In her systematic review, Chen noted a few variables that could be the only advantages of self-ligating brackets: shortened chair-time and a slightly less lower incisors proclination. She still concluded that evidence is lacking to prove the real advantage of self-ligating brackets over conventional bracket[36-41]. Tang et al. investigated 19 non-extraction patients and found that the Damon appliance could not rescue extraction cases. Straight soft tissue profile and upright incisor position are prerequisite for non-extraction treatment. Also, a harmonious chin and lip position is the key factor in the success of non-extraction treatment with the Damon appliance. However, because of the small sample size in Tang's study, the ability of the Damon system to reduce the number of tooth extractions remains undetermined[42]. Other new devices decreasing friction in the stage 1 treatment may be categorized under the same title as the "Damon" device.

- Increased use of growth modification devices / modern surgery

Proffit created a diagram, "the envelope of discrepancy" which shows the amount of change that could be produced by orthodontics only, growth modification and orthodontics, and oral surgery and orthodontics to obtain an ideal position of the upper and lower incisors (Figure 1.).

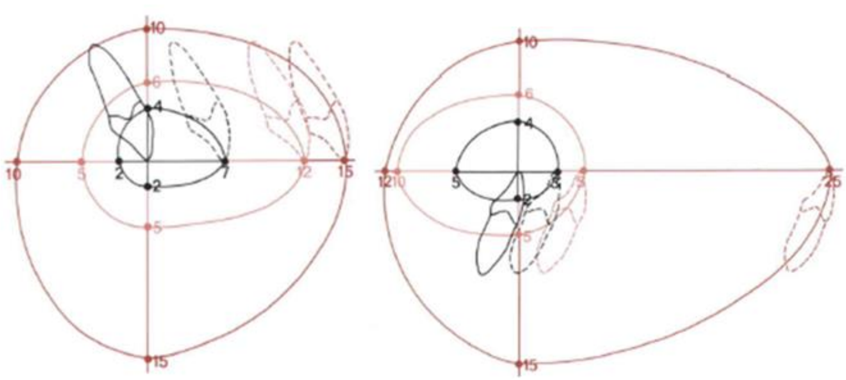

Figure 3. "Envelope of discrepancy" shows the amount of change of tooth position that could be produced by orthodontic tooth movement alone, orthodontic tooth movement combined with growth modification, and orthognathic surgery. Adapted from Proffit[12].

This diagram provides a guideline to help the clinician choose options between using a growth modification appliance without extraction, extracting teeth during comprehensive treatment during teenage years, or waiting until the growth is over to treat the patient with orthognathic surgery and orthodontics[12].

Currently, no existing data correlate orthognathic surgery with the prevalence of tooth extractions. It appears that the percentage of Class III patients undergoing orthognathic surgery is increasing while the percentage of Class II patients undergoing surgery is decreasing at the University of North Carolina. Some demographic factors could be part of the explanation (the ethnicity of the patient population has changed with more African-American, Hispanic and Asian patients). Also, the increased use of non-surgical appliances like the Herbst appliance or the Forsus appliance could explain the decrease in Class II patients seeking surgery[43].

Psychological- and philosophical factors:

In addition to the major variables mentioned above, the psycho-social dimension and personal philosophy play a major role in the treatment plan.

- Esthetics

The concept of facial beauty and esthetics is of major importance for orthodontists and their patients. Wahl wrote: "now it appears that facial esthetics is again in the forefront as we realize why patients come to us in the first place"[44]. Ker showed in his survey that an ideal and an acceptable range for smile esthetics can be identified reliably[23]. As an example, Parekh showed that both laypersons and orthodontists prefer smiles in which the smile arc parallels the lower lip and buccal corridors are minimal[45]. Orthodontists and laypersons can then evaluate accurately the smile esthetics. There is a debate about the consequence of extractions on the patient's profile. Some argue that extractions would cause a "dished in" profile, but this could not be proven[18]. Bowman in his study asked 58 laypersons and 42 dentists to evaluate pre and post-treatment profiles of 70 extractions and 50 non-extractions Class I and Class II Caucasian patients. His results showed that non-extraction treatment produced very minimal effect on the profile whereas extractions could improve the patient's facial esthetics when they presented with a combination of crowding and protrusion at the beginning of treatment[46]. Similarly, Drobocky estimated that 90% of the patients treated with extractions saw their profile improved after treatment[22]. In opposition, some studies could not find any differences in esthetic outcome between the two treatment options[47-48]. Janson stated in his review of the literature that extraction and non-extraction protocols seemed to have no predictable effect on smile esthetics[32-49]. In another study, he compared Class II Division 1 patients treated with different extractions protocols (one, three or four premolars extractions). He asked 70 orthodontists and 46 laypersons to rate the posed-smile on a 10-point scale. His results showed that there was no significant difference in smile attractiveness between orthodontists and laypersons or between the different extraction patterns[50].

- Personal philosophy

Individual orthodontists are influenced by their educational background, their vision of esthetics, and their personal philosophy. As seen previously, extractions could impact the patient's profile[1-2-51], and some orthodontists or patients may prefer a fuller profile[21-23-44-45-46]. In protrusive patients, the fullness of the lip improves after the extraction of four premolars. This improvement is predictable but the changes are small and individual responses are very diverse.

**Previous studies**

Proffit[14] surveyed the extraction frequency between the 1950's and 1990's at the University of North Carolina (Figure 2.). He found that the extraction percentage was 30% in

1953, reached 76% in 1968, and declined to 28% in 1993. He hypothesized that this variation was due to considerations in outcome stability, facial esthetics, and technological changes. However, new appliances (e.g. self-ligating brackets), development of growth modification techniques, and improved orthognathic surgery procedures did not mature until the beginning of the twenty-first century. It is uncertain whether these recent clinical approaches have had an impact on the extraction frequency after 2000.

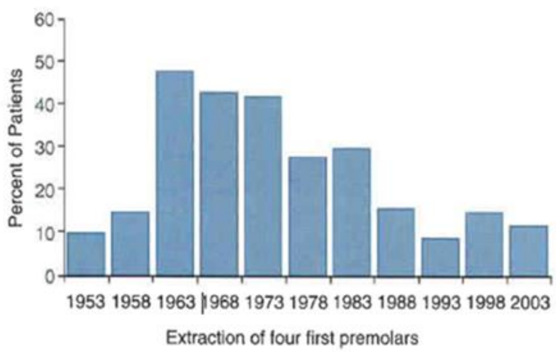


Figure 4. Extraction of four first premolars percentages in the Department of Orthodontics at the University of North Carolina over a 50-year period, from 1953-2003. Adapted from Proffit, Contemporary Orthodontics

Janson[52] conducted a retrospective study at the University of Sao Paulo in Brazil to evaluate the frequency of different extraction patterns. His sample comprised 3,413 records since 1973. He divided the sample in 10 groups depending on their extraction protocol, the first group being the non-extraction patients. His results showed an overall increase of the non-extraction group with a decrease of all the extraction protocols except for the two maxillary premolars extraction groups which remained stable. There is a trend towards non-extraction treatments [31]. O'Connor found a similar trend in his survey of 814 questionnaires returned by orthodontists[2].

These studies of the extraction trend over time are very valuable because it can be difficult for the practitioner to self-evaluate his extraction rate: the actual rate can differ from the perceived extraction rate[24].

**Conclusions**

Extractions have been performed for centuries as a treatment option in orthodontics. Their frequency has fluctuated greatly over the years, with a very low percentage at the beginning of the twentieth century due to the influence of Angle, a significant increase in the 1960s and 70s and a general decrease since then. Variations in the extraction rate cannot be easily explained as there are several criteria involved in the decision to extract teeth in addition to the practitioner deciding based on his knowledge and philosophy of orthodontics.

The following study provides connections on how the aforementioned factors may be associated with the likelihood of electing tooth extraction as an orthodontic treatment modality.

However, there is a consistent tendency to choose the less invasive treatment option, and some practitioners in some occasions choose to delay the decision to extract until several months into treatment.

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## A CONTEMPORARY PERSPECTIVE ON TOOTH EXTRACTION IN ORTHODONTICS

### Introduction

The US Public Health Service collectively documented the first organized data on malocclusion in the United States as part of the National Health and Nutrition Examination Survey (NHANES) in the 1960s. According to the NHANES study, Kelly et al reported that 24.4% of the children between 6 and 11 years had normal occlusion, 22.4% had a definite malocclusion, 8.7% had severe malocclusion, and 5.5% were classified as having a very severe malocclusion[1]. Kelly's study was the first epidemiological investigation showing that at least 35% of American children are candidates for orthodontic treatment. More recently, the American Association of Orthodontists stated that in 2004, there were 5,750,000 patients undergoing orthodontic treatment, and that this statistic had undergone a steady and significant increase since 1989. For those individuals who may benefit from orthodontic therapy, tooth extraction represents one major treatment option to relieve crowding or reduce protrusion. Dogmatic non-extraction arch-expansion, originally proposed by Edward Angle, was found to be unstable and unaesthetic in many cases[2]. The work of Angle's student, Charles Tweed, who re-treated an impressive series of patients with the extraction of four premolars, serves as a classic counterpoint to the notion that in all cases it is best to align a full complement of teeth within the arches[2].

Contemporary guidelines suggest that patients presenting with severe crowding (greater than 6-7mm) in the upper and lower jaws may be treated successfully by extracting four premolars with satisfactory alignment of lower incisors up to ten years and more post-retention[3]. In many cases however, either extraction or non-extraction treatment may offer good stability and results[4-5-6]. The factors that dictate the choice to extract are multi-faceted, and different approaches have been attempted to objectify and improve the extraction decision. Takada created a mathematical model to guide the treatment plan decision and optimize orthodontic treatment outcome: His model used 25 morphologic traits with four major categories (sagittal dentoskeletal and soft tissue relationship, vertical dentoskeletal relationship, transverse dental relationship and intra-arch conditions)[7]. Nonetheless, a reliable criterion for extracting teeth remains elusive and the topic continues to be one of controversy. Accordingly, extraction rates have varied over the decades. Depending upon the year of treatment, it has been estimated that anywhere from 28% to 76% of orthodontic patients have undergone permanent tooth extraction, other than third molars[8-9-10].

Proffit[11] surveyed the extraction frequency between the 1950's and 1990's in orthodontic patients cases treated at the University of North Carolina. He found that the extraction rate for four premolars was 30% in 1953, reached a peak of 76% in 1968, and declined to 28% in 1993. He hypothesized that this variation was due to considerations in outcome stability, facial esthetics, and changes in technique. In addition to this study, recent research supports the notion that the choice to extract teeth has to be made after consideration of three main aspects: esthetics, stability, and occlusion[12]. Appliance design, surgical intervention and patient-related factors are additional confounding factors. Individual orthodontists are influenced by their educational background, the difference in treatment length[13], and their vision of esthetics. Extractions can impact the patient's soft tissue profile[1-8], and orthodontists like patients have individual esthetic preferences[14-15-16-17-18]. Patient's age, the quality and prognosis of their teeth and bone, gender, demographic background, and diagnostic information (e.g., crowding, overjet, and overbite) also contribute to the decision[19]. In short, the extraction decision is not a simple one, and some of today's clinicians are more inclined to extract teeth than expand the arches in borderline cases while others would rather conserve the teeth if possible and rely on arch expansion to relieve crowding.

With the increased access to information and esthetic demands of orthodontic patients today, clinicians are facing ever greater pressures to perform evidence-based decision-making. To keep pace with advances in the field of orthodontics, it is important to understand what factors affect the extraction decision for orthodontic purposes.

We hypothesize that the chronological trend for tooth extraction is non-constant and depends upon a multifactorial decision aforementioned. As a follow-up of Proffit's 40-year review, we analyzed the extraction rate at the University of North Carolina from 2000 to 2013. Specifically, contemporary considerations for extraction, including appliances type (e.g., self-ligating brackets) and patient-related diagnostic factors were examined.

**Materials and Methods**

The Orthodontic Graduate Clinic at the University of North Carolina maintains pre- and post-treatment records for each patient using standardized forms that record diagnostic information as well as information capturing treatment approach and outcome. This data is organized within a centralized database. Our study sample included all the patients who started treatment on January 1, 2000 or later and completed treatment before December 31, 2011. Inclusion criteria are that both the pre- and post- treatment forms are present and complete. Patients that failed to complete treatment were excluded from the study. The sample consisted of

2,184 patients, with 1,263 females (58%) and 913 males (42%). The age at the start of treatment ranges from 7 to 67 years old. The primary outcome measure was extraction of permanent teeth for orthodontic purposes; third molars extractions were not included. Explanatory measures included demographic, clinical and treatment factors. The demographic measures were the age at start of treatment, the gender and the ethnicity of the patient. Clinical measures included the initial overjet and overbite in millimeters, the crowding of the maxillary and mandibular arches, the initial Angle classification, the initial skeletal anterior/posterior classification, the periodontal health, the curve of Spee and the presence of root resorption at the end of treatment.

Additionally, the patient pool was divided in two groups based on the use of conventional brackets or self-ligation brackets. The extraction rate in the self-ligation user group was compared to the conventional (non-self-ligation) bracket user group.

Demographic and clinical characteristics of patients were described by mean and standard deviation for continuous variables and proportions for categorical variables. Group difference between patients with and without extraction was compared either based on two-sample t-test or chi-square tests when appropriate. Characteristics that are significantly different between extraction and non-extraction groups were considered potential risk factors for extraction. Year by year extraction rate was explored in a time series plot and smoothed by three-year moving average. Due to a significant lower extraction in 2005, we applied both linear and quadratic term of (year - 2005) in the logistic model (Model I) for extraction probability. The model was further adjusted by potential risk factors (Model II, III, and IV, Table 2) to investigate the adjusted time effects. All of the statistical tests were 2-sided and p-value smaller than 0.05 was considered significant. Analyses were implemented using SAS 9.2 (SAS Inc., Cary NC).

**Results**

Patient Distribution: The sample composition varied over time as shown in Table 1. The male to female ratio remained quite constant over time with female representing 52.9% to 63.9% of the patients' pool. The age of the patient at start of treatment ranged from 7 to 67 years old. Our sample became more diverse in ethnicity between 2000 and 2011: The proportion of Caucasian patients decreased from 82.3% in 2000 to 62.9% in 2011 while the African American patients and other ethnicities increased from 11.5% to 13.3% and from 6.2% to 23.8%, respectively.

Year Effect: The year effect on extraction rate was found to be significant (p value of 0.048). The extraction rate at the University of North Carolina fluctuated significantly throughout the years and peaked at 40.9% in the first year studied. This peak rate represents a choice of extraction in almost half of the patients treated in the Graduate Clinic (Figure 1). This percentage decreased significantly after 2000, going from 40.9% to 18.6% in 2005. The extraction rate then increased to 27.9% in 2007 and remained relatively stable until 2011.

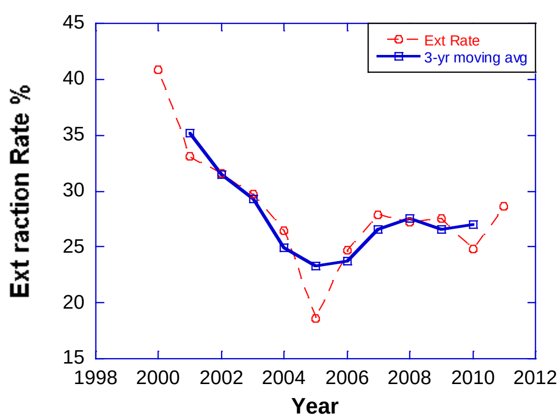


Figure 5. Extraction rate per year.

Several variables were found to exert a significant influence on the overall extraction rate (p-value less than 0.05): the year of treatment, the ethnicity of the patient, overjet and overbite, crowding, the Angle and skeletal classification, root resorption, and the bracket used for the patient (Table 1 and Table 2).

Effect of Angle Classification: Extraction rates were examined for each dental antero-posterior diagnostic (Angle) classification: Class I dental, Class II division 1, Class II division 2 and Class III dental. The overall number of patients who underwent extractions is higher for the Class I category which represents the largest pool of patients (47.1% of the patients). For the extraction rate averaged over the past ten years, the extraction rate is higher for Class II and Class III dental relationships than Class I patients. Patients with a Class II division 1 pattern had the highest rate of extractions (Figure 2).

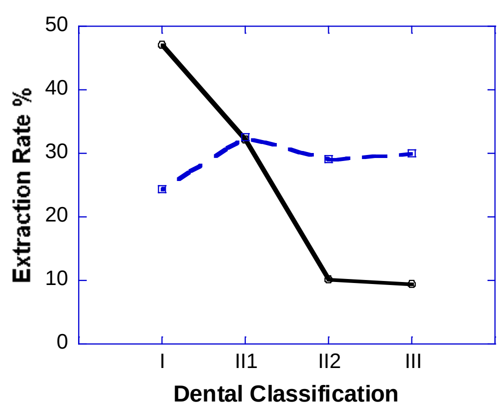


Figure 6. Extraction percentage and Angle classification. Solid line indicates total percentage of extraction for each classification over the entire 13 years' time period. Dash line represents % extraction within individual classification.

The extraction percentages for each Angle classification were relatively stable from 2000 to 2011, with no significant variation noted (Table 2).

Effect of Skeletal AP: The second variable is the skeletal antero-posterior classification (Figure 3). For Class II and Class III patients the distinction was made between mild, moderate and severe forms of skeletal discrepancies. This categorization of mild/moderate and severe forms of malocclusion was made by the Resident and the Faculty and based arbitrarily on Overjet measurements. The extraction percentage increased with the severity of the skeletal Class II, going from 30% for the mild Class II malocclusion to more than 50% for severe skeletal Class II patients. This is not true for the Class III patients, where we see fewer extractions for the severe patients. In general, the patients with either skeletal or dental Class II or III malocclusion experienced higher extraction rates than Class I patients.

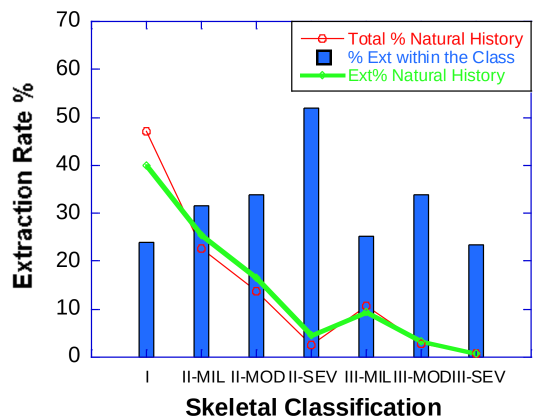


Figure 7. Extraction percentages and skeletal antero-posterior classification (mild, moderate, severe). The red line represents the extraction rate within the classification while the red and green line represent the extraction rate overall.

Skeletal Class I patients extraction rate did not change meaningfully from 2000 to 2011. On the contrary, skeletal Class II patients underwent more extractions in 2011 than 2000, (from 36.8% in 2000 to 39% in 2011) while Skeletal Class III patients underwent fewer extractions (from 18.4% in 2000 to 14.3% in 2011).

Effect of Appliance: One other significant variable extracted from the data is the type of bracket that was used for each patient. There is a significant difference in extraction rate between self-ligating brackets and non-self-ligating brackets groups. The extraction rate for patients treated with self-ligation was substantially lower than the non-self-ligation patients group, with 21 % of extractions in the self-ligation group compared to 42% in the non-self-ligation group. The use of self-ligating brackets in the Graduate Clinic increased from 7% in 2000 to 23.8% in 2011.

The extraction rate was at its lowest in 2005 and decreased over time. Table 3 shows all the variables included in four logistic models to study the relationship between each variable and the extraction trend over time. Model 1 is composed of the extraction rate by year. Model 2 is expanding Model 1 with gender, race, ethnicity and the use of self-ligating brackets. Model 3 adds the Angle classification, the skeletal classification, overjet and overbite to Model 2. Finally Model 4 is Model 3 including only patients with crowding (1320 patients). The odds ratio (<1.0) using (year – 2005) indicated that the extraction rate linearly decreased over year ($p<0.05$). The models 2-4 proved that this decrease trend was not influenced by other confounding factors. The odds ratio in the quadratic form (year-2005)2 confirmed that the extraction did increase after 2005, but it did not return to year 2000 because the linearly downward trend was significant. Looking more closely at Model 4 which only included patients with crowding, we can observe in Table 2 that in 2004, 2005 and 2006 patients had overall less crowding than the other years. This could explain the lowest point in 2005.

The extraction rate decreased linearly over the years, but the trend is not affected by any of our confounding factors.

## Discussion

We discovered a trend of decreasing numbers of tooth extractions in our sample of patients treated at the UNC Graduate Orthodontic Clinic between 2000 and 2011 (n=2148). Our patient pool was treated using an attending-resident model with twenty-five faculty members having taught during this 11-year period. The patients were followed throughout treatment by one faculty member and one (sometimes two) resident(s); thus, the patient sample is representative of a variety of practitioners and their treatment philosophies. The total of 2184 subjects is a substantial sample size, which contributes to an epidemiological finding of the extraction trend. Our data revealed that the percentage cases treated with tooth extractions varied annually, ranging from 17% to 41%, with the greatest drop in 2005. Statistically, the extraction rate was in linear decline from 40.9% in 2000 to 28.6% in 2011. A similar decreasing trend was noted in previous studies. Janson[20] conducted a retrospective study at the University of Sao Paulo in Brazil to evaluate the frequency of different extraction patterns. His sample comprised 3,413 records since 1973. He divided the sample into 10 groups based on their extraction protocol, the first group being the non-extraction patients. His results showed an overall increase of the non-extraction group with a decrease of all the extraction protocols with the exception of the two maxillary premolars extraction group, which remained stable. O'Connor found a similar trend in his survey of 814 questionnaires returned by orthodontists[8]. There is a trend towards non-extraction treatments[20].

This linear decline over time was not influenced in our study by any explanatory variables according to the logistic models (Table 3). Progressively adding the explanatory factors provided a clear picture of the trend of the declined extraction rate in the past decade. No single factor that has been taught in the past appeared to alter this trend. The lowest extraction rate in

2005 was not statistically significant, which might be related to the low mean values of crowding cases obtained in that year. The extraction rate, however, remained stable at 29% since 2007.

Although the explanatory variables could not explain the decreasing trend of the extraction rate over time, eight major factors were found to be significantly related to the overall extraction decision. The eight factors included year, ethnicity, Angle classification, skeletal anterior-posterior classification, crowding, overjet, overbite, and technology. By averaging all data from 2000 to 2011, a bivariance association analysis could detect a significant difference between the extraction group versus the non-extraction group when each of the eight factors was examined.

The ethnic diversity of our sample changed during these 11 years. The proportion of Caucasian patients decreased from 82.3% in 2000 to 62.9% in 2011. This trend was also observed by Proffit[21] with an increase of African-Americans, Native-Americans, Hispanics, and Asians patients seeking surgical treatment since 2000. Different ethnic groups present different facial features and perceptions of esthetics, which ultimately dictate the decision to extract. As an example, 42 Japanese dental students and 42 orthodontists were asked to rank their 3 favorite profiles among 30 constructed profiles with different lip protrusion. The study showed that Japanese preferred a retrusive profile even though natural Japanese facial features are somewhat convex[22]. Proffit found in his study that more Class III patients and fewer Class II patients were seeking surgery at UNC these days compared to ten years ago[21]. This change could be attributable to the demographic changes but may also be due to the increased use of growth modification appliances such as the Herbst appliance. These appliances offer a valid option for growing patients in borderline surgical cases.

Skeletal and dental anterior-posterior classifications were also significant factors for the extraction decision. Extractions are frequently used in the correction of Class II and Class III cases. They can be used as camouflage or as preparation for surgical treatment[20-23]. In our data, patients presenting with a severe skeletal Class III underwent fewer extractions than the mild and moderate Class III patients. This could be explained in that severe Class III patients seek surgical treatment more so than their counterparts with milder discrepancies[21], therefore not necessarily needing extractions depending on the surgical plan.

Crowding, overjet, and overbite were also shown to influence the extraction decision. Tooth extraction in orthodontics represents a major treatment option to relieve crowding[3-12-24] and achieve acceptable overjet and overbite. For instance, we know that a non-extraction treatment will likely procline the teeth and consequently decrease the overbite, and the opposite is true with an increase of overbite in extraction cases[25]. Future analysis to find the threshold values of crowding, overjet and overbite could provide information to guide orthodontists' treatment decision.

Finally, our results showed that treatment technology could influence the practitioner's decision. 23.8% of the faculty members were using self-ligating brackets in 2011. This proportion increased with 42% of them using self-ligation in 2015. 3 of the 14 attending faculty members in the orthodontic clinic use passive self-ligating brackets (Damon or equivalent) and rarely extract. Three other attending faculty members use active self-ligating brackets and their extraction rate is also lower than the conventional twin bracket users group.  The increased use of these self-ligating brackets in clinical practice could be one of the variables explaining the trend toward fewer extractions. Since the Russel Lock became the first self-ligating bracket on the market in 1935, followed by the Ormco Edgelock in 1972, the SPEED bracket in 1980, and the Damon SL in 1996, technological improvements have allowed them to gain greater acceptability with clinicians. In the 11-year span of our study, self-ligating brackets have seen increased use from 7% of cases in 2000 to 23.8% of cases in 2011.

Some patients may have concerns about orthodontic extractions and how their dental and general health might be affected. Epidemiologic studies have linked the loss of teeth with an increased predisposition for Alzheimer's disease and early dementia. Tooth loss has been shown to affect memory and learning in animal studies: the data suggests that tooth loss may inhibit neurogenesis in the dentate gyrus of adult mice[26]. A recent 5 year prospective cohort study by Okamoto[27] finds a link between mild memory impairment and tooth loss in the elderly population. One possible explanation would involve chemical components present during periodontal disease, which should not concern our orthodontic patients. More studies are needed to explore this detrimental effect.

Despite all the factors identified as having an effect on extraction rate, none were found to be significant in explain the decreasing trend over time. This leads us to believe that the decision to extract teeth is in the end highly irrational and seems to be a subconscious behavior of the orthodontist. This decision is influenced by a multitude of variables and the same orthodontist could probably opt for a different treatment plan for the same patient if asked at different times.

## Conclusions

The extraction rate fluctuated greatly since 2000 and has decreased linearly over the years ($p<0.05$). Several explanatory variables were found to influence the overall extraction decision:  ethnicity, Angle Classification, skeletal anterior-posterior classification, presence of root resorption, overjet, overbite, amount of crowding and technology used.

However, none of these variables were able to explain the decrease of the extraction rate over time. This decision is highly irrational and personal to each practitioner.

## Tables

Table 1 – Influence of explanatory variables on the overall extraction rate.

| | Total | non-extraction | extraction | p-value |
|---|---|---|---|---|
| **n** | 2184 | 1569 | 615 | |
| **Gender** | | | | |
| **Female** | 58.0% | 58.2% | 57.5% | 0.772 |
| **Male** | 42.0% | 41.8% | 42.5% | |
| **Race** | | | | |
| **Caucasian** | 68.6% | 74.8% | 52.8% | <0.001 |
| **African American** | 16.4% | 13.5% | 23.9% | |
| **Other** | 15.0% | 11.7% | 23.4% | |
| **Technology** | | | | |
| **Self-ligation** | 11.9% | 13.7% | 7.3% | <0.001 |
| **Non Self-ligation** | 88.1% | 86.3% | 92.7% | |
| **Age at start, mean (SD)** | 17.8 (9.7) | 17.5 (9.9) | 18.4 (9.2) | 0.073 |
| **Initial Reduced Gingival Attachment** | | | | |
| **No** | 65.6% | 66.8% | 62.6% | 0.07 |
| **Yes** | 34.4% | 33.2% | 37.4% | |
| **Initial overjet (absolute value), mean (SD)** | 4.1 (2.5) | 3.9 (2.3) | 4.5 (3.0) | <0.001 |
| **Initial maxillary crowding, mean (SD)** | -3.8 (3.0) | -3.1 (2.4) | -5.4 (3.6) | <0.001 |
| **Initial mandibular crowding, mean (SD)** | -3.8 (2.6) | -3.1 (2.1) | -5.3 (3.0) | <0.001 |
| **Initial curve of Spee, mean (SD)** | 2.1 (1.0) | 2.1 (1.0) | 2.1 (1.0) | 0.506 |
| **Initial overbite (absolute value), mean (SD)** | 3.4 (1.9) | 3.5 (1.9) | 3.1 (2.0) | <0.001 |
| **Skeletal A/P** | | | | |
| **1** | 47.1% | 49.9% | 40.0% | <0.001 |
| **2-MIL** | 22.6% | 21.5% | 25.5% | |
| **2-MOD** | 13.7% | 12.6% | 16.5% | |
| **2-SEV** | 2.5% | 1.7% | 4.6% | |
| **3-MIL** | 10.6% | 11.0% | 9.5% | |
| **3-MOD** | 2.7% | 2.5% | 3.3% | |
| **3-SEV** | 0.8% | 0.8% | 0.7% | |
| **Angle Classification** | | | | |
| **1** | 47.1% | 49.6% | 40.6% | 0.001 |

| | | | | |
|---|---|---|---|---|
| **2** | 43.4% | 41.2% | 49.3% | |
| **3** | 9.5% | 9.3% | 10.1% | |
| **End of Treatment Root Resorption** | | | | |
| **Generalized** | 3.1% | 2.5% | 4.8% | <0.001 |
| **Localized** | 10.4% | 9.0% | 14.0% | |
| **Not present** | 85.6% | 88.5% | 81.2% | |

Table 2 – Extraction rate versus explanatory variables from 2000 to 2011 per year.

| | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | p-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Extraction rate** | 40.9% | 33.1% | 31.6% | 29.7% | 26.5% | 18.6% | 24.7% | 27.9% | 27.2% | 27.6% | 24.8% | 28.6% | 0.048 |
| **Gender** | | | | | | | | | | | | | |
| **Female** | 56.0% | 57.5% | 58.4% | 63.9% | 57.5% | 52.9% | 58.9% | 56.3% | 59.0% | 57.2% | 58.3% | 59.0% | 0.968 |
| **Male** | 44.0% | 42.5% | 41.6% | 36.1% | 42.5% | 47.1% | 41.1% | 43.7% | 41.0% | 42.8% | 41.7% | 41.0% | |
| **Race** | | | | | | | | | | | | | |
| **Caucasian** | 82.3% | 81.7% | 70.5% | 78.1% | 73.5% | 68.6% | 66.4% | 64.5% | 67.1% | 62.0% | 63.5% | 62.9% | <0.001 |
| **African American** | 11.5% | 13.5% | 21.7% | 9.7% | 16.8% | 17.6% | 18.5% | 19.1% | 13.5% | 20.0% | 15.0% | 13.3% | |
| **Other** | 6.2% | 4.8% | 7.8% | 12.3% | 9.7% | 13.7% | 15.1% | 16.4% | 19.4% | 18.0% | 21.5% | 23.8% | |
| **Technology** | | | | | | | | | | | | | |
| **SL** | 7.0% | 7.1% | 7.8% | 12.3% | 7.1% | 10.8% | 8.9% | 8.4% | 2.9% | 20.1% | 20.9% | 23.8% | <0.001 |
| **NSL** | 93.0% | 92.9% | 92.2% | 87.7% | 92.9% | 89.2% | 91.1% | 91.6% | 97.1% | 79.9% | 79.1% | 76.2% | |
| **Dental problem** | | | | | | | | | | | | | |
| **1** | 49.1% | 51.2% | 48.4% | 43.2% | 55.9% | 54.9% | 56.8% | 51.9% | 41.2% | 44.4% | 42.3% | 34.3% | 0.008 |
| **2** | 42.0% | 44.1% | 39.8% | 48.4% | 38.7% | 33.3% | 37.0% | 38.2% | 48.7% | 45.2% | 46.3% | 57.1% | |
| **3** | 8.9% | 4.7% | 11.9% | 8.4% | 5.4% | 11.8% | 6.2% | 9.9% | 10.1% | 10.4% | 11.3% | 8.6% | |
| **Skeletal AP** | | | | | | | | | | | | | |
| **1** | 44.7% | 40.9% | 43.4% | 39.4% | 50.4% | 47.1% | 47.9% | 53.1% | 45.6% | 47.2% | 50.9% | 46.7% | 0.370 |
| **2** | 36.8% | 46.5% | 39.3% | 44.5% | 34.5% | 37.3% | 39.0% | 35.5% | 43.9% | 39.6% | 34.0% | 39.0% | |
| **3** | 18.4% | 12.6% | 17.2% | 16.1% | 15.0% | 15.7% | 13.0% | 11.5% | 10.5% | 13.2% | 15.0% | 14.3% | |
| **Initial overjet** | | | | | | | | | | | | | |
| **Mean** | 4.60 | 4.69 | 3.73 | 4.40 | 3.92 | 4.20 | 4.22 | 4.15 | 3.89 | 3.96 | 4.05 | 3.97 | 0.022 |
| **SD** | 2.79 | 3.00 | 2.43 | 3.03 | 2.49 | 2.83 | 2.26 | 2.53 | 2.48 | 2.41 | 2.27 | 2.21 | |
| **Initial overbite** | | | | | | | | | | | | | |
| **mean** | 3.72 | 3.80 | 3.41 | 3.33 | 3.34 | 3.59 | 3.40 | 3.26 | 3.25 | 3.29 | 3.35 | 3.26 | 0.223 |
| **SD** | 2.01 | 1.89 | 1.95 | 1.87 | 1.98 | 1.89 | 1.91 | 1.90 | 1.93 | 2.01 | 1.82 | 1.73 | |
| **Initial max alignment** | | | | | | | | | | | | | |
| **mean** | -3.75 | -3.53 | -4.15 | -3.70 | -3.33 | -3.56 | -3.37 | -3.95 | -3.87 | -4.08 | -4.13 | -3.75 | 0.417 |
| **SD** | 2.56 | 2.73 | 3.51 | 2.79 | 2.80 | 2.36 | 2.67 | 3.18 | 3.38 | 3.16 | 3.06 | 2.67 | |
| **Initial mand alignment** | | | | | | | | | | | | | |
| **mean** | -3.87 | -3.95 | -4.08 | -3.66 | -3.68 | -3.44 | -3.09 | -3.77 | -3.96 | -3.71 | -3.91 | -3.64 | 0.259 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SD** | 2.59 | 2.75 | 2.99 | 2.72 | 2.51 | 2.21 | 2.07 | 2.94 | 2.88 | 2.43 | 2.54 | 2.15 | |
| **EoTxRootResorp** | | | | | | | | | | | | | |
| **G** | 2.7% | 3.2% | 7.1% | 3.9% | 2.7% | 1.0% | 1.4% | 3.5% | 2.1% | 2.8% | 3.1% | 1.0% | <0.001 |
| **L** | 23.9% | 23.0% | 14.5% | 13.6% | 9.7% | 13.7% | 8.9% | 6.5% | 4.2% | 8.4% | 6.2% | 7.7% | |
| **N** | 73.5% | 73.8% | 78.4% | 82.5% | 87.6% | 85.3% | 89.7% | 90.0% | 93.7% | 88.8% | 90.7% | 91.3% | |

Table 3 – Logistic regression model adjusted by potential risk factors for assessing extraction probability over time. Model 1 is the extraction per year. Model 2 is Model 1 plus gender, ethnicity and technology used. Model 3 is Model 2 plus Angle classification, skeletal anterior-posterior classification, overjet and overbite. Model 4 is Model 3 only including patients with crowding.

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | |
|---|---|---|---|---|---|---|---|---|
| | N=2184 | | N=2167 | | N=2136 | | N=1320 | |
| | OR (95% CI) | p-value | OR (95% CI) | p-value | OR (95% CI) | p-value | OR (95% CI) | p-value |
| **Year – 2005** | 0.95 (0.92, 0.98) | 0.001 | 0.93 (0.90, 1.34) | <0.001 | 0.92 (0.90, 0.96) | <0.001 | 0.92 (0.88, 0.96) | <0.001 |
| **(Year – 2005)^2** | 1.01 (1.00, 1.02) | 0.020 | 1.02 (1.01, 1.03) | 0.004 | 1.02 (1.01, 1.03) | 0.004 | 1.01 (1.00, 1.03) | 0.073 |
| **Gender** | | | | | | | | |
| **Female** | | | Ref | | Ref | | Ref | |
| **Male** | | | 1.10 (0.90, 1.34) | 0.353 | 1.18 (0.96, 1.45) | 0.108 | 1.19 (0.90, 1.59) | 0.226 |
| **Race** | | | | | | | | |
| **Caucasian** | | | Ref | | Ref | | Ref | |
| **African American** | | | 2.66 (2.07, 3.41) | <0.001 | 2.71 (2.08, 3.53) | <0.001 | 6.21 (4.07, 9.46) | <0.001 |
| **Other** | | | 3.12 (2.41, 4.05) | <0.001 | 2.88 (2.20, 3.78) | <0.001 | 2.59 (1.78, 3.76) | <0.001 |
| **Technology** | | | | | | | | |
| **SL** | | | Ref | | Ref | | Ref | |
| **NSL** | | | 2.07 (1.46, 2.95) | <0.001 | 2.06 (1.44, 2.95) | <0.001 | 2.85 (1.70, 4.79) | <0.001 |
| **Dental** | | | | | | | | |

| | | | | |
|---|---|---|---|---|
| **problem** | | | | |
| **1** | Ref | | Ref | |
| **2** | 1.56 (1.20, 2.03) | 0.001 | 1.45 (1.00, 2.10) | 0.050 |
| **3** | 1.25 (0.82, 1.89) | 0.294 | 1.39 (0.77, 2.52) | 0.280 |
| **Skeletal AP** | | | | |
| **1** | Ref | | Ref | |
| **2** | 1.31 (1.01, 1.69) | 0.042 | 1.40 (0.98, 1.99) | 0.065 |
| **3** | 0.91 (0.63, 1.32) | 0.908 | 0.82 (0.49, 1.38) | 0.455 |
| **Initial overjet (absolute value)** | 1.08 (1.04, 1.13) | <0.001 | 1.16 (1.08, 1.25) | <0.001 |
| **Initial overbite (absolute value)** | 0.83 (0.78, 0.88) | <0.001 | 0.86 (0.79, 0.93) | <0.001 |
| **Initial maxillary crowding** | | | 0.80 (0.76, 0.85) | <0.001 |
| **Initial mandibular crowding** | | | 0.75 (0.71, 0.80) | <0.001 |

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