FACULDADE DE MEDICINA
UNIVERSIDADE Ð
COIMBRA

INTEGRATED MASTER OF DENTISTRY – THESIS

LUÍS PEDRO PRETO VICENTE

Impact of dentofacial growth on dentoalveolar changes in adolescents and young adults

Determinants on a prospective clinical trial

REVIEW

Scientific Area of

ORAL REHABILITATION (FIXED PROSTHODONTICS AND IMPLANTOLOGY) AND ORTHODONTICS

Word done with the supervision of

PROFESSOR DOUTOR JOÃO PAULO DOS SANTOS TONDELA

PROFESSOR DOUTOR FRANCISCO VALE

PROFESSOR DOUTOR FRANCISCO CARAMELO

Faculty of Medicine, University of Coimbra, Portugal

COIMBRA, JUNHO 2021

Integrated Master in Dentistry

Faculty of Medicine, University of Coimbra, Portugal

Impact of craniofacial growth on dentoalveolar changes in adolescents and young adults

Determinants on a prospective clinical trial

Vicente L[1], Vale F[2], Caramelo F[2], Tondela, JP[2, 3]

[1] 5th year student of Integrated Master in Dentistry, Faculty of Medicine, University of Coimbra, Portugal

[2] Assistant Professor, Faculty of Medicine, University of Coimbra, Portugal

[3] Assistant Professor, Faculty of Medicine, University of Coimbra, Portugal, jtondela@fmed.uc.pt

Área da Medicina Dentária da Faculdade de Medicina da Universidade de Coimbra

Avenida Bissaya Barreto, Bloco de Celas

3000-075 Coimbra, Portugal

Tel.: +351 239 484 183

Fax: +351 239402910

E-mail: lppvicente@sapo.pt

Abstract

Introduction: Craniofacial and dentoalveolar dimensional changes never really cease. Although growth decreases rapidly after adolescence, being almost imperceptible after the second decade of life, the continuous physiological eruption develops throughout life continuous dentofacial dimensional changes. Fixed rehabilitation with implant supported crowns can lead to aesthetic problems, which may result in infraocclusion or implants' submersion due to dentoalveolar dimensional changes, mainly during faster growth periods. Our aim was to review some methods used to determine dentofacial dimensional changes and how they can be valued in the rehabilitation of the aesthetic zone in adolescents and young adults.

Methodology: Some standardized techniques and methods in determining the clinically insignificant period of residual craniofacial growth and dentofacial maturation were reviewed. Those methods comprised the analysis and superimposition of photographs, the analysis and superimposition of cephalometric radiographs and the superimposition of digital images with intraoral scanners (IOS) and plaster dental cast models. We included 103 relevant references, after evaluating titles, abstracts and full-text analysis, from the following databases: Cochrane Library, Embase, PubMed/MEDLINE, Scopus and Web of Science. Only articles in English, French or Portuguese, published until January 2021, were included.

Results: There is low evidence regarding the methods of assessment and analysis of the identified parameters of craniofacial growth evaluation in this review.

Discussion: The development rate of maxilla decreases throughout life, while dentofacial and dentoalveolar dimensions achieve non-valuable short-term measurements due to very small variations. This demonstrates how residual growth occurs, mainly during the skeletal maturation phase along the second and third decades of life. Several different standardized methods are accurate techniques used to evaluate dentoalveolar changes in adolescents and young adults during the continuous physiological eruption.

Conclusions: More than one digital technique seems to be advisable, including the analysis of standardized clinical photographs and/or superimposition of digital images of dental cast models with IOS.

Keywords: Adolescents; Craniofacial Growth; Dental Implant; Dentoalveolar Changes; Growth and Development; Young Adults

Index

Abbreviations

2D – Two-dimensional

3D – Three-dimensional

ANS-PNS – Horizontal plane between the anterior nasal spine and the posterior nasal spine

CAD – Computer-aided design

CAM – Computer-aided manufacturing

CBCT - Cone Beam Computed Tomography

CEREC – Chairside Economical Restorations of Esthetic Ceramic

DDAR – Diagrams of dental aesthetic references

DSD – Digital Smile Design

IOS – Intraoral scanners

LAFH – Lower anterior face height

LPFH – Lower posterior face height

MPS – Midpalatal suture

NPH – Natural position of head

PNG - Portable Network Graphics

SCT – SmileCurves template

STL – Standard tessellation language

UAFH – Upper anterior face height

UN – United Nations

UPFH – Upper posterior face height

Introduction

The United Nations (UN) Convention on the Rights of the Child defines a child as an individual under the age of 18 years, while the UN defines "adolescence" as a stage of life between 10 and 19 years old that comprises childhood and adulthood with a range of social transitions and biological growth. Most of the recent terms introduced in the literature define "young adult" ranging from about 18 to 26 years of age. [1]

Growth can be defined as an increase in size or dimension, and also as a process of restructuring or of continuous development and remodelling. Growth in the maxilla and mandible is variable and multidirectional since it occurs in the sagittal, transversal and vertical plane. Throughout this gradual process, slow periods of growth are observed before periods of accelerated growth called growth spurts. [2,3]

Remodelling and drifting within the alveolar bone allow the teeth to remain in the same position in the dental arches by following the continuous physiological eruption and a stable occlusal dynamic can balance functional forces by compensatory mechanisms. [2,3] Then, it's essential to understand the study of the craniofacial complex and carry out a brief review of some concepts about the growth of cranial base and the maxillary growth.

Growth of cranial base occurs through an association between the elongation in synchondrosis (sphenoethmoidal, sphenooccipital and intersphenoid synchondrosis), suture growth and an extensive vertical displacement with remodelling. On the other hand, the cranial base is considered one of the most stable anatomical structures of the craniofacial skeleton being the one which suffers less influence from external actions, such as an orthodontic treatment or changes in neuromuscular function. [4]

Maxillary growth is based on a regulatory mechanism of craniofacial development from a suture system that surrounds the maxilla (frontomaxillary suture, zygomatic-temporal suture, zygomatic-maxillary suture, pterygopalatal suture) and drives it in 3 planes: anteroposterior, transversal and vertical. [5,6]

Maxillary growth in width is mostly dependent on the midpalatal suture (MPS), which generally follows the individual's general growth. The MPS remains opened until adolescence, closes between 16 and 17 years of age and grows, on average, 6-9 mm between 4 and 20 years of age. Even so, maxillary growth in length occurs by suture growth and bone deposition in the maxillary tuberosity. Thus, the maxilla is driven down and forward since its growth occurs upwards and backwards, considering the cranial base as the landmark. [6]

According to different studies (Sawyer, 2018; Heij, 2007), growth peak normally occurs in boys around 13 years old and girls around 11 years old, although the age can vary by about 6 years. Nonetheless, there is still a residual craniofacial growth in humans after this period during puberty. [1,7]

Through puberty, there are multiple hormonal changes linked to the adrenal gland (in which the activation of adrenal fatigue hormones starts between 6 and 9 years of age), the growth spurt and the gonadarche. Besides, its beginning occurs since the activation of the hypothalamic-pituitary-gonadal axis, which also means the biological landmark of adolescence's beginning. [1,7,8]

Significant and appreciable craniofacial growth begins with fetal development and continues from birth to adolescence. Through adolescence, the skeletal structure decreases in relation to body volume until adulthood, while body mass may continue to increase. In fact, several regions of the cranium reach adult dimensions throughout childhood at around 10 years of age. For example, the length of the cranium reaches approximately 90% of its full size at nearly 5-7 years. [2,9]

In the early 1980s, Behrents et al. demonstrated that facial maturation continues into adulthood. Some studies by Bjork, Skieller and Valletta reported that vertical changes of the facial skeleton during adulthood are more significant than anteroposterior changes during this period. Otherwise, transverse changes are less noticeable. [10,11]

Therefore, the association between craniofacial growth and dentoalveolar changes in the maxilla plays a fundamental role in the evolution of the facial skeleton, which remains a controversial topic throughout the years in the scientific literature.[2,11]

Indeed, according to more recent studies (Ely, 2014; Cocchetto, 2019; Jensen, 2019), craniofacial and dentoalveolar growth never cease and the continuous physiological eruption occurs throughout life, but decreases rapidly after adolescence, being residual and almost imperceptible after the second decade of life. Along this period, a continuous tooth eruption occurs, even after the occlusion has been established in the post-adolescence period, which leads to an increase in the height of the alveolar process. Long-term studies highlighted an annual vertical incisor eruption rate of 0,07-0,1mm in adults aged 20-40 years. Consequently, facial height increases over this period. [8,12,13]

One should be aware that dentoalveolar dimensions are established when the teeth of opposite jaws are in contact with each other and vary their development with the eruption of the teeth throughout the continuous development. Thus, craniofacial modifications are observed in all facial dimensions, size and shape, so it appears to carry on the facial growth pattern during maturation.[10,11]

Furthermore, the gradual increase in the palatal vault into adulthood appears to be an outcome of the continuous eruption of the teeth over time. [14]

However and sadly, the absence of permanent teeth in the aesthetic zone (anterior region of the maxilla) often occurs in children, adolescents and young adults, mostly as a consequence of dental trauma or agenesis. [15]

Generally, the treatment plan associated with these cases should also take into account the individual's systemic condition, individual’s age, the stage of skeletal development, the jaw growth pattern, facial and dental aesthetics, occlusion, the number of missing teeth and the anatomy of hard and soft tissues. [14,16]

Moreover, all these factors influence the long-term aesthetic results, which are usually another treatment’s objective in rehabilitation with implant supported crowns. [14,16-19]

Commonly, orthodontic closure of spaces, self-transplants and prosthetic rehabilitation can be considered as treatment possibilities for dental absences in the anterior region. Fixed rehabilitation with implant supported crowns has particularly become an option in the last decades avoiding adjacent tooth involvement, which serves as a support for the prosthesis in these individuals during the growth phase. This treatment modality is increasingly used and definitely considered a valid treatment option with high survival and success rate, as demonstrated in some studies (Klinge, 2020; Fudalej, 2007).[15,20]

One should keep in mind that implant placement in a development socket results in disruption of local alveolar growth, while growth continues in adjacent areas. Consequently, the vertical passive eruption of adjacent teeth along with dentoalveolar growth and the implant’s absence of periodontal ligament unlike natural teeth causes the "ankylosis" of dental implants. In fact, implants do not follow the movement of the surrounding structures, ultimately leading to aesthetic compromises in rehabilitation with implant-supported crowns such as submersion or infraocclusion. This phenomenon is more evident in the region of the upper incisors, which is considered a critical area for implant placement in the aesthetic zone, and it may impair psychosocial comfort, speech and chewing. [8,12,14-19]

According to several authors, there is still no consensus in the literature on the ideal timing and positioning of implant placement in individuals during growth, development and maturation periods in order to provide long-term clinical success. According to an implant conference in 1995, it was established that it is preferable to postpone implant placement beyond the end of craniofacial growth, especially in the presence of partial edentulism. [16,17]

Besides, the chronological age is not significant enough to indicate the terminus of the growth owing to individual susceptibility. Nevertheless, some authors (Ely, 2014) found out that the placement of implants at the age of 17 in boys and 14 in girls takes a biological and aesthetic risk, which can extend for longer periods until the age of 25 according to the different types of facial morphology. [8]

As a result, treatment of the aesthetic zone becomes a clinical challenge in the field of implant dentistry to select the appropriate treatment based on a clinical and radiographic examination that should assess and include the degree or severity of the vertical discrepancy of the equivalent contralateral tooth, the position of the incisal edge and the gingival margin of the same tooth as a reference. [19,21,22]

Last but not least, some diagnostic methods through measurements (e.g. craniometry and anthropometry) or experimental procedures may be used to perform growth prediction. [23]

In addition, cephalometric study, analysis of standardized clinical photographs, superimposition of digital images of dental cast models and scanning with IOS may be other complementary diagnostic methods able to verify and quantify dentoalveolar and facial modifications over time due to the dentofacial maturation and the continuous physiological eruption. Our aim was to review these methods used to determine dentofacial variations of positional changes and how they can be valued in the rehabilitation of the aesthetic zone in adolescents and young adults.

Analysis and superimposition of cephalometric radiographs

Cephalometric analysis has been a fundamental tool to detect and to quantify dentofacial anomalies, and also to measure the degree of dentoskeletal disharmony in orthodontic planning. It allows the tracing of teleradiographies at different development and maturation stages of subjects, which provide a detailed description of their skeletal maturation, facial growth and the possible effects of orthodontic treatment. [24,25,26]

First, there are several indicators of skeletal growth, which aim to identify the periods of acceleration and deceleration during the adolescents' skeletal maturation such as secondary sexual maturation characteristics, height dimension, changes in upper and lower body proportions and vertical changes of the continuous tooth eruption. One of the methods for assessing craniofacial growth is based on the superimposition and analysis of cephalometric tracings taken every 6 months until there are no growth changes for at least for one year. [8,25]

The "structural method", introduced in 1963 by Arne Bjork through research with implants, uses anatomical planes and elements rather than arbitrarily determined points and lines. This is the cephalometric method that currently has the greatest scientific validity, which indicated as stable natural references: the anterior wall of the sella turcica (and its point of intersection with the inferior contours of the clivus), the great wings of the sphenoid, the crimped blade, the floor of the orbit and the cortex internal front. [24]

Although Ba-Na or S-Na (recorded in “Sella” or “Nasion”) usually forms a reference line for overlaps in the anterior base of the cranium, some studies (Planch, 2006) have shown that the “Sella” and the “Nasion” or “Basion” are involved in local remodelling phenomena during the growth period. Considering that growth influences the change in the position of “Basion” and “Nasion”, both cephalometric points cannot be considered stable structures. On the other hand, the superimposition of the maxilla is also conventionally performed according to the ANS-PNS plane. However, this method tends to introduce significant distortions at the level of vertical displacement of incisors and molars. [24]

Moreover, radiation exposure and the long duration of this diagnostic method represent some of the disadvantages. There are also problems related to its lack of reliability, which leads to the difficulty at attributing scientific value to cephalometric analysis since several errors can occur, including the magnification of some anatomical landmarks or linear and angular dimensions’ identification. [8,27]

Otherwise, hand and wrist radiographs are mainly used to predict the adolescent growth peak, but they are not considered ideal to assess the cessation of craniofacial growth. [13]

Analysis and superimposition of clinical photographs

Currently, access to high-quality digital tools and the increasing use of social networks have been changing photography sources and anthropological analysis in human identification, mainly related to craniofacial analysis and dental superimposition methods. [28]

The aesthetic analysis of a smile is performed based on aesthetic dental references of dental morphology. To do this, it is possible to use digital guidelines as templates to help in the diagnosis and aesthetic planning of orthodontic and integrated treatments. [28,29]

In order to take the photographic analysis, it's necessary to establish and define the "natural position of the head" (NPH) to obtain standardized clinical photographs due to the impossibility of finding reproducible reference points with the head in its resting position. NPH is defined by the position of the head with the subject standing and looking straight ahead parallel to the ground as established by Broca. However, there are different ways to reproduce this position, so a cephalostat can also be used to find this position by taking standardized clinical photography. [30,31]

At this point, criteria for standardization of clinical photographs should be established to provide stability and analysis' reproducibility of all the details. A cephalostat attached to a rotating chair, which is one meter in front of the background, and both could be rotated together in order to take clinical photographs in many standard views. Also, the distance between the camera and the subject should be kept in 1 meter and a 10 mm paper ruler should be connected to different facial strategic points not only to focus the camera but also to adjust the size of the image in Photoshop (1 mm ruler scale represented 1 mm of actual size). [30]

Other overlapping method described was based on several horizontal and vertical smile lines, angles and a ratio between some of these lines in order to provide more reproducibility and quantify the dentofacial dimensional changes by Photoshop's functions and analysis. [32]

Besides, the dentoalveolar analysis is mostly performed with two-dimensional (2D) images, which have a lower recognition rate than tridimensional (3D) images owing to their minor content of information and precision. [33]

Intraoral scanners analysis and superimposition of digital images of dental cast models

The digital era of dental practitioners has been increasingly enhanced in recent years, with CAD/CAM (computer-aided design and computer-aided manufacturing) technology systems, introduced by Duret and Termoz in the 1970s, used in the area of Operative Dentistry and Prosthetic Oral Rehabilitation. Later, Mörmann and Brandestini developed the first digital IOS as a complementary tool to the CEREC system (economic aesthetic ceramic restorations in the office). [34]

At the same time, over the past few years, researchers have also been using softwares intending to align 3D digital models of dental plaster models and measure tooth movement over time. Superimpositions are made after selecting at least three landmarks as stable reference points in each model. Hence, literature shows that medial and lateral points of the third rugae area remain valuable reference points for superimposing dental cast models. [32,35]

Methodology

Search of literature

A literature review was carried out in order to select some of the most relevant and recent articles focused on the elected methods (as mentioned before) that allow an evaluation of dentoalveolar dimensional changes and their potential impact on prosthetic rehabilitation with implants of the aesthetic zones.

First, a screening of the articles was aggregated based on the review of the titles and abstracts for full-text reading. Only articles in English, French or Portuguese, published until January 2021 were included.

The initial search was made in October and November 2020 and was updated in April 2021. It was also amplified with manual searches of full-text articles identified by the electronic databases. Thus, this search included 103 relevant references after evaluating titles and abstract and full-text analysis from different databases, as described in ***Table 5***.

Eligibility criteria

The inclusion and exclusion criteria for selection and extraction of data are described in ***Table 1***.

Table 1 - **Inclusion and exclusion criteria**

Inclusion criteria	Randomized controlled trials (RCTs) and controlled clinical trials (CCTs)
	Systematic reviews
	Cohort studies
	Studies in adolescents and young adults
	Studies reported dentoalveolar changes through cephalometric landmarks/aesthetics evaluation based on photographic analysis/digital scanning and dental cast models' superimposition
	English, Portuguese or French abstract
	Last 20 years (since 2001), full-text
Exclusion criteria	Non-clinical studies and all other research types (for example, editorials, textbooks, and technical reports)
	Animal studies
	Studies that included patients with craniofacial anomalies, severe malocclusions, temporomandibular dysfunction, previous history of orthognathic surgery or undergoing orthodontic treatment
	Edentulous patients or missing teeth adjacent to implant-supported crown
	Studies with missing data

Search strategies

The bibliographic search was assessed by the following electronic databases: Cochrane Library, Embase, PubMed/MEDLINE, Scopus, and Web of Science.

Keywords used and searched in different databases of this study for each diagnostic method are presented and summarised in ***Table 2, Table 3 and Table 4.***

Table 2 - **Search strategy for each database of cephalometry**

Diagnostic method	**Database**	**Keywords**	**Articles included**
Cephalometry	Cochrane Library	"Cephalometry", "Dental implant", "Growth and development", "Young adult"	1
	Embase	"Cephalometry", "Dental implant", "Growth, development and aging", "Skeletal maturity", "Young adult"	5
	Pubmed (Medline)	"Cephalometry", "Craniofacial growth", "Dental implant", "Growth and development", "Young adult"	43
	Scopus	"Adolescents", "Cephalometry", "Dental implant", "Growth and development", "Young adults"	2
	Web of Science	"Adolescents", "Cephalometry", "Dental implants", "Dentoalveolar changes", "Growth and development", "Young adults"	2

Table 3 - **Search strategy for each database of photogrammetry**

Diagnostic method	**Database**	**Keywords**	**Articles included**
Photogrammetry	Cochrane Library	"Dental implant", "Growth and development", "Photography", "Young adult"	0
	Embase	"Dental implant", "Growth, development and aging", "Photography", "Skeletal maturity", "Young adult"	1
	Pubmed (Medline)	"Craniofacial growth", "Dental implant", "Growth and development", "Photography", "Young adult"	19
	Scopus	"Adolescents", "Dental implant", "Growth and development", "Photography", "Young adults"	0
	Web of Science	"Adolescents", "Dental implants", "Dentoalveolar changes", "Growth and development", "Photography", "Young adults"	0

Table 4 - **Search strategy for each database of IOS and digitization of dental cast models**

Diagnostic method	**Database**	**Keywords**	**Articles included**
IOS and digitization of dental cast models	Cochrane Library	“Dental implant”, “Growth and development”, “Intraoral scanners”, “Young adult”	0
	Embase	“Dental implant”, “Growth, development and aging”, “Intraoral scanners”, “Skeletal maturity”, “Young adult”	2
	Pubmed (Medline)	“Craniofacial growth”, “Dental implant”, “Growth and development”, “Intraoral scanners”, “Young adult”	17
	Scopus	“Adolescents”, “Dental implant”, “Growth and development”, “Intraoral scanners”, “Young adults”	0
	Web of Science	“Adolescents”, “Dental implants”, “Dentoalveolar changes”, “Growth and development”, “Intraoral scanners”, “Young adults”	1

Objectives

This review aims to identify and value the dentofacial parameters used to determine the significant deceleration of dentofacial growth and maturation, which results in dimensional dentofacial changes and influence the rehabilitation of the aesthetic zone in adolescents and young adults. Therefore, the objective remains to determine ways to measure these dentofacial factors in: cephalometry, dentofacial photographs, digital and facial dental models' superimposition.

Cephalometry

Cephalometry was introduced in Orthodontics in 1922 when Paccini published the first paper about the cephalogram, a method of assessing the relationship of craniofacial and dental structures on a radiograph, which are produced in a standardized manner. The first clinical application of the cephalogram took place in 1948 by Downs. For Down's clinical application the patient is placed in a cephalostat, which positions the head of the patient oriented 90 degrees to the X-Ray beam 5 ft from the tube. The film is then placed 15 inches from the head. These are standards under which all cephalometric radiographs are taken worldwide. [10]

According to Cervera et al., the cephalometric analysis or study is obtained by a series of measurements from an individual to be compared with tabulated values that are considered average (normal) in a population sample. It allows for an easier assessment of growth and the effects of treatment. Once the film is produced it's then traced and the necessary standard landmarks, lines, both skeletal and dental horizontal and vertical measurements and angles of dentofacial morphology are measured and recorded. These are then compared to the normal standard tracing to see any modifications. Besides, dentoalveolar heights can be evaluated in four measurements: upper anterior (UAFH), lower anterior (LAFH), upper posterior (UPFH), and lower posterior (LPFH). [10,11]

Facial growth pattern may be defined by Bjork's sum of the saddle angle (regarded as the cranial base angle), gonial angle and articular angle. Also, two reference structures can be determined: the Sella-Nasion line as the primary one due to its stability and the nasal line, comprising the anterior nasal spine and the posterior nasal spine, as the secondary one. [37] Later, Jarabak found another method based on Bjork's research in order to calculate and to compare linear and angular measurements in cephalometries. [24,36]

According to this method, the most relevant cephalometric points and planes are mentioned in ***Table 5***.

Table 5 - **Cephalometric measurements of Jarabak's analysis**

Dimension	**Definition**
Linear dimensions (mm)	
Anterior cranial base: S-N	Distance from Sella to Nasion
Posterior cranial base: S-Ar	Distance from Sella to Articulare
Ramus height: Ar-Go	Distance from Articulare to Gonion
Anterior facial height: N-Me	Distance from Nasion to Menton
Posterior facial height: S-Go	Distance from Sella to Gonion
Mandibular body length: Go-Me	Distance from Gonion to Menton
Angular dimensions (º)	
Saddle angle: N-S-Ar	Angle between anterior and posterior cranial base
Articular angle: S-Ar-Go	Angle between posterior cranial base and ramus height
Gonial angle: Ar-Go-Me	Angle between ramus height and mandibular plane
Upper gonial angle: Ar-Go-N	Angle between ramus height and Gonion-Nasion line
Lower gonial angle: N-Go-Me	Angle between Gonion-Nasion line and mandibular plane
Jarabak sum	Sum of angles (Saddle angle, Articular angle and Gonial angle)

In conclusion, this analysis cannot be exclusively utilized as a diagnostic and treatment method to plan decisions, but also to predict and assess craniofacial and skeletal changes over time. [35]

Photogrammetry

We also take into account a review of measurement techniques applied to photographs to facilitate the evaluation of the dentofacial changes on the smile.

First, the importance of use a cephalostat is shown as undoubtably as a fundamental way to define the NPH of the head before taking standardized clinical photographs. [30,31,38,39]

In fact, the cephalostat may be fixed and attached to a rotating chair that is always kept in the same position in order to obtain a standardized technique of clinical photographs. This system stabilizes the head's NPH and guarantees high reproducibility. The coronal facial plane presented two stable reference points as support in the cephalostat and remained constant: in the frontal and chin regions. The frontal support prevents the face from moving forward and the chin support limits the anterior and inferior advance of the face. Moreover, the height of the photographic cephalostat is maintained by a wheel connected to the vertical rod that connected the cephalostat to the chair. The clinical photographs are taken in standard and parameterized positions and under the same light and exposure conditions with each individual seated 1 meter away in front of a wall of the office and the camera 1 meter away from the chair. [30,38]

Facially driven smile design tools such as Digital Smile Design (DSD), which helps to plan orthodontic and prosthodontic cases before or even during therapy, can also be used. The aesthetic analysis of the smile according to DSD is based, at least, on 5 images that must be imported into a software (PowerPoint, Keynote or a similar program). Dental photographs are required to evaluate the smile and its integration with the subject's face, including a full smile (maximum display), a photograph in maximum intercuspation with the soft tissues apart, and a photograph with the lips at rest. In addition, photographs with a half-open smile (close-up) with lip retraction are needed in order to create the smile design for the final aesthetic evaluation. [18] Furthermore, other similar techniques may also be used and can complement the dentofacial dimensions' evaluation, for example, FaceFlow and SmileCloud.

SmileCurves Template (SCT) is another digital smile tool of diagnostic. It's a digital template with Diagrams of Dental Aesthetic References (DDAR), presented as a whole with the six horizontal smile lines (upper lip line, cervical line, papillary line, line of contact points, incisal line and lower lip line). It enables the guidance of positions and proportions of teeth, but also gingival contour and lips. This aesthetic smile analysis software benefits from its easy and simple use and execution. It can be used with any 2D or 3D imaging software, being adapted to a PNG (Portable Network Graphics) file. [28]

Also, clinical photographs may be managed with a 10 mm digital milimeter ruler calibrated with a conventional ruler to focus the camera and to measure dental and facial discrepancies of the smile in the aesthetic zone. Effectively, this electronic transparent ruler is superimposed and it helps to obtain a 1:10 ratio (1 mm on the model is equal to 10 mm on the photographs). It allows for the evaluation of several dentofacial measures in the aesthetic zone, such as the actual width of the maxillary left central incisor. [12,30,36,40]

Schwartz-Arad and Bichacho studied vertical dimension changes between the incisal edge of an implant-supported crown replacing a central incisor and the adjacent central incisor (natural tooth). This retrospective study [41] assessed vertical discrepancies by a direct measurement technique using the Image J software. They defined the mean submersion rate as a mathematical expression in terms of percent of crown occlusal-gingival length per year. [41]

In addition, another method (De Angelis, 2007) was based on two lines drawn: a tangent line to the most occlusal points of the distal surface of both canines (line q) and another line perpendicular to line q and tangent to the mesial profile of a central incisor tooth (line r). Then, the contact points between line q and canines are identified as A and B and both lines (q and r) are intersected at the point C. After that, ratio AB/AC measured between both width segments represents an indicator of the variation of torsion. Furthermore, an angle α is created by the intersection of a straight line from point A, tangential to a reference point, and line q, which measures the extension in a smiling position. [32]

Intraoral scanners and digitization of dental cast models

The use of IOS allows us to capture information about the dental arches and calculate volumetric changes. The digital development of this tool allowed an assessment and measurement of 3D surfaces. Then, standard tessellation language (STL) files store all the digital data and allow the recognition of all the geometry of 3D objects by triangulation. Its applicability extends from the planning of implant surgeries and orthodontic treatments, as well as prosthetic rehabilitation planning as a whole. [21,34,42]

3D digital dental models can be produced from digital images of teeth and soft tissues, after the scanning of conventional impressions, intraoral digital impressions or scanning of plaster cast models. In this last case, conventional dental plaster models are taken and digitized with a surface scanner, similar to the one obtained intraorally. This analysis and evaluation of study models depend on several parameters evaluated at different timepoints of the treatment, such as the length of the crown measured from the gingival zenith to the incisal edge, the distance between gingiva and mucosa, measured from neighbouring natural tooth zenith to implant mucosa zenith, and incisal edge gap measured between lowest incisal edge position of implant crown and adjacent teeth. The distance between zenith points aims to identify modifications in the mucosal level. [6,42,43]

As stated by recent studies (Ghislanzoni, 2017; Kiliaridis, 2019), the plaster models may be scanned with Trios of 3Shape, as used by those authors, stored in STL format, and palate's superimposition may be performed in 2 different ways among different time points using Viewbox (dHAL Software, Kifissia, Greece). [19,44] However, we should first understand how volumetric changes can be evaluated. One evaluation method is based on the superimposition on the palatal vault in a region called the "mushroom area" - this region is comprised of the palatine rugae to a posterior region along the palatine raphe in the hard palate. Palatal rugae are anatomical references derived from hard connective tissue covered by stratified epithelium into the anterior part of the palate. Their analysis is considered one of the most reproducible and reliable methods for personal identification following well-preserved soft tissues and has an additional advantage of their central localization in the oral cavity. When a comparison is made by the superimposition of the silhouette of palatal rugae, the percentage of accuracy is high and reaches 100%. [19,43-45]

Other superimposition's method is performed along the occlusal surface of the premolars and molars, that is, the functional occlusal plane. After the superimposition of both models, an occlusal point and a gingival point of all maxillary teeth from the first molar to the first molar is digitized and the vertical displacement of the tooth crown and the gingival height is measured. Then, fourteen digitized points are obtained (one occlusal point and one gingival point for each tooth) from each digital model that represented the gingival and occlusal limits of the vestibular axis of the clinical crown. In this case, the method aims to calculate 3D coordinates of all the points in order to measure the vertical discrepancy of the digitised points. [19,44]

Results

Analysis and superimposition of cephalometric radiographs

Some tooth eruption parameters, including dental and alveolar components of upper incision eruption, described a significant increase after 20 years. Particularly, it was described an increased growth of anterior and posterior facial height, mainly in the LAFH, was described. [46,47]

The inter-gender difference was statistically significant for the distance between the palatal plane and the incisal edge of the maxillary incisor. [48]

Summary of findings for cephalometric studies in the anterior maxilla is presented in ***Table 6***.

Table 6 - **Results of analysis and superimposition of cephalometric radiographs**

Study publisher	Type of study	Mean age of subjects	Results	Conclusions
Valletta, 2020	RCT	15.5 ± 5.5 years	For each increase of one degree in SNˆGoGn occurred an increase in UAFH by 0.8 mm.	Dentoalveolar heights are dependent on the mandibular growth pattern.
Oualalou, 2016	RCT	13-17 years (follow-up: 3.7 ± 2.3 years)	The vertical dimension value for S-Ena showed an increase. ANB angle and Go-Gn-SN angle reduced. All parameters related to the sagittal dimension, Ar-Pog, Ar-Gn, Go-Gn, Co-Pog, Co-Gn, Pog-NB and Co-A, increased significantly.	Boys are associated to a greater reduction of the vertical dimension than girls.
Poelmans, 2016	RCT	21.5 years (follow-up: 20 years)	The average eruption at incisors in the maxilla was 1.0 mm.	Making a comparison between measurements at the cusp or incisal level (dental factor) and measurements at the alveolar (alveolar factor), it was concluded the increase was smaller for eruption measurements at the alveolar level.
Aarts, 2015	Cohort	15.4 years (follow-up: 2, 5 and 10 years)	At the end of the observation period, approximately 20% of the subjects were related to an increase in the anterior facial height (N-Me).	Facial type pattern and the timing of cessation of facial growth are not associated.
Davidovitch, 2015	RCT	-	Only lower anterior facial height was considered to have a significant effect with the age of subjects among all Bjork indicators.	Bjork's structural method shows low unanimity.

Table 6 - **Results of analysis and superimposition of cephalometric radiographs (continuation)**

Study publisher	**Type of study**	**Mean age of subjects**	**Results**	**Conclusions**
Tavares, 2014	Review	-	Both males and females were associated with an increase in facial height (mainly in the lower face) and an increase in mandibular length.	The most reliable diagnostic method to evaluate the terminus of facial growth is superimposition of cephalometric radiographs with a minimal 6-month interval.
Heij, 2006	Review	-	The average eruption along the active growth phase was 1.2-1.5 mm/y, and was reduced annually to 0.1-0.2 mm afterward, even after the age of 18.	Timing of cessation of craniofacial growth and facial type can also be associated.
Planché, 2006	Review	-	According to Bjork, the stable maxillary structure is the anterior contour of the zygomatic process.	Bjork's structural method can highlight the potential effects of a wide variety of treatment strategies.
Bernard, 2004	Cohort	15.5-21 years (young adults) (Follow-up: 4.2 years)	Infraocclusion of dental implants was evidenced with an average value of 0,7 mm (range: 0.1-1.9 mm) related to maxillary incisors adjacent to implants in a sample of adults (mean age of 43.6 years) for an average period of 4 years.	No differences in vertical eruption changes of adjacent teeth and changes of implant position.
Kokich, 2004	RCT	-	No vertical facial height changes (Nasion to Menton) after superimposition of cephalometric radiographs.	A second cephalometry should be performed after 6 months to a year to assess whether skeletal growth terminus has been reached.

Analysis and superimposition of clinical photographs

The direct measurement technique based on submersion rate measurement (Schwartz-Arad, 2015) assessed and quantified vertical discrepancies using the Image J software. However, this software showed a lack of uniformity and scale in the photos. [41]

SCT, another direct measurement method, involves some characteristics of the smile, such as the tooth axes, symmetry, gingival contour, incisal edges, interproximal contacts and dental proportions, which helps to transfer the design of the dental and gingival lines in order to compare and measure different clinical photographs. This results in a such useful tool into an aesthetic pattern of dentofacial analysis. [28]

Summary of findings for photographic analysis and evaluation of dentofacial changes is presented in ***Table 7.***

Table 7 - **Results of analysis and superimposition of clinical photographs**

Study publisher	Type of study	Mean age of subjects	Results	Conclusions
Whiteman, 2020	Review	-	DSD procedure is completed with the retracted close-up image before the teeth outline can be converted to smile images (both close-up and portrait).	The two-dimensional evaluation of the DSD does not allow the evaluation of teeth pro-inclination, malocclusion, the plane of occlusion, open bite and the anteroposterior dimension of the teeth.
Câmara, 2019	Article	-	The width of the upper central incisors should coincide on frontal smile or intraoral image, and it should be assessed by the use of DDAR references and the six horizontal smile lines.	SCT facilitated the visualization and interpretation of the data obtained and allowed the transformation of subjective concepts into objective information.
Cocchetto, 2019	RCT	Older than 20 years (follow-up: minimal of 5 years)	Infraposition or submersion of implants was verified in 21 cases out of 44 in the young/adult group (<30 years). Otherwise, 23 out of 44 were related to the mature/adult group (>30 years).	Infraocclusion is expected to have a high incidence in adults treated with implants in the aesthetic zone in the maxilla.
Mahn, 2019	RCT	18-32 years	83.7% of patients showed papilla or more for posed smiles, as well it was an increase to 97.9% for spontaneous smiles.	Women showed a higher rate of gingival display than men for both posed and spontaneous smiles.
Schwartz-Arad, 2015	RCT	29.2 ± 10.09 years (follow-up: 7.4 ± 4.5 years)	The amount of eruption was more than three times in the younger age group (≤30 years) than in the older age group, yielding submersion rates of 1.02 and 0.27% 24 per year, respectively. Although, there were no statistical differences between the second and third or between the fourth and fifth decades of life.	No vertical discrepancies of anterior maxillary teeth adjacent to a single implant in young and mature adults, as well in males and females.

Table 7 - **Results of analysis and superimposition of clinical photographs (continuation)**

Study publisher	Type of study	Mean age of subjects	Results	Conclusions
Han, 2010	RCT	20-29 years	No significant statistical variations of the validation's analysis of the standardized photography (e.g., the repeatability of photographs obtained was excellent).	The repeatability of the technique described based on standardized clinical photography was very high.
De Angelis, 2007	Experimental study	-	The correct correspondence cast a score higher than the index of correspondence 50, which was attributed in all the cases described.	This method ensures a cheap and quick technique, unlike other more frequent methods that are not applicable.
Usumez, 2001	RCT	18-24 years	Method errors of 0.7° (SD, 0.8) and 0.6° (SD, 1.0) and correlation coefficients of 0.977 and 0.984 were detected by sets of films, respectively.	The cephalostat with the inclinometer device show to have high repeatability and reproducibility.

Intraoral scanners analysis and superimposition of dental images from dental cast models

Teeth that suffered the most eruption alterations were the central and lateral incisors. In this study, wide inter-individual variability was also observed, in which some subjects showed no changes in the eruption, while others presented a significant eruption (greater than 1.0 mm). [19]

87% and 78% percent of the central incisor measured in the test group moved more than 0.25 mm vertically and 0.25 mm horizontally, respectively, compared with the control group after 5 years. [35]

Summary of the findings for analysis of dental images from IOS and scanning of dental cast models is presented in ***Table 8***.

Table 8 - **Results of intraoral scanners analysis and superimposition of dental images from dental cast models**

Study publisher	Type of study	Mean age of subjects	Results	Conclusions
Wiedemann, 2021	RCT	20-79 years (follow-up: 16 years)	Vertical changes in the continuous eruption were 0.33 ± 0.3 mm during a 16-year study period, which means an average of 0.021 mm/y.	Functional, periodontal and aesthetics long-term outcomes can be compromised due to the increase in continuous eruption, although it does not affect each patient to the same degree.
Wittneben, 2021	RCT	23-79 years (follow-up: 3 years)	Vertical eruption of the incisal edge-to-edge landmarks was always observed over the 36 months of the study period.	Vertical tooth eruption adjacent to a single dental implant crown was continuously observed in adults.
Henninger, 2019	RCT	22.1–35.7 years (follow-up: 15.1 months)	The smaller the reference area chosen, the higher the risk of artifacts in the detected tooth movements.	A tendency was observed between the decrease of effects described in this study and the increase of the reference area used for overlapping.
Jensen, 2019	Review	-	The interruption of skeletal growth should not be considered the only predictor factor of implant submersion.	The risk of infraocclusion of implants may be minimized while skeletal growth documented by two body height dimensions is ensured, at least 1 year apart, with ideal interocclusal contact.
Kiliaridis, 2019	RCT	-	The mean vertical displacement of anterior teeth neighboring to single implants was recorded to be about 0.7 mm over a period of 1-3 years.	The continuous tooth eruption of the maxillary incisors was significantly correlated to masseter muscle thickness and clinical crown lengthening.

Table 8 - **Results of intraoral scanners analysis and superimposition of dental images from dental cast models (continuation)**

Study publisher	Type of study	Mean age of subjects	Results	Conclusions
Brahem, 2017	RCT	29.7 ± 10 years (follow-up: 7 ± 1 years)	87% and 78% percent of the central incisors measured in the test group moved more than 0.25 mm vertically and 0.25 mm horizontally, respectively, compared with the control group after 5 years.	Small large amounts of defects in the plaster models caused the exclusion of 1% of the teeth.
Ghislanzoni, 2017	RCT	33-58 years (follow-up: 10 years)	Vertical changes in the maxilla after 10 years associated with an average eruption of 0.3 mm in the aesthetic zone.	Although the results presented, the actual discrepancy of teeth next to an implant crown may be bigger, due to some vertical remodelling that can happen with the palatal reference plane used in the study.
Wittneben, 2016	RCT	-	Supraimplant emergence profile modifications highlighted a mean extension of 41.9 ± 20.3 mm3 and 25.8 ± 10.4 mm3 for central and for laterals incisors, respectively.	At the moment, precision analysis for volumetric soft tissue changes by the use of IOS devices has not been exhaustively tested with high accuracy.

There is very low-quality evidence for continued development in the alveolar bone of the anterior maxilla and dentofacial maturation, even after skeletal growth is considered residual in adolescents and young adults.

Furthermore, there is low evidence regarding the methods of assessment and analysis of the identified parameters of craniofacial growth evaluation.

Discussion

Ideally, the treatment of choice should be the least invasive option that satisfies the expected aesthetic and functional goals. Bonded bridges, removable dentures, Maryland bridges or orthodontic treatment are some reliable therapies that could be selected for replacing a missing tooth until the cessation of residual growth and dentofacial maturation. The patient's psychosocial factors must be considered. [17]

First, the development rate of the maxilla decreases and stagnates throughout life, while dentofacial and dentoalveolar dimensions achieve non-valuable short-term measurements due to very small variations. This demonstrates how residual growth occurs, mainly during the skeletal maturation phase along adulthood. [10,17]

Whereas post pubertal craniofacial changes affect the maxilla, incisors can erupt 6 mm incisal and 2.5 mm forward, while molars have the potential to erupt 8 mm occlusal and 3 mm forward, from the age of 9 to 25. It explains the development of the facial skeleton and continuous eruption of adjacent anterior teeth that continues after puberty, leading to a significant risk of aesthetic and/or functional changes in adolescents and young adults. Simultaneously, the amount of growth gradually decreases throughout life and seems to be clinically insignificant and residual after the second decade of life. [17,41,49]

At this point, we should take in account that the analysis of the angular variables also reported a posterior rotation of the mandible and an uprighting of the maxillary incisors with a greater incidence in women according to some studies (Kritzler, 2015; Kritzler, 2017). Also, the anterior face height increased 1.60 mm on average, which highlights an eruptive movement of teeth and a vertical growth of their surrounded tissues. [14,17]

We should always be aware of an increasing daily challenge in clinical practice in achieving satisfactory aesthetic and functional long-term outcomes owing to the increase in patients' expectations and in particular to the rehabilitation with insertion of dental implants. From this point of view, although implants' submersion is continuous throughout life, this phenomenon is more evident during the second and third decades of life compared to older ages and men have a lower risk of submersion. Even so, this aesthetic outcome is rarely detected within the first 5 years after implant placement. [12,17,21,41]

At the Consensus Conference "Oral Implants in Young Patients" it was established that implants should not be placed until the end of growth or almost complete development of the individual. In fact, its placement in the aesthetic zone should be postponed after the age of 25 years as a consequence of the continuous changes in anterior face height and posterior rotation of the mandible, mainly in women. [22,50]

Also, even mature adults, older than 40 years of age, may present implant submersion of, at least, 1.5 mm when assessed 5-18 years after the baseline of its placement according to some studies (Schwartz-Arad, 2015; Jensen, 2019). Thus, skeletal and dental maturation of the craniofacial complex should be taken as a deciding factor in the timing of implants' placement instead of chronological age in order to avoid their infraocclusion. [13,17]

Analysis and superimposition of cephalometric radiographs

The determination of vertical dimensions in a specific patient can be made from superimposed cephalometric radiographs at 6-month or 1-year intervals. One of the main disadvantages of this method is that the continuous natural eruption of teeth in adults occurs slowly over decades, rather than being rapid as it happens in children. Consequently, cephalometric analysis shows difficulty in quantifying and measuring dentoalveolar modifications from the second and third decades of life, when dentofacial maturation is considered residual. [46,51]

Besides, the positive correlation of LAFH with increasing age is consistent with the increase in anterior facial height reported in previous studies (Davidovitch, 2016). [23]

Analysis and superimposition of clinical photographs

There are many techniques and study protocols to take standardized clinical photographs, which are able to assess the dimensional modifications throughout different timelines.

Some disadvantages are associated with DSD. Actually, it's a two-dimensional method of photographic analysis, which makes it impossible to evaluate the teeth pro-inclination, malocclusion, the plane of occlusion, open bite and anterior-posterior dimension of the teeth. Otherwise, the main advantage of this aesthetic dental assessment tool is the ease of communication between professional and patient. [18]

The validation of the standardization of a clinical photography technique with the use of cephalostat and the setup of the standard NHP reported that the repeatability of the standardized photographs of this method showed statistical significance. In fact, it seems to be the most reproducible and accurate method to perform in order to obtain standardized clinical photographs and to measure dimensional changes. [30]

SCT may be used in many clinical cases, for instance, in 3D planning software programs. Therefore, this tool can be clinically useful to support dental planning of aesthetic evaluation of the maxillary anterior teeth. However, its efficiency shall be better studied in future studies. [28]

Intraoral scanners analysis and superimposition of digital images of dental cast models

Dentoalveolar dimensional changes can also be measured by superimposition of dental images from intraoral scanners and dental cast models.

The potential application of 3D superimposition of plaster dental models for dental identification is determined in several studies (Mou, 2020; Gibelli, 2018; Brahem, 2017). Actually, some authors reported that the majority of the subjects with the cast superimposition method showed a small amount (<0.5 mm) of tooth discrepancy in the vertical and horizontal plane. Also, the authors concluded that radiographic photographs alone are not accurate enough, so they recommended a more active investigation of digital techniques. [33,35,45]

Besides, findings in a study with cast analysis among all-time points detected vertical eruption discrepancies in anterior maxillary teeth adjacent to single-implant-supported crowns after 3 years of follow-up. [5]

In addition, vertical discrepancies and the pattern of continuous eruption at the level of the maxillary teeth were assessed, from the first molar to the first molar, through the superimposition of 3D digital models in a stable area - the palatal rugae. This region, described as the “mushroom area”, shows a relatively low accuracy due to some vertical remodelling. [19,44]

Most studies (Wittneben, 2016; Tomita, 2018; Henninger, 2019) mention the high precision of IOS, while plaster models do not differ significantly. Summing up, IOS becomes an easy and fast tool to use, a risk-free scanning process that avoids the use of radiation and non-invasive. Both methods, IOS analysis and digital models’ analysis, incrare associated with some disadvantages like the high cost of equipment and the long chair time during digitization. However, the accuracy of measuring soft tissue volumetric parameters using IOS devices has not been extensively tested and needs further studies. [21,34,43]

Thus, it seems advisable to incorporate more than one digital technique due to the difficulty to quantify dentoalveolar changes on cephalograms, such as with the analysis of standardized clinical photographs and/or with the superimposition of digital images of dental cast models with IOS.

Conclusions

To summarise, the craniofacial growth and dentoalveolar modifications in adolescents and young adults along the continuous physiological eruption can be accurately assessed using different standardized techniques described in this review.

Especially from the second and third decades of life onwards, an increase growth of the LAFH remains, while dentofacial maturation is considered residual.

On the one hand, cephalometry establishes the most accentuated growth after puberty with several significant changes until the end of the second decade of life. After this period, dentoalveolar changes seem to be more difficult to quantify by cephalometric techniques.

Nevertheless, features of this review highlight the lack of prospective studies with a study protocol, a well-defined and a calibrated investigation technique to improve the scientific knowledge. Therefore, new prospective study designs are needed to validate each evaluation's method of dentoalveolar changes and to understand the impact of adult craniofacial growth on the long-term clinical outcomes of implant-retained restorations in the aesthetic area.

Acknowledgements

First of all, I would like to thank my supervisor and co-supervisor Professor Doutor João Paulo Tondela, Professor Doutor Francisco do Vale and Professor Doutor Francisco Caramelo for all the support in this research, and also for being personal and professional references along all these academic years. Thank to Professor Francisco Silva and Débora Gomide for their assistance and encouragement during this study.

Secondly, I would like to thank my two colleagues, João Pedro Matos and Constança Pessoa, for giving me an anchor of all the most difficult hours. There is no doubt that some friendships are for life.

I would also like to thank all the Teachers, who helped me to evolve and stimulate the ambition of wanting more and better, without whom I would not have reached this moment and improved my abilities and skills as a future doctor.

To all the Department staff who have always been available, I would love to express my deep gratitude for your availability, dedication and generosity.

A special thank to my family not only for their unconditional support day after day but also for always giving me the best opportunities to pursue my dreams and to teach me such rich principles and values that I will always keep in mind. Without them, nothing else would make sense. I could not feel more grateful and proud of them.

I would also like to thank my friends for supporting me unconditionally every single day, impelling me in the worst of times and for always applauding me in the best. Particularly, I would also like to give a special thank to Joana Coelho for always being there when I needed it.

A special reference for Dentistry… When we focus on things with a lot of passion, we make them happen even faster. Whatever it happens, this is the life I chose.

Last but not the least, I would also like to thank Coimbra… Through a time of uncertainty, you became one of the greatest certainties of a lifetime. Now, I am saying goodbye with an enormous desire that it becomes a “see you soon”.

Bibliographic References

1. Sawyer SM, Azzopardi PS. Viewpoint The age of adolescence. Lancet child Adolesc Heal. 2018;2(18):223–8.
2. Daftary F, Mahallati R, Bahat O, Sullivan RM. Craniofacial growth in adults and its implications for implant reconstruction. Dent Implant Complicat Etiol Prev Treat Second Ed. 2015;572–84.
3. Agarwal N, Kumar D, Anand A, Bahetwar S. Dental implants in children: A multidisciplinary perspective for long-term success. Natl J Maxillofac Surg. 2016;7(2):122.
4. Enlow D. Handbook of Facial Growth. 3rd ed. W.B. Saunders; 1975.
5. 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. 2021;1–6.
6. Moyers R. Handbook of orthodontics. 4th ed. Year Book Medical Pub; 1988.
7. Heij DGO, Opdebeeck DDSH, Steenberghe DDSD Van, Kokich VG, Belser MSDU, Quirynen DMDM. Facial development, continuous tooth eruption, and mesial drift as compromising factors for implant placement. J Prosthet Dent. 2007;98(2):88.
8. Ely B, Tavares C. What is the appropriate age for dental implant placement? Dent Press Implantol. 2014;8(2):91–9.
9. Ross AH, Williams SE. Craniofacial growth, maturation, and change: Teens to midadulthood. J Craniofac Surg. 2010;21(2):458–61.
10. Proffit WR, Fields HW, Sarver DM, Ackerman JL, Ortodontia Contemporânea, 5th. edition, Rio de Janeiro: Elsevier Editora Ltda; 2013. 92-104 p.
11. Valletta R, Rongo R, Madariaga ACP, Baiano R, Spagnuolo G, D’Antò V. Relationship between the condylion-gonion- menton angle and dentoalveolar heights. Int J Environ Res Public Health. 2020;17(9).
12. 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.
13. Jensen SS. Timing of Implant Placement after Traumatic Dental Injury. J Endod. 2019;45(12):S52–6.
14. Kritzler K, Kritzler U. Damned if we do and Damned if we don ´ t . The Role of Implants in the Combined Orthodontic- Restaurative Treatment of Lateral Incisor Agenesis . Review of an Orthodontic Dilemma . 2015;(December):1–34.

15. 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. 2021;79(1):59–68.
16. 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.
17. Kritzler K, Bartzela T, Kritzler U. Damned if we do and Damned if we don ´ t part II. Adverse effects of implant treatment in the combined orthodontic-restorative treatment of maxillary incisor agenesis . Review of an esthetic dilemma . 2017;(April):1–23.
18. Whiteman YY. A Communication Guide for Orthodontic-Restorative Collaborations: Digital Smile Design Outline Tool. Dent Clin North Am. 2020;64(4):719–30.
19. Kiliaridis S, Jonasson G, Ghislanzoni LTH. Functional factors associated with continuous eruption of maxillary incisors in adulthood: A 10-year prospective cohort study. Int J oral Implantol (Berlin, Ger. 2019;12(3):329–35.
20. 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 Dentofac Orthop. 2007;131(4 SUPPL.).
21. Wittneben J-G, Brägger U, Buser D, Joda T. Volumetric Calculation of Supraimplant Submergence Profile After Soft Tissue Conditioning with a Provisional Restoration. Int J Periodontics Restorative Dent. 2016;36(6):785–90.
22. Zitzmann NU, Arnold D, Ball J, Brusco D, Triaca A, Verna C. Treatment strategies for infraoccluded dental implants. J Prosthet Dent. 2015;113(3):169–74.
23. Davidovitch M, Eleftheriadi I, Kostaki A, Shpack N. The use of Bjork's indications of growth for evaluation of extremes of skeletal morphology. Eur J Orthod. 2016;38(6):555–62.
24. Planch G. La m é t h o d e structurale d e Arne Bjôrk et Vibeke Skieller. 2006;347–58.
25. Al-Jewair TS, Preston CB, Flores-Mir C, Ziarnowski P. Correlation between craniofacial growth and upper and lower body heights in subjects with class I occlusion. Dental Press J Orthod. 2018;23(2):37–45.
26. Vale F. Análise estética da face da população portuguesa com base na posição natural da cabeça. 2004;
27. Durão AR, Bolstad N, Pittayapat P, Lambrichts I, Ferreira AP, Jacobs R. Accuracy and reliability of 2D cephalometric analysis in orthodontics. Rev Port Estomatol Med Dent e Cir Maxilofac. 2014;55(3):135–41.

28. Câmara CA. Analysis of smile aesthetics using the smilecurves digital template. Dental Press J Orthod. 2020;25(1):80–8.
29. Shirley P, Prado A. Superimposing Images of the Smile on Carbonised Remains for Human Identification Purposes. 2019;10(1):1–3.
30. Han K, Kwon HJ, Choi TH, Kim JH, Son D. Comparison of anthropometry with photogrammetry based on a standardized clinical photographic technique using a cephalostat and chair. J Cranio-Maxillofacial Surg. 2010;38(2):96–107.
31. Üşümez S, Orhan M. Inclinometer method for recording and transferring natural head position in cephalometrics. Am J Orthod Dentofac Orthop. 2001;120(6):664–70.
32. De Angelis D, Cattaneo C, Grandi M. Dental superimposition: A pilot study for standardising the method. Int J Legal Med. 2007;121(6):501–6.
33. Mou Q nan, Ji L ling, Liu Y, Zhou P rong, Han M qi, Zhao J min, et al. Three-dimensional superimposition of digital models for individual identification. Forensic Sci Int. 2021;318:110597.
34. Tomita Y, Uechi J, Konno M, Sasamoto S, Iijima M, Mizoguchi I. Accuracy of digital models generated by conventional impression/plaster-model methods and intraoral scanning. Dent Mater J. 2018;37(4):628–33.
35. 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.
36. Alshahrani I, Kamran MA, Alhaizaey A, Abumelha N. Evaluation of skeletal variations and establishment of cephalometric norms in saudi sub population using bjork jarabak’s analysis. Pakistan J Med Sci. 2018;34(5):1104–9.
37. Feher B. The effect of residual craniofacial growth on implants in the anterior maxilla- a long-term cephalometric study. Clin Oral Implants Res. 2019;30(S19):7–8.
38. Paccanaro RC, Gragnani A, Calil JA, Secco LG, Miranda RE de, Bersou G, et al. Padronização e avaliação fotográfica em cirurgia periorbital. Rev bras cir plást. 2010;25(2):278–84.
39. Janu A, Azam A, Tandon R, Chandra P, Kulshrestha R, Umale V. Photographic Evaluation, Analysis and Comparison of Aesthetically Pleasing Smiles: A Prospective Study. Turkish J Orthod. 2020;33(3):177–82.
40. Mahn E, Sampaio CS, Pereira da Silva B, Stanley K, Valdés AM, Gutierrez J, et al. Comparing the use of static versus dynamic images to evaluate a smile. J Prosthet Dent. 2019;1–8.

41. 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.
42. Flügge T V., Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofac Orthop. 2013;144(3):471–8.
43. Henninger E, Vasilakos G, Halazonetis D, Gkantidis N. The effect of regular dental cast artifacts on the 3D superimposition of serial digital maxillary dental models. Sci Rep. 2019;9(1):1–12.
44. 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.
45. Gibelli D, De Angelis D, Pucciarelli V, Riboli F, Ferrario VF, Dolci C, et al. Application of 3D models of palatal rugae to personal identification: hints at identification from 3D-3D superimposition techniques. Int J Legal Med. 2018;132(4):1241–5.
46. Poelmans S, Clijmans M, Fieuws S, Willems G. Cephalometric appraisal of post-treatment tooth eruption: A 20 year follow-up study. Eur J Orthod. 2016;38(1):71–8.
47. 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.
48. 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 Cranio-Maxillofacial Surg. 2015;43(10):2106–11.
49. Oualalou Y, Antouri MA, Pujol A, Zaoui F, Azaroual MF. Residual craniofacial growth: A cephalometric study of 50 cases. Int Orthod. 2016;14(4):438–48.
50. Bergendal B. When should we extract deciduous teeth and place implants in young individuals with tooth agenesis? J Oral Rehabil. 2008;35 Suppl 1(4):55–63.
51. Kokich VG. Maxillary lateral incisor implants: Planning with the aid of orthodontics. J Oral Maxillofac Surg. 2004;62(SUPPL. 2):48–56.
52. Chang M, Wennström 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.
53. Gunes H, Piccardi M. Assessing facial beauty through proportion analysis by image processing and supervised learning. Int J Hum Comput Stud.

2006;64(12):1184–99.
54. 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.
55. Ponce-Garcia C, Ruellas ACDO, Cevidanes LHS, Flores-Mir C, Carey JP, Lagravere-Vich M. Measurement error and reliability of three available 3D superimposition methods in growing patients. Head Face Med. 2020;16(1):1–20.
56. Heinz J, Stewart K, Ghoneima A. Evaluation of two-dimensional lateral cephalogram and three-dimensional cone beam computed tomography superimpositions: a comparative study. Int J Oral Maxillofac Surg. 2019;48(4):519–25.
57. Nilsson A, Johansson L åke, 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;21(5):953–9.
58. Oesterle LJ, Cronin RJ. Adult growth, aging, and the single-tooth implant. Int J Oral Maxillofac Implants. 2000;15(2):252–60.
59. Park GH, Son KB Da, Lee KB. Feasibility of using an intraoral scanner for a complete-arch digital scan. J Prosthet Dent. 2019;121(5):803–10.
60. Tekın A, Cesur Aydın K. Comparative determination of skeletal maturity by hand–wrist radiograph, cephalometric radiograph and cone beam computed tomography. Oral Radiol. 2020;36(4):327–36.
61. Joshi V, Yamaguchi T, Matsuda Y, Kaneko N, Maki K, Okano T. Skeletal maturity assessment with the use of cone-beam computerized tomography. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012;113(6):841–9.
62. Ahmed M, Shaikh A, Fida M. Diagnostic performance of various cephalometric parameters for the assessment of vertical growth pattern. Dental Press J Orthod. 2016;21(4):41–9.
63. Carmichael RP, Sándor GKB. Dental Implants, Growth of the Jaws, and Determination of Skeletal Maturity. Atlas Oral Maxillofac Surg Clin North Am. 2008;16(1):1–9.
64. Bousquet P, Ansermino H, Canal P, Renaud M, Artz C. Growth and dental implants: assessment and prevention of the long-term aesthetic risk. Orthod Fr. 2016;87(3):321–8.
65. Mishra S, Chowdhary N, Chowdhary R. Dental implants in growing children. J Indian Soc Pedod Prev Dent. 2013;31(1):3–9.
66. Op Heij DG, Opdebeeck H, Van Steenberghe D, Quirynen M. Age as

compromising factor for implant insertion. Periodontol 2000. 2003;33:172–84.

67. Kamatham R, Avisa P, Vinnakota DN, Nuvvula S. Adverse effects of implants in children and adolescents: A systematic review. J Clin Pediatr Dent. 2019;43(2):69–77.
68. Schneider UE, Moser L, Pellitteri G, Siciliani G. Orthodontic space closure vs. implant-borne crowns in patients with congenitally missing maxillary lateral incisors. J Clin Orthod. 2018;52(5):284–96.
69. Sc B, Ed B. and Orthodontic Treatment Considerations for the Single-Tooth Implant. 2001;67(1):25–8.
70. Tarlow JL. The effect of adult growth on an anterior maxillary single-tooth implant: A clinical report. J Prosthet Dent. 2004;92(3):213–5.
71. Uslenghi S, Liversidge HM, Wong FSL. A radiographic study of tooth development in hypodontia. Arch Oral Biol. 2006;51(2):129–33.
72. Flores-Mir C, Nebbe B, Major PW. Use of skeletal maturation based on hand-wrist radiographic analysis as a predictor of facial growth: A systematic review. Angle Orthod. 2004;74(1):118–24.
73. Dierens M, De Bruecker E, Vandeweghe S, Kisch J, De Bruyn H, Cosyn J. Alterations in soft tissue levels and aesthetics over a 16-22year period following single implant treatment in periodontally-healthy patients: A retrospective case series. J Clin Periodontol. 2013;40(3):311–8.
74. Silva BP, Mahn E, Stanley K, Coachman C. The facial flow concept: An organic orofacial analysis—the vertical component. J Prosthet Dent. 2019;121(2):189–94.
75. Ottoni J, Gabriella M. Dental implants three-dimensional position affected by late facial bone growth: Follow-up of 12 to 15 years. J Osseointegration. 2011;3(3):61–8.
76. Costello BJ, Rivera RD, Shand J, Mooney M. Growth and Development Considerations for Craniomaxillofacial Surgery. Oral Maxillofac Surg Clin North Am. 2012;24(3):377–96.
77. Ferrario VF, Sforza C, Serrao G, Ciusa V, Dellavia C. Growth and aging of facial soft tissues: A computerized three-dimensional mesh diagram analysis. Clin Anat. 2003;16(5):420–33.
78. Hesby RM, Marshall SD, Dawson D V., Southard KA, Casko JS, Franciscus RG, et al. Transverse skeletal and dentoalveolar changes during growth. Am J Orthod Dentofac Orthop. 2006;130(6):721–31.
79. Thilander B, Ödman J, Lekholm U. Orthodontic aspects of the use of oral implants in adolescents: A 10-year follow-up study. Eur J Orthod. 2001;23(6):715–31.
80. Eisenstein E. Adolescência: definições, conceitos e critérios. Adolescência &

Saúde. 2005;2 (2):6–7.

81. De Menezes M, Rosati R, Baga I, Mapelli A, Sforza C. Three-dimensional analysis of labial morphology: Effect of sex and age. Int J Oral Maxillofac Surg. 2011;40(8):856–61.
82. Rosati R, De Menezes M, Rossetti A, Ferrario VF, Sforza C. Three-dimensional analysis of dentolabial relationships: Effect of age and sex in healthy dentition. Int J Oral Maxillofac Surg. 2012;41(11):1344–9.
83. Bae E. Changes in longitudinal craniofacial growth in subjects with normal occlusions using the Ricketts analysis. 2014;77–87.
84. Cericato GO, Franco A, Bittencourt MAV, Nunes MAP, Paranhos LR. Correlating skeletal and dental developmental stages using radiographic parameters. J Forensic Leg Med. 2016;42:13–8.
85. Durka-Zajac M, Marcinkowska A, Mituś-Kenig M. Bone age assessment using cephalometric photographs. Polish J Radiol. 2013;78(2):19–25.
86. He D, Gu Y, Sun Y. Evaluation of aesthetic anteroposterior position of maxillary incisors in patients with extraction treatment using facial reference lines. J Int Med Res. 2019;47(7):2951–60.
87. Kihara H, Hatakeyama W, Komine F, Takafuji K, Takahashi T, Yokota J, et al. Accuracy and practicality of intraoral scanner in dentistry: A literature review. J Prosthodont Res. 2020;64(2):109–13.
88. Takeuchi Y, Koizumi H, Furuchi M, Sato Y, Ohkubo C, Matsumura H. Use of digital impression systems with intraoral scanners for fabricating restorations and fixed dental prostheses. J Oral Sci. 2018;60(1):1–7.
89. Kuhr F, Schmidt A, Rehmann P, Wöstmann B. A new method for assessing the accuracy of full arch impressions in patients. J Dent. 2016;55:68–74.
90. Lentini-Oliveira DA, Carvalho FR, Rodrigues CG, Ye Q, Hu R, Minami-Sugaya H, et al. Orthodontic and orthopaedic treatment for anterior open bite in children. Cochrane Database Syst Rev. 2014;2014(9).
91. Lenza MA, De Carvalho AA, Lenza EB, Lenza MG, De Torres HM, De Souza JB. Radiographic evaluation of orthodontic treatment by means of four different cephalometric superimposition methods. Dental Press J Orthod. 2015;20(3):29–36.
92. Gu Y, McNamara JA. Cephalometric superimpositions: A comparison of anatomical and metallic implant methods. Angle Orthod. 2008;78(6):967–76.
93. 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;70(3):155–

60.

94. Moghadam MM. Implant applications for children. Int J Contemp Dent Med Rev. 2017;7.
95. Morris JM, Park JH. Correlation of dental maturity with skeletal maturity from radiographic assessment. J Clin Pediatr Dent. 2012;36(3):309–14.
96. Farnell DJJ, Richmond S, Galloway J, Zhurov AI, Pirttiniemi P, Heikkinen T, et al. Multilevel principal components analysis of three-dimensional facial growth in adolescents. Comput Methods Programs Biomed. 2020;188:105272.
97. Joo J-Y, Son S, Lee J-Y. Implant Site Development for Enhancing Esthetics of Soft and Hard Tissue and Simplification of Implant Surgery Using a Forced Eruption. Int J Periodontics Restorative Dent. 2016;36(4):583–9.
98. Mamoun JS, Cervini E. A pin amalgam or composite core foundation technique for teeth with minimal coronal structure. J Prosthet Dent. 2004;91(6):599–602.
99. Novaes AB, de Barros RRM, Malheiros FAS, Muglia VA. Esthetic Outcome of Immediately Implanted and Loaded Implants in the Esthetic Region. Adv Esthet Implant Dent. 2018;49–68.
100. Graber. Orthodontics Principles and Practice. 3rd ed. Saunders; 1972.
101. Broadbent BH. Bolton Standards and Technique in Orthodontic Practice. Angle Orthod. 1937;7:209–33.
102. Downs WB. Variations In Facial Relationship: Their Significance In Tretament and Prognosis. Am J Orthod. 1948;34:812–40. Citado por: Leitão P. Contribuição para o estudo das características craniofaciais da população portuguesa. 1997.
103. Riedel R. The relation of maxillary structures to cranium in malocclusion and in normal occlusion. Angle Orthod. 1952;22:142–5.