Pre-implant surgery complexity for achieving implant-supported prosthetic rehabilitation in oligodontia patients: a retrospective study.

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Ludovic Lauwers[1*], Gwénaël Raoul[2] and Romain Nicot[2]

Abstract

Introduction Oligodontia is a rare dental developmental pathology that requires prolonged, complex and multidisciplinary treatment. Although bone augmentation is frequently required during a complete implant treatment of oligodontia. Therefore, we evaluated the ability to predict pre-implant surgery complexity based on age, number of missing teeth, and number of implants required to achieve implant-supported prosthetic rehabilitation.

Material and methods This retrospectively registered study included all patients who underwent surgical treatment for oligodontia in our Oral and Maxillofacial Surgery Department between January 2012 and May 2023. Demographic data, number and location of missing teeth, pre- and per-implant surgical procedures, and the number of planned implants were recorded. A quantitative variable called "complexity score of pre-implant surgery" was created. This 10-point score was calculated by adding one point for each preimplant surgical procedure registered. A simple linear regression was calculated to explain the number of targeted implants based on number of missing teeth. A multiple linear regression model was used to explain the complexity score of pre-implant surgery and age, number of missing teeth and number of targeted implants.

Results 119 oligodontia patients were included in the study. The median number of tooth agenesis was 10. A total of 825 implants were placed, 14 (1.7%) of which failed. A significant regression equation was used ($F(1,118) = 1098,338$; $p < 0.0001$) to explain the number of targeted implants based on number of missing teeth, with a R^2 of 0.903. A significant regression equation was found ($F(3,116) = 107,229$; $p < 0.0001$) to explain the complexity score of pre-implant surgery and age, number of missing teeth and number of targeted implants, with a R^2 of 0.735.

Discussion These results based on patient data indicate that age, number of missing teeth and number of targeted implants could reliably explain the complexity of pre-implant surgery.

Keywords Anodontia, Oligodontia, Hypodontia, Tooth agenesis, Bone graft, Bone transplantation, Alveolar ridge augmentation, Dental implants

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Introduction

Oligodontia is a rare dental developmental pathology characterized by the absence of six or more permanent teeth, excluding the third molars [1, 2]. The prevalence of oligodontia in white populations of North America, Australia and Europe varies from 0.08 to 0.16% [3]. Diagnosis is based on routine clinical and radiographic examinations, such as panoramic imaging. French health policy provides for a free oral check-up every 3 years, from the age of 3 years until the age of 24 years, enabling early diagnosis and appropriate treatment. Oligodontia may result from environmental or genetic factors and can occur as an isolated anomaly or as a feature of a systemic syndrome such as in ectodermal dysplasia [1, 4]. Several other dental and oral symptoms may be present, including abnormalities in tooth size or shape, delayed growth of alveolar processes, failure of tooth eruption, persistence of deciduous teeth, taurodontism, and significant diastemas. Speech and masticatory problems are also common in these patients [5, 6]. This rare condition requires prolonged, complex, and multidisciplinary treatment [7, 8]. Since 2005, France has adopted a series of national plans for rare diseases, associated with a national network of centers of reference and competence. Successive phases of treatment are coordinated by an expert center according to the patient's age, based around three key periods: pediatric period with deciduous and mixed dentition, adolescence with permanent dentition, and adulthood.

During the pediatric period and adolescence, implant attachment treatment may be proposed to stabilize a prosthesis [9, 10]. Thus, two or four para-symphyseal implants can be placed after the age of 6 years with implant-supported prostheses, which are regularly replaced as the mandible grows. Following an initial assessment report on pediatric implant-prosthetic treatment by the French National Authority for Health (HAS) in 2006, certain therapeutic procedures have been included in the Common Classification of Medical Acts (CCAM), and are priced and reimbursed by the French health insurance system.

For adults, in few patients with minor form, orthodontic treatment can close diastemas or spaces due to the missing teeth [11]. In some cases it's possible to replace the missing teeth with tooth-supported or fixed partial dentures [12]. The rehabilitation with implant-supported prostheses is therefore the most favorable treatment option for patients with oligodontia [8, 13–15]. It requires collaboration among different specialties: dentist, orthodontist, oral surgeon, and maxillofacial surgeon [16]. A HAS evaluation report on implant-prosthetic treatment for adults was published in 2010 [17]. The implant and pre-implantation therapeutic procedures were registered with the CCAM, and are priced and reimbursed through health insurance under *Affection Longue Durée* N-31 (long-term illness; ALD 31). Authorities reimburse pre-implant surgery and up to 10 dental implants, allowing implant-supported prosthetic rehabilitation. Pre-implant surgery covered by the health insurance includes all procedures and examinations required to achieve therapeutic goals, as well as pre-implant surgical procedures, such as onlay grafts, nerve bypass grafts, and sinus lifts. Therefore, despite bone deficiencies being common in oligodontia, bone augmentation can usually be performed to place conventional implants in an ideal or strategic position to optimize the long-term prognosis of rehabilitation [18]. Although standards are evolving in implantology, we consider for this study that the standard is represented by Narrow (3.3 to 3.75 mm) and Regular (4 to 4.7 mm) implants with lengths ranging from 8 to 14 mm depending on the positioning of the implant.

Although pre-implant surgery is frequently required during comprehensive implant treatment [19], it is difficult to assess its necessity, extent, and complexity at the time of initial diagnosis. In fact, the pre-implant phase can only be accurately planned after three-dimensional imaging at the end of growth and during implant planning.

We hypothesized that the number of missing teeth was correlated with the number of implants placed, but also with the number of pre-implant surgery procedures and therefore its complexity. Therefore, to answer the questions of patients and their parents who are often worried about this surgical phase and its complexity, we evaluated, in a large series of oligodontia patients, the ability to predict pre-implant surgery complexity based on age, number of missing teeth, and number of implants required to achieve implant-supported prosthetic rehabilitation.

Materials and methods

Patients and ethics

This retrospective study included all patients who underwent oligodontia treatment at the Oral and Maxillofacial Surgery Department of the Lille University Hospital between January 2012 and May 2023. The inclusion criteria were patients who had completed the growth, had ≥ 6 missing permanent teeth excluding the third molars and the combination of missing #12, #22, #15, #25, #35, and #45 (oligodontia reimbursed by the French health insurance within the framework of ALD 31), and those who underwent complete pre-implant and/or implant surgical treatment resulting in fixed implant-supported rehabilitation. Patients who underwent only pedodontic or orthodontic treatment were excluded. Smokers were not excluded from the study.

The procedures were performed in accordance with the declaration of Helsinki. Informed consent was obtained from all subjects and/or their legal guardian(s). Institutional review board approval was obtained by the Ethics Committee of the "Société Française de Stomatologie, Chirurgie Maxillo-Faciale et Chirurgie Orale" (French Society of Stomatology, Oral and Maxillofacial Surgery) N° CEth-SFSCMFCO 002/2024.

Patient management

As described in a previous study [19], all patients underwent multidisciplinary consultations with pedodontists, orthodontists, implantologists, and maxillofacial surgeons, all of whom approved the treatment plan and follow-up procedures. All patients underwent bone volume and intermaxillary ratio analyses for implantation at the end of growth or orthodontic treatment. Based on these analyses, the patients were offered implant surgery and, if necessary, pre- and per-implant surgery leading to fixed implant-supported rehabilitation. Pre-implant surgical procedures included orthognathic surgery, bone grafting procedures, including onlay additive osteoplasties and sinus lift procedures, and inferior alveolar nerve (IAN) lateralization. Implant planning was performed after three-dimensional assessment through computed tomography (CT) or cone-beam CT 5.5 months after pre-implant surgery. Implants were placed following the adapted instrumental sequence under local or general anesthesia, along with the removal of the osteosynthesis material.

Data collection

Demographic data, number and location of missing teeth, pre- and per-implant surgical procedures, and the number of planned implants were recorded.

A quantitative variable called "complexity score of pre-implant surgery" was created. This 10-point score was calculated by adding one point for each preimplant surgical procedure registered in the *Classification Commune des Actes Médicaux*. The procedures included Le Fort I and bilateral sagittal split osteotomies (LBPA001–LBPA043), sinus lift (GBBA002), onlay additive osteoplasties for 1–3 teeth (HBBA003), onlay additive osteoplasties for 4–6 teeth (HBBA002), onlay additive osteoplasties for ≥7 teeth (HBBA004), calvarial bone graft harvesting (LAFA008), intra-oral bone harvesting (PAFA003 and PAFA010), and IAN lateralization (ADCA004). Additional surgical time required for the procedures was also taken into account.

Bone graft failures and implant survival were also recorded. Implant failure was defined as implants that were lost, did not conform to the prosthetic objectives, or could not be loaded.

Statistical analysis

Quantitative variables with normal distributions were expressed as means (standard deviation [SD]), while those with non-normal distributions were expressed as medians (interquartile range [Q1; Q3]). Categorical variables were expressed as numbers (percentage). Normality of distributions was assessed using histograms and the Shapiro-Wilk test.

Spearman's correlation was used to determine correlations between non-normally distributed variables. The strengths of correlations were described for the absolute values of the ratios of the compared variables as follows: very weak (0–0.19), weak (0.20–0.39), moderate (0.40–0.59), strong (0.60–0.79), and very strong (0.80–1.0). A multiple linear regression model was used to explain the complexity score for pre-implant surgery related to age, number of missing teeth, and number of implants. All tests were two-sided, and p-values <0.05 were considered significant. The analysis was performed using Xlstat statistical software.

Results

A total of 119 oligodontia patients were included in the study, including 46 males and 73 females, with a median age of 24 (21;27) years. The median number of tooth agenesis was 10 (8;14). First molars were rarely missing [$n=6$ (5%), = 5 (4.2%), = 10 (8.4%), and =12 (10.1%), respectively], while premolars were the most frequently missing teeth. Agenesis of second premolars was the most common [#15: 86 (72.3%); #25: 89 (74.8%); #35: 97 (81.5%), and #45: 99 (83.2%)], while first premolars were less commonly affected [#14: 79 (66.4%); #24: 76 (63.9%); #34: 53 (44.5%), and #44: 51 (42.0%)]. Other commonly missing teeth were lateral incisors [#12: 73 (61.3%); #22: 73 (61.3%); #32: 46 (38.7%), and #42: 40 (33.6%)] and second molars [#17: 48 (40.3%); #27: 44 (37%); #37: 59 (49.6%), and #47: 58 (48.7%)]. There was also a high proportion of canine agenesis [#13: 56 (47.1%); #23: 53 (44.5%); #33: 37 (31.1%), and #43: 32 (26.9%)]. The distribution of agenesis is shown in Fig. 1.

The median complexity score for pre-implant surgery was 3 (2;3), while the median number of planned implants was 7 (5;10).

A total of 825 implants were placed, 14 (1.7%) of which failed. Most of the implants were Nobel Biocare (Kloten, Switzerland) 440 implants, Anthogyr (Sallanches, France) 254 implants and Zimmer Biomet (Warsaw, United States) 94 implants. All titanium implants had surface of moderately rough. They had an internal conical connection (820) except for 4 Nobel Speedy Groovy with a diameter of 3.3 with an external connection and a monobloc implant Zimmer Biomet "One piece 3.0". The implants were 8 to 14 mm in length. Eight implants were of greater length, 2 in canine pilar and 6 at the mandible associated with a nerve bypass and immediate implant placement.

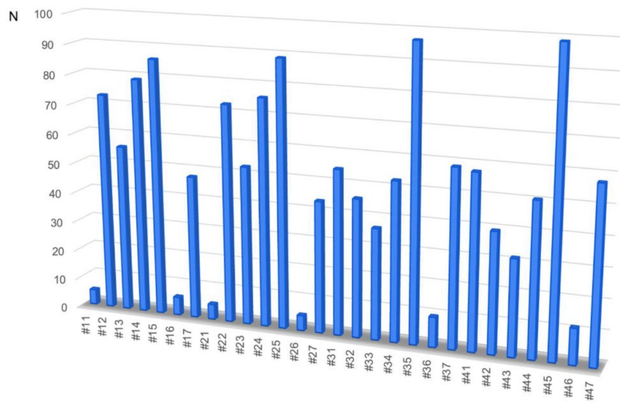

Fig. 1 Distribution of missing teeth

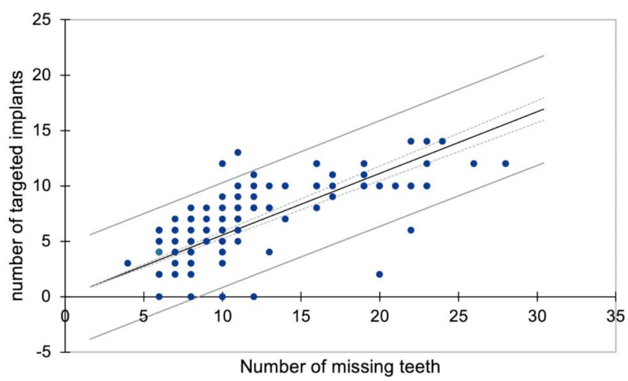

Fig. 2 Regression of the number of planned implants and number of missing teeth

Only 5 implants (regular diameter) were shorter than 8 mm and they had a conjunction with other implants. The implants were of the "Narrow" or "Regular" type depending on their position. 52 implants (51 Nobel Biocare and 1 Zimmer Biomet) were 3.0 mm diameter reduced and they were all in the mandibular incisor or maxillary lateral incisor position as indicated.

Correlation between number of missing teeth and number of planned implants

There was a significantly strong correlation between the number of missing teeth and number of planned implants ($r_s = 0.744$; $p < 0.0001$).

Linear regression models for the relationship between number of missing teeth and number of planned implants

A simple linear regression was used to predict the number of required implants based on number of missing teeth. A significant regression equation was developed ($F(1,118) = 1098.338$; $p < 0.0001$), with a R^2 of 0.903. The predicted number of planned implants was found to be equal to 0.556 × [number of missing teeth] (Fig. 2).

Correlation of pre-implant surgery complexity score with age, number of missing teeth, and number of planned implants

There was a significant weak correlation of the complexity score of pre-implant surgery with the number of missing teeth (r_s = 0.270; $p < 0.003$) and the number of planned implants ($r_s = 0.304$; $p < 0.001$).

Multiple linear regression was used to analyze the relationship of the complexity score with the age, number of missing teeth, and number of planned implants. A significant regression equation was developed ($F(3,116) = 107,229$; $p < 0.0001$), with a R^2 of 0.735. The predicted complexity score of pre-implant surgery was equal to 0.02 × [Age] + 0.06 × [Number of missing teeth] + 0.14 × [Number of targeted implants].

Discussion

The present study demonstrated a significant strong correlation between the number of missing teeth and the number of planned implants and established a strong linear correlation between them. We also demonstrated a linear correlation of the complexity score of pre-implant surgery with age, number of missing teeth, and number of planned implants. This indicates that these three factors are reliable predictors of the number of surgical steps and therefore of pre-implant surgery complexity for the patients' point of view. These results are particularly important for planning choices at the end of the growth period. Indeed, the number of implants and their required strategic positions to obtain a fixed prothesis lead to the indications of pre-implant surgery to improve the prognosis by avoiding compromises. It is also essential to be able to discuss this with parents very early in the consultations and give them a surgical planning.

The mean number of implants placed is lower than the number of missing teeth. This was because the second molars were not always restored, and because implants were used to support fixed prostheses for multiple teeth without adversely affecting the aesthetic and functional outcomes (Fig. 3). Few patients had 10 or more implants placed, mostly in patients with anodontia or those without any conservable teeth. Although oligodontia patients who underwent full-arch maxillary and mandibular rehabilitations with eight and six implants, respectively, have been commonly reported in literature [20–22] (Fig. 4), the technical nature of implants has evolved over time, and it is now possible to provide fixed prostheses for both arches with 10 implants. Most treatments, therefore, fall within the scope of French ALD 31, allowing reimbursement of the implant cost and making these treatments accessible for those with poor socio-economic conditions [19]. Stabilizing implant-supported dentures is another therapy [23, 24], but it still requires the same number of implants for bar-retained overdentures. [25].

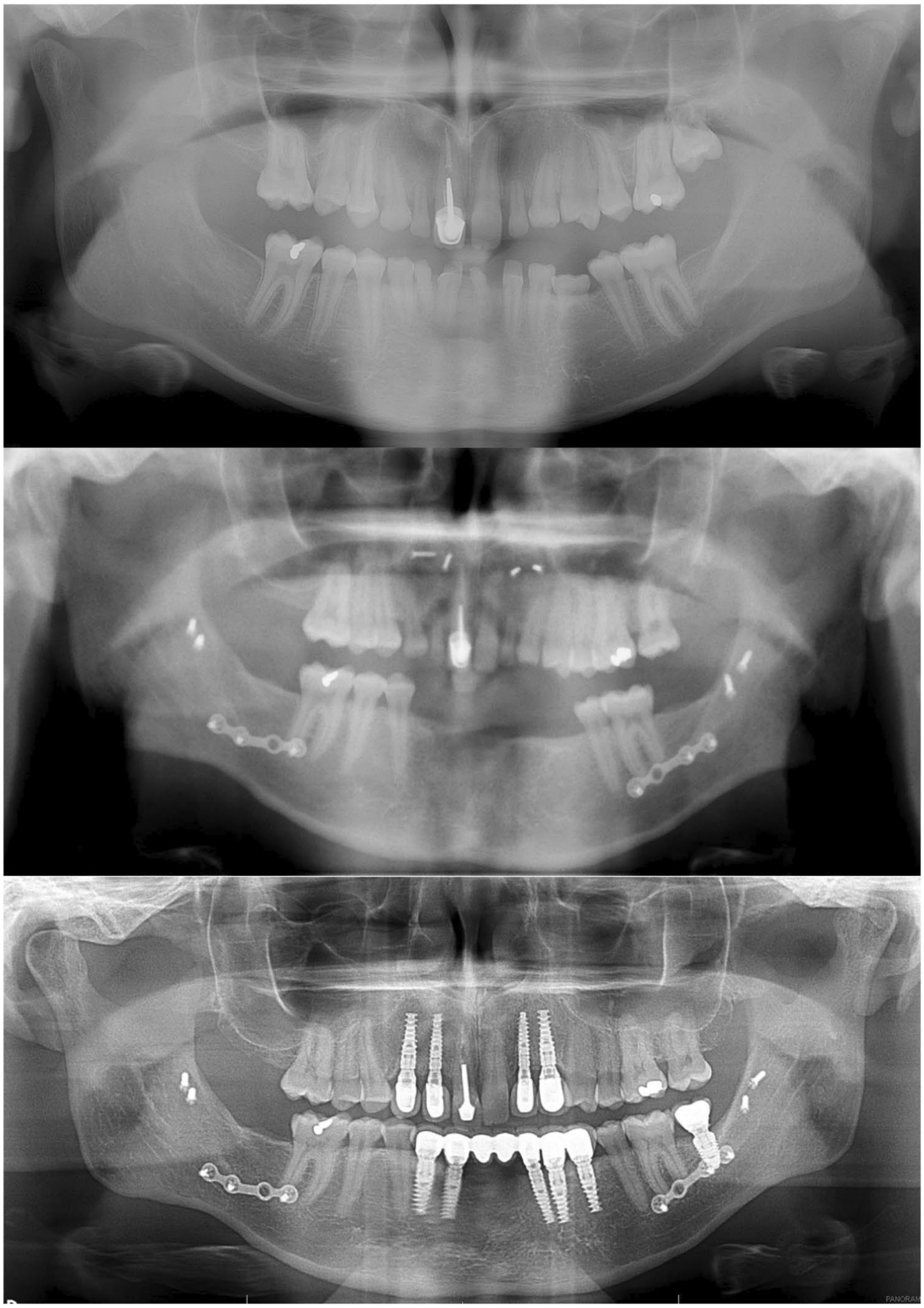

Fig. 3 (**A**) Panoramic radiograph of a patient aged 15 years with 14 missing permanent teeth. (**B**) Panoramic radiograph at 18 years after maxillary bone grafting and mandibular sagittal osteotomy. (**C**) Control panoramic radiograph of a patient aged 30 years with 12-elements fixed implant-supported bridge and single-tooth prosthesis

Post-implant follow-up is more important in these cases because of frequent attachment changes and the need for resin relining.

Implant planning requires the analysis of three essential parameters: the number, position, and dimensions (diameter and length) of implants. Implants must be distributed in priority areas of strength, such as the canine and first molar regions, while limiting cantilevers. The simulation of the therapeutic objectives gives us the implant positions, and according to this, the prosthetic platforms, the implant diameters and the ideal lengths needed. It's often necessary to perform pre-implant grafting to ensure adequate bone volume and thickness [13]. Bone graft surgery is also guided by implant planning, which defines the ideal volume and position of the graft. In some cases, basal implants with IAN lateralization

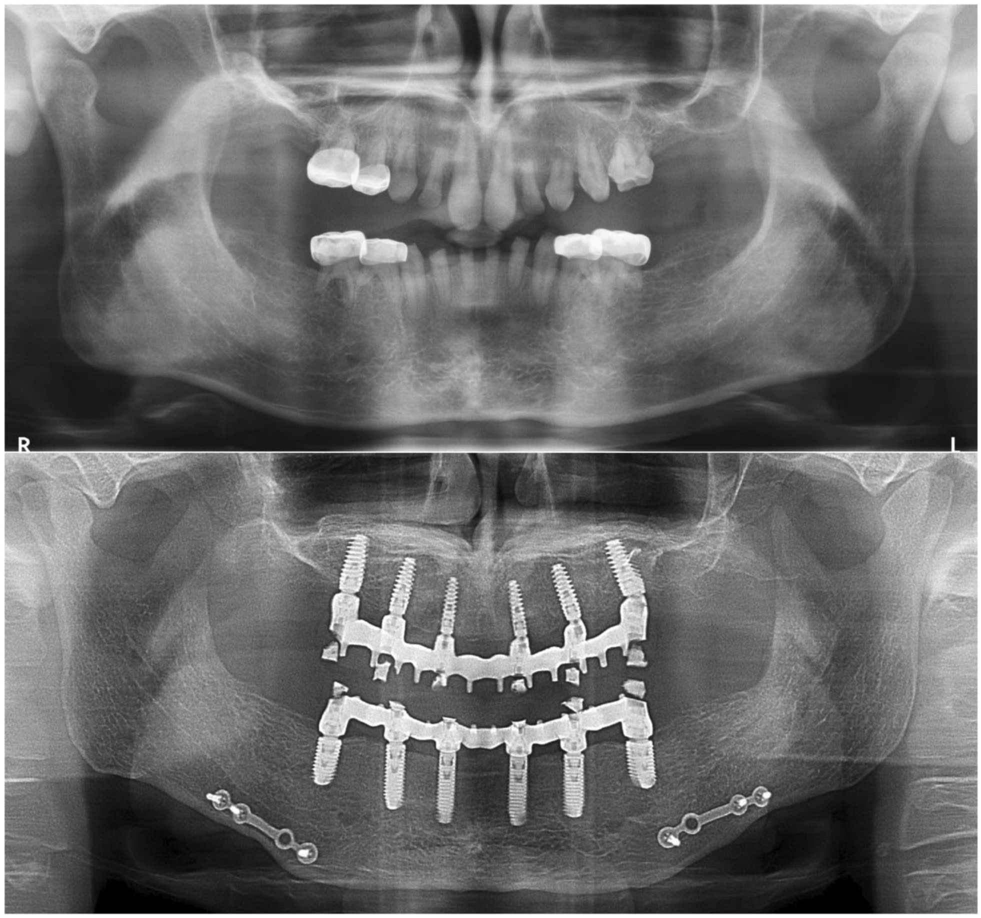

Fig. 4 (**A**) Panoramic radiograph of a patient at the age of 17 years with 26 missing permanent teeth and fixed pedodontic prostheses. (**B**) Follow-up 3 years after full-arch maxillary and mandibular implant-supported rehabilitation. Le Fort I surgery with bone grafting and mandibular sagittal osteotomy was followed by the placement of 12 dental implants

may also be considered. The mandibular canal may rule out the use of short implants, both for treatment of small or large areas. IAN lateralization in patients with low prosthetic height will allow placement of longer dental implants for initial stability during the same surgery [26]. In this procedure, the patient should be informed that hypoesthesia may be permanent [14].

Although biomaterials provide outcomes for vertical sinus augmentation, autologous appositional grafts are the gold standard for thickness deficits, with low resorption rates [27–29] (Fig. 5). Orthognathic surgery including Le Fort I osteotomy, increases operative time and surgical difficulty but, if indicated by existing jaws discrepancies, it can ensure less bone resorption because perfect positioning of jaws avoids prosthetic imbalance.

In cases of severe maxillary atrophy, especially in the anterior area, requiring numerous large appositional grafts, Le Fort I osteotomy can be performed along with bone grafting to correct the jaws discrepancy [30–32].

Several anatomical structures and bone volumes must be considered in cases of multiple tooth agenesis, this can limit intra-oral collection. Mandibular bone harvesting as ramus and symphyseal chin are good options for limited grafts [33]. Indeed, calvarial harvesting provides large quantities of bone with optimal quality, and is preferable for these cases, particularly in younger patients [18, 34]. This, however, increases the duration and complexity of the surgery [35].

Implantation without grafting is an alternative that may be considered. Although rarely proposed as a first-line treatment, zygomatic implants may be used in the lateral maxillary segments, particularly in cases with reduced sub-sinus bone [36, 37]. The zygomatic “quad” technique was performed in one patient in the present study, and is a useful technique for patients with significant maxillary atrophy. However, the length and thickness of the zygomatic bones are reduced in patients with ectodermal dysplasia due to lack of growth, making it difficult, if not impossible, to place four zygomatic implants [38]. In these patients, it may also be necessary to place extra-sinusal implants, which are associated with soft tissue recession and periodontal problems [39]. These

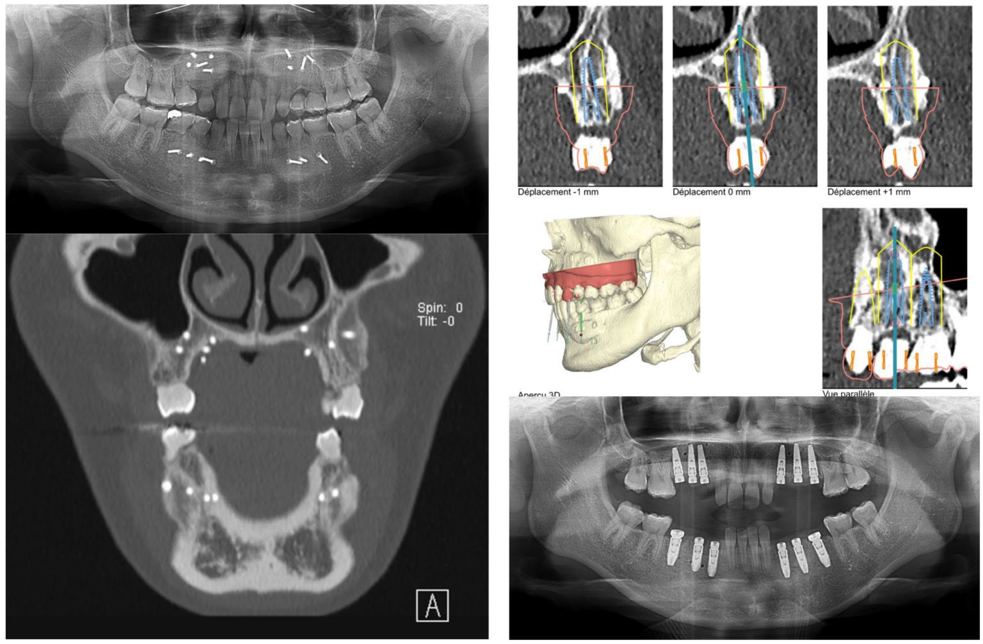

Fig. 5 (**A**) Panoramic radiograph after bone grafting in a 21-year-old patient with 12 missing permanent teeth. (**B**) CT scan 6 months after appositional grafting; coronal section showing the bone volume obtained at the site of 24. (**C**) Planning for implant placement at this site with grafting for implant stability.(**D**) Panoramic radiograph after placement of maxillary and mandibular implants

techniques reduce implant treatment time and, in some cases, allow immediate loading. It should be noted that zygomatic implants are rarely used in segmental rehabilitations. Therefore, in our department, the indication is limited to total rehabilitation in anodontia patients. In addition, zygomatic implants do not significantly improve the quality of life compared to bone grafts and conventional implants [40]. They have, however, been used by some surgeons for lateral bridges with good results [41]. From a financial point of view, they are more expensive than conventional axial implants and are not covered by health insurance. It is therefore a bias in the choice of treatment in our department.

Although mandibular implants can usually be placed with IAN lateralization [42] (Fig. 6), in some cases of total or large edentulous, four para-symphyseal implants may be placed for an “all on four” type rehabilitation with a resinous metal bridge [43–45] (Fig. 7). This type of restoration can be performed using two implants in the canine position and two in the second premolar position. Vertical deficits in the mandible can be compensated using a titanium framework and prosthetic teeth with false gingiva, leading to satisfactory aesthetic, phonetic, and biomechanical outcomes. From a financial point of view, a fixed metal-resin bridge is equivalent or even cheaper than a removable prosthesis on a stabilization bar. Moreover, long-term prosthetic follow-up is simpler than with a bar prosthesis.

It has been demonstrated that implants placed before the end of growth behave like ankylosed teeth and do not undergo spontaneous eruption. They can also disrupt the normal development of the jaws, particularly the adjacent alveolar bone [46]. This can lead to aesthetically and functionally compromised conditions due to the loss of occlusal contacts. The prevalence of this condition has been reported as high as up to 3 in every 4 patients, but no specific predisposing factors have been identified [47]. The development of alveolar processes continues throughout the life, although it slows down after growth cessation. Studies have demonstrated continuous late eruption of around 1 mm in young adults aged 21–26 years, with a similar magnitude of eruption for incisors and molars [48]. This must be considered while planning implant treatment, particularly for lateral edentulous segments and maxillary lateral incisors. Larger edentulous areas appear to be less susceptible to these phenomena, probably because the alveolar bone as a whole is less developed [49]. In this study, the patients had an average age of 19 (18;21) years at the time of implant surgery. Only two of our patients demonstrated continued alveolar growth after implantation, resulting in significant malocclusions. This condition was, however, clinically insignificant, indicating that a greater number of implants may play a role in stabilizing the occlusal height.

There is a general consensus on multidisciplinary treatment taking successive phases based on patient age into

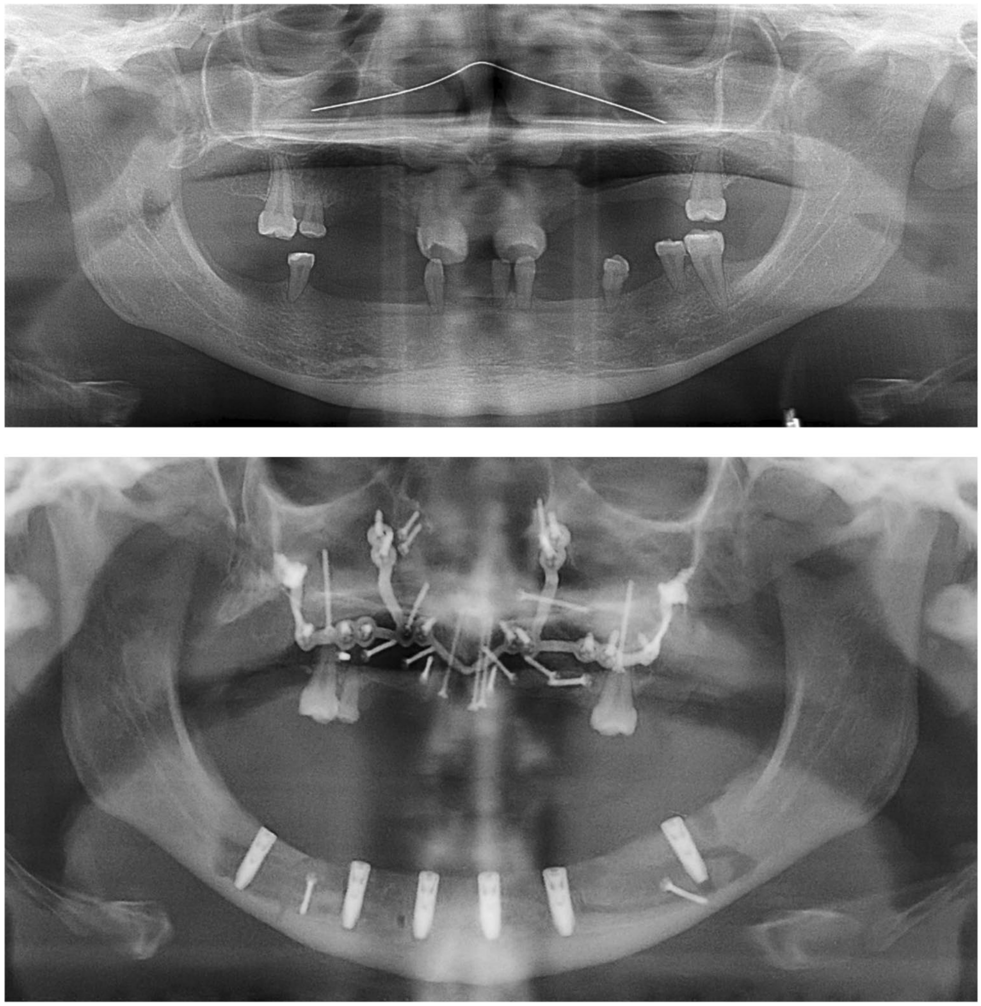

Fig. 6 (**A**) Panoramic radiograph of a patient at the age of 16.5 years with 23 missing permanent teeth. (**B**) Panoramic radiograph at 18 years after Le Fort I procedure, bone grafting, bilateral IAN lateralization, and placement of six mandibular implants

account [14]. The management of adult patients often requires collaboration between orthodontic, surgical, and prosthetic specialties [50]. Multidisciplinary consultations are required for planning implant-supported restorations [16, 51], and we emphasize discussing complex pre-implant surgery early during the process. The predictability of this surgical phase is of great interest to describe and explain to the patient the overall process of their care. The complexity of pre-implant surgery was based on the number of operative procedures, as this is what the patient perceives.

This study requires confirmation through a multicenter study involving other teams with equivalent series. This study is limited to our active list of patients and to specific management in France. Indeed, our center of expertise is specialized in management of complex cases, and the financial coverage of dental implantology also presents a bias in our therapeutics. Additionally, further data may facilitate the development of a predictive algorithm to assess the complexity of surgical management more specific to the surgical procedure and its location according to missing teeth.

Coordinating care after treatment confirmation is essential but can be challenging, especially when involving both private practice and hospital settings. Digital technology enables improved communication between disciplines, leading to enhanced patient care. E-health, utilizing mobile applications (m-health), plays a crucial role in empowering patients, promoting autonomy, and encouraging cooperation [52, 53]. Informing patients about their overall care pathway and the complex surgeries involved in fixed implant rehabilitation is essential, as patient involvement is essential for successful outcomes.

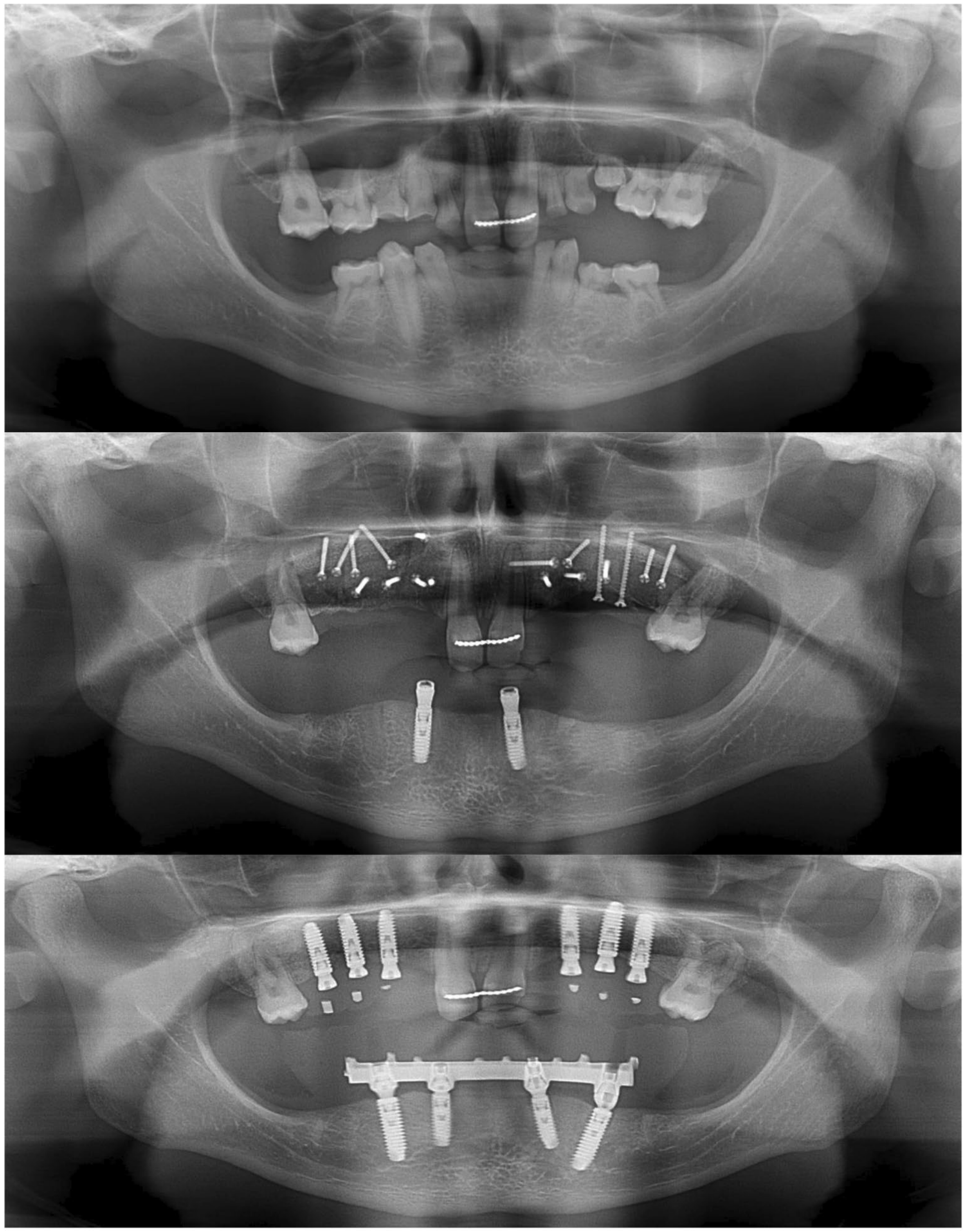

Fig. 7 (**A**) Panoramic radiograph of a patient at the age of 17 years with 23 missing permanent teeth. (**B**) Panoramic radiograph at the age of 18 years, after maxillary bone grafting. Two para-symphyseal implants with attachments to stabilize the mandibular full arch prosthesis. (**C**) Panoramic radiograph after placement of six maxillary implants and two additional mandibular implants for an "all on 4" type prosthesis

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Author contributions
LL and RN analyze the data and write the manuscriptLL prepared figures RN and GR reviewed the manuscript.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval and consent to participate
The procedures were performed in accordance with the declaration of Helsinki. Informed consent was obtained from all subjects and/or their legal guardian(s). Institutional review board approval was obtained by the Ethics Committee of the "Société Française de Stomatologie, Chirurgie Maxillo-Faciale et Chirurgie Orale" (French Society of Stomatology, Oral and Maxillofacial Surgery) N° CEth-SFSCMFCO 002/2024 with the conclusion that it

was a research-type study that does not involve the human person known as a "non-law Jardé" study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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