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Dental and periodontal post-operative complications in patients treated with multisegmented LeFort I (MSLFI) osteotomy in the upper maxilla: a retrospective evaluation

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ABSTRACT

The aim of this retrospective study was to evaluate dental and periodontal complications in patients who underwent Multi-Segment LeFort I osteotomy (MSLFI) as part of ortho-surgical procedure performed to correct dento-skeletal malocclusion. The study specifically focused on issues concerning the maxillary bone, maxillary soft tissues, dental pulp and dental roots. A sample of patients treated between 2008 and 2015 at the University of Verona was considered; all patients underwent MSLFI with interdental osteotomies in the area between upper lateral incisor and canine, bilaterally. The following parameters were assessed on teeth: mobility, probing pocket depth (PPD), gingival recession (GR), pain at palpation, sensitivity and vitality - through percussion test, cold test (CT) and electric pulp test (EPT) - and external root resorption (ERR). All patients underwent pre/post-operative radiographic evaluation with the use of Cone-Beam Computed Tomography (CBCT) and panoramic radiograph. In case of suspect of endodontic or periodontal lesions, or loss of tooth vitality, periapical intraoral radiographs were also performed. 420 teeth in 52 patients were evaluated with a mean follow-up of 42 months. Vascular complications or bone necrosis, unproper union of bone segments and oronasal fistulas were not reported. Despite 49 (11,67 %) teeth did not respond to CT, and 6 of them were also insensitive to the EPT, only 4 teeth (0,95 %) required root canal therapy following surgery. No dental elements showed mobility greater than grade 1; 22 GR (5,34 % of the analyzed sites) of at least 1 mm were observed in 11 patients. As segmented osteotomies are associated with a moderate incidence of dental and periodontal trauma, a proper pre-surgical plan seems to be essential in minimizing complications.

1. Introduction

Le Fort I maxillary osteotomy is the most common surgical procedure to correct dentofacial deformities involving the maxillae. Thanks to its versatility, Le Fort I osteotomy has been proposed for a wide range of maxillary position corrections, including advancement, retrusion, elongation, and shortening, since this surgical procedure allows movements in three dimensions. This technique is often indicated in conjunction with mandibular surgery for the correction of class II and III malocclusion, facial asymmetry, obstructive sleep apnea, and maxillary atrophy (Buchanan and Hyman, 2013). Furthermore, Le Fort I osteotomy may be performed in the multi-segment version, which is recommended for the management of transverse maxillary deficiency, e.g. for single-stage correction of cross defects up to 10 mm, anterior open bite that is not orthodontically solvable, or excessive buccal proclination of the anterior teeth (Bell, 1975).

On the other hand, Le Fort I osteotomy carries non-negligible risks and a variety of complications, concerning anatomical, septic, ischemic, vascular and neurologic. Patients with major anatomical irregularities, such as cleft lip and palate, have further risk of complications. Moreover,

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patients undergoing segmented LeFort I osteotomy with anterior advancement greater than 9 mm are more likely to undergo undesirable outcomes (Kramer et al., 2004). The primary challenges faced by the surgeons during orthognathic surgery regard intraoperative bleeding and maintenance of vascular supply to the maxilla which decreases after Le Fort I osteotomy (Nelson et al., 1977), and is due to the mobilization and repositioning of the osteotomized maxilla (Buchanan and Hyman, 2013). If blood flow is compromised, a spectrum of adverse sequelae may result, ranging from minor pulpal changes to partial or complete loss of the repositioned segment (Geylikman et al., 1995). In this perspective, laser Doppler flowmetry was proposed to measure blood circulation in the dental pulp: some authors support the concept of a direct link between maxillary osteotomy procedures and the occurrence of short- and long-term functional or structural pulpal tissue changes (Emshoff et al., 2000). This could result from the trauma of surgery or a reactive deposition of secondary dentin, leading to a reduction in the size of the pulp chamber (Ramsay et al., 1991). In the mobilized segment of the maxilla, not all teeth have the same risk of losing pulpal sensibility, which increases by performing an interdental osteotomy beside the tooth or placing a wire osteosynthesis close to the apex (Vedtofte and Nattestad, 1989; Lanigan et al., 1990).

Furthermore, a direct consequence of the decreased blood flow is root remodeling: up to date, few authors evaluated morphological changes of teeth roots (Schultes et al., 1998; Mordenfeld and Andersson, 1999; Alqahtani et al., 2022; Alqahtani et al., 2024a; Alqahtani et al., 2024b), declaring a positive correlation between the quantity of maxillary advancement and an increased root remodeling; in addition, root resorption was assessed to happen mainly in the apical part of the teeth. It is thus of the highest importance to properly evaluate all parameters involved in this type of surgery, especially for the estimation of root morphology changes.

Compromised blood flow resulting from soft tissue incisions and osteotomies is often associated with several changes in periodontal tissues, mainly involving gingival recession, bone loss, scar formation and delayed wound healing. Despite controversial data reported in literature for different techniques [Posnick et al., 2016], it was suggested [Bohner et al., 2023] that surgical incisions of one-piece Le-Fort I osteotomy may avoid excessive periodontal trauma, preserving the natural anatomy and architecture of interdental papillae, to ensure satisfactory outcomes both in terms of functionality and esthetics.

In the light of these considerations, the purpose of this study was to evaluate ischemic complications involving the maxillary bone, soft tissues, dental pulp and roots in patients who underwent segmental LeFort I osteotomy surgery with interdental osteotomies between lateral incisors and canine elements.

2. Materials and methods

2.1. Study design

This retrospective study included patients who were consecutively treated for orthognathic surgery at the Department of Dentistry and Maxillofacial Surgery of University of Verona (Italy) between 2008 and 2015. The retrospective evaluation of the follow-up was conducted in 2024, in compliance with the principles of the Declaration of Helsinki on medical protocol and ethics and good clinical practice guidelines for research on human beings.

Conforming with data protection regulations, every patient signed an informed consent about the use of their data for research purposes; none of them refused to participate. All patient data were anonymized before the analysis. Ethical approval for the retrospective evaluation was requested and obtained from University of Verona Institutional Review Board (protocol code 2046 CESC, date of approval January 09, 2019).

2.2. Inclusion and exclusion criteria

The inclusion criteria set to analyze data retrievable from patients' medical records were:

- age more than 18 years old;
- patients treated for dento-facial deformities (DFD) who underwent a LeFort 1 osteotomy and a bilateral sagittal split osteotomy (BSSO), eventually with concomitant ancillary procedures (D'Agostino et al., 2016; Iaquinta et al., 2019; Manfrini et al., 2015; Mazzoni et al., 2017);
- patients treated with a follow-up of at least 12 months.

The exclusion criteria were:

- patients surgically treated cleft lip and/or palate;
- patients previously treated with orthognathic surgery;
- patients with history of facial trauma.

2.3. Surgical protocol and follow-up examination

Each patient followed a personalized treatment plan set by the same ortho–surgical equipe, following FAB principles according to Arnett et al. (Arnett, 1993a, b; 2022; Arnett et al., 2022a; Arnett et al., 2022b; Trevisiol et al., 2022; D'Agostino et al., 2025): all subjects underwent pre-surgical and post-surgical orthodontics, performed by the same orthodontist, whereas surgical procedures were performed by the same surgeons (A.D.A. & L.T).

All patients underwent pre-operative radiographic evaluation with the use of Cone-Beam Computed Tomography (CBCT) and panoramic radiograph. In case of suspect of endodontic or periodontal lesions, or loss of tooth vitality, periapical intraoral radiographs (two 30 × 40mm radiographs for pre-molar area, or three 20x30 radiographs for canine and incisors) were performed.

Surgery required general anesthesia and nasotracheal intubation. All patients underwent *multisegmented* Le Fort I *osteotomy (MSLFI) (*Arnett et al., 2022a, 2022b*): the upper maxilla was segmented into in 3 pieces plus a central palatal island, with interdental vertical osteotomies performed* in most of cases (>90 %) *in the spaces between canines and lateral incisors that had been adequately prepared by the orthodontist.* The interdental osteotomies were performed after subperiosteal dissection in the apexes area of canines and lateral incisors; vertical osteotomies run from the piriform aperture to the maxillary alveolar ridge and were first executed with piezosurgical instrument, then completed with an osteotome. The Le Fort I segmental osteotomy consisted in bilateral axial cut from the piriform aperture to the pterygomaxillary junction, the axial cut run through the lateral nasal walls and the maxillary sinuses walls, above the dental root tips and below the infraorbital foramen and the zygomaticomaxillary buttresses. The pterygomaxillary junction was separated completely and the foot of nasal septum was separated from the palate. Once the maxillary downfracture was executed, the vertical osteotomies were completed with palatal osteotomies running medially to the lateral nasal walls. Palatal osteotomies are performed to accomplish necessary transverse expansion of the palatal vault. All osteotomies were performed using a piezosurgical instrument, where necessary - as in the execution of the axial osteotomy from the piriform to the pterygomaxillary junction – a reciprocating saw was employed, too. Access to the upper maxilla is executed by a high horseshoe-shaped incision, bucco-labially and from canine to canine. The mucoperiosteal flap was elevated to identify the bony structures, the piriform rim, and the infraorbital nerves. Laterally, the dissection was carried around the lateral maxillary buttress, usually ending once the pterygomaxillary junction is encountered (Buchanan and Hyman, 2013) and then separated with a curved chisel. The osteotomy was thus directed to the ipsilateral piriform rim, always below the level of the inferior turbinate to avoid damage to the nasolacrimal system. The same osteotomy was performed on the contralateral side and the posterior osteotomies of the lateral and medial maxillary buttresses were completed (Buchanan and Hyman, 2013). Dissection of any possible remaining portion of nasal mucosa adherent to the nasal floor was completed; nasal mucosa was sutured, whereas the Schneiderian membrane was removed to better visualize the osteotomy areas. A Kerrison Rongeur was used to remove osseous fragment of the lateral wall of nasal surface, of the pyramidal process of palatine bone and of the nasal bone of maxillary and of the anterior crestal maxillary bone.

The blood supply of the Le Fort I segment is mainly based on the ascending palatine and ascending pharyngeal arteries, which reach the Le Fort I segment from the posterior aspect (Siebert et al., 1997). In addition, soft tissues were stretched to allow for a greater range of motion, which was done with mobilization forceps or manual traction of the osteotomized maxilla (Buchanan and Hyman, 2013).

Postoperatively, Cone-Beam Computed Tomography (CBCT) was taken a few days after surgery, after 8 months and at subsequent regular follow-up visits. In addition, eventual periapical intraoral radiographs (two 30 × 40mm radiographs for pre-molar area, or three 20x30 radiographs for canine and incisors) were performed to be compared with pre-operative radiographic examinations.

2.4. Outcomes of the study

The following covariates were considered in the study: age, sex, time from surgery to follow-up, *the superior vertical repositioning of the maxilla ("Mx1 vert" (*Sakharia and Muthusekar, 2015*)); the values of this last one* ranged from −6 mm to +4 mm, *as it causes a significant decrease of the gingival blood flow not detected* with posterior or anterior movements (negative values for superior movement and positive values for inferior movement).

Outcomes of the study included cases of dental and periodontal complications. Any damage to dental elements occurred during surgery was registered. During the follow-up visit, the upper arch elements from the right first premolar to the left first premolar were examined for the following clinical parameters and conditions:

- Tooth mobility (Jan Lindhe and Karring):
  - grade 0: physiological mobility measured at the level of the crown (the tooth moves approximately 0,1-0,2 mm within the socket in a horizontal direction);
  - grade 1: increased horizontal mobility of the dental crown, up to a maximum of 1 mm;
  - grade 2: visually detectable increase in horizontal mobility of the dental crown, greater than 1 mm.
  - grade 3: severe mobility of the dental crown in both horizontal and vertical directions; the mobility hinds the function of the tooth.
- Probing pocket depth (PPD): measured in mm with a graduated periodontal probe as the distance from the cementum-enamel junction (CEJ) to the deepest probable point of the gingival/periodontal pocket; PPD up to 3 mm were considered as physiological;
- Recession (REC): measured in mm with a graduated periodontal probe as the distance between the free gingival margin and the CEJ, and classified according to the latest updates (Cairo et al., 2023). Example of clinical case is reported in Fig. 1.
- Pain at palpation of the periapical area (Stephen Cohen, 2006): performed with fingers on both the buccal and palatal sides, to detect areas of tender mucosa due to the extension of inflammatory mediators from a necrotic or inflamed pulp into the peri-radicular region; once the inflammation and infection penetrate through the cortical bone, palpation of the overlying mucosa usually causes pain.
- External root resorption: presence or absence of this condition was assessed comparing radiographs at follow-up visit compared to pre-operative visit. Examples of clinical cases are reported in Figs. 2 and 3.

The following tests were used for the evaluation of tooth sensitivity and vitality:

- Percussion test (Stephen Cohen, 2006): conducted using the handle of a dental mirror to identify teeth with early periodontal inflammation; sensitivity to percussion often precedes sensitivity to palpation, since the inflammatory process initially affects the peri-radicular region.
- Cold test (Stephen Cohen, 2006): after drying the tooth surfaces with cotton rolls, a cotton swab cooled with spray was applied to the buccal surface of the crown of each individual tooth to evaluate the degree of response to thermal stimulation (if there is no response, the test is repeated on the palatal surface), which can be divided into 4 possible grades:
  - grade I: no response;
  - **grade II: mild/moderate** sensation of pain that disappears within 1–2 s after the removal of the stimulus;
  - grade III: an intense but brief response that also disappears within 1–2 s after the removal of the stimulus;
  - grade IV: a moderate to intense response that persists for several seconds or more after the stimulus is removed.

If there is no response to the thermal test, the cause is often a non-vital pulp, although it can also be a false negative due to excessive calcification or recent trauma: a mild/moderate transient response to thermal changes is generally considered normal; an exaggerated response that quickly disappears is a characteristic of reversible pulpitis; a painful response which lasts for several minutes after the stimulus is removed is indicative of irreversible pulpitis.

- **Electric pulp test (EPT) (**Stephen Cohen 2006**):** the electric test was performed only in case of teeth which previously showed a negative response to the cold test (if a tooth responds to the cold test but not to

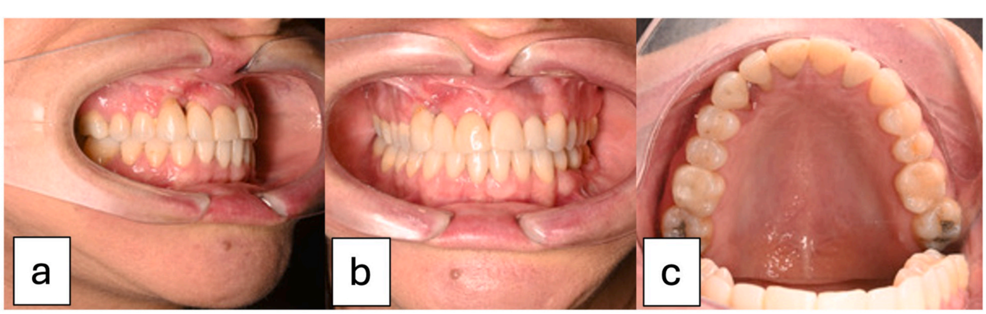

Fig. 1. Gingival recession
Case of gingival recession: a 35-year-old female patient underwent bimaxillary orthognathic surgery (a). Five years later she developed a significant gingival recession of 3 mm visible on the buccal side of elements 12 and 13 (b, c).

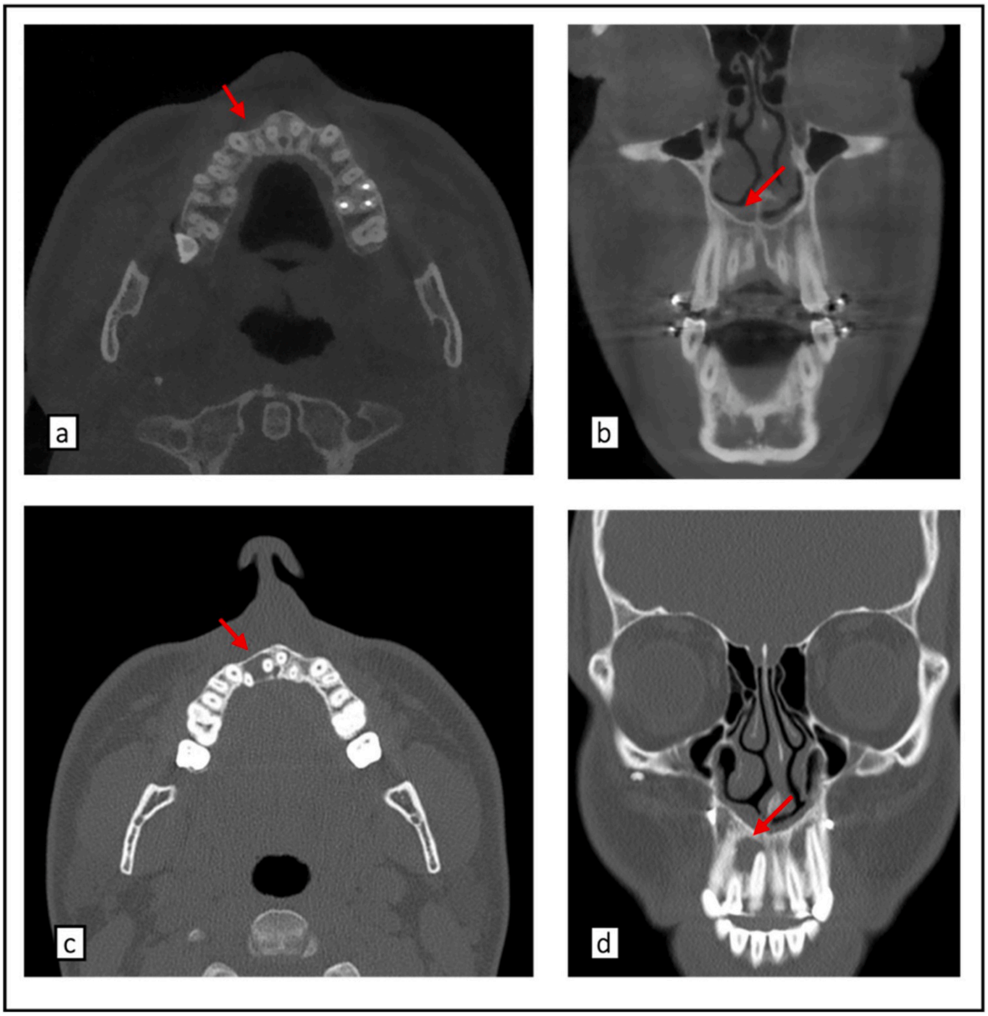

Fig. 2. External root resorption
Case of external root resorption: a 23-year-old male patient. Preoperative CT scan: axial view (a); coronal view (b); an appropriate bone volume and contour is visible at the level of the premaxilla; the anterior palatine canal is clearly delimited. Follow-up CT scan (48 months after surgery): axial view (c); coronal view (d); maxillary bone has undergone a significant resorption, moreover severe inflammation can be noticed in periapical areas of upper incisors and left upper canine, extending within the spongy bone but with maintenance of buccal cortical bone. Notwithstanding the radiological findings, occlusion was maintained and at physical examination the patient did not refer any symptoms.

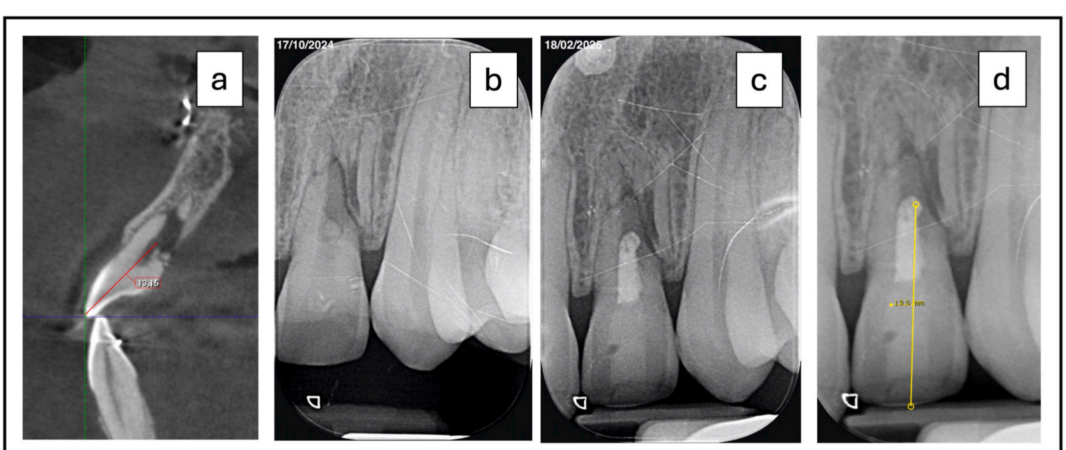

Fig. 3. External root resorption
Case of external root resorption: a 22-year-old patient underwent bimaxillary orthognathic surgery. Two years after surgery the orthodontist detected a radicular resorption involving the upper left lateral incisor. CBCT in sagittal view of the left upper lateral incisor that shows a severe root resorption (a). Intraoral x-ray before root canal treatment (b). Intraoral x-ray immediately after root canal treatment (c) and intraoral x-ray after root canal treatment at follow-up (d).

the EPT, the EPT result is more likely to be a false negative (Chen and Abbott, 2009)). The dental surfaces must be dried to avoid false positives due to electrical conduction to adjacent teeth, attaching also a lip clip, and the electrode tester is generously coated with a viscous conductor. The EPT uses electrical excitation to stimulate A-delta sensory fibers inside the pulp: a positive response to this test does not definitively indicate the integrity or health of the pulp, but rather that vital sensory fibers are present within the pulp.

2.5. Data management and statistical analysis

For data collection, a database including all patients evaluated in the study was created with Microsoft Excel. All data analysis was carried out using Stata v.13.0 for Macintosh (StataCorp). The normality assumptions for continuous data were assessed by using the Shapiro–Wilk test; mean and standard deviation were reported for normally distributed data, median and interquartile range (iqr) otherwise. For categorical data, absolute frequencies, percentages and 95 % confidence intervals were reported. The association between categorical variables was tested with $\chi 2$ test; if any of the expected values was less than 5, a Fisher's exact test was performed.

The comparison between the means of two different groups was performed using Wilcoxon rank-sum test. The comparison of the means among more than two groups was done using Kruskal-Wallis equality-of-populations rank test. A multivariate analysis (logistic regression) was carried out to find possible association between clinical parameters/conditions related to teeth and covariates (sex, age, follow-up range from surgery, Mx1 vert). Significance level was set at 0,05. The study presents compliance with the STROBE checklist guidelines (von Elm et al., 2007).

3. Results

Fifty-two patients were overall evaluated: 30 (58 %) were males and 22 (42 %) were females, with a mean age of 25 (range 18–47) years. The mean follow-up period was 42 (18–104) months.

The total number of teeth examined (see Tables 1–5) was 420, including 106 maxillary central incisors, 105 maxillary lateral incisors, 104 maxillary canines and 105 maxillary premolars. No dental element showed mobility greater than grade 1. 22 GR (5,34 % of the analyzed sites) of at least 1 mm were observed in 11 patients: 20 sites in 10 patients were classified as gingival recession type 1 (RT1, that means with no interproximal attachment loss), while 2 sites in one patient as type 2 (RT2, with an interproximal attachment loss less than or equal to buccal attachment loss).

Statistical tests showed no statistically significant associations between EPT, percussion, external root resorption of the teeth and respectively age, sex, follow-up and Mx1 vert, for all types of teeth (central incisors, lateral incisors, canines, premolars).

On the other hand, significant associations were observed (see Table 6) between:

Table 1
Overall maxillary teeth (420 teeth).

Maxillary teeth (420 teeth)				
	Positive	*Negative*	Devitalized Post Surgery	Devitalized Pre Surgery
Cold test	350 (83,33 %)	49 (11,67 %)	4 (0,95 %)	17 (4,05 %)
EPT	43 (87,76 %)	6 (12,24 %)		
Percussion	1 (0,24 %)	419 (99,76 %)		
	Present	*Absent*		
External Resorption	86 (20,48 %)	334 (79,52 %)		
Recession	22 (5,24 %)	398 (94,76 %)		

Table 2
Maxillary central incisors (106 teeth).

Maxillary central incisors (106 teeth)				
	Positive	*Negative*	Devitalized Post Surgery	Devitalized Pre Surgery
Cold test	93 (87,74 %)	6 (5,66 %)	1 (0,94 %)	6 (5,66 %)
EPT (measured at negative cold test teeth)	6 (100 %)	0 (0 %)		
Percussion	1 (0,94 %)	105 (99,06 %)		
	Present	*Absent*		
External Resorption	29 (27,36 %)	77 (72,64 %)		
Recession	2 (1,89 %)	104 (98,11 %)		

Table 3
Maxillary lateral incisors (105 teeth).

Maxillary lateral incisors (105 teeth)				
	Positive	*Negative*	Devitalized Post Surgery	Devitalized Pre Surgery
Cold test	85 (80,95 %)	15 (14,29 %)	1 (0,95 %)	4 (3,81 %)
EPT (measured at negative cold test teeth)	14 (93,33 %)	1 (6,67 %)		
Percussion	0 (0 %)	105 (100 %)		
	Present	*Absent*		
External Resorption	37 (35,24 %)	68 (64,76 %)		
Recession	3 (2,86 %)	102 (97,14 %)		

Table 4
Maxillary canines (104 teeth).

Maxillary canines (104 teeth)				
	Positive	*Negative*	Devitalized Post Surgery	Devitalized Pre Surgery
Cold test	79 (75,96 %)	21 (20,19 %)	2 (1,92 %)	2 (1,92 %)
EPT (measured at negative cold test teeth)	18 (85,71 %)	3 (14,29 %)		
Percussion	0 (0 %)	104 (100 %)		
	Present	*Absent*		
External Resorption	11 (10,58 %)	93 (89,42 %)		
Recession	9 (8,65 %)	95 (91,35 %)		

Table 5
Maxillary premolars (105 teeth).

Maxillary premolar (105 teeth)				
	Positive	*Negative*	Devitalized Post Surgery	Devitalized Pre Surgery
Cold test	93 (88,57 %)	7 (6,67 %)	0 (0 %)	5 (4,76 %)
EPT (measured at negative cold test teeth)	5 (71,43 %)	2 (28,57 %)		
Percussion	0 (0 %)	105 (100 %)		
	Present	*Absent*		
External Resorption	9 (8,57 %)	96 (91,43 %)		
Recession	8 (7,62 %)	97 (92,38 %)		

- cold test and sex, for central and lateral incisors;
- cold test and age, for incisors and canines;
- cold test and follow-up, for canines and premolars;
- gingival recession and age, for incisors;
- gingival recession and follow-up, for canines;
- gingival recession and Mx1 vert, for central incisors.

Specifically, cold test was more frequently negative:

- in central incisors for males (4 cases out of 6), compared to females;
- in lateral incisors for males (11 cases out of 15), compared to females;
- in central incisors for age >25 years (4 cases out of 6), compared to age <25 years;
- in lateral incisors for age >25 years (10 cases out of 15), compared to age <25 years;
- in canines for age >25 years (11 cases out of 21), compared to age <25 years;
- in canines for follow up < 42 months (11 cases out of 21), compared to follow up > 42 months;
- in premolars for follow up < 42 months (4 cases out of 7), compared to follow up > 42 months.

Gingival recession was more frequent:

- in canines for age <25 years (6 cases out of 9), compared to age >25 years;
- in canines for follow up > 42 months (6 cases out of 9), compared to follow up < 42 months;
- in central incisors for Mx1 vert with values ≥ 5 (8 cases out of 9), compared to Mx1 vert with values < 5.

Finally, logistic regressions showed a significant correlation between (see Table 7):

- cold test as negative in lateral incisors and age >25 years (p = 0,02);
- gingival recession in canines and follow up > 42 months (p = 0,02).

4. Discussion

MSLFI osteotomy can severely affect dental elements and periodontal structures, as well as the nasopalatine and the anterior-middle-posterior-superior alveolar structures in case iatrogenic vascular damages or neurosensory damages occur during the procedure. Additionally, intra-operative

Table 7
Logistic regressions between the parameters of cold test and gingival recession, and sex, age, follow-up and Mx1 vert, for lateral incisors and canines.

Cold test - lateral incisors	variable	odds ratio	p>|z|	95 % C.I.
	SEX	2,32	0,2	0,63-1,8
	AGE	0,9	0,02[a]	0,84-0,98
	FW	0,98	0,46	0,95-1,01
	MX1VERT	0,91	0,48	0,72-1,16
Recession - canines	variable	odds ratio	p>|z|	95 % C.I.
	SEX	3,5	0,11	0,75-1,65
	AGE	0,97	0,62	0,86-1,08
	FW	1,03	0,02[a]	1,01-1,07
	MX1VERT	1,03	0,84	0,76-1,39

[a] Statistically significant.

Table 6
Associations (p value) between the parameters of cold test, EPT, percussion, external root resorption and gingival recession, and respectively sex, age, follow-up and Mx1 vert, for all types of teeth (central incisors, lateral incisors, canines, premolars).

		Cold test	EPT	Percussion	External resorption	Recession
SEX	*central incisors*	0,006[a]	/	0,41	0,58	0,34
	lateral incisors	0,02[a]	0,26	/	0,55	0,06
	canines	0,11	0,68	/	0,08	0,1
	premolars	0,07	0,71	/	0,2	0,18
AGE	*central incisors*	0,01[a]	/	0,16	0,13	0,08
	lateral incisors	0,01[a]	0,9	/	0,07	0,07
	canines	0,04[a]	0,15	/	0,68	0,14
	premolars	0,39	0,43	/	0,39	0,38
FW	*central incisors*	0,07	/	0,35	0,99	0,74
	lateral incisors	0,27	0,07	/	0,24	0,83
	canines	0,05[a]	0,12	/	0,79	0,02[a]
	premolars	0,02[a]	0,4	/	0,18	0,98
MX1VERT	*central incisors*	0,42	/	0,32	0,9	0,01[a]
	lateral incisors	0,62	0,34	/	0,75	0,9
	canines	0,69	0,08	/	0,12	0,71
	premolars	0,68	0,09	/	0,87	0,15

[a] Statistically significant.

mobilization of the maxillary segments may damage the greater palatine nerves and arteries. Findings from studies evaluating dental lesions following multi-segmented osteotomies are comparable to those emerging from the present study and will be discussed below (de Mol van Otterloo et al., 1991; Wolford et al., 2002; Kahnberg et al., 2005; Chow et al., 2007; Landes et al., 2008; Kretschmer et al., 2010; Ho et al., 2011; Robl et al., 2014; Posnick et al., 2016; Haas Junior et al., 2017).

4.1. Vascular complications

Alteration of nerves and blood supply leads to several complications that are clinically visible in the weeks or months after surgery, e.g. periodontal defects, degenerative pulp damage, irreversible loss of pulp vitality, unproper union of repositioned segments; in extreme cases avascular necrosis of the maxilla was reported (Ranna et al., 2016). No vascular complications involving the bone segments or soft tissues were reported in this study, as no cases of maxillary necrosis, unproper union of bone segments, or oronasal fistulae were observed. Avascular necrosis following maxillary osteotomies is reported as a potential consequence of compromised blood flow to dentoalveolar segments in MSLFI osteotomies. Laningan et al. collected 800 reports concerning maxillary vascular complications and chose 36 cases of Le Fort I osteotomy (Lanigan et al., 1990), 34 of which were multi-segment osteotomies, to present possible patterns of maxillary necrosis. Other authors (Sakharia and Muthusekar, 2015) evaluated variations in gingival blood flow between the central incisors in both MSLFI and single-piece Le Fort I osteotomies and found no statistically significant difference between the two study groups; nevertheless they reported a statistically significant reduction in gingival blood flow when superior repositioning of the maxilla was performed. The authors stated that these phenomena are due to compression, bending or stretching of the palatine arteries when the osteotomized segments are placed in their new position. Diversely, other investigations found no significant influence on bone blood flow after maxillary advancement, vertical repositioning or transverse expansion (Kretschmer et al., 2009).

4.2. Dental complications

The highest rates of dental complications reported in the literature following segmental Le Fort I osteotomies, concern pulp vitality which can be influenced by the proximity of horizontal osteotomy to the root apexes; moreover it was reported that teeth adjacent to vertical osteotomy sites may experience at least temporary loss of sensitivity (Ranna et al., 2016). A history of dental trauma can also compromise the vitality of the dental pulp during orthodontic treatment (Bauss et al., 2009), and teeth can be traumatized by the resection of their vessels during surgery; thus, the application of orthodontic forces on previously traumatized teeth can lead to the loss of pulp vitality. In general, segmented osteotomies are therefore associated with a higher incidence of dental and periodontal trauma (Schultes et al., 1998).

A literature review (Haas Junior et al., 2017) which evaluated the long-term stability and surgical complications in MSLFI reported dental damage in 8 % of patients. Moreover, it was reported (Emshoff et al., 2008) that the probability of adverse outcomes was higher in patients undergoing MSLFI compared to single piece Le Fort I, highlighting how maxillary segmentation compromises pulp sensitivity in teeth adjacent to vertical osteotomy lines. Another study (Bauss et al., 2009) confirmed that orthodontic treatment combined with MSLFI may have a negative impact on vascularization and pulp sensitivity.

Most of studies provide data on pulp vitality and sensitivity following traditional one-piece Le Fort I osteotomies (Sato et al., 2003; Mesgarzadeh et al., 2010; Garg and Kaur, 2014), whereas data from the current investigation exclusively regard patients who underwent MSLFI osteotomies with vertical osteotomies placed between canines and lateral incisors. In this sample, orthodontic preparation paid close attention in separating the dental roots between the lateral incisors and canines by at least 3–5 mm, on the purpose to maximize interproximal root distances and minimize dental and periodontal damages that might occur at the time of interproximal osteotomy. Diversely, interproximal distances between dental crowns were maintained at around 1–2 mm, evaluated through CBCT (Fig. 4). Such an orthodontic approach is consistent with indications given by other authors (Lanigan et al., 1990) who strongly recommended good orthodontic prepation of teeth in areas of osteotomy cuts to prevent dental and periodontal damages in the interdental bone areas. In addition it has been hypothesized that pre-surgical orthodontic root separation of at least 2 mm at the cementum-enamel junction and 4 mm at the apical third level may prevent vascular compromise or damage to roots adjacent to interdental osteotomies (Ho et al., 2011).

An increase in pulp blood flow was observed during the healing process between the first and the third week after surgery (Justus et al., 2001); similarly, initial increase in blood flow was measured in the pulp of the upper central incisors immediately after surgery, suggesting that this could represent a hyperemic inflammatory response (Buckley et al., 1999), followed by a statistically significant reduction in pulp perfusion that had not yet recovered 4–6 months after surgery. Another longitudinal study reported a noticeable decrease in blood flow across all teeth for a period of 12 months (Eroglu and Sabuncuoglu, 2014). A systematic review (Ranna et al., 2016) indicated that pulp blood flow decreases from the 1st to the 10th day post-surgery, and this reduction seems to persist in the long term: canines and premolars were reported to have the greatest variability in pulp response recovery (80 %), due to the proximity of these teeth to vertical interdental osteotomies in MSLFI, as well as to the proximity of the root apexes to the horizontal osteotomy cut. However, these findings are in contrast with a study featuring a follow-up of 11–29 months (Aanderud-Larsen et al., 1995), which hypothesized that the observed reduction in blood supply is an early postoperative phenomenon that eventually returns to preoperative baseline level.

A significant reduction in pulp blood flow after Le Fort I osteotomy has been observed also by Sato et al. (2003) in a study investigating changes in blood flow, measured through laser Doppler flowmetry (Jafarzadeh and Abbott, 2010), and recovery of pulpal sensitivity of the upper incisors after one-piece Le Fort I osteotomy. They reported a drop in pulpal blood flow in the 1st day after surgery, followed by gradual recovery; simultaneously, pulpal sensitivity resulted negative in the first 14 days and finally recovered in 50 % of examined teeth (Sato et al., 2003). In the present study pulpal sensitivity was tested after a mean follow-up period of 42 months, which is relatively long in comparison to current literature: among 420 examined teeth, 11,67 % did not respond to the cold sensitivity test, and 13 % of clinically vital teeth were insensitive to both the cold test and the electric stimulation. The presence of teeth clinically vital but without any objective issue (e.g. discoloration, abscess, or periapical lesions) may be explained by the occurrence of a transient ischemic insult with temporary dysfunction of intra-pulpal nerve fibres and, consequently, to negative response to sensitility tests. The damage occurring after surgery (Vedtofte and Nattestad, 1989) can be reversible (in case of increasing blood flow, temporary non-vital tooth, without clinical signs of periapical lesions or necrosis) or irreversible (in case of severe stretching, compression or section of nerve fibres with definitive, non-recoverable vitality). After surgery, vascular perfusion recovery may allow for the restoration of pulpal tissue vitality and, in some cases, partial or complete recovery of sensory function, too. Teeth that do not respond to pulp sensitivity tests are often assumed to be non-vital, leading to frequent indication for root canal treatment (Sato et al., 2003). In our study, only 4 teeth (0,95 %) required root canal therapy due to necrosis following surgery, including one central incisor, one lateral incisor and two canines. Such a low percentage of teeth undergoing endodontic treatment may be interpreted as evidence of regained pulpal vitality, albeit with persistent loss of sensibility, with only a significant limited number of symptomatic teeth.

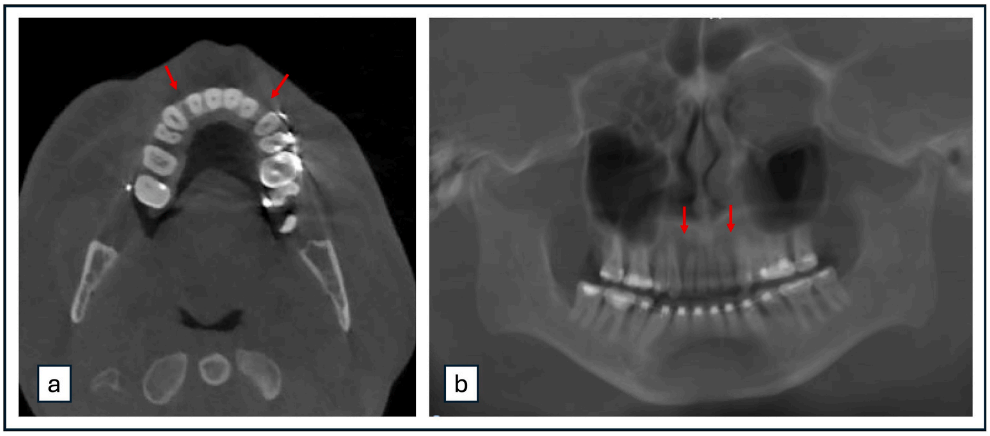

Fig. 4. Preoperative Orthodontic preparation
The CBCT of the upper maxilla in axial (a) and coronal (b) cuts shows the interproximal spaces created during preoperative orthodontics. Close attention was paid in separating the dental roots between the lateral incisors and canines (red arrows) by at least 3–5 mm, on the purpose to maximize interproximal root distances and minimize dental and periodontal damages that might occur at the time of interproximal osteotomy. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

4.3. Periodontal complications

Periodontal complications were observed in 12,83 % of patients undergoing segmental Le Fort I (Haas Junior et al., 2017). In our study a single periodontal pocket was found mesial to a canine, near the inter-dental osteotomy line: this periodontal damage was likely caused by a vertical osteotomy performed particularly close to the root of the dental element, which also required endodontic treatment. Another periodontal complication is gingival recession, whose risk factors are surgical trauma and subsequent post-operative healing process (Weinspach et al., 2011). The development of gingival recessions (GR) seems more frequent in our sample in comparison to the data provided by other authors. More in detail, 22 recessions (5,34 % of the analyzed sites) of at least 1 mm were observed in 11 patients that corresponds to 21 %. 22 GR (5,34 % of the analyzed sites) of at least 1 mm were observed in 11 patients: 20 sites in 10 patients were classified as gingival recession type 1 (RT1, that means with no interproximal attachment loss), while 2 sites in one patient as type 2 (RT2, with an interproximal attachment loss less than or equal to buccal attachment loss). Gingival recessions appear to be more frequent as the follow-up period increases ($p = 0{,}02$), suggesting that the longer the time between surgery and follow-up, the greater the likelihood that additional etiological factors may contribute to gingival damage. It can be also noted that the superior repositioning of the maxilla was associated with the onset of gingival recessions. These data differ from the ones reported in the literature: Ho et al. reported a GR rate of 4 % in a sample of 85 patients; Kramer et al. reported a GR rate of 0,8 % in a sample of 1000 patients; Posnik et al. noticed 2 % of patients with GR in the sample of patients undergoing one-piece Le Fort I and 1,5 % GR in the sample undergoing MSLFI. (Ho et al., 2011; Kramer et al., 2004; Posnick et al., 2016).

A further aspect to be considered in the context of a combined ortho-surgical treatment is root resorption: a systematic review (Alqahtani et al., 2022) concluded that orthognathic procedures may induce root resorption, but the lack of evidence in this context does not allow for a proper conclusion related to the amount of root remodeling for a specific surgical procedure (Alqahtani et al., 2022). Afterwards, in a retrospective study by the same research group (Alqahtani et al., 2024a), it was stated that three-pieces Le Fort I surgery resulted in more evident root remodeling, followed by two-pieces and one-piece Le Fort I surgery respectively, due to the involvement of more segments, potentially larger surgical movements and blood flow impairment (Alqahtani et al., 2024a, 2024b); a relationship between increased maxillary advancement during orthognathic surgery and increased root remodeling was hypothesized to be attributed to the repositioning of the maxilla during surgery, contributing to changes in blood flow, despite the amount of root resorption was considered as minimal (within the range of 4 %–7 %). In our study root resorption was found in 86 out of 420 sites (20,48 %); examples are shown in Figs. 2 and 3.

Notwithstanding the diversity of results reported in literature, several studies examining periodontal changes after segmental osteotomies concluded that surgical techniques are safe procedures and that the consequences for periodontal tissues are of minimal clinical significance (Mordenfeld and Andersson, 1999; Morgan and Fridrich, 2001; Ueki et al., 2006). In this way, surgeon's experience together with the use of advanced technologies, such as piezoelectric surgery (Eggers et al., 2004; Bertossi et al., 2018), can reduce the risk of complications by minimizing soft tissues damage and increasing the precision of the osteotomy: these techniques limit the risk of trauma to adjacent structures and dental elements, consequently reducing blood loss and simultaneously promoting bone healing. This approach results in better surgical outcomes in comparison to traditional osteotomy methods that mainly consists in using drills and saws. In this study interproximal osteotomies were always performed following precise steps: first the buccal cortical bone of the maxilla was cut with piezoelectric instrument, the osteotomy run from the piryform towards the papilla, medially to the canine eminence; then a chisel was employed to gently cut the medullary bone of the premaxilla and the palatal cortical bone, keeping a finger on the palate to prevent the mucosal lining to be damaged.

4.4. Study limitations

Concerning the study limitations, its retrospective nature and the limited number of patients encourage larger investigations, preferably based on a prospective approach: a control group could be represented, in this case, by patients treated with one-piece Le Fort I or other types of segmented osteotomies. Another limitation, it is difficult to make objective comparisons between studies because a variety of parameters to assess pulp and gingival health are used in literature and measurements are often non-homogeneously collected and reported (use of different methods or different devices). Nevertheless, our study presents a precise evaluation of endodontic and periodontal complications since a significant number of sites per patient was screened.

5. Conclusion

MSLFI osteotomy seems to be a predictable technique in terms of minimal presence of vascular complications involving the bone segments or maxillary soft tissues: to note, vascular complications or bone necrosis, unproper union of bone segments and oronasal fistulas were not reported.

Despite the prevalence of gingival recessions of moderate severity was statistically significant, pulp damage in terms of vitality and sensitivity was limited, likely due to the appropriate preparation in maximizing interproximal root distances and minimizing dental and periodontal damages.

Appropriate intraoperative surgical technique employed in segmenting the maxillary bone, with the use of piezoelectric surgery and accurate preoperative three-dimensional CBCT evaluation, might have limited damages to dental and periodontal structures, with correct positioning of radicular apexes related to the areas involved in osteotomies.

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Conflict of interest

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