

Systematic Review Orthognathic Surgery

Cranial nerve injuries in Le Fort I osteotomy: a systematic review

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Abstract. The aim of this systematic review was to describe the anatomical and surgical factors related to cranial nerve injuries in Le Fort I osteotomy. The protocol of this systematic review was registered in the International Prospective Register of Systematic Reviews (PROSPERO). Two independent reviewers performed an unrestricted electronic database search in the MEDLINE/PubMed, LILACS, Scopus, Web of Science, and Cochrane databases up to and including August 2018. Thirty-two articles were selected for data extraction and synthesis: 30 studies were identified in the main search and two by a manual search. The level of agreement between the reviewers was considered excellent ($\kappa = 0.779$ for study selection and $\kappa = 0.767$ for study eligibility). This study revealed that the main nerve affected was the trigeminal nerve, followed by the oculomotor, abducens, optic, facial, and vagus and accessory nerves. Cleft lip and palate patients presented the highest incidence of cranial nerve damage. Cranial nerve damage after Le Fort I osteotomy is not rare. Anatomical and structural knowledge of the patient are necessary in order to minimize the risks of cranial nerve injury in Le Fort I osteotomy.

Key words: cranial nerve injury; complications; Le Fort I osteotomy; maxillary surgery; orthognathic surgery.

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The Le Fort I osteotomy is a technique used for the correction of skeletal deformities and is mainly indicated for the correction of class II and III malocclusions, hypoplasia of the middle third of the face, and vertical excess of the face^{1,2}. This surgical technique involves horizontal osteotomy of the maxilla, followed or not by segmentation^{1,3}. Thus, anterior–posterior repositioning¹, bone rotation, or intrusion can be performed, providing

aesthetic and functional benefits, such as improvements in masticatory function², phonation³ and breathing⁴, and in some cases, a reduction of the painful symptomatology of temporomandibular disorders⁵. Pterygomaxillary disjunction is a surgical procedure used during the Le Fort I osteotomy and can lead to several intra- and extracranial problems^{6,7}. Therefore, many unfavourable factors are reported in the literature, with most of them related to

inflammatory⁴, vascular⁶, and nervous system⁷ complications. As a result, different surgical techniques have been developed and used to reduce the complications and injuries to the patients⁸.

Nerve injuries are not rare⁹ and may occur from hours to days after Le Fort I osteotomy^{5,10–12}. These include a decrease in sensitivity in the surgical area¹³ and in more serious cases, amaurosis¹⁴. The functional recovery time can vary from

days to months^{13,14}. Some studies have shown that 50% of orthognathic surgeries lead to nerve injuries or alterations in sensitivity and that these can occur during surgical manoeuvres or as postoperative complications¹⁵. According to Seddon¹⁶, these injuries can be classified into three types: neurapraxia, axonotmesis, and neurotmesis. The damage related to neurapraxia and axonotmesis shows a better prognosis, while in neurotmesis, total nerve rupture leads to findings of no clinical recovery^{17,18}.

Knowledge of the anatomy is important to increase the safety and reduce the postoperative complications of Le Fort I osteotomy. Therefore, the aim of this study was to conduct a systematic review to describe the anatomical and surgical factors related to cranial nerve injury in Le Fort I osteotomy.

Methods

This review was conducted in agreement with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines¹⁹ and was registered in the International Prospective Register of Systematic Reviews (PROSPERO; CRD42018096714). The focused question based on the PICO strategy (participants, interventions, controls, and outcomes) was: “Which cranial nerve injuries are related to the Le Fort I osteotomy?”

Search strategy

For the main search, a bibliographic search was performed by two independent researchers in five medical databases: PubMed, LILACS, Scopus, Web of Science, and Cochrane Library. The search covered the period from database inception to August 2018. The search strategy was composed of the following medical subject headings (MeSH): “Le Fort Osteotomy” AND “Cranial Nerve Injuries” OR “Le Fort osteotomy” AND “Cranial Nerves” OR “Maxillary Surgery” AND “Cranial Nerve Injuries” OR “Maxillary Surgery” AND “Cranial Nerves” OR “Orthognathic Surgery” AND “Cranial Nerve Injuries” OR “Orthognathic Surgery” AND “Cranial Nerves” OR “Le Fort osteotomy” AND “Olfactory Nerve” OR “Le Fort osteotomy” AND “Optic Nerve” OR “Le Fort osteotomy” AND “Oculomotor Nerve” OR “Le Fort osteotomy” AND “Trochlear Nerve” OR “Le Fort osteotomy” AND “Trigeminal Nerve” OR “Le Fort osteotomy” AND “Abducens Nerve” OR “Le Fort osteotomy” AND “Facial

Nerve” OR “Le Fort osteotomy” AND “Vestibulocochlear Nerve” OR “Le Fort osteotomy” AND “Glossopharyngeal Nerve” OR “Le Fort osteotomy” AND “Vagus Nerve” OR “Le Fort osteotomy” AND “Accessory Nerve” OR “Le Fort osteotomy” AND “Hypoglossal Nerve” OR (“complications” [Subheading]) AND “Orthognathic Surgery”.

After the main search, the reference lists of all articles selected were checked through a manual search to identify any additional relevant papers for this systematic review.

Study selection

Titles and abstracts were identified after the completion of the database searches. Duplicate studies were excluded, and two independent reviewers (BWFA, JMSA) examined all abstracts for inclusion. A third reviewer (DVG) was available to assist in resolving cases of disagreement and full texts were obtained when necessary. The level of agreement between the two reviewers (BWFA, JMSA) was evaluated using the kappa statistic (κ).

Eligibility criteria

Observational studies involving individuals submitted to Le Fort I osteotomy, without sex or age restriction, and that reported signs and symptoms associated with cranial nerve injuries were considered eligible for this systematic review. There was no restriction on publication date. Only articles published in the English language were selected for this study. Studies on nerve injuries caused by other surgical procedures and literature reviews were not considered for this systematic review.

Data extraction

The data from each study were extracted and recorded independently by each of the two review authors (BWFA, JMSA). Any discrepancies were resolved through discussion or with the involvement of a third reviewer (DVG).

Analysis of cranial nerve injury

After reading each article, the following data were extracted: the nerve injury, study design, recovery time, patient’s age, signs and symptoms present during the postoperative period related to the nerve injury, nerve branch affected (if necessary), the follow-up, and any comorbidities.

Analysis of the association between intraoperative complications and cranial nerve injuries

The association between intraoperative complications and cranial nerve injuries in Le Fort I osteotomy was analyzed. The study articles were read and the following data were extracted: the nerve injury, the intraoperative complications, the complementary surgery management, the nerve injury management, and the postoperative supplementary procedures.

Analysis of methodological quality

The evaluation of the methodological quality of the selected studies was performed using a risk of bias scale, as used in previous systematic reviews^{20,21}. The criteria analyzed were: (1) randomization or consecutive patients in a prospective study, (2) comparison between treatments, (3) blind assessment, (4) validation of measurements, (5) statistical analysis, (6) defined inclusion and exclusion criteria, and (7) report of follow-up. The risk of bias was considered low if all items were present, medium if five or six items were present, and high in the presence of four or fewer items.

Results

A flowchart describing the steps of the search strategy to the final inclusion of articles in this systematic review is presented in Fig. 1.

Search strategy

Initially, 8762 articles were identified in the database search (PubMed, $n = 1516$; LILACS, $n = 1479$; Scopus, $n = 4822$; Web of Science, $n = 835$; Cochrane, $n = 110$). After the removal of duplicates, 3144 articles remained for the study selection stage. After the selection of eligible papers identified by the main search, a manual search of the reference lists of these studies was conducted, resulting in the inclusion of an additional two articles in this systematic review.

Study selection and eligibility

The titles and abstracts of the 375 selected studies were read by two reviewers (BWFA, JMSA); the inter-rater agreement coefficient (κ) was equal to 0.779. Thirty-two of these studies were chosen for full-text reading; 30 articles were selected through the main search and two through the manual search. Whenever the two

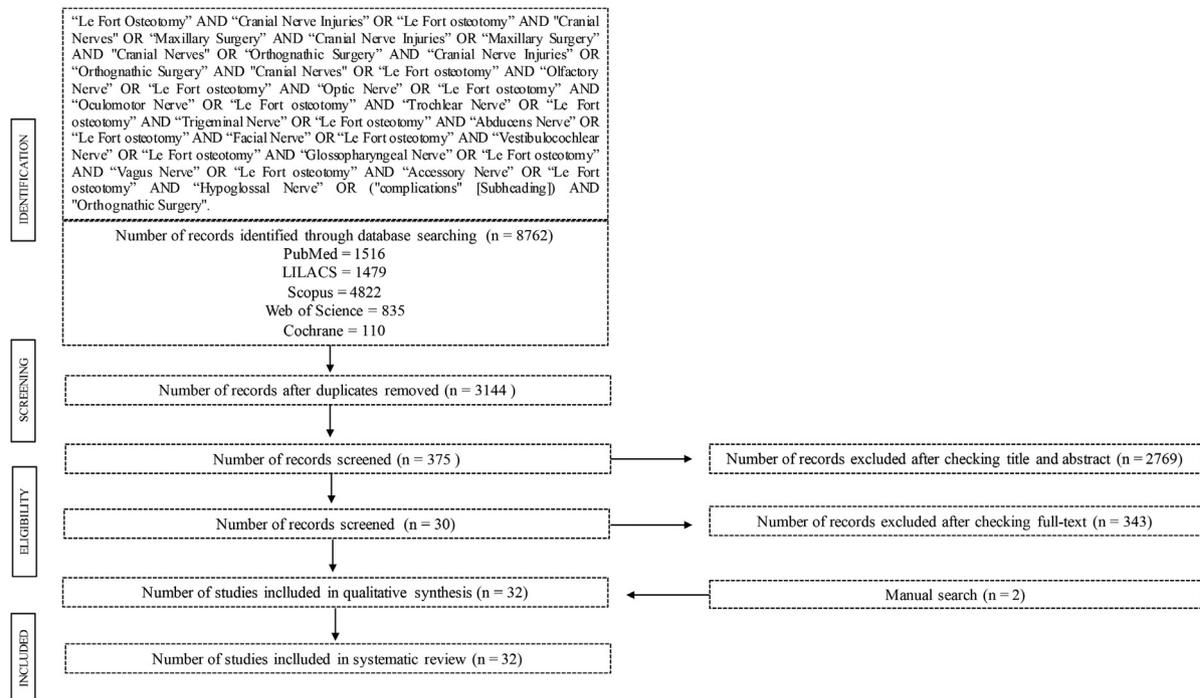


Fig. 1. PRISMA flowchart of the electronic search.

authors differed as to the selection of a paper, the disagreement was resolved by choosing the broadest possible study. The level of agreement between the two authors in selecting studies to be read in full was measured at $\kappa = 0.767$.

Description of the results of the studies

Analysis of cranial nerve injury

The general information of each study and the cranial nerve injuries during Le Fort I osteotomy are presented in Table 1. The year of publication of the studies selected for the systematic review ranged from 1984 to 2018. Eight studies reported injuries to the optic nerve, 12 to the oculomotor nerve, 15 to the trigeminal nerve, 11 to the abducens nerve, four to the facial nerve, and one to the vagus and accessory nerves. Of the 32 articles included, 20 were case reports or case series, one was a cross-sectional study, one was a retrospective study, and 10 were prospective studies. The patients ranged in age from 11 to 88 years and the follow-up ranged from 5 days to 37 months.

Analysis of the association between intraoperative complications and cranial nerve injuries

The association between intraoperative complications and cranial nerve injuries in Le Fort I osteotomy is presented in

Table 2. Most of the Le Fort I osteotomies were uneventful and did not require intraoperative complementary management.

Analysis of methodological quality

The quality assessment of the included studies is provided in the **Supplementary Material**. The risk of bias in the included articles ($\kappa = 0.796$) was classified as medium for three studies and high for 29 studies.

Discussion

The Le Fort I osteotomy is a technique based on two principles: pterygomaxillary disjunction and down-fracture, which allows mobility of the maxilla and is associated with vascular and nervous complications in the intraoperative and postoperative period^{14,22}. This systematic review shows cranial nerve damage correlated to the use of this technique.

The trigeminal nerve was the most affected in Le Fort I osteotomy, followed by the oculomotor, abducens, optic, facial, and vagus and accessory nerves. It was interesting to note that damage associated with the second division of the trigeminal nerve has been poorly reported in the literature^{22–29}. It is considered that this fact is related to the expected injury in Le Fort I osteotomy.

The most common symptom associated with the Le Fort I osteotomy was maxillary

hypoesthesia due to injury to the superior alveolar, greater palatine, nasopalatine, and infraorbital nerves^{7,10,11,22,23,26,30–36}. It is believed that the highest prevalence shown for trigeminal nerve injuries is due to the use of the retractor and the mucosal incision needed for the surgical approach, which can frequently lead to nerve damage. Dental, mucosal, and facial sensory disturbances generally return to normal function within 3 months after the Le Fort I osteotomy²⁶. However, some studies have shown an incomplete recovery after 6 months^{24,31,37}.

The most common injury associated with the oculomotor and abducens nerves was ophthalmoplegia^{7,10,11,14,22,32,33,38}. The abducens nerve innervates the lateral rectus muscle and damage to this nerve blocks the lateral movement of the eyeball. The oculomotor nerve is divided into two branches: the first division innervates the superior rectus and levator palpebrae superioris muscles, and the second division innervates the medial rectus, inferior rectus, and oblique muscles¹¹ and the pupillary smooth muscles with its parasympathetic fibres from the Edinger–Westphal nucleus and the dilator pupillae with its sympathetic fibres from the internal carotid plexus¹⁴; this explains the eye muscle paresis^{21,38} and the mydriasis^{14,22,39}. Pupil-sparing oculomotor palsy³⁸ occurs when only the superior division is disturbed¹⁴, although it has

Table 1. General information and cranial nerve injuries related to Le Fort I osteotomy.

Author, year	Study design	Recovery time	Age (years)	Onset of signs and symptoms postoperative	Nerve branch	Signs and symptoms	Follow-up	Comorbidity type
Optic nerve (II)								
Sirikumara and Sugar, 1990 ⁵²	CR	Partial recovery	24	1 day		Non-consensual light reflex	18 months	Asthma
Lanigan et al., 1993 ³⁷	CRs	Case 1: 5 days	33	1 day		Amaurosis fugax	5 days	Facial pain, TMD
		Case 3: Partial recovery	17	1 day		No light perception; amaurosis	6 weeks	ND
Lo et al., 2002 ²²	CRs	Case 1: No recovery	11	1 day		Amaurosis and non-consensual light reflex	37 months	CLP
		Case 2: No recovery	11	2 days		Amaurosis	26 months	ND
Cruz and Dos Santos, 2006 ⁴⁰	CR	ND	22	1 week ^a		Amaurosis	ND	ND
Kim et al., 2011 ⁷	CR	6 months	19	1 day		Amaurosis fugax	1 year	CLP
Chrcanovic and Custódio, 2011 ¹⁴	CR	No recovery	28	1 day		Amaurosis	28 months	None
Mathew et al., 2015 ⁴¹	CRs	Case 1: Complete recovery	19	2 days		Amaurosis fugax	Several months	Bilateral CLP
		Case 2: No recovery	22	1 day		Amaurosis	1 month	Unilateral CLP
Rodriguez-Navarro and Gonzalez-Valverde, 2018 ²³	CR	No recovery	41	1 day		Amaurosis	ND	None
Oculomotor nerve (III)								
Carr and Gilbert, 1986 ¹¹	CR	8 weeks	17	1 day	1 st and 2 nd division	Blepharoptosis, strabismus, and anisocoria	8 weeks	CLP
Lanigan and Tubman, 1987 ³⁸	CR	10 months	23	4 months ^a	ND	ND	9 months	ND
Lanigan et al., 1993 ³⁷	CRs	Case 1: 5 days	33	1 day	1 st and 2 nd division	Blepharoptosis, mydriasis	5 days	Facial pain, TMD
		Case 3: Partial recovery	17	1 day	2 nd division	Reduction of the pupillary response	6 weeks	ND
Herold and Falworth, 1996 ³⁰	CR	6 weeks	35	2 days	1 st division	Blepharoptosis	6 weeks	None
Lo et al., 2002 ²²	CRs	Case 1: ND	11	2 days	2 nd division	No pupillary light reflex	37 months	CLP
		Case 2: ND	11	1 day	2 nd division	Anisocoria	26 months	CLP
Newlands et al., 2004 ⁴⁸	CR	1 week	33	1 day	1 st division	Blepharoptosis and ophthalmoplegia	ND	ND
Cruz and Dos Santos, 2006 ⁴⁰	CR	ND	22	1 week ^a	1 st division	Eyelid paralysis	ND	ND
Kim et al., 2011 ⁷	CR	2 months	19	1 day	1 st division	Blepharoptosis	1 year	CLP
Chrcanovic and Custódio, 2011 ¹⁴	CR	5 days	28	2 days	1 st and 2 nd division	Blepharoptosis and mydriasis	28 months	None
Sirikumara and Sugar, 1990 ⁵²	CR	Partial recovery	24	1 day	2 nd division	Mydriasis and non-consensual light reflex	18 months	Asthma
Brookes et al., 2015 ³⁹	CRs	Case 2: 1 day	20	1 day	2 nd division	Mydriasis	ND	None

Mathew et al., 2015 ⁴¹	CRs	Case 3: 2.5 weeks	31	1 day	2 nd division	Mydriasis	2.5 weeks	None	
		Case 4: 2 days	16	1 day	2 nd division	Mydriasis	ND	Asthma	
		Case 1: ND	19	2 days	2 nd division	Reduction of the pupillary response	Several months	Bilateral CLP	
		Case 2: ND	22	1 day	2 nd division	Reduction of the pupillary response	1 month	Unilateral CLP	
Trigeminal nerve (V)									
De Jongh et al., 1986 ²⁷	CSS	6–54 months	21 ^b	6–54 months ^c	SAN	Pulpal and soft tissue hypoesthesia	14 months	ND	
Lanigan et al., 1993 ³⁷	CRs	Case 6: Partial recovery	20	3 months	ZFN	Malar hypoesthesia	ND	ND	
Posnick et al., 1994 ²⁴	PS	Group 1: Partial recovery	18 ^b	1 year ^c	ION	Hyperesthesia	1 year	Unilateral CLP	
		Group 2: Partial recovery	19 ^b	1 year ^c	ION	Hyperesthesia	1 year	Bilateral CLP	
		Group 3: Partial recovery	19 ^b	1 year ^c	ION	Hyperesthesia	1 year	Without cleft	
Rosenberg and Sailer, 1994 ²⁸	PS	ION: 3 months GPN and PSAN: Partial recovery	27 ^b	1 month ^c	ION, GPN, and PSAN	Hypoesthesia	6 months	1 amelogenesis imperfecta, 1 unilateral CLP, 4 edentulous	
Al-Din et al., 1996 ³¹	PS	SAN and GPN: Partial recovery	25 ^b	2 days ^c	SAN and GPN	Pulpal, palatal, and mucosal hypoesthesia	6 months	ND	
Schultze-Mosgau et al., 2001 ¹³	PS	12 months	24.9 ^b	7 days ^c	ION	Hypoesthesia	12 months	ND	
Harada et al., 2004 ⁵³	PS	3 months	18 ^b	1 day	SAN	Pulpal hypoesthesia	3 months	Unilateral cleft lip, palate and alveolus; soft cleft palate; maxillary hypoplasia without deformity	
Chuah and Mehra, 2005 ²⁵	CR	87 days	29	3 days ^a	LN	Tongue paresthesia	12 weeks	None	
Ueki et al., 2007 ⁵	PS	1 year	23.6 ^b	1 week ^c	SLN	Upper lip hypoesthesia	1 year	ND	
Ueki et al., 2008 ²⁹	PS	1 year	24.3 ^b	1 week ^c	SLN	Upper lip hypoesthesia	1 year	ND	
Thygesen et al., 2009 ³⁵	PS	12 months	25 ^b	3 months ^c	ION and GPN	Pulpal and soft tissue hypoesthesia	1 year	None	
Park et al., 2011 ³⁶	PS	6–12 months	30 ^b	3 months ^c	ION	Hypoesthesia	1 year	None	
Kim et al., 2011 ⁷	CR	2 months	19	1 day	ZN	Upper cheek paresthesia	1 year	CLP	
Kang et al., 2014 ⁵⁰	CRs	Case 1: ND	18	1 week	ZFN	Malar hypoesthesia	6 months	ND	
Moran et al., 2018 ²⁶	RS	ND	24 ^b	ND	ION	Paresthesia and pulp necrosis	13 months (mean)	Syndromic patients and CLP	
Abducens nerve (VI)									
Watts, 1984 ¹⁰	CR	7 weeks	18	1 day		Lateral rectus palsy	7 weeks	ND ^d	
Lanigan and Tubman, 1987 ³⁸	CR	10 months	23	5 months		Lateral rectus palsy	9 months	ND	
Reiner and Willoughby, 1988 ³³	CR	5 months	88	1 day		Lateral rectus palsy	5 months	None	
Lo et al., 2002 ²²	CR	Case 1: ND	11	1 day		Lateral rectus palsy	37 months	CLP	
Newlands et al., 2004 ⁴⁸	CR	10 weeks	11	1 day		Lateral rectus palsy	ND	ND	

Table 1 (Continued)

Author, year	Study design	Recovery time	Age (years)	Onset of signs and symptoms postoperative	Nerve branch	Signs and symptoms	Follow-up	Comorbidity type
Cruz and Dos Santos, 2006 ⁴⁰	CR	ND	22	1 week ^a		Lateral rectus palsy	ND	ND
Hanu-Cernat and Hall, 2009 ³⁴	CR	6 weeks	16	5 days		Lateral rectus palsy	6 weeks	None
Chrcanovic and Custódio, 2011 ¹⁴	CR	5 days	28	2 days		Lateral rectus palsy	28 months	None
Kim et al., 2011 ⁷	CR	1 year	19	1 day		Lateral rectus palsy	1 year	CLP
Brookes et al., 2015 ³⁹	CRs	Case 2: 1 day	20	1 day		Lateral rectus palsy	ND	None
Sirinoglu et al., 2015 ³²	CR	6 weeks	21	14 days		Lateral rectus palsy	6 weeks	ND
Facial nerve (VII)								
Lanigan and Tubman, 1987 ³⁸	CR	ND	23	3 months ^a	GSPN	Epiphora	9 months	ND
Lanigan et al., 1993 ³⁷	CRs	Case 4: Partial recovery	42	8 days	GSPN	Dry eye	2 years	ND
		Case 5: Partial recovery	39	1 month	GSPN	Dry eye	14 months	ND
		Case 6: Partial recovery	20	3 months	GSPN	Dry eye	ND	ND
Gent et al., 2003 ⁴⁵	PS	Partial recovery	24.6 ^b	2 months ^c	GSPN	Hypogeusia	9 months	ND
Kang et al., 2014 ⁵⁰	CR	Case 1: Partial recovery	18	1 week	GSPN	Dry eye	6 months	ND
		Case 2: Partial recovery	32	6 months	GSPN	Dry eye	8 months	ND
Vagus and accessory nerves (X and XI)								
Hacein-Bey et al., 2013 ¹²	CR	Partial recovery	18	ND	RLN, PN (X), and external branch (XI)	Vocal cord paresis and dysphagia; trapezius muscle atrophy	1 year	None

CLP, cleft lip and palate; CR, case report; CSS, cross-sectional study; GPN, greater palatine nerve; GSPN, greater superficial petrosal nerve; ION, infraorbital nerve; LN, lingual nerve; ND, no data; PN, pharyngeal nerve; PS, prospective study; PSAN, posterior superior alveolar nerve; RLN, recurrent laryngeal nerve; RS, retrospective study; SAN, superior alveolar nerve; SLN, superior labial nerve; TMD, temporomandibular disorder; ZFN, zygomaticofacial nerve; ZN, zygomatic nerve.

^a The patient sought assistance, but the precise time of onset is unknown.

^b Mean value.

^c If the author made remarks about the patient's health, the comorbidity was considered as non-existent.

^d The related comorbidity caused by Le Fort I osteotomy gradually resulted in nerve injury.

Table 2. Cranial nerve injuries associated with intraoperative complications in Le Fort I osteotomy.

Author, year	Intraoperative complications	Complementary surgery management	Nerve injury management	Postoperative supplementary procedures
Optic nerve (II)				
Lanigan et al., 1993 ³⁷	Uneventful	No management	Corticosteroid	ND
Lo et al., 2002 ²²	Case 1: excessive bleeding	No management	Corticosteroid	DO
	Case 2: anisocoria, reduced pupillary response	Corticosteroid	Corticosteroid	None
	ND	ND	Corticosteroid	None
Cruz and Dos Santos, 2006 ⁴⁰	Bleeding	Packing gauze + Surgicel	Corticosteroid	None
Kim et al., 2011 ⁷	Uneventful	No management	Corticosteroid	IMF with elastics
Chrcanovic and Custódio, 2011 ¹⁴	Case 1: Uneventful	No management	Corticosteroid	ND
	Case 2: Uneventful	No management	Corticosteroid	ND
Rodriguez-Navarro and Gonzalez-Valverde, 2018 ²³	Uneventful	No management	Corticosteroid	ND
Oculomotor nerve (III)				
Carr and Gilbert, 1986 ¹¹	Uneventful	No management	Corticosteroid	External fixation
Lanigan and Tubman, 1987 ³⁸	Difficulty in down-fracturing and sectioning of both descending palatine arteries	Artery clips	Occlusion of the carotid-cavernous sinus fistula	MMF
Lanigan et al., 1993 ³⁷	Uneventful	No management	Corticosteroid	ND
Herold and Falworth, 1996 ³⁰	Haemorrhage from nostrils on extubation	Reintubation, posterior and anterior nasal packing	Observation	None
Lo et al., 2002 ²²	Case 1: excessive bleeding	No management	Corticosteroid	DO
	Case 2: anisocoria, reduced pupillary response	Corticosteroid	Corticosteroid	None
Newlands et al., 2004 ⁴⁸	Bleeding from maxillary artery	Surgicel, local pressure	Corticosteroid and eye patch	None
Cruz and Dos Santos, 2006 ⁴⁰	ND	ND	Corticosteroid	None
Kim et al., 2011 ⁷	Bleeding	Packing gauze + Surgicel	Corticosteroid	None
Chrcanovic and Custódio, 2011 ¹⁴	Uneventful	No management	Corticosteroid	IMF with elastics
Sirikumara and Sugar, 1990 ⁵²	None	No management	No management	None
Brookes et al., 2015 ³⁹	None	No management	Corticosteroid	ND
Mathew et al., 2015 ⁴¹	Uneventful	No management	Corticosteroid	ND
Trigeminal nerve (V)				
De Jongh et al., 1986 ²⁷	ND	ND	ND	IMF
Lanigan et al., 1993 ³⁷	Uneventful	No management	Corticosteroid	ND
Posnick et al., 1994 ²⁴	ND	ND	ND	ND
Rosenberg and Sailer, 1994 ²⁸	1 patient had the GPN freed out of its canal	Autologous bone or lyophilized bone + BMP	ND	ND
Al-Din et al., 1996 ³¹	5 patients had the GPN sectioned	ND	ND	ND
Schultze-Mosgau et al., 2001 ¹³	Uneventful	No management	Observation	None
Harada et al., 2004 ⁵³	ND	ND	ND	D-group: external maxillary distraction (advancement); C-group: medium intermaxillary elastics Postoperative expansion twice daily
Chuah and Mehra, 2005 ²⁵	Bleeding	Avitene and Surgicel	Observation	Postoperative expansion twice daily
Ueki et al., 2007 ⁵	Uneventful	No management	Observation	IMF with elastics
Ueki et al., 2008 ²⁹	Uneventful	No management	Observation	IMF with elastics

Table 2 (Continued)

Author, year	Intraoperative complications	Complementary surgery management	Nerve injury management	Postoperative supplementary procedures
Thygesen et al., 2009 ³⁵	ND	ND	Observation	None
Park et al., 2011 ³⁶	ND	ND	Observation	None
Kim et al., 2011 ⁷	Bleeding	Packing gauze + Surgicel	Corticosteroid	None
Kang et al., 2014 ⁵⁰	ND	ND	Ophthalmic ointment and artificial tears	ND
Moran et al., 2018 ²⁶	ND	ND	ND	ND
Abducens nerve (VI) Watts, 1984 ¹⁰	Difficulty of positioning the chisel and performing pterygoid disjunction	No management	Observation	IMF
Lanigan and Tubman, 1987 ³⁸	Difficulty in down-fracturing and sectioning of both descending palatine arteries	Artery clips	Occlusion of the carotid-cavernous sinus fistula	MMF
Reiner and Willoughby, 1988 ³³	Uneventful	No management	Eye patch and daily eye exercise	None
Lo et al., 2002 ²²	Uneventful	No management	Eye patch and daily eye exercise	None
Newlands et al., 2004 ⁴⁸	Bleeding from maxillary artery	Surgicel, local pressure	Corticosteroid	None
Cruz and Dos Santos, 2006 ⁴⁰	ND	ND	Corticosteroid	None
Hanu-Cernat and Hall, 2009 ³⁴	ND	ND	Observation	None
Chrcanovic and Custódio, 2011 ¹⁴	Uneventful	No management	Corticosteroid	IMF with elastics
Kim et al., 2011 ⁷	Bleeding	Packing gauze + Surgicel	Corticosteroid	None
Brookes et al., 2015 ³⁹	Uneventful	No management	Corticosteroid	ND
Sirinoglu et al., 2015 ³²	Uneventful	No management	Observation	None
Facial nerve(VII) Lanigan and Tubman, 1987 ³⁸	Difficulty in down-fracturing and sectioning of both descending palatine arteries	Artery clips	Occlusion of the carotid-cavernous sinus fistula	MMF
Lanigan et al., 1993 ³⁷	Uneventful	No management	Corticosteroid	ND
Gent et al., 2003 ⁴⁵	Uneventful	No management	ND	ND
Kang et al., 2014 ⁵⁰	Case 1: ND	ND	Ophthalmic ointment and artificial tears	ND
	Case 2: ND	ND	Artificial tears	ND
Vagus and accessory nerves (X and XI) Hacein-Bey et al., 2013 ¹²	Uneventful	No management	Carotid artery stent and coil obliteration of the pseudoaneurysm and antiplatelet therapy	IMF with elastics

BMP, bone morphogenetic protein; DO, distraction osteogenesis; GPN, greater palatine nerve; IMF, intermaxillary fixation; MMF, maxillomandibular fixation; ND, no data.

been suggested that this happens because the pupillomotor fibres are more resistant to compression and ischemia³⁸. Isolated mydriasis may also be found when only the inferior division of the oculomotor nerve is affected¹⁴.

Haemorrhage, oedema, and even contusion are causes of compression of the optic nerve⁴⁰, and can lead to reversible or irreversible damage. However, it is the unwanted fractures of the base of the skull that extend to the superior orbital fissure that are the main cause of amaurosis after orthognathic surgery⁴¹. They can cause neurapraxia up to total nerve rupture^{14,22} due to the displacement of bone fragments^{7,14,32} through the optic canal¹⁴ and sphenoid body into the cavernous sinus^{7,32}. Increased local pressure from a retrobulbar haemorrhage²¹ or even an impediment of the orbit venous drainage from carotid-cavernous shunts can also lead to blindness²³.

Another hypothesis for damage to the optic nerve and other cranial nerves is ischemia or nerve infarction from the blood hypoperfusion to the brain, which may cause ischemic optic neuropathy and retinal artery occlusion^{7,42}. This may explain cases that have shown no alteration on computed tomography⁴⁰. Cerebral hypoperfusion may be due to lower blood pressure caused by controlled hypotension, which is routinely used as an anaesthetic procedure to avoid excessive bleeding and a decrease in blood volume, as well as to improve visibility of the surgical field, especially during down-fracture; this may increase the risk of damage to the sphenopalatine artery^{7,43-45}. Hypotensive anaesthesia has potential risks when considering the age and systemic condition of the patients^{44,46,47}.

Facial nerve disturbances are divided into secretomotor disturbances^{21,47-50} and decrease in taste sensitivity³⁴. The first impairment occurs due to direct or indirect lesions or even irritation to the sphenopalatine ganglion at the pterygomaxillary fissure, during maxillary osteotomy. This anatomical structure receives the vidian nerve, which carries parasympathetic and sympathetic fibres from the greater superficial petrosal nerve and carotid plexus, respectively²². These fibres are carried through the maxillary nerve branch that innervates the lacrimal gland²², as from the sphenopalatine ganglion. The descending palatine nerves pass through this ganglion, but they do not show any functional relationship with it, and innervate the mucosal nasal glands⁵⁰. When the damage affects the facial nerve in its course through the base of the skull,

pterygopalatine fossa, or inferior orbital fissure, this can lead to a lack of tearing^{21,23,47,49,50}, epiphora²¹, or even to vasomotor rhinorrhea⁵⁰. Gent et al.⁴⁵ showed that the function of taste in the palate was significantly decreased at 6 to 9 months after Le Fort I osteotomy, probably due to impairment of the major function of the superficial petrosal nerve from the facial nerve. Another explanation is that the postganglionic parasympathetic fibres are more vulnerable to injury because they are non-myelinated and can be damaged more easily than myelinated fibres under the same circumstances⁵⁰.

Damage to the vagus and accessory nerves was described in one case; this patient showed dysphagia, cough, vocal fold paralysis, and trapezius muscle atrophy¹². The aetiological factor was a pseudoaneurysm of the internal carotid artery that induced a pulsating effect on the nerves, which was reverted after treatment. In that study, the authors associated the carotid artery aneurysm with the unwanted fracture of the skull base or with a shear injury to the artery caused by movement of the head and neck during nasotracheal intubation or the surgical approach^{21,23,51}.

Five studies showed severe nerve injuries, such as amaurosis, in patients with cleft lip and palate^{11,31,37,40,52}. The Le Fort I osteotomy is considered a difficult surgery for these patients because they may have anatomical variations of the nerve positions⁵³, pterygomaxillary sclerosis^{54,55}, fibrosis of the soft tissues and low blood flow of the descending palatine artery resulting from previous surgeries⁵⁵⁻⁵⁷.

According to Wikkeling and Koppendraaier⁵⁸, there are three fracture types from pterygomaxillary disjunction: (1) the ideal fracture, (2) an oblique fracture through the maxillary sinus, and (3) a high pterygoid process fracture. The main cause of nerve injury is related to the third fracture type, an ascending fracture towards the orbit^{10,14,30} or the base of the skull^{7,12,22,23,32} through the pterygoid bone. The size and positioning of the chisel can be related to the use of excessive forces or inadequate directions of forces applied during the pterygomaxillary disjunction, the main causes related to these nerve injuries^{7,12,14,22,32}. The use of intermaxillary fixation with elastics can aggravate adverse fractures, causing displacement of the hair-line fracture and direct or indirect compression by haematoma³³.

Adequate positioning of the curved chisel anteromedially and inferiorly in the pterygomaxillary fissure is imperative to avoid unwanted fractures⁵⁹. Modifications of the conventional technique such as maxillary

tuberosity osteotomy^{60,61}, swan's neck osteotome use⁶², shark-fin osteotome use^{63,64}, use of digital pressure, alone or in combination with Tessier spreaders⁶⁵⁻⁶⁷, and piezoelectric surgery^{50,68,69} are measures that have been used in an attempt to avoid the risks related to pterygomaxillary separation with a curved Obwegeser osteotome⁷⁰. However, these measures are still rarely used⁷¹.

Excessive bleeding and difficulty performing down-fracture were frequent intraoperative complications; both are respectively associated with retrobulbar haemorrhage and direct and indirect neurovascular damage²¹. Studies have reported the use of corticosteroids after Le Fort I osteotomy^{7,21,22,30,37,40,43,52}. The literature associates the use of these drugs with a reduction in postoperative swelling and its complications^{58,72}.

Cranial nerve damage after Le Fort I osteotomy is not rare, and in most cases this damage is related to unwanted fractures of the base of the skull and anatomical variations. Knowledge of the surgical anatomy and an understanding of the patient's anatomical variations are necessary in order to minimize the risk of nerve injury.

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There is no relationship between any author and commercial firms that may pose a conflict of interest.

Ethical approval

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Patient consent

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Appendix A. Supplementary data

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