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Systematic Review
Orthognathic Surgery

Minimally invasive orthognathic surgery: a systematic review

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Abstract. Minimally invasive techniques are currently applied in many oral and maxillofacial surgical procedures, including orthognathic surgery. A systematic review on the application of potentially minimally invasive procedures in orthognathic surgery was performed to provide a clear overview of the relevant published data. Articles in English on minimally invasive orthognathic procedures, published in the scientific literature, were obtained from the PubMed, Embase, and Cochrane Library databases, and an additional manual search (revised 31 December 2016). After screening the abstracts and applying the eligibility criteria, 403 articles were identified. All articles reporting the potential for minimally invasive orthognathic surgery were included ($n = 44$). The full papers were evaluated in detail and categorized as articles on a minimally invasive surgical approach ($n = 4$), endoscopically assisted orthognathic procedures ($n = 17$), or the use of a piezoelectric device in orthognathic surgery ($n = 25$); two articles were each included in two categories. Although a small incision and minimal dissection is the basic principle of a minimally invasive technique, most articles (90.9%) reported the endoscope and piezoelectric instrument as important tools in minimally invasive orthognathic surgery. Evidence from available studies suggests that patients undergoing minimally invasive orthognathic surgery have less morbidity and make a faster recovery. Further research should aim to obtain higher levels of evidence.

Key words: corrective jaw surgery; endoscopically assisted orthognathic procedures; minimally invasive surgery; orthognathic; orthognathic surgery; piezoelectric osteotomy; Piezosurgery; Piezotome.

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The correction of dentofacial deformities has evolved substantially since the 1800s when Hullihen and Von Langenbeck performed the first osteotomies on the jaw. The number of patients opting for orthognathic surgery to correct deformities has continued to grow, although a proportion of patients refuse surgery and request camouflage orthodontic treatment[1–3]. The fear of ‘going under the scalpel’ has always deterred some patients from surgery, but the concept of ‘minimally invasive surgery’ (MIS) is changing this belief.

The contemporary literature has reported MIS in various medical specialties for a considerable time[4–12]. There is no clear definition of MIS that can be related to preoperative planning, intraoperative techniques and instruments, and postoperative care. Hunter described it as a discipline that involves procedures performed in a novel way to diminish the sequelae of standard surgical care[13]. MIS was introduced to orthognathic surgery primarily to fulfil the goals of aesthetics, function, and stability. Modification of the ‘wide-open’ conventional approach towards short incisions and minimal dissection enables the surgeon to perform procedures in a gentler manner, to reduce complications, and facilitate a faster recovery.

Recent additions to the surgical armamentarium offer surgeons the option of performing a less invasive procedure. Among these, the endoscopic approach has become the standard of care in many surgical specialties. The evidence-based literature supports this approach as an important tool of MIS, because of the advantages of smaller incisions and reduced reflection with magnified visualization[14]. Ultrasonic or piezoelectric devices (piezoelectric osteotomes, e.g. Piezotome) are another useful tool with proven efficacy in bone cutting. They offer soft tissue preservation, higher precision and control, and the ability to provide a dry operation field because of the cavitation effect and micromovement[15,16].

There is much debate in the literature over the longer duration and complexity of the MIS technique and the steep learning curve required. Hence, the aim of this systematic review was to evaluate and reach a consensus on the applicability of minimally invasive techniques in the current practice of orthognathic surgery.

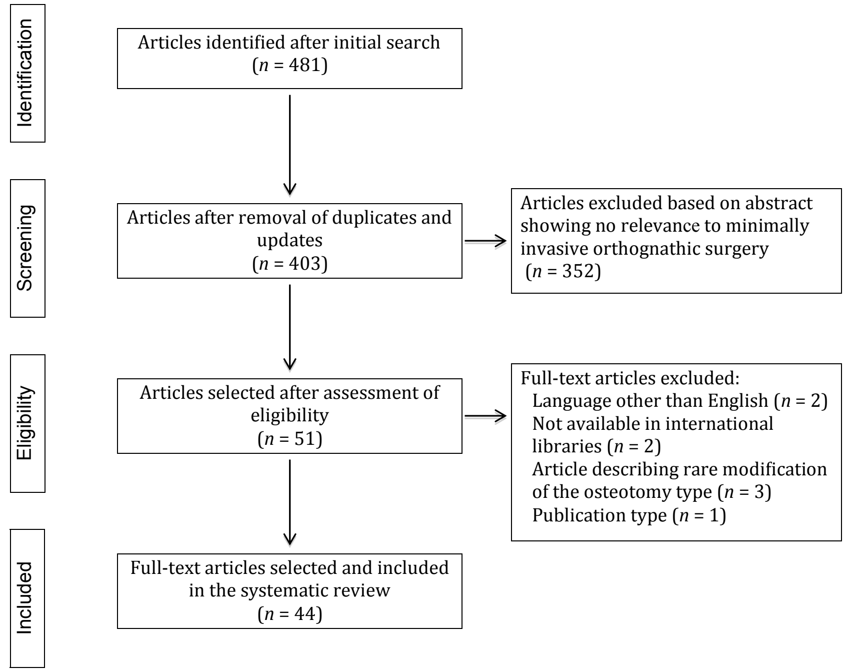

Fig. 1. Methodology of the search and selection process using PubMed, Embase, and the Cochrane Library. (Note: one article was excluded for two reasons.)

Materials and methods

A systematic search was conducted in the English-language scientific literature for studies on potential minimally invasive techniques in orthognathic surgery published between 1 January 1990 and 30 November 2016. The PubMed (National Library of Medicine, National Center for Biotechnology Information (NCBI)), Embase, and Cochrane Library databases were used, and an additional manual search was performed (revised 31 December 2016). The limiting year of 1990 was chosen because the concept of MIS had not been established in the scientific literature prior to that year. The key words used in the search consisted of all possible combinations of 12 primary key words related to MIS; and 18 secondary key words to restrict the search to MIS in orthognathic surgery (Table 1). The methodology of the search and selection process for this systematic review (using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines) is illustrated in Fig. 1.

The initial search revealed 481 articles published between 1990 and 2016. The removal of duplicate references yielded 403 articles. After an extensive reading of the topics of interest in the field of minimally invasive orthognathic surgery, the final inclusion criteria encompassed any report of a minimally invasive approach (i.e., small incision and less reflection) or any article that assessed the use of an endoscope or piezoelectric device in orthognathic surgery, either separately or in combination.

The titles and abstracts of the 403 selected studies were read and evaluated by one author (N.A.), and then reviewed and discussed with the other author (G.S). In the event of a disagreement, the final decision was based on discussion to consensus. The full texts of the selected articles were read after applying the inclusion and exclusion criteria (Table 2). References that contributed to the purpose of the study were retrieved. One hundred and nine articles were related to MIS in other fields outside the scope of this review, such as temporomandibular joint endoscopy, salivary gland endoscopy, piezoelectric surgery in dentoalveolar surgery, and dental implantology. These studies were not included in this review. Two hundred and forty-three papers were excluded because they were not relevant to the topic. Two papers were excluded because they

Table 1. Primary and secondary key words used as search terms in the systematic review on minimally invasive orthognathic surgery.

Primary key word	Secondary key word
Minimally invasive	Orthognathic
Less invasive	Orthognathic surgery
Non-invasive	Corrective jaw surgery
Less aggressive	Maxillary osteotomy
Less traumatic	Mandibular osteotomy
Conservative	Le Fort I osteotomy
Endoscope	Bilateral sagittal split osteotomy
Ultrasonic	Sagittal split osteotomy
Piezotome	Sagittal split ramus osteotomy
Piezoelectric	Vertical subsigmoid osteotomy
Piezosurgery	BSSO
Piezo-osteotomy	SSO
	SSRO
	BSSRO
	IVRO
	EVRO
	Genioplasty
	Chin osteotomy

BSSO, bilateral sagittal split osteotomy; BSSRO, bilateral sagittal split ramus osteotomy; EVRO, endoscopic vertical ramus osteotomy; IVRO, intraoral vertical ramus osteotomy; SSO, sagittal split osteotomy; SSRO, sagittal split ramus osteotomy.

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Table 2. The exclusion and inclusion criteria.

Condition	Article type	Number of papers
Excluded[a]	Not relevant to minimally invasive orthognathic surgery	352
	Language other than English	2
	Not available in international libraries	2
	Article describing a rare modification of the osteotomy type	3
	Publication type (i.e., not a full-text article)	1
Included[b]	Minimally invasive surgical approach	4
	Endoscopically assisted orthognathic procedure	17
	Use of piezoelectric device in orthognathic surgery	25

[a] One paper was excluded because of the publication type and because it was not available in international libraries.
[b] Two articles were each included in two categories.

were written in a language other than English (French and German) and a translation was not available. One paper was excluded because it was not available in international libraries. Three papers were excluded because they described rare modifications of orthognathic osteotomy procedures[17–19]. One paper was excluded because it was published as a correspondence and communication article and because it was not available in international libraries. Forty-four eligible articles were finally included[14,20–62].

These full papers were evaluated in detail and classified as articles on a limited surgical approach ($n = 4$)[20–23], endoscopically assisted orthognathic procedures ($n = 17$)[14,24–38,61], or the use of a piezoelectric device in orthognathic surgery ($n = 25$)[26,30,39–59,60,62]. If one paper met the criteria for two or more groups, it was assigned to each relevant group. For this reason, the sum of the papers in all groups ($n = 46$) is larger than the total number of papers ($n = 44$).

The following data were collected from articles reporting clinical studies and were recorded for analysis: title, year of publication, authors, sample size, age, sex, surgical approach used, type of procedure, type and size of device used, surgical technique, duration of the procedure, type of fixation, blood loss, hospital stay, follow-up period, detailed results, and complications. The data from all studies were used for the analysis.

Results

This systematic review included 44 records, which were categorized into three groups (Table 3).

Minimally invasive surgical approach

Only four papers discussed the minimally invasive surgical approach (limited approach) in orthognathic surgery. The earliest article was published by Morselli, who performed a straightforward Le Fort I osteotomy, including midline and pterygomaxillary disjunction (PMD), for maxillary widening in 24 patients (i.e., similar to transcutaneous nasal osteotomy)[20]. These patients experienced a rapid recovery and less postoperative pain. Only one patient experienced a failed procedure and required the open technique.

Thirteen years later, Hernández-Alfaro et al. described a minimally invasive approach for surgically assisted rapid palatal expansion (SARPE) under intravenous sedation, with the introduction of the twist technique to separate the pterygomaxillary suture, through a small incision (2–3.5 mm) and vestibular corridors[21]. The technique was performed successfully in a large series of 283 patients with a 12-month follow-up period. The surgical time from incision to suture was 19 min (range 15–32 min). Only three patients required a secondary intervention due to expansion failure.

Another clinical report published by Hernández-Alfaro and Guijarro-Martinez reported the same limited approach for 1297 Le Fort I osteotomies (564 monosegmental osteotomies and 733 multisegmental osteotomies)[22]. The technique effectively separated the maxilla and allowed adequate visualization of the anatomy in an average surgical time of 44 min (range 31–72 min). No significant neurovascular complications were recorded and early hospital discharge was achieved.

Finally a technical note demonstrated a minimally invasive approach for midline mandibular osteotomy through a short vertical midline incision in the lower lip frenulum[23]. This technique allowed good access to the symphyseal region without the need for a complete horizontal incision of the mentalis muscle.

Endoscopically assisted orthognathic surgery

Synopsis articles

All papers that provided a general overview of endoscopic applications in orthognathic surgery with no clinical data reported were assigned to this group. Four papers highlighted endoscopic assistance in orthognathic surgery. One paper fully described the endoscope and associated equipment, and described the technical protocol of endoscopic assistance in sagittal split osteotomy (SSO), such as the handling of the instruments and identification of the lingula[24]. This allowed better control of the osteotomy from the sigmoid notch to the inferior border, visualization and control of the distal and proximal segments, and the identification of any bony interferences. Another article addressed the use of the endoscope in vertical ramus osteotomy (VRO) and in condylectomy for cases of condylar hyperplasia or idiopathic condylar resorption[25]. The use of endoscopy and distraction osteogenesis as the two main disciplines in minimally invasive orthognathic surgery was discussed in another paper[14]. The paper provided an overview of the available data and a detailed description of endoscopic assistance in different orthognathic procedures. A technical report illustrated the supplementary advantage of combining the endoscope and piezoelectric surgery in VRO[26].

Clinical studies

Five papers reported the use of endoscopy in Le Fort I osteotomy. The first report was by Sakai et al. in 1996, who presented their experience in safely separating the pterygomaxillary suture during Le Fort I osteotomy under endoscopic guidance through a small hole in the maxillary sinus wall in 10 patients[27]. A preliminary study reported the feasibility and minimal complications in using endoscopically assisted Le Fort I osteotomy in two patients, although rigid fixation was performed under direct vision[28]. Three papers discussed Le

Table 3. Classification of 44 relevant papers that were analyzed in detail for this systematic review[a].

Category	Number of papers	References	Percentage
Minimally invasive surgical approach	4	20–23	9.1
Endoscopically assisted orthognathic surgery	17	14,24–38,61	38.6
Piezoelectric device in orthognathic surgery	25	26,30,39–60,62	56.8

[a] Two articles were each included in two categories[26,30], hence the percentages do not add up to 100%.

Fort I in SARPE procedures performed on a total of 75 patients. In a small series of three patients, a 4-mm endoscope with varying angulations was used successfully and safely through a small vertical vestibular incision in the canine region and a bur hole in the anterior and medial maxillary walls; however, the procedure had the downside of an increased operating time[29]. Robiony et al. addressed the same procedure in 13 patients using a 2.7-mm endoscope with a piezoelectric osteotome for PMD[30]. A unique technique for performing endoscopically assisted Le Fort I osteotomy and a midline split for maxillary expansion through transnasal incisions was reported by Mommaerts et al., who operated on 59 patients in various age groups[61]. The technique resulted in less postoperative oedema and a decreased surgical threshold, but there was no significant reduction in operating time or in intra- and postoperative complications.

Five papers discussed the use of endoscopy for VRO in 43 patients. Three papers reported good feasibility and minimal morbidity when using the endoscope in VRO with rigid fixation through a small submandibular approach. Among these patients, one had a temporary marginal mandibular nerve injury, four patients had inferior alveolar nerve paresthesia, and one patient had an unaesthetic scar[32–34]. One author described the endoscopically assisted fixation approach through a 3-mm stab incision inferior to the ear lobe[35]. Finally, a study of 10 patients presented the usefulness of and good visibility provided by the endoscope in intraoral vertical ramus osteotomy (IVRO); however, no rigid fixation was reportedly achieved through this approach[36].

The clinical use of endoscopy in bilateral sagittal split osteotomy (BSSO) through two separate small incisions and one corridor in the external oblique ridge was reported in one study of 34 patients[31]. A significant reduction in postoperative oedema and recovery occurred; however, the mean duration of the procedure was 15 min longer than for the conventional method. The port needed to be shifted to the conventional method on three sides, and a bad split occurred in one patient[31].

Table 4 provides a summary of all clinical studies regarding endoscopically assisted orthognathic surgery.

Experimental studies

Two reports, which involved six human cadavers and five minipigs (two cadavers and three in vivo), investigated the use of the endoscope in VRO and Le Fort I osteotomy[28,37]. The use of the endoscope in VRO increased the operating time compared to open VRO; however, better exposure, easier identification of surgical landmarks, and the capability of screw fixation were achieved successfully in these studies[37].

Educational articles

A single study investigated the use of a surgical simulation model for endoscopically assisted fixation (monocortical miniplate or bicortical fixation) through two stab incisions for the IVRO procedure[38]. The study aimed to provide appropriate surgical training before clinical use.

Wiltfang and Kessler performed endoscopically assisted Le Fort I osteotomy on four cadavers before applying the procedure clinically in three patients[29]. The aim of this preclinical training was to determine the optimal endoscopic approach to the maxillary sinus and the selection and handling of the proper instruments to perform the procedure in an efficient and safe manner.

Piezoelectric bone cutting in orthognathic surgery

Synopsis articles

Three papers described the technical use of a piezoelectric osteotome in orthognathic surgery. One article elaborated on the safety and precision of the piezoelectric bone cutting device in segmental maxillary Le Fort I osteotomy[39]. A technical note illustrated the use of piezoelectric surgery in SARPE, including PMD, under local anaesthesia[40]. Robiony et al. demonstrated the advantages of using both a piezoelectric device and an endoscope in IVRO[26]. This technical innovation was found to decrease the risk of facial nerve injury and avoid an external scar; however, rigid fixation was not mentioned.

Clinical studies

Two studies described the use of an ultrasonic bone curette for pterygomaxillary separation in the Le Fort I osteotomy procedure[41,42]. In one study, Ueki et al. used an ultrasonic device to produce a bilateral pterygomaxillary fracture above the level of the Le Fort osteotomy, without damaging the descending palatine bundle, in 11 of 14 patients[41]. Completion of the osteotomy and mobility of the pterygoid plates were evaluated postoperatively using three-dimensional (3D) computed tomography (CT) images. In a later study, Ueki et al. used this technique to remove bony interferences between the maxillary segment and pterygoid plates, after performing a complete Le Fort I osteotomy without separating the pterygomaxillary sutures, in 58 of 74 sides[42].

With regard to the use of MIS in maxillary expansion, one randomized controlled prospective trial investigated 30 patients who underwent SARPE with a combined orthodontic and surgical approach[43]. One group ($n = 15$) received treatment with the conventional oscillating saw and the other group ($n = 15$) underwent piezoelectric surgery. The investigators found that neither laboratory values nor the length of hospital stay differed significantly between the two groups. However, there was a significant reduction in bleeding during surgery, in damage to the main vessels, and in postoperative complications (e.g., haematoma, swelling) for patients who underwent surgery with the piezoelectric device.

Another technique – ultrasound endoscopic rapid maxillary expansion – combines a rigid 30° 2.7-mm endoscope with a piezoelectric device. In one study that used these instruments, 13 SARPE procedures were performed through three small vertical mucosal incisions[30]. None of these patients had excessive oedema, haematoma formation, or nerve injury.

Eight studies reported on the use of a piezoelectric device in Le Fort I osteotomy (326 monosegment and 233 multisegment)[44,47,48,50,51,54,60,62]. One author reported performing a Le Fort I piezoosteotomy in combination with surgical navigation through a minimally invasive mucosal incision in 10 patients[44]. This combination allowed more precise and safe cutting under 3D guidance, particularly in segmental osteotomy.

The use of the piezoelectric bone device in SSO either separately or in combination with other osteotomies was reported in 11 studies, consisting of a total of 782 SSOs[45–54,60]. Some articles reported the use of auxiliary chiselling or sawing to accomplish piezoelectric SSO[47,48,50].

Three articles reported 29 genioplasty procedures[51,55,56]. Piezosurgery was performed in critical mandibular procedures such as symphyseal osteotomy ($n = 22$)[48,50,51], mandibular body osteotomy ($n = 8$)[48,50], and total mandibular subapical osteotomy ($n = 1$)[57].

Table 5 provides a summary of all clinical studies regarding the use of a piezoelectric device in orthognathic surgery.

Experimental studies

Two studies evaluated the use of a piezoelectric device in orthognathic surgery on

Table 4. Clinical studies related to endoscopically assisted orthognathic surgery.

Author and year	Sample, *n* Sex	Age (years)	Approach	Endoscopically assisted surgery: Procedure	Endoscopically assisted surgery: Device: diameter, angulation; name[a]	Procedure duration, min	Blood loss Nerve injury	Outcome
Sakai et al. 1996[27]	10 2F, 8M	17–36	1-cm hole in the maxillary sinus wall	PMD in LFI ($n = 20$)	4-mm, straight angle; Shinko Optical Corp.	15–20 per side	<50 ml None	PMD performed safely with no notable complications
Rohner et al. 2001[28]	2 NA	22–25	Four vertical incisions in the maxillary vestibule	LFI including PMD ($n = 2$)	2.7-mm, straight and 30° angle; Karl Storz	90	Minimal None	Successful procedures Reduced postoperative oedema and swelling
Troulis and Kaban 2001[32]	3[b] 3M	21–42	1.5-cm submandibular incision	VRO with rigid fixation ($n = 4$)[c]	2.7-mm, 30° angle; Karl Storz	P1: 120 P2: 110 P3: 40	NA None	Good feasibility and minimal morbidity
Wiltfang and Kessler 2002[29]	3 NA	16–17	1.5-cm vertical incision in the canine region, bur hole at the angle of the anterior and medial sinus walls	LFI ($n = 3$)	4-mm, straight, 30° or 70° angle; NA	90	Minimal NA	Correct osteotomy positions and less trauma Time was longer than with the conventional method
Troulis and Kaban 2004[33]	14 5F, 9M	16–42	1.5-cm submandibular incision	VRO with rigid fixation ($n = 28$)	2.7-mm, 30° angle; Karl Storz	37 per side	Minimal Temporary marginal mandibular weakness ($n = 1$)	Good feasibility and less trauma Good occlusal and radiographic results No IMF postoperatively
de Miranda and Abrahao 2007[36]	10 7F, 3M	NA	Intraoral	VRO ($n = 20$)	4-mm, 30° angle; NA	60 per side	Minimal None	Good visibility Successful occlusal and aesthetic results No rigid fixation
Mommaerts et al. 2008[61]	59 33F, 26M	9–50	Transnasal (i.e., nasal vestibule on each side and one on the caudal membranous septum)	LFI ($n = 59$)	NA, 25° offset-view angle, straight, and 30° angle; Karl Storz	68	Nasal bleeding requiring admission to control ($n = 1$) Prolonged cheek hyperesthesia ($n = 1$)	Time and complications were similar to the conventional method Less oedema and patient surgical threshold was decreased
Mommaerts 2010[31]	34 21F, 13M	15–49	Two small incisions in the external oblique ridge, working in two tunnels and one corridor	BSSO ($n = 31$)	4-mm, 30° angle; NA	15 longer than classic	NA	Hypoesthesia: IAN ($n = 17$), lingual nerve ($n = 1$)

Table 4 (*Continued*)

Author and year	Sample, *n* Sex	Age (years)	Approach	Endoscopically assisted surgery		Procedure duration, min	Blood loss Nerve injury	Outcome
				Procedure	Device: diameter, angulation; name[a]			
Oedema was significantly reduced and patients returned to daily activities within 1 week Limited access for fixation Port was shifted to the classic approach on three sides One patient had a bad split requiring transbuccal fixation								
Cheung and Lo 2010[35]	6 NA	15–22	Intraoral and incisions below the ear lobe	VRO with rigid fixation ($n = 12$)	4-mm, 30° angle; Karl Storz	15–110 per side (fixation time)	NA IAN, full recovery within 3 months ($n = 5$)	Minimal morbidity and good stability Reasonable operation time
Papadaki et al. 2014[34]	10 6F, 4M	17–36	1.5-cm submandibular incision	IVRO with rigid fixation ($n = 20$)	2.7-mm, NA; Karl Storz	33 per side (range 29–42)	197 ml (range 50–350 ml); measured with other combined procedures IAN paresthesia ($n = 4$)	Minimal blood loss Quick recovery and long-term skeletal stability
Robiony et al. 2014[30]	13 7F, 6M	5–26	Three vertical incisions in the maxillary vestibule	SARPE ($n = 13$)	2.7-mm, straight and 30° angle; Karl Storz	74 ± 11	NA None	Excellent mucosal healing Minimal bleeding and postoperative oedema Precise and safe osteotomy PMD was performed by piezoelectric surgery

BSSO, bilateral sagittal split osteotomy; EVRO, endoscopic vertical ramus osteotomy; F, female; IAN, inferior alveolar nerve; IMF, intermaxillary fixation; IVRO, intraoral vertical ramus osteotomy; LFI, Le Fort I; M, male; NA, not available; P, patient; PMD, pterygomaxillary disjunction; SARPE, surgically assisted palatal expansion; VRO, vertical ramus osteotomy.

[a] Shinko Optical Corp., Tokyo, Japan; Karl Storz, Tuttlingen, Germany, or Carver City, CA, USA.

[b] Three out of 10 patients.

[c] Patient 1, EVRO + high condylectomy; patient 2, bilateral EVRO; patient 3, unilateral EVRO.

Table 5. Clinical studies related to the use of a piezoelectric device in orthognathic surgery.

Author and year	Sample, *n* Sex	Age (years)	Piezoelectric surgery		Procedure duration	Blood loss Nerve injury	Outcome
			Procedure	Device[a]			
Ueki et al. 2004[41]	11 10F, 1M	NA	PMD in LFI ($n = 22$)	Sonopet, Miwatec Co., Ltd	NA	Minimal Palatine bundle intact in all patients	Achieved PMD safely with no notable complications
Gruber et al. 2005[45]	7 5F, 2M	16–37	BSSO ($n = 7$)	Piezosurgery, Mectron	Required longer time	Minimal Few neurosensory disturbances	Safe and precise Quick nerve recovery (subjective assessment)
Geha et al. 2006[46]	20 14F, 6M	27.6 ± 8.8	BSSO ($n = 20$)	Piezosurgery, Mectron	NA	Minimal IAN intact in all patients	Osteotomy started with a bur and was then continued with a Piezotome Prompt recovery of IAN neurosensory function within 2 months (objective and subjective assessment) 65% had a complete split using the Piezotome only
Beziat et al. 2007[47]	NA NA	NA	LFI ($n = 144$) LFI for palatal expansion ($n = 140$) BSSO ($n = 140$) LFIII ($n = 2$)	Piezosurgery, Mectron	Required longer time	NA IAN intact in all patients	Safe segmental osteotomies of the maxilla into 4–8 parts Faster recovery of the nerve (objective assessment)
Nordera et al. 2007[49]	2[b] 1F, 1M	25–32	BSSO ($n = 2$)	Piezosurgery, Mectron	10–20% longer (subjective assessment)	Minimal No sensory loss	Safe Less pain and swelling
Landes et al. 2008[50]	50 study, 86 control 24F, 26M	16–46	LFI ($n = 22$) Segmented LFI ($n = 26$) SSO ($n = 48$) Symphyseal ($n = 6$) Mandibular body ($n = 4$)	Piezosurgery, Mectron	Same (objective assessment)	Less (objective assessment) Less (subjective assessment)	In 22 (46%) patients, the pterygoid processes had to be chiselled The SSO required a longer time, and additional sawing was required in four patients Less swelling (subjective assessment)
Landes et al. 2008[48]	90 study, 90 control 56F, 34M	NA	LFI ($n = 34$) Segmented LFI ($n = 47$) SSO ($n = 94$) Symphyseal ($n = 11$) Mandibular body ($n = 4$)	Piezosurgery, Mectron	No significant difference	Minimal 2% IAN (i.e., less)	Three bad splits Two broken blades, did not reach pterygoid Fourteen patients required additional saw
Ueki et al. 2009[42]	29[c] NA	16–42	Removal of bony interferences after PMD ($n = 58$)	Sonopet, Miwatec Co., Ltd.	NA	NA Palatine bundle intact in all patients	Safe removal of the interference in the pterygomaxillary area
Peter 2010[55]	1 1F	21	Genioplasty ($n = 1$)	NA	NA	NA No neurosensory disturbances	Less swelling
Rana et al. 2013[43]	15 study, 15 control 18F, 12M	18–54	SARPE ($n = 15$)	Piezosurgery, Mectron	10 min longer	Same (paranasal level lower in Piezosurgery) Same	No significant differences between the two groups in Hb and Hct values and inpatient stay Bleeding level in the paranasal sinus was a significant advantage of Piezosurgery

Table 5 (*Continued*)

Author and year	Sample, *n* Sex	Age (years)	Piezoelectric surgery		Procedure duration	Blood loss Nerve injury	Outcome
			Procedure	Device[a]			
Bertossi et al. 2013[60]	55 study, 55 control NA	NA	LFI ($n = 55$) BSSO ($n = 55$)	Piezosurgery, Mectron	Less	Less Less	Reduced surgical time, blood loss, and IAN injury
Gilles et al. 2013[51]	83 43F, 40M	13–65	Osteotomies ($n = 183$) LFI ($n = 49$) LFI for expansion ($n = 19$) Symphyseal ($n = 5$) SSO ($n = 102$) Genioplasty ($n = 8$)	BoneScalpel, Misonix Inc.	NA	Less (significant) Fewer neurosensory disturbances	Improved control of the osteotomy and higher efficiency No bad split occurred 58.3% showed perfect PMD
Monnazzi et al. 2014[52]	20 study, 20 control NA	20–48	SSO ($n = 20$)	NA	NA	NA Same (objective assessment)	No significant difference in neurosensory disturbance between the reciprocating saw and piezoelectric surgery
Olate et al. 2014[62]	19 NA	17–34	Segmented LFI ($n = 1$)	Piezotome 2, D4 mode, Acteon Satelec	48 min	NA NA	No lacerations of the palatal mucosa PMD performed by chisel
Shirota et al. 2014[53]	29 study, 30 control 35F, 24M	16–49	BSSO ($n = 29$)	Piezosurgery, Mectron	Same	Same Higher	Piezoelectric surgery reduced neither blood loss nor the incidence of neurosensory disturbance
Scolozzi and Herzog 2014[57]	1 1M	NA	Total mandibular subapical osteotomy ($n = 1$)	Piezosurgery, Mectron	NA	NA No injury	Precise osteotomy
Robiony et al. 2014[30]	13 7F, 6M	5–26	SARPE ($n = 13$)	Piezosurgery, Mectron	74 ± 11 min	NA None	Excellent mucosal healing Precise and safe osteotomy Minimal bleeding, oedema, and nerve injury
Spinelli et al 2014[54]	12 7F, 5M	18–35	Unilateral LFI ($n = 12$) SSO ($n = 12$)	NA	35% longer	25% less Less	Saw in mandibular surgery provided more predictable outcomes and well-controlled osteotomy PMD performed with endoscopic assistance
Bianchi et al. 2015[44]	10 NA	NA	LFI with navigator assistance ($n = 10$)	Piezosurgery, Mectron	NA	NA NA	Precise cutting, avoidance of the roots, and no palatal laceration
Rullo et al. 2016[56]	20 study, 20 control 13F, 7M	NA	Genioplasty ($n = 20$)	Piezotome 2, Acteon Satelec	NA	NA Same	Less pain and discomfort in the immediate postoperative period

BSSO, bilateral sagittal split osteotomy; Hb, haemoglobin; Hct, haematocrit; IAN, inferior alveolar nerve; F, female; LFI, Le Fort I; LFIII, Le Fort III; M, male; NA, not available; PMD, pterygomaxillary disjunction; SARPE, surgically assisted rapid palatal expansion; SSO, sagittal split osteotomy.

[a] Miwatec Co., Ltd., Kawasaki, Kanagawa, Japan; Mectron, Carasco, Italy; Misonix Inc., Farmingdale, NY, USA; Acteon Satelec, Norwich, UK.

[b] Out of 15 patients.

[c] Out of 37 patients.

14 fresh cadaver heads. One study found that the ultrasonic bone curette did not require more time than the reciprocating saw and noted an improved pattern of lingual fracture lines in SSO[58]. The pattern of pterygomaxillary separation in Le Fort I osteotomy procedures was evaluated on 3D CT scan. One study reported good feasibility and palatal tissue integrity with the use of piezoelectric surgery for posterior segmental maxillary osteotomy in four cadaver heads[59].

Discussion

Despite recent widespread studies on MIS in the surgical field, there is no consensus definition for this terminology. MIS also refers to precise surgery involving a small incision and minimal dissection. Hence, endoscopic procedures were initially considered the ultimate application of MIS. Minimally invasive techniques are applied to a wide variety of oral and maxillofacial surgical procedures, including orthognathic surgery. The wide range of possible applications of MIS in orthognathic surgery could significantly help to alleviate complications and facilitate the achievement of treatment goals in a safe and gentle manner.

Improvements in imaging techniques, such as cone beam CT and the use of 3D virtual planning software, are highly beneficial in orthognathic surgery, improving accuracy and thus enhancing safety and reducing surgical hazards[63,64]. Induced hypotensive anaesthesia, proper head position, and the administration of local anaesthesia are potential factors that can minimize blood loss and optimize the surgical field[65,66]. A minimally invasive surgical approach (i.e., small incision and limited periosteal reflection) has the benefits of diminishing surgical exposure and tissue dissection, and thereby improves recovery and shortens the rehabilitation period.

The development of special intraoperative instruments and equipment has enabled surgeons to perform various procedures in a more gentle and precise manner, with minimal invasiveness. The endoscope and piezoelectric osteotome are two remarkable tools used in various surgical specialties, and have proven to be important tools in MIS.

This systematic review included all published studies investigating limited surgical approaches, endoscopy, and piezoelectric surgery in orthognathic surgery. It appears that no such systematic review on minimally invasive orthognathic surgery has been published to date.

One article, which contained the term ‘minimally invasive orthognathic surgery’ in its title, elaborated on the use of the endoscope and distraction osteogenesis as the main minimally invasive techniques available for orthognathic surgery[14]. Orthognathic procedures and distraction osteogenesis may be similar in terms of osteotomy type (e.g., Le Fort I osteotomy is needed for maxillary movement in both procedures, but with no down-fracture in distraction osteogenesis), but these procedures are not identical in terms of invasiveness. However, the treatment of the dentofacial deformities by distraction osteogenesis is mostly a separate discipline in maxillofacial surgery and cannot be categorized as a minimally invasive technique in orthognathic surgery. In the current review, several articles were evaluated regarding the use of the endoscope and distraction osteogenesis (separately or in combination) in various osteotomies to treat different maxillary and mandibular deformities, such as condylar resorption, condylar hyperplasia, and facial asymmetry.

Although a small incision and minimal dissection is the basic principle of a minimally invasive technique, most articles (90.9%) reported the endoscope and/or piezoelectric instrument as important tools in minimally invasive orthognathic surgery. The concept of a minimal approach in orthognathic surgery is not new. In 1997, Morselli described a less traumatic procedure for maxillary osteotomy in SARPE by performing the osteotomy entirely without the need for a mucosal incision or mucoperiosteal reflection, with the use of only a 2-mm osteotome for midline and horizontal and pterygopalatine suture osteotomies[20]. Since then, there have been no major developments in the modification of the surgical incision and reflection in orthognathic procedures. There could be three reasons for this. First, some surgeons continue to be trained with the philosophy of ‘big incisions for big surgeons’, which makes them unwilling to use a minimally invasive approach. Second, there is the fear of an inability to control potential haemorrhage using a limited access. Third, a mucosal scar is not as cosmetically significant as a scar on the skin. Therefore, the minimally invasive procedure should aim to minimize unnecessary tissue trauma with safe adherence to the basic principle of the procedure in order to obtain better or equivalent end results.

With regard to the length of the incision and extension of reflection in different orthognathic procedures, no significant changes were reported in the literature until Hernández-Alfaro et al. described a limited approach for SARPE and Le Fort I osteotomy through a short vestibular incision and limited dissection[21,22]. PMD was accomplished smoothly by twisting, using a 2-cm-wide osteotome at the level of the zygomatic buttress. The mean time to complete both procedures, from incision to wound closure, was 19 min for SARPE and 44 min for Le Fort I osteotomy; this was not longer than the time required for conventional approaches. This minimally invasive technique was suitable for application to all SARPE cases in an outpatient setting under local anaesthesia with intravenous sedation by an anaesthesiologist. There were no notable complications. During the Le Fort I surgery, piezoelectric surgery was used to remove bone interferences from the palatine neurovascular bundle. Both studies by Hernández-Alfaro et al. involved a large series of patients and showed good results; however, their study design was retrospective and neither study reported any comparisons with the conventional method.

A vertical labial incision is another interesting minimally invasive means of gaining access for midline mandibular osteotomy, and avoids an extended incision through the mentalis muscle and subsequent local problems[23]. In future, this technique may be utilized for the genioplasty approach.

There are several applications of endoscopic surgery in the maxillofacial field, with growing support in the literature due to its potential for minimizing morbidity and enhancing safety in various surgical procedures[67]. Craniofacial trauma (particularly frontal sinus, orbital, and condylar fractures), temporomandibular joint, salivary gland, and orthognathic surgery are areas of active growth in this field[68].

The main advantages of endoscopic assistance in orthognathic surgery include a small incision, minimal tissue dissection, and a magnified view of the osteotomy field. The earliest report describing the use of the endoscope in orthognathic surgery dates back to 1996[27]. In that study, it was used solely during PMD in the Le Fort osteotomy procedure to optimize visualization and avoid working blindly in this critical area. Since then, the number of reports in diverse orthognathic procedures has gradually increased from one article in 1996 to 17 articles in 2016.

This systematic review identified 11 articles reporting clinical studies, with the most common use of endoscopy being for VRO and Le Fort I. The feasibility of endoscopic VRO and rigid fixation through a small submandibular access was first assessed by Troulis and Kaban in a series of 10 patients who underwent an endoscopic approach for different ramus/condyle unit applications, including four endoscopic VRO procedures[32]. Troulis and Kaban reported good feasibility and minimal morbidity, with no increase in operating time. Two papers subsequently showed good early and long-term results for the same technique in 24 patients[33,34]. Both papers presented the endoscope as a promising minimally invasive tool in VRO, although it was not free of complications. To avoid the risk of nerve injury associated with the submandibular endoscopic approach, Cheung and Lo, in a preliminary study, introduced endoscopically assisted rigid fixation (through a stab incision inferior to the ear lobe) for intraoral vertical subsigmoid osteotomy in six patients; the patients experienced minimal morbidity, and good stability and aesthetic results were achieved[35].

The Le Fort I osteotomy is considered a safe procedure, although haemorrhage from the maxillary artery or its branches, extensive tissue dissection, or laceration may lead to serious complications[69,70]. Endoscopically assisted Le Fort I osteotomy allows limited and controlled dissection of the buccal and nasal mucosa and hence minimizes blood loss, swelling, and haematoma. In addition, it allows vertical incisions and working in vestibular tunnels, thus more vascularity is retained in the mucosa[28]. The use of the endoscope has made maxillary osteotomy access for palatal osteodistraction possible transnasally (i.e., via three 1-cm incisions in the nasal vestibule). Through this access, an osteotomy can be performed and monitored using a limited approach under endoscopic guidance. This new technique has been shown not to differ considerably from the conventional (i.e., open-sky) approach in terms of complications and operative time, although the minimally invasive approach was found to favourably and significantly decrease swelling and the patient's surgical threshold.

An endoscope can also be a helpful tool for minimizing potential intraoperative complications during sagittal split procedures, especially for complex cases. Under endoscopic guidance, a surgeon can more accurately identify the position of the lingula before performing a medial osteotomy and subsequently can verify the extension and depth of the lingual cut. It also allows evaluation of the involvement of the inferior mandibular border in a vertical (i.e., buccal) osteotomy[24]. Despite these many advantages, only one study that applied this approach in clinical scenarios was found; this study reported less postoperative oedema and a shorter recovery time[31].

Cost is an important concern for many clinical practitioners when they accept and attempt new technology. In many operating theatres, the standard rigid endoscope is often available for different surgical uses (e.g., ear, nose and throat) and is usually sufficient for orthognathic surgery. The 2.7-mm diameter with different angulations was the most commonly reported endoscope size noted in this systematic review[28,30,32–34,37], followed by the 4-mm-diameter endoscope[27,29,31,35,36]. A suction-assisted endoscopic elevator is an additional useful tool for vertical subsigmoid osteotomy[34]. Additionally, a specialized retractor was designed to provide a channel for transbuccal instrumentation through a hole near the instrument tip during the fixation step of the aforementioned procedure[35].

It is often recommended that endoscopic handling and training are commenced on human or animal cadavers, before attempting clinical applications, to ensure a certain level of expertise in novice surgeons[28,37]. Another approach would be to develop an educational surgical simulation tool, which could be designed and manufactured for use in such training[38].

The piezoelectric osteotome (a bone cutting device) has been proven as a bone cutting tool that meticulously spares the soft tissues (e.g., nerves, vessels, and mucosa). It has various clinical applications in many surgical specialties (e.g., orthopaedic and hand surgery, neurosurgery, ophthalmology, and otolaryngology)[16,71–74]. In the oral and maxillofacial regions, piezoelectric surgery was applied first in the sinus lift procedure to avoid undesirable mechanical and thermal effects on the sinus membrane[75]. More indications were subsequently reported, with positive clinical and experimental evidence of its efficacy as a minimally invasive tool for harvesting bone grafts, achieving ridge expansion, and for performing distraction osteogenesis, nerve lateralization, excision of bony lesions, and craniofacial surgery[76,77]. In orthognathic surgery, most surgical trauma occurs particularly during osteotomy. Hence, any surgical tool that can provide safe and precise cutting, microvibration, and a dry surgical operating field (i.e., cavitation effect) is an excellent option.

In line with the widespread use of minimally invasive techniques, there is increasing interest in the use of the piezoelectric osteotome in orthognathic surgery in many centres. This may explain the high proportion (56.8%) of articles in this category among the other techniques reviewed. Although the piezoelectric osteotome appears to be a promising tool for bone cutting, it has disadvantages such as a reduced capacity to cut dense bone, longer time required to perform an osteotomy, and additional cost.

The time needed to perform the procedure, blood loss, neurosensory effects, and pain were the main factors assessed in determining the efficacy of the piezoelectric osteotome in orthognathic surgery. Three studies showed no significant difference in osteotomy time for an SSO, as compared to the conventional method[48,50,53]. A randomized controlled trial by Bertossi et al. involving 110 patients undergoing a bimaxillary osteotomy, who were divided equally into two groups, showed a reduced surgical time in the piezoelectric osteotomy group[60]. In contrast, five other studies showed a longer operating time when using a piezoelectric osteotome in different orthognathic procedures[43,45,47,49,54].

With regard to blood loss, five comparative studies reported reduced operative blood loss with the use of piezoelectric surgery[43,48,50,54,55]. In contrast, Shirota et al. reported no reduction in blood loss with the use of a piezoelectric device in SSO, as compared to the Lindeman burr and chisel[53].

The neurosensory effect of the piezoelectric bone cut was the main factor evaluated by several authors, primarily the effect on the inferior alveolar nerve during SSO. Most clinical studies reported no or little nerve injury when using piezoelectric surgery[30,41–43,45–52,54–57,60]. However, one comparative study found less neurosensory disturbance after SSO performed by saw and chisel[53].

In conclusion, the findings of this systematic review suggest that the application of minimally invasive techniques in orthognathic surgery is safe, feasible, and effective. Despite the reported distinct benefits of the available techniques, the steep surgical learning curve, operating time, and costs are important factors that should be strongly considered before their routine application in orthognathic surgery. Only four studies in this systematic review reported a 'minimally invasive surgical approach', although the limitation of incisions and, in particular, limiting periosteal degloving by tunnelling, with or without the use of endoscopy or piezoelectric surgery, have the greatest potential for making orthognathic surgery less invasive.

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A limitation of this systematic review was that most of the reports constituted case series and comparative studies. These types of study do not provide strong reliable evidence. Therefore, additional good quality controlled clinical trials are needed to provide better evidence on this topic. Nevertheless, taking the available evidence into consideration, it is concluded that the application of this modality in the routine practice of orthognathic surgery is possible.

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