Bad splits in orthognathic surgery, prevention and management

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Introduction

Orthognathic surgery is mostly used for the correction of dentofacial deformities, asymmetry, skeletal malocclusion or obstructive sleep apnea (OSA). While the procedure is generally consid- ered safe, a large spectrum of complications has been reported such as unfavorable fractures, paresthesia, infection, relapse and TMJ problems .[1] However, life-threatening outcomes such as severe intra or postoperative bleeding are very rare .[1] The most common osteotomies performed are Le Fort I osteotomy and mandibular sagittal split osteotomy, also known as sagittal ramus osteotomy (SRO) have been in active use for seventy years .[2] In LeFort I osteotomy the change from wire fixation to mini-plate and screw fixation has been the most dramatic change, whereas Dal Pont, Hunsuck and Epker have published their modifications to mandibular osteotomies, which are rather commonly used. [3-6] Segmentation of the maxilla, high Le Fort osteotomies, malar plasty, vertical mandibular ramus osteotomies and genioplasty form a versatile toolkit for maxillo-mandibular complex correction in orthognathic surgery. However, commonly the 1 piece Le Fort I osteotomy and bilateral sagittal split osteotomy (BSSO) serve as a reliable technique for everyday use.

Unfavorable fractures or “bad splits” are undesirable fracture pattern complications that can occur during orthognathic surgery. [2, 4, 7, 8] Various classifications for bad splits in BSSOs have been suggested, including those based on anatomical location, management strategies or the necessity for treatment. [7, 9, 10] Bad splits in Le Fort I osteotomies are notably rarer and typically described by their anatomic location .[11] Reported incidence of bad splits during SSOs ranges from 0.2% to

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22.72% .[12] Contributing factors remain controversial, but potential contributors have been identi- fied, such as: age, gender, osteotomy method, third molars, mandibular morphology, instrumen- tation, and surgeon's experience. [7,13-17] The incidence of bad splits during Le Fort I osteotomies ranges from 0% to 2.4%. [11,19] Potential risk factors include an edentulous maxilla, anatomical mal- formations and the use of specific types of instrumentation .[18] If not properly managed, bad split can lead to complications such as hemorrhage, neural disturbance, bone sequestration, infec- tion, delayed healing, pseudoarthrosis, instability of the fixation, condylar malposition leading to temporomandibular disorders (TMD) and postoperative relapse .[1] The most common salvage surgical intervention is fixation of the fractured segments, although in some cases, aborting the procedure to allow for reconsolidation might be recommended .[9] This highlights the need for additional research to identify potential risks and to evaluate management protocols. This study aims to review existing literature concerning bad splits associated with BSSO and Le Fort I os- teotomies, focusing on prevention, management and to provide new insights. Examining each osteotomy type, their associated bad splits, management, outcomes and known risk factors will allow for a comprehensive literature-based perspective on prevention and management of bad splits.

Unfavorable fracture patterns in BSSO and Le Fort I

We classified bad splits of the mandible into 4 categories: buccal plate fractures of the proxi- mal segment, distal segment lingual fractures, fractures where the condyle remains on the distal segment and condylar fractures. Fig. 1 describes different fracture types. Isolated coronoid pro- cess fractures are not included in this classification as they typically do not require treatment or affect the outcome.

1. Buccal plate fractures of the proximal segment appear to be the most common types of bad splits. They can occur in various forms and severities but are typically straightforward to manage, either through fixation or removal of the fractured segment. [9,12]
2. Distal segment lingual fractures are considered the second most common type of bad splits. [9,12] Their occurrence may vary depending on the surgical technique used, with both vertical and horizontal split patterns reported. Intraoperative fixation can be applied but may not be necessary.

A more complex type of bad split occurs, when it 3. involves the condyle or 4. if the condyle remains on the distal segment, as they can be difficult to treat intraoperatively and may predis- pose to condylar malposition, delayed healing or neurovascular bundle damage .[7]

Condylar fractures can include part of the buccal plate, or horizontally involve upper part of the ramus and coronoid process, or as an isolated fracture of the condylar neck.

Unfavorable fractures during Le Fort I operation can include various structures such as ptery- goid plates or fossa, sphenoid bone and fractures extending up to the cranial base, tuber and palatinum can also be affected. [11,19] Also, the anterior part of the maxilla may be fractured, or an unplanned interdental segmentation may occur. The management of the fractures depends on the type and localization of the fracture. Finishing the fracture line and mobilizing the block along with the rest of the maxilla may be sufficient in the case of unintended segmentation, whereas fractures extending to the base of the skull may predispose the patient to severe com- plications due to possible cranial nerve injuries .[27]

Materials and methods

A search was undertaken in February 2024 in the following databases: PubMed, Scopus, and Web of Science with the following paragraph: ("COMPLICATION" OR "BAD SPLIT") AND ("Sagittal Split Ramus Osteotomy" OR "BSSO" OR "Bilateral Sagittal Split Osteotomy" OR "Sagittal split Os- teotomy" OR "SSRO") AND ("Prevention" OR "Management" OR "Treatment"). Inclusion criteria

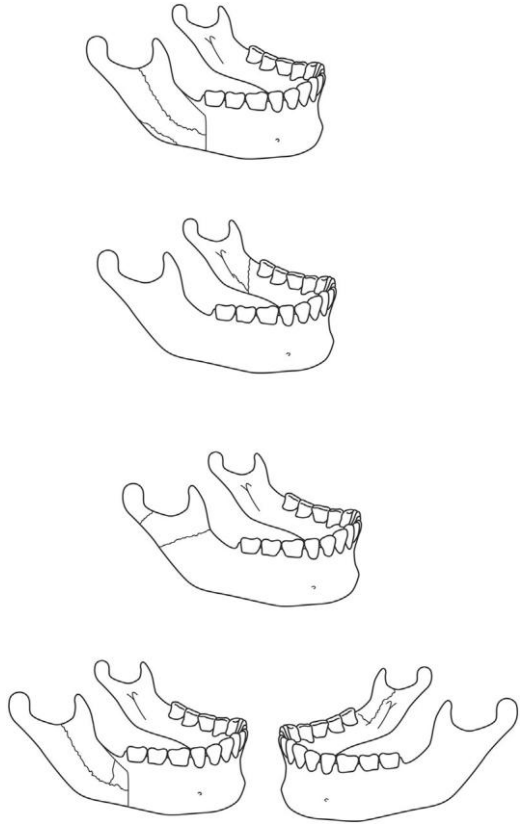

Fig. 1. Illustrations of different fracture types 1, 2, 3 and 4.

targeted studies of BSSO with reported sample size, incidence, fracture types and management. The search concluded 65 PubMed, 311 Scopus, and 72 Web of Science publications. After remov- ing duplicate records, we evaluated eligibility of the articles by reading the titles and abstracts. Reference lists of studies with the title involving the term “bad split” were checked. Thirty four articles from the search and reference lists were selected for reading, concluding to 23 studies selected. Fig. 2 presents a flow diagram of the search.

The authors conducted another search across the same electronic databases in March 2024, with the following paragraph: (“UNWANTED FRACTURE” OR “BAD SPLIT” OR “COMPLICATION”) AND (“LE FORT I “OR “LEFORT1”) AND (“ORTHOGNATHIC SURGERY”). Inclusion criteria required the study to report unfavorable fracture as a complication of Le Fort I osteotomy. The search concluded 55 PubMed, 318 Scopus, and 91 Web of Science publications. After removing dupli- cate records, we evaluated eligibility of the articles by reading the titles and abstracts. Reference lists of studies with the title involving the term “bad split”, “unfavorable fracture” or “unwanted fracture” were checked. The search initially revealed 54 studies, titles, abstracts and their refer- ence lists were read. Seven articles were selected. Fig. 3 presents a flow diagram of the search.

Data collection focused on the study type, publication year, study population, incidence of bad splits, fracture types, management, outcomes, potential risk factors. The excluded publica- tions did not contain unfavorable fractures. Data collection was conducted by 2 authors inde- pendently.

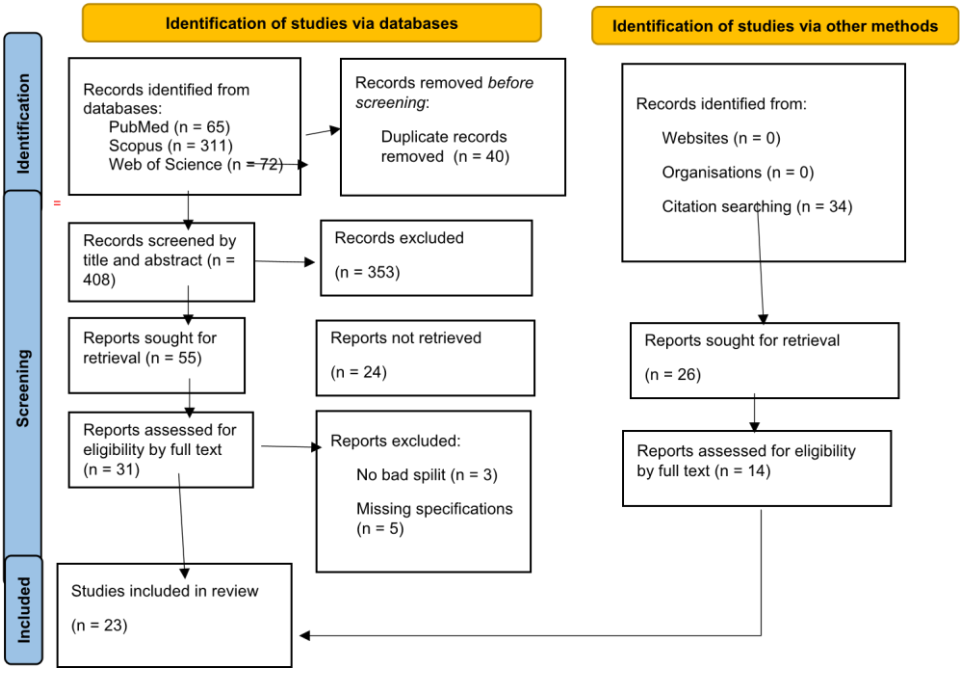

Fig. 2. Flow diagram for searching studies involving BSSO related bad splits.

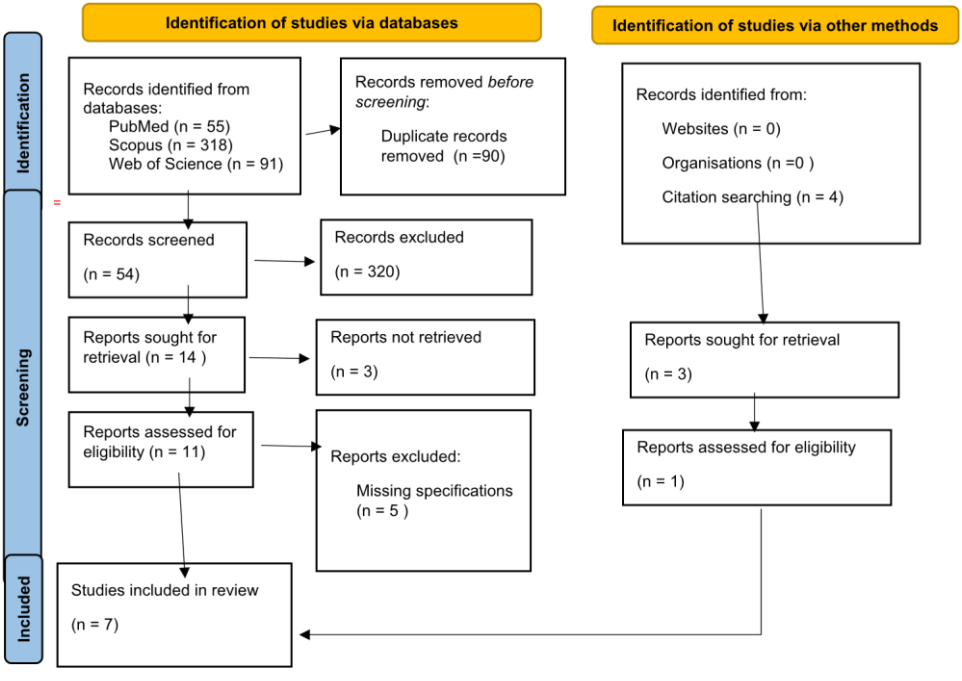

Fig. 3. Flow diagram for searching studies involving Le Fort I -related bad fractures.

Results

The most effective way to manage bad splits is prevention. However, it presents a challenge due to the lack of evidence of significant risk factors .[17] The incidence of bad splits during BSSO ranged from 0.45% to 11.2% per patient. Bilateral unfavorable fractures were reported in 4 stud- ies. [7,10,13,20] The most frequently reported bad split type was buccal plate fractures of the proxi- mal segment. Distal segment lingual fractures were also common, while fractures involving the condyle, or where the condyle remained on the distal segment were rare. Among all studies reporting bad split management, intraoperative osteosynthesis was the primary management method. Fracture types 3 and 4. That involved the condyle and were not possible to fixate, were managed with postoperative IMF in 3 patients, and in 1 instance, surgery had to be abandoned for reconsolidation following a large proximal segment fracture. [7,10,15] The incidence of bad splits as a complication of Le Fort I osteotomies ranged from 0% to 2.4%. One study reported an excep- tionally high incidence of 20%, which consisted of edentulous patients .[18] Tables 1 and 2 summa- rize the studies reporting fractures related to BSSO and Le Fort I osteotomy, respectively.

Prevention

During the BSSO, the inferior vertical bone cuts should extend to lingual cortex for sufficient split, [21-23] although 1 study noted no difference if the cut traverses through the buccal cortex .[24] High discrepancy between planned and actual inferior border cuts was also observed .[24] Both vertical and horizontal cuts should be carefully observed and opened uniformly. A bad split will most likely occur either during the osteotomy cuts or when the operator initiates the fracture with an instrument at the cut points or while torquing the proximal segment. If the separa- tion at the vertical cut tends to move up towards the buccal side instead of the inferior border, creating a new osteotomy line anteriorly may be attempted to avoid unfavorable fracture .[25] Hor- izontal osteotomy cut should be kept superficial to avoid transverse fractures of the mandibular ramus .[7] If the split in the ascending ramus tends to move towards the condyle, the best option may be to fully separate ascending ramus by the Trauner and Obwegeser modification, in which a lateral nose osteotome can be used for the osteotomy line proximal to the inferior alveolar nerve at the lingula. [2,25] Also, the use of Piezo saw can facilitate the completion of the osteotomy at this site.

In the context of Le Fort I osteotomy, special attention should be paid to fully complete cuts before proceeding to down-fracture .[26] In case of noticeable resistance during the down-fracture, ensuring the proper cuts is advised. The separation of the pterygomaxillary junction has been named as one of the most critical phases during the Le Fort I osteotomy, because it lies behind the maxillary tuberosity and the separation has to be made without direct visualization. [27,28] Also, many important structures are situated in close proximity to the pterygomaxillary junction and even blindness has been reported as a complication of maxillary bad splits. [27,28]

The first step in addressing bad splits involves inspection and evaluation of the split pattern, location and fracture size. Small fragments enveloped in periosteum do not typically require in- tervention and can be left in place. However, when the periosteum is compromised, removal of these fragments may be necessary to prevent sequestration. [1,7] Larger unfavorable fractures should primally be managed with reduction and plate or screw fixation. [7,8,10,15,16,19,25,29,30] The utmost care should be taken for proper condyle-to-fossa seating to avoid further complications and the condylar position should be re-evaluated intraoperatively after the release of IMF .[31] Ad- ditionally, excessive mucosal elevation for the fixation and manipulation may compromise the blood supply to the structures .[32] Intermaxillary fixation (IMF) 24/7 for 6 weeks may be utilized when intraoperative fixation attempts are unsuccessful. [7,15] In situations with complex fracture patterns such as bilateral bad splits, discontinuing the procedure and reattempting after a con- solidation period of approximately 6 months may be a rightful approach to prevent additional complications.

Table 1
Studies reporting unfavorable fractures related to BSSO.

Author	Study type	Population	Incidence per patient	Fracture types	Management
Chandegra et al. [10]	Retrospective	311	6.8%	14 buccal plate fractures (type 1), 2 fractures with the condyle on the distal segment (type 4)	Plate osteosynthesis, mono or bicortical screws, conversion to VRO
De Souza et al. [14]	Systematic review	4065	4.4%		
Kotaniemi et al. [19]	Retrospective	127	1.6%	1 major buccal plate (type 1) fractures, 4 minor unspecified	Plate osteosynthesis
Telha et al. [45]	Retrospective	985	11.2%		
Aydil et al. [8]	Retrospective	85	1.2%	1 buccal plate fracture (type 1)	Plate osteosynthesis
Jiang et al. [46]	Retrospective	484	7.44%	8 proximal segment fractures (type 1), 2 horizontal ramus fractures (type 3), 26 unspecified minor fractures	Plate osteosynthesis, IMF, removal of small fragments
Salzano et al. [16]	Retrospective	1120	0.45%	5 buccal plate fractures (type 1)	Plate or screw fixation
Eshghpour et al. [35]	prospective cohort	140	2.9%	1 buccal plate fracture (type 1), 1 lingual fracture (type 2), 1 with both type 1 and 2 fractures	
Hamada et al. [20]	Retrospective	778	1.7%	7 buccal plate of the proximal segment (type 1), 1 distal segment (type 2), 2 condylar fractures (type 3), 2 coronoid fractures	
Houppermans et al. [24]	Prospective	41	7.3%	2 lingual fractures (type 2), one with both distal and proximal segment, type 1 and 2 fractures.	Plate osteosynthesis
Wang et al. [39]	Retrospective	625	1.3%		
Robl et al. [29]	Retrospective	684	3.9%	11 "major", 16 "minor"	Alteration of the fixation or osteotomy
Verweij et al. [36]	Retrospective	251	3.0%		

Mensink et al. [15]	Retrospective	427	4.0%	11 buccal plate fractures (type 1), 5 lingual plate fractures (type 2), 1 condylar fracture (type 3)	Plate osteosynthesis, screws, IMF, conversion to VRO
Falter et al. [25]	Retrospective	1003	1.4%	13 buccal plate fractures (type 1), 1 lingual plate fracture (type 2)	Plate osteosynthesis
Plooij et al. [22]	Prospective	40	5.0%		Reduction and fixation, IMF
Borstlap et al. [37]	prospective	222	8.0%	8 buccal plate fractures (type 1), 12 lingual plate fractures (type 2)	
Acebal-Bianco et al. [30]	Retrospective	802	1.0%	6 buccal plate fractures (type 1), 1 lingual plate fracture (type 2), 1 coronoid fracture	Plate osteosynthesis, bicortical screws

Table 2
Studies reporting unfavorable fractures related to Le Fort I osteotomy.

Author	Study type	Size	Incidence	Fracture location/type	Management	Additional
Kotaniemi et al.[19]	retrospective	127	2.4%	Alveolar fracture, maxillary tuber and palatinum, anterior maxilla	Plate osteosynthesis, fracture block mobilization	OBJ
Kotaniemi et al.[11]	retrospective	98	1.0%	Maxillary tuber	OBJ	OBJ
Ferri et al.[34]	retrospective	5025	0.20%	sphenoid sinus, sinus roof, cranial base	Repair of dura tear	OBJ
Eshghpour et al.[33]	retrospective	114	0.87%	Between palatine bone and palatine process	IMF	Green stick fracture
Garg and Kaur[47]	retrospective	25	0.00%	OBJ	OBJ	OBJ
Ho et al.[48]	retrospective	85	1.20%	Unplanned interdental segmentation	correction of interdental cuts	Segmental Le Fort I
Li et al.[18]	retrospective	20	20.0%	Horizontal plate of palatine bone, Lateral wall of maxillary sinus	OBJ	Fractures only in edentulous group

Management of BSSO related bad split

Buccal plate of the Proximal segment fracture

After a proximal segment bad split, if bone for adequate sagittal overlap exists, the osteotomy cut should be completed, and the segments stabilized into their desired position using screw or plate fixation. Additional fixation for the fractured segment can be considered .[29] In cases where there is no sufficient sagittal overlap of bone, a vertical ramus osteotomy (VRO) can be performed to create overlap for adequate fixation .[29] If the proximal segment remains in multiple pieces after splitting of the mandible, management should include reduction and fixation with plates to restore the integrity of the proximal segment .[29]

Lingual distal segment fracture

Management of the fractured lingual segment does not necessarily require additional treat- ment, especially if the lingual fragment is passively aligned. However, screw fixation may be used to attach the fractured lingual segment to the proximal segment for added stability to both the fractured lingual segment and to the proximal segment. [10,29]

Condylar fracture

In cases of condylar fractures, BSSO split should be completed as usual. Condylar fractures may occur in isolation or in comminution with the buccal cortex. When a sufficient amount of buccal cortex is involved, reduction and fixation with osteosynthesis plates and screws should be attempted .[10] Isolated condylar fracture and horizontal ramus fracture involving the coronoid process and the condyle may be managed conservatively during the operation, then reviewed postoperatively. [7,10] Internal fixation may be attempted but it is prone to fail because of the mouth's narrow surgical field, while simultaneously scars from extra oral approach could be unacceptable to the patient .[7] When the procedure is discontinued, it may be repeated after 6- weeks recovery .[7]

Proximal segment fracture, where the condyle remains attached to the distal segment

Completion of the split should be attempted, and in some cases, the osteotomy can be trans- formed into a VRO, separating the condyle from the distal segment .[10] The fractured buccal seg- ment is inserted between the condyle and distal segment and fixated with bicortical screws to provide stability and promote healing .[10] However, the VRO conversion will limit the amount of possible mandibular advancement. [10]

Management of Le Fort I related bad split

In the context of Le Fort I osteotomy, unwanted fractures can also be managed with addi- tional fixation, depending on the anatomical location and severity .[19] Unfavorable fractures oc- curring before down-fracture can complicate the completion of mobilization. Greenstick frac- tures may be manageable conservatively with IMF .[33]

Outcome after bad split

Seven studies related to BSSO reported the patient outcomes of bad splits. Of the 77 bad splits reported, there were 10 additional complications that were potentially influenced by the bad split. Seven of the complications had a long-term effect on the overall patient outcome. Complications included suboptimal condylar position, hematoma, infection of the fracture sites, lower lip hypoesthesia, persistent neurosensory disturbances, asymmetry of the mandibular an- gle and anterior disc displacement. [7,15,22,30] Three studies observed no complications associated with bad splits. [20,25,29]

Unfavorable fractures during Le Fort I resulted in excess bleeding, and the need for erythro- cyte transfusion in 1 case. [11,19] Cranial base fractures led to severe headaches and cerebrospinal rhinorrhea, without recurrence or further complications .[34]

Additional risk factors

Concomitant removal of mandibular third molars

We analyzed 2 systematic reviews with 1 meta-analysis and 5 study specific find- ings. [14, 15, 17, 35-38] The systematic reviews found no significant differences in outcomes, whereas the individual study results varied. One study identified an associated risk of lingual plate frac- ture when third molars were removed during BSSO. Furthermore, another study investigated age as a factor in third molar removal, suggesting that concomitant removal in younger patients may be a risk factor for bad splits .[38] More research is needed specifying the location and the anatomy of the studied third molars. Our review indicates that the safest time point for removal of lower third molars remain under discussion. Third molars can be either removed 6-9 months before the BSSO or concomitantly during the operation and remain as a matter of clinical judgement.

Anatomical considerations

A thin buccal cortex, thin mandibular buccolingual width of the molar area, and a short ra- mus were found to be associated with bad split. [13, 39] Additionally, 1 study reported the poste- riorly thinning shape of the ramus as a risk factor .[40] Anatomical irregularities, including cleft palate, and atrophied edentulous maxilla appeared to increase the risk of unwanted fractures
during Le Fort I. [18, 26]

Instrumentation, age, gender and experience

The use of splitters or separators or the choice between a burr, saw and piezo did not affect the incidence of bad splits. [15, 16] However, 1 study revealed a greater rate of successful inferior border cuts during sagittal splits with piezo (61.3%) vs. Lindemann burr (38.7%) .[24] In the max- illa, the use of obwegeser pterygoid osteotome may raise the risk of unfavorable pterygoid plate fractures .[41] Surgeons´ experience did not seem to influence the incidence of bad splits. [15, 24, 25] Steenen found statistically significant but weak correlation between increasing age and occur- rence of bad splits in a systematic review of 18 studies .[17] Four other studies reported associa- tion with older age, [8, 22, 36, 39] while 2 did not. [16, 39] One study reported no significant difference on incidence when comparing if the operation was either Bimax or BSSO .[7]

Discussion

Perhaps, the most important factor for prevention of bad split is to ensure proper osteotomy cuts during separation, especially on the inferior border during BSSO. [12, 22] Low and short medial osteotomy design is also believed to prevent bad splits .[42] Focus should also be put on eliminat- ing sharp angles where abnormal stresses occur on the bony segments .[43] Most bad splits can be managed without additional complications with either additional fixation or removal of the frac- tured fragment. Minor fractured segments enveloped inside periosteum may be left untouched. Bad splits involving the condyle can require additional management such as IMF or may even lead to abandonment of the procedure for reconsolidation. Nonetheless, complex split patterns may increase the risk of unsatisfactory outcomes like neural disturbances, condylar malposition or asymmetry. Variations of complications relating to Le Fort I related bad splits are notable, with above average bleeding being a common finding. High pterygoid fractures extending to the cranial base can cause severe neural disturbances .[27] Unwanted fractures during the sagit- tal splits often result in successful outcomes when managed appropriately, typically viewed as complications without long-term consequences. [25, 42] However, complex split patterns may lead to increased morbidity, and it should thus be a high priority for the practitioner to minimize the incidence of unfavorable fractures and when possible, manage the fractures with osteosynthesis. As the thickness of mandibular cortex, short or posteriorly thinning ramus and large anatomical variation identified in the pterygomaxillary region have been identified as potential risk factors for bad splits, the increasing use of 3D planning might decrease the risk for bad splits in the future, as 3D imaging reveal abnormal and demanding variation of the anatomy of both the mandible and maxilla .[44] When these variations and demands are notable prior to surgery, they can be taken into consideration in advance to diminish complications during surgery.

Limitations

Most studies did not report patient outcomes. Lack of objective measurement of the long- term patient outcome causes a risk of bias. Classification for bad splits in the literature is very variable. Le Fort I related bad splits appears to be notably rare and very limited cases mentioned in literature. Most of the studies regarding risk factors reported a potential heterogeneity among study groups and concern for selection bias.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal rela- tionships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cpsurg.2024.101587 .

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