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Multicentre retrospective study on plate osteosynthesis for non-condylar mandibular fractures in paediatric patients with deciduous, mixed, and permanent dentition: A World Oral Maxillofacial Trauma (WORMAT) project

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ABSTRACT

Mandibular fractures are common maxillofacial injuries among children and adolescents, but treatment remains controversial. The aim of this study was to analyse the methods and outcomes of open reduction and internal fixation (ORIF) for non-condylar mandibular fractures in paediatric patients among 14 maxillofacial centres.

Patients ≤16 years of age undergoing ORIF for non-condylar mandibular fractures between 2011 and 2022 were included. Age, gender, dentition stage, site and type of fracture, surgical approach, material, thickness, and number of plates, and outcome were recorded.

179 patients (mean age, 11.1 years) reported 120 single and 59 double fractures, 79% involving at least one displaced or comminuted site. Single fractures were preferentially treated with rigid osteosynthesis in all dentition groups (64%), while double fractures with non-rigid osteosynthesis in mixed and permanent dentition patients (59% and 43%) and mixed osteosynthesis in deciduous dentition patients (50%). Mean follow-up was 21 months. Surgical would infection was the most common complication (8.9%), followed by minor malocclusion (1.7%) and osteitis (1.7%).

In conclusion, the centres opted for fixation patterns like those recommended for adults, favoring non-rigid or mixed osteosynthesis for double fractures. The low complication rate shows ORIF is effective and safe for non-condylar mandibular fractures in paediatric patients.

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1. Introduction

Although mandibular fractures are among the most common facial fractures in the paediatric population, treatment choices remain controversial (Costa Ferreira et al., 2005, 2016; Segura-Palleres et al., 2022). While well-defined guidelines and treatment protocols exist for adults, the literature provides only general recommendations for the surgical management of paediatric mandibular fractures, particularly non-condylar fractures.

Paediatric non-condylar mandibular fractures, especially in young children, present surgeons with unique anatomical challenges, making therapeutic management more complex compared to adults. These challenges include smaller skeletal dimensions, occlusal instability owing to mixed dentition, dental germs, greater bone elasticity, and faster bone healing (Aizenbud et al., 2009; Andrade et al., 2015; Bobrowski et al., 2017; Kao et al., 2019). The potential risks to dental development and mandibular growth have constrained the use of open reduction and internal fixation (ORIF) with titanium plates. Hence, more conservative treatments, such as observation with a liquid diet and physiotherapy, maxillomandibular fixation (MMF) with or without guiding elastics, and various types of splints, are often preferred (Aizenbud et al., 2009; Bansal et al., 2021; Bobrowski et al., 2017; Goth et al., 2012).

Recently, a growing trend in the use of plate osteosynthesis, not only in adolescents but also in children with displaced or comminuted non-condylar mandibular fractures, has been reported (Abdullah, 2009; Aizenbud et al., 2009; Iatrou et al., 2015; Joshi et al., 2015; Lee et al., 2021; Lopez et al., 2021; Rahul et al., 2018; Srinivasan et al., 2013; Yesantharao et al., 2020; Yesantharao et al., 2020). However, clear guidelines on the choice of ORIF based on the fracture site and stage of dentition, as well as data on complications and long-term outcomes, are lacking. This is partly because of the limited sized of study samples in previous studies (Abdullah, 2009; Aizenbud et al., 2009; Iatrou et al., 2015; Joshi et al., 2015; Lee et al., 2021; Lopez et al., 2021; Rahul et al., 2018; Srinivasan et al., 2013; Yesantharao et al., 2020; Yesantharao et al., 2020).

This retrospective study, which to the best of our knowledge involves the largest sample size reported in the literature, aimed to analyse the methods and outcomes of surgical treatment with plate osteosynthesis for non-condylar mandibular fractures in paediatric patients with deciduous, mixed, or permanent dentition across 14 maxillofacial centres participating in the WORMAT (World Oral Maxillofacial Trauma) project (Cena et al., 2024; Cremona et al., 2024; Roccia et al., 2024).

2. Materials and methods

An Excel database was sent to 14 maxillofacial surgery centres participating in the WORMAT project: Department of Oral and Maxillofacial Surgery, Paracelsus Medical University (Salzburg, Austria); Department of Oral and Maxillofacial Surgery, University Hospitals (Leuven, Belgium); Clinics for ENT and OMS, University Clinical Hospital (Mostar, Bosnia and Herzegovina); Department of Diagnosis and Surgery, Division of Oral and Maxillofacial Surgery, São Paulo State University, UNESP, Araraquara (São Paulo, Brazil); Department of Oral Surgery, Faculty of Dental Medicine, Medical University (Plovdiv, Bulgaria); Department of Maxillofacial Surgery, Dubrava University Hospital (Zagreb, Croatia); Department of Oral and Maxillofacial Surgery, Aligarh Muslim University (Aligarh, India); Oral and Maxillofacial Diseases Research Center, Mashhad University of Medical Sciences (Mashhad, Iran); Division of Maxillofacial Surgery, Città della Salute e della Scienza Hospital, University of Turin (Turin, Italy); Department of Oral and Maxillofacial Surgery, College of Medicine, University of Ibadan (Ibadan, Nigeria); Clinic of Maxillofacial Surgery, School of Dentistry, University of Belgrade (Belgrade, Serbia); Department of Maxillofacial and Oral Surgery, University Medical Center (Ljubljana, Slovenia); Department of Oral and Maxillofacial Surgery, Muhimbili University of Health and Allied Sciences (Dar es Salaam, Tanzania); Department of Oral and Maxillofacial Surgery, University of Dundee (Dundee, United Kingdom).

Data were collected on patients aged ≤16 years who underwent surgery under general anaesthesia between January 2011 and December 2022 for maxillofacial fractures. The inclusion criterion for this study was non-condylar mandibular fractures treated with plate osteosynthesis. Patients with condylar fractures or those who underwent closed treatment were excluded from the study.

The following data were collected: age, sex, cause of injury (road traffic accident [RTA], fall, assault, sport- or work-related injury, or other), site (categorised in symphysis/parasymphysis, body, or angle/ramus) and type (non-displaced, displaced, or comminuted) of fracture, associated facial fractures, time of surgery (<24 h, 24–72 h, or > 72 h), surgical approach (intraoral, extraoral, combined intraoral and extraoral, or translesional), material (titanium or resorbable), number and thickness of plates used, indication for hardware removal, and outcome.

Three dentition groups were identified, based on age: deciduous dentition (≤6 years; group A), mixed dentition (7–12 years; group B), and permanent dentition (13–16 years; group C) (Sobrero et al., 2023). The minimum follow-up was set at 6 months.

Osteosynthesis was defined as 'non-rigid' when the fracture was fixed with a single plate ≤1.4 mm thick or a single lag screw, and as 'rigid' when a single plate ≥1.5 mm in thickness, or at least two plates of any thickness were employed (Ehrenfeld et al., 2012; Ellis, 2013, 2014). For a bifocal fracture, fixation was defined as 'mixed' when one fracture was rigidly fixed and the other non-rigidly fixed (Rughubar et al., 2020).

The following complications were recorded: dental developmental abnormalities (any alteration in the pattern or timing of dental eruption), tooth root damage, surgical wound infection/dehiscence, hardware loosening/failure, post-traumatic sensory changes in the inferior alveolar nerve (IAN) area, and notable facial asymmetry. Postoperative infection was defined clinically as purulent discharge from the surgical site, oedema or induration with erythema, or hardware exposure with pus discharge (Sobrero et al., 2024). Facial asymmetry was defined as any notable differences in morphology between the two sides of the face in areas affected by the trauma that were not present before the injury, as reported by the patient or a parent and confirmed by the surgeon (Roccia et al., 2024).

This study was approved by the institutional committee (reference number S67588), and all procedures were performed in accordance with the 1964 Declaration of Helsinki.

2.1. Data analysis

Statistical analyses were performed using SPSS software (version 29.0.2.0; IBM Corp., Armonk, NY, USA). The predictors and outcomes were analysed using Fisher's exact test and Chi-squared test, as appropriate. The Bonferroni correction was applied for multiple comparisons. All statistical analyses were two-tailed. The significance level was set at $p < 0.05$.

3. Results

During the study period, 740 patients aged ≤16 years underwent surgery under general anaesthesia for maxillofacial fractures, 424 of whom had fractures in the lower third of the face. A total of 179 patients (mean age, 11.1 years; standard deviation [SD] 4.1) met the inclusion criteria: 29 patients (22 males and 7 females; mean age 4.3 years) in Group A, 69 patients (49 males and 20 females; mean age, 9.5 years) in Group B, and 81 patients (66 males and 15 females; mean age 14.8 years) in Group C.

The causes of non-condylar mandibular trauma were RTA in 62 patients (35%), falls in 41 patients (23%), assault in 37 patients (20%), sports activities in 33 patients (18%), and other causes in 7 patients (4%).

Of the 179 study patients, 120 (67%) had single fractures, and 59 (33%) had double fractures, with 79% involving at least one displaced or comminuted fracture site, accounting for a total of 238 fracture sites (1.3 fractures per patient). The symphyseal and parasymphyseal regions were most commonly affected in both single and double fractures and were often associated with the angle/ramus region, as detailed in Table 1.

Thirteen patients had associated midface fractures, whereas one patient had fractures involving all three facial thirds. The timing of treatment was <24 h in 48 patients (27%), 24–72 h in 68 patients (38%), and >72 h in 63 patients (35%). The most common surgical approach was intraoral (79%), followed by extraoral (8%), combined (4%), and translesional (3%).

Of the 302 plates used for ORIF (1.2 plates per fracture), 295 were titanium and 7 were resorbable. As summarised in Table 2, more than half of the plates (61%) used had a thickness of 1–1.4 mm, making them the most utilised across all age groups, with a statistically significant association in patients with permanent dentition (Group C, $p = 0.005$, chi-square test). Among the other types of plates, only those <1.0 mm were significantly associated with deciduous dentition (Group A) ($p = 0.005$, chi-square test) (Fig. 1).

Regarding the methods of osteosynthesis in single fractures, excluding the dentoalveolar process, all non-condylar mandibular sites were predominantly treated (64%) with rigid fixation, which was statistically associated with displaced or comminuted fractures (68%) compared with non-displaced fractures (39%, $p = 0.011$, chi-square test). In double fractures, non-rigid fixation was more commonly used (46%), with no significant association between the fracture types ($p = 0.18$, Fisher's exact test, Table 3).

Considering the patients by age group and dentition type (Table 4), rigid fixation was the most used method across all groups and in all single non-condylar mandibular fracture sites. In contrast, in double fractures, half of the patients in Group A were treated with mixed fixation, whereas 59% and 43% of those in Groups B and C, respectively, were treated with nonrigid fixation (Fig. 2).

Of the 295 titanium plates placed, 57% were removed (82% in group A, 84% in group B, and 35% in group C). In 40% of the cases, hardware removal was performed for reasons not correlated with clinical symptoms (primarily scheduled removal according to each center's specific protocol, 35%). In comparison, 17% of the plates were removed for either pain (9%) or local infection (7%).

Table 2
Thickness of osteosynthesis plates by dentition group.

	Plates <1.0 mm n (%)	Plates 1.0–1.4 mm n (%)	Plates ≥1.5 mm n (%)	Total n
Group A	7 (16)	25 (58)	11 (26)	43
Group B	8 (8)	48 (48)	44 (44)	100
Group C	1 (0.6)	110 (69.2)	48 (30.2)	159
Total	16 (5)	183 (61)	103 (34)	302

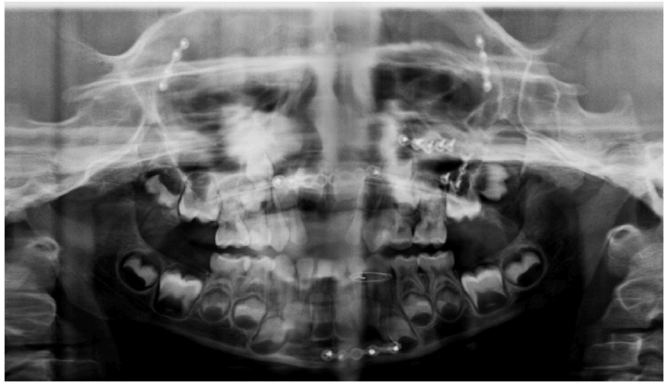

Fig. 1. Group A patient with a singular parasymphysis fracture treated with non-rigid osteosynthesis (plate <1.0 mm) and associated fractures of the middle third of the face.

The mean follow-up period was 21.0 months (SD, 21.7). Overall, 15% of the patients experienced at least one complication during the postoperative follow-up, with surgical wound infection being the most common (8.9%), followed by temporary IAN deficit (2.8%), as detailed in Table 5. Only three patients, one from Group B and two from Group C, with symphysis/parasymphysis + angle/ramus fractures treated with non-rigid osteosynthesis, developed minor postoperative malocclusion resolved with selective grinding.

Table 1
Site and displacement of non-condylar mandibular fractures.

	Single mandibular fractures n (%)					
	Symphysis/parasymphysis	Body	Angle/ramus	Dentoalveolar		Total
Total	52	32	33	3		120
Non-displaced	10	5	8	0		23 (19)
Displaced	40	24	25	3		92 (77)
Comminuted	2	3	0	0		5 (4)
	Double mandibular fractures n (%)					
	Symphysis/parasymphysis + symphysis/parasymphysis	Symphysis/parasymphysis + body	Symphysis/parasymphysis + angle/ramus	Body + body	Body + angle/ramus	Total
Total	1	9	33	4	12	59
Displacement of most anterior fracture						
Non-displaced	0	3	18	1	4	26 (44)
Displaced	1	4	14	3	8	30 (51)
Comminuted	0	2	1	0	0	3 (5)
Displacement of most posterior fracture						
Non-displaced	0	2	14	2	4	22 (37)
Displaced	1	6	19	2	8	36 (61)
Comminuted	0	1	0	0	0	1 (2)

Table 3
Modality of surgical treatment by site and type of non-condylar mandibular fracture.

	Single mandibular fractures n (%)				
	Symphysis/parasymphysis	Body	Angle/ramus	Dentoalveolar	Total
Non-rigid	18 (35)	10 (31)	14 (42)	3 (100)	45 (36)
Non-displaced	5	1	8	0	14
Displaced	13	7	6	3	29
Comminuted	0	2	0	0	2
Rigid	34 (65)	22 (69)	19 (58)	0	75 (64)
Non-displaced	5	4	0		9
Displaced	27	17	19		63
Comminuted	2	1	0		3

	Double mandibular fractures n (%)					
	Symphysis/parasymphysis + symphysis/parasymphysis	Symphysis/parasymphysis + body	Symphysis/parasymphysis + angle/ramus	Body + body	Body + angle/ramus	Total
Non-rigid	0	5 (55)	17 (52)	2 (50)	3 (25)	27 (46)
Non-displaced		0	7	1	1	9
At least 1 displaced		5	10	1	2	18
At least 1 comminuted		0	0	0	0	0
Mixed	0	0	8 (24)	0	6 (50)	14 (24)
Non-displaced			1		0	1
At least 1 displaced			7		6	13
At least 1 comminuted			0		0	0
Rigid	1 (100)	4 (44)	8 (24)	2 (50)	3 (25)	18 (30)
Non-displaced	0	0	3	1	1	5
At least 1 displaced	1	2	4	1	2	10
At least 1 comminuted	0	2	1	0	0	3

Table 4
Type of osteosynthesis of non-condylar mandibular fractures by dentition group.

	Single mandibular fractures n (%)					Double mandibular fractures n (%)
	Symphysis/parasymphysis	Body	Angle/ramus	Dentoalveolar	Total	
Group A						
Non-rigid	5	3	3	–	11 (48)	2 (33)
Mixed	–	–	–	–	–	3 (50)
Rigid	7	4	1	–	12 (52)	1 (17)
Group B						
Non-rigid	7	5	1	2	15 (29)	10 (59)
Mixed	–	–	–	–	–	2 (12)
Rigid	11	13	13	0	37 (71)	5 (29)
Group C						
Non-rigid	6	2	10	1	19 (42)	16 (43)
Mixed	–	–	–	–	–	9 (24)
Rigid	16	5	5	0	26 (58)	12 (33)

4. Discussion

This multicentre retrospective study demonstrated that plate osteosynthesis is an effective and safe treatment strategy for non-condylar mandibular fractures in patients with deciduous, mixed, and permanent dentition, as evidenced by the low incidence of postoperative complications, consistent with the literature (Abdullah, 2009; Bansal et al., 2021; Hardt and Gottsauner, 1993; Iatrou et al., 2015; Joshi et al., 2015; Yesantharao et al., 2020).

Several studies have reported that ORIF is primarily indicated as the treatment of choice for displaced mandibular fractures, while closed reduction is preferred for non-displaced fractures (Ehrenfeld et al., 2012; Lopez et al., 2021; Yesantharao et al., 2020; Yesantharao et al., 2020). However, this choice can pose significant challenges, especially in children. Specifically, MMF can restrict mandibular movement, compromising oral hygiene and adequate nutritional intake (Aizenbud et al., 2009; Bobrowski et al., 2017; Joshi et al., 2015). Additionally, it may cause respiratory issues, leading to psychological and social discomfort (Aizenbud et al., 2009; Bobrowski et al., 2017; Joshi et al., 2015).

In contrast, plate osteosynthesis, by restoring pre-traumatic bone continuity, promotes primary bone healing and facilitates earlier resumption of normal mandibular functions, thereby minimising the functional and psychological issues associated with MMF (Aizenbud et al., 2009; Allred et al., 2015; Bobrowski et al., 2017; Joshi et al., 2015; Kao et al., 2019; Laurentjoye et al., 2009; Zimmermann et al., 2006).

A literature review revealed that only a few studies with limited sample sizes reported the type and number of plates used, usually indicating the type of plate system (Abdullah, 2009; Hardt and Gottsauner, 1993; Iatrou et al., 2015; Lopez et al., 2021; Yesantharao et al.,

Fig. 2. Group B patient with a double parasymphysis and body fracture treated with non-rigid osteosynthesis (plates <1.0 mm).

Table 5
Complications of non-condylar mandibular fractures treatment by dentition stage.

	Deciduous dentition (n = 29) n (%)	Mixed dentition (n = 69) n (%)	Permanent dentition (n = 81) n (%)	Total (n = 179) n (%)
Malocclusion				
Minor malocclusion	0	1 (1.4%)	2 (2.5%)	3 (1.7%)
Major malocclusion	0	0	0	0
Surgical wound infection/ dehiscence	0	11 (15.9%)	5 (6.2%)	16 (8.9%)
Hardware exposition without infection	0	0	1 (1.2%)	1 (0.6%)
Osteitis/ osteomyelitis	0	3 (4.3%)	0	3 (1.7%)
Tooth bud disruption	1 (3.4%)	0	0	1 (0.6%)
Impaired sensitivity of inferior alveolar nerve				
Temporary	1 (3.4%)	2 (2.9%)	2 (2.5%)	5 (2.8%)
Permanent	0	0	0	0
Residual facial asymmetry	0	1 (1.4%)	1 (1.2%)	2 (1.1%)

2020; Yesantharao et al., 2020b). However, there are no universally accepted guidelines on fixation schemes for paediatric non-condylar mandibular fractures. Internationally recognised protocols almost always pertain to the adult population and are based on biomechanical and clinical studies, which, for ethical reasons, are often not feasible in the paediatric population (Fernández-Olarte et al., 2017).

In the absence of recommended surgical protocols, Haug and Foss (Haug and Foss, 2000) studied paediatric maxillofacial injuries and reported that 'semirigid fixation with small (1.0–1.3 mm outer diameter) titanium plating systems currently offers the best fixation alternative' to conservative treatment. In the context of isolated angle fractures, Yesantharao et al. (2020b) suggest that a single miniplate on the superolateral border of the mandible results in fewer complications compared with two-plate fixation while also acknowledging that their study was 'underpowered' and that 'the adequacy of ORIF in the mixed dentition population is still unclear and further analysis with larger sample sizes is necessary.'(Yesantharao et al., 2020).

In the latter group of patients, as well as those with deciduous dentition, numerous recommendations in the literature suggest placing monocortical plates and screws along the inferior border of the mandible to reduce the risk of damage to developing tooth germs, with particular attention paid to the canine region because of the low position of the canine germ (Aizenbud et al., 2009; Bansal et al., 2021; Berlin et al., 2021; Bobrowski et al., 2017; Goth et al., 2012; Zimmermann et al., 2006).

Fourteen centres participating in the WORMAT group shared their experiences with the surgical treatment of this type of trauma, reporting the number and type of plates used for internal fixation. This study revealed variability in plate choice and, consequently, in the type of fixation for single and double non-condylar mandibular fractures. However, the predominant use of rigid fixation was observed for single fractures, particularly displaced and comminuted fractures, across all age groups. In contrast, in double fractures, non-rigid or mixed fixation slightly outnumbered rigid fixation.

By comparing the internal fixation patterns with the guidelines of the Arbeitsgemeinschaft für Osteosynthesefragen (AO) Foundation (Ehrenfeld et al., 2012) and those of the Texas school (Ellis, 2013, 2014), it can be inferred that the 14 maxillofacial centres chose to treat more than two-thirds of the patients following the protocols recommended for the adult population: mixed or rigid fixation for bilateral fractures and rigid or non-rigid fixation for single fractures, depending on the fracture site. In the remaining patients, the choice of nonrigid fixation, particularly in double fractures, aligns with the findings of a recent study by Sobrero et al. (2023) This decision is believed to stem from the fact that children generate lower bite forces and, consequently, require less mechanical support from the hardware in the presence of a fracture (Aizenbud et al., 2009; Andrade et al., 2015; Lee et al., 2023; Smartt et al., 2005).

In a recent review by Lee et al. (2023), the authors stated that 'plates designed for load sharing in adults may provide sufficient strength to achieve load-bearing fixation in children.' Additionally, the use of non-rigid fixation patterns may be motivated by the limited bone surface available and the need to avoid tooth germs in deciduous and mixed dentition, also favoured by the use of plates <1.0 mm, designed for the treatment of fractures of the adult midface skeleton (Sobrero et al., 2023). As reported by other authors, a portion of the study sample was treated with these plates, and their use was statistically associated with the younger patients in Group A (Abdullah, 2009; Hardt and Gottsauner, 1993; Iatrou et al., 2015; Joshi et al., 2015). Timing and indication for hardware removal were discussed in a separate paper from the same project (Cremona et al., 2024).

In this retrospective study, the incidence of minor malocclusion was consistent with that reported previously (Abdullah, 2009; Bansal et al., 2021; Hardt and Gottsauner, 1993; Iatrou et al., 2015; Joshi et al., 2015; Yesantharao et al., 2020). Only one case of tooth germ damage owing to a screw was reported, which is in line with the rare occurrences documented in the literature; most studies did not report complications related to the development or eruption of tooth germs (Abdullah, 2009; Bansal et al., 2021; Hardt and Gottsauner, 1993; Iatrou et al., 2015; Joshi et al., 2015; Lopez et al., 2021; Yesantharao et al., 2020).

The main strengths of this study include its multicentre nature, large sample size, and inclusion of information on plate thickness, which allowed for a detailed analysis of fixation patterns. However, its retrospective nature introduces limitations, including potential biases such as sampling and information bias. Surgical procedures were performed by different maxillofacial surgeons across various centres, and operator experience may have influenced the outcomes. Future prospective studies with more detailed information on fixation types and long-term follow-up are required to establish shared surgical protocols and clarify potential complications related to tooth germs and facial skeletal development.

5. Conclusions

This multicentre retrospective study highlighted that in paediatric patients across the 14 centres participating in the WORMAT project, plate osteosynthesis is predominantly used to treat displaced or comminuted single and double non-condylar mandibular fractures. In

the absence of protocols defining the optimal treatment for these fractures, centres frequently opted for fixation patterns like those used in adults, with a preference for non-rigid or mixed osteosynthesis in double fractures. The low incidence of postoperative complications in a large series of paediatric patients demonstrates the effectiveness and safety of plate osteosynthesis in treating this type of fracture, regardless of the patient's age or type of dentition.

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