Original Article

Indications for alloplastic temporomandibular joint replacement in maxillofacial trauma—an analysis of condylar trauma patients with scoping review of the literature

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Background: We undertook a review of the literature to assess the role of temporomandibular joint (TMJ) replacement (TMJR) in maxillofacial trauma and examined our own experience of temporomandibular joint bony complications.

Methods: A scoping review of (I) a systematic literature research performed for the German evidence and consensus based (S3) guideline on total joint replacement, (II) a recent systematic review and meta-analysis by Niezen *et al.* [2022] (comprising 13,093 patients and 20,860 prostheses), (III) a systematic literature review of PubMed, google scholar and Cochrane database between November 2021 and February 2022 including English and German studies. In addition, we evaluated our cohort of surgically treated condylar fractures (n=604; head fractures: n=405 since 1993; neck and base fractures: n=199 since 2007) regarding complications which may potentially necessitate a TMJR.

Results: Our search identified 8 studies including 10 patients in addition to the 83 cases found by Niezen *et al.* Although many reports on TMJR describe trauma as an aetiological factor, overall, merely 4 cases received an alloplastic TMJR as a primary treatment. Three cases met the criteria for an early secondary treatment within 6 months, 9 cases after 6 months past trauma. None of the surgically treated condylar fractures (n=604) in our cohort required joint replacement. Within the condylar head dataset (n=405) there was a significant correlation (P<0.05) between the presence of major fragmentation (n=52) and bony complications (n=23, 5.7%) such as osteoarthrosis, pseudarthrosis and heterotopic ossification (HO)/ankylosis. HO (n=9) correlated with delayed surgical treatment (>10–14 days, P<0.01). There was a significant correlation between subjective borderline feasibility of osteosynthesis (n=12/270, 0.4%) and major fragmentation (P<0.001), severe comminution (P<0.001), multilevel fractures (P<0.001) and severe osteoporosis (P<0.001).

Conclusions: In contrast to orthopedic practice alloplastic TMJR does not play a noticeable role in primary or early secondary condylar fracture management. There may be indications in selected cases of major fragmented fractures where safe and stable osteosynthesis is not feasible. Most condylar fractures if treated according to best practice should not result in significant bony complications, but those that do may ultimately require further intervention including TMJR.

Keywords: Temporomandibular joint replacement (TMJR); condylar trauma; major fragmentation (comminution); condylar fracture; alloplastic joint replacement

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Introduction

The mandible is the most frequently fractured bone in the maxillofacial skeleton, with the condyle being the most common fracture identified either in isolation or in combination with other fractures (1).

Historically the primary treatment for condylar fractures was non-surgical, especially those fractures directly involving the condylar head (2-8). This is despite the fact that as many of around 40% of the patients managed non-surgically have been reported to exhibit complications (9,10), such as asymmetry, malocclusion, impaired mastication, loss of function and chronic pain (5-15), that is, presenting various signs and symptoms of temporomandibular joint (TMJ) disorders (TMD) (8-10). Ankylosis is amongst the most problematic complications of condylar trauma (15-18). Although overall being a rather rare event in adults and occurring most commonly in children (16), according to a recent systematic review posttraumatic ankylosis nevertheless ranks among the most frequently quoted indications for temporomandibular joint replacement (TMJR) in adults (14).

Facial trauma may chiefly result in arthrogenic TMD due to (I) the displacement of the fracture leading to disordered anatomy and/or function of the TMJ, (II) traumatic displacement of the disc and resultant short and long term effects of internal re-arrangement of the joint, or (III) due to the damaging effects of traumatic inflammation, synovitis and/or haemarthrosis on the structure and/or function of the joint (19,20). Resulting asymmetries and/or impairment of function on their part will promote myogenic dysfunction and potentially lead to a vicious circle ending up in severe loss of functionality of the joint (10).

Most temporomandibular disorders (TMD) resulting from condylar trauma, however treated primarily, may be managed in line with TMD of other causes, initially by so-called conservative or non-surgical means, and in appropriate cases with minimally invasive or invasive TMJ surgery (21).

TMJR may be considered in the management of condylar trauma, in several circumstances. There may be early significant structural damage and functional disability requiring reconstruction of the joint, or there may be delayed deformity or dysfunction of the TMJ, such as arthritis or ankylosis, which fails to respond to non-surgical or minimally invasive measures and fulfils the criteria for TMJR (22-25). Complications of treatment of condylar trauma, such as infection or avascular necrosis, may be other indications for TMJR and considered as part of the early or the delayed indications depending on what structural and functional problems they produce.

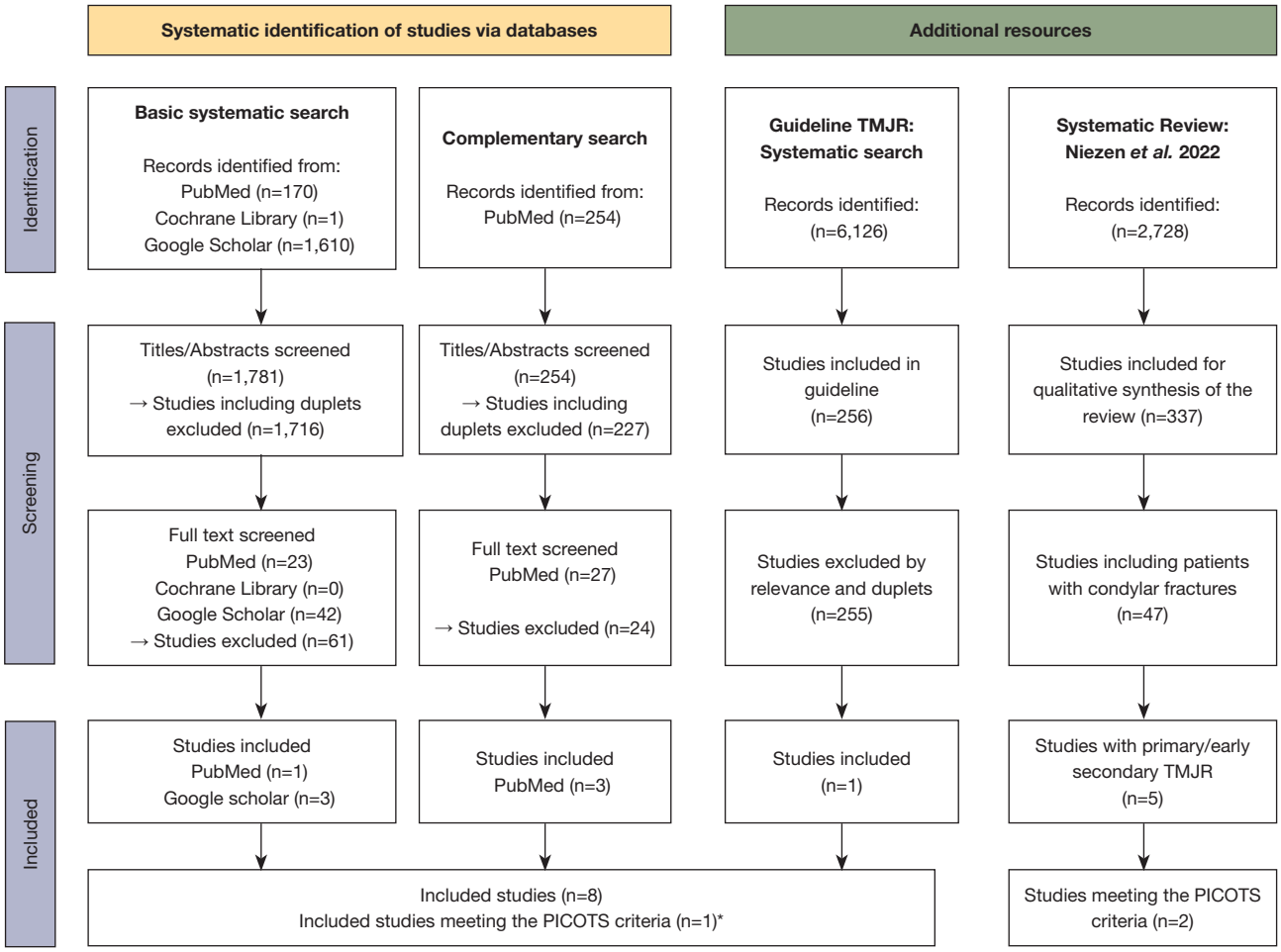
The objective of this paper on TMJR in maxillofacial trauma was to (I) review the frequency and details of TMJR due to trauma, particularly in primary treatment, in the published literature by means of a scoping review, (II) to evaluate experience within our collective of the outcomes of the management of condylar fractures and the need for TMJR, and (III) to consider factors relating to the management of condylar fractures that may have a bearing on the need for TMJR after condylar trauma. We present the following article in accordance with the PRISMA-ScR reporting checklist (available at https://fomm.amegroups.com/article/view/10.21037/fomm-22-16/rc).

Methods

Literature search

We amalgamated the literature searches undertaken in the production of the German S3 (that is, evidence and consensus based) guideline on total alloplastic joint replacement (22,23) and the findings of a recent systematic review by Niezen *et al.* on Temporomandibular Joint Prosthesis (14) as a treatment option for mandibular condylar fractures and supplemented these with our own updated literature search, to identify literature focusing on the use of TMJR in condylar trauma (*Figure 1*) (For further details with regard to the literature search performed by the German S3 guideline (22,23) and the literature research conducted by Niezen *et al.* (14) (Appendix 1).

Between November 2021 till February 2022 we conducted a systematic literature search (*Table 1*) following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist (26). The search was performed by two independent researchers (JJ, CS) in the databases PubMed, Google Scholar and Cochrane Library using the terms "temporomandibular joint [AND] condylar fracture [AND] (prosthesis [OR] prostheses [OR] replacement



* (Systematic search: n=1, complementary search: n=0, TMJR guideline: n=0)

Figure 1 Systematic literature search and additional resources. TMJR, temporomandibular joint replacement.

[OR] reconstruction [OR] implant)".Inclusion criteria were the application of TMJR in the context of condylar fracture as well as the use of English or German language. Studies using non-human subjects (e.g., animal studies, laboratory studies and finite element studies) were excluded. We further excluded studies already included by the S3 guidelines, or by Niezen *et al.* Studies dealing with central dislocation of the condyle into the middle cranial fossa were also excluded, as these cases usually are not associated with condylar fractures in a proper sense and should be considered as an entity of its own with regard to fossa replacement. Due to a generally low level of evidence (LoE), we decided against limiting the search to specific years of publication or study types. To select studies for a full text analysis, the titles and abstracts of the results were screened for thematic relevance by two independent researchers (JJ, CS). All studies describing an alloplastic joint reconstruction (total and other types) in the context of a condylar fracture were initially included. Subsequently specific research questions were formulated using the PICOTS scheme based on the AHRQ's evidence-based practice centers program issued by the FDA, and were applied to the studies) (*Table 2*) (27).

In addition, a further search in the PubMed database was conducted using the method of Niezen *et al.* with a more general search strategy/term: "temporomandibular joint [AND] (prosthesis [OR] prostheses [OR] replacement [OR] reconstruction [OR] implant)", using the timeframe 2020/12/12 to 2022/02/18, to supplement their findings.

The LoE of publications identified in the above mentioned systematic searches by the authors of this paper was assessed by two medical experts (AN, CS) independently

Table 1 The search strategy summary

Items	Specification
Date of search	2021/11/01 (basic systematic search), 2022/02/18 (complementary search)
Databases and other sources searched	PubMed, Google Scholar and Cochrane Library for articles in English or German language; German S3 Guideline 007-106 (22,23); systematic review and meta-analysis by Niezen *et al.* (14)
Search terms used	Basic systematic search: "temporomandibular joint [AND] condylar fracture [AND] (prosthesis [OR] prostheses [OR] replacement [OR] reconstruction [OR] implant)"
	Complementary search: "temporomandibular joint [AND] (prosthesis [OR] prostheses [OR] replacement [OR] reconstruction [OR] implant)"
Timeframe	Basic systematic search: no restriction
	Complementary search: 2020/12/12 to 2022/02/18
Inclusion and exclusion criteria	Inclusion criteria: application of TMJR in the context of condylar fracture, use of English or German language
	Exclusion criteria: studies using non-human subjects (e.g., animal studies, laboratory studies and finite element studies); studies dealing with central dislocation of the condyle into the fossa; studies already included by the S3 guideline (22) or by Niezen *et al.* (14) were excluded as duplicates
Selection process	Screening and search conducted by two independent researchers JJ and CS
	Assessment of LoE by CS and AN, in case of doubt consensus by NML
Search questions	Confer PICOTS criteria, *Table 2*

TMJR, temporomandibular joint replacement; LoE, level of evidence.

Table 2 PICOTS criteria

Acronym	Criteria
Patient population	Patients with condylar fractures of any localization (CBF, CNF, CHF)
Intervention	Total joint replacement either as primary treatment or salvage surgery after failed ORIF or failed non-surgical therapy, the term "early" being defined within a timeframe from less than 6 months after trauma
Comparator	ORIF as primary treatment of condylar fracture of any localization and any type of fragmentation or salvage surgery after failed ORIF by means of ORIF
Outcome	The rate of unfavorable late sequelae such as malocclusion, asymmetry, limitations and/or loss of functionality with regard to mouth opening, protrusion and laterotrusion, impaired mastication, nerve lesions (facial nerve and auriculotemporal nerve), and chronic pain
Timing	The respective intervention is defined as "early" within a timeframe of less than 6 months after trauma to exclude TMJR indicated for osteoarthritic late sequelae
Setting	All health care institutions dealing with condylar trauma

CBF, condylar base fracture; CNF, condylar neck fracture; CHF, condylar head fracture; ORIF, open reduction and internal fixation; TMJR, temporomandibular joint replacement.

from each other, based on the Oxford Criteria (28). In case of doubt, a third expert was consulted (NML).

Evaluation of our condylar trauma experience

We examined our condylar fracture database, which includes a prospectively collected cohort of patients with condylar head fractures treated surgically since 1993 (29-32) and an overlapping cohort with condylar fractures, of any location, since 2007 to create a dataset of patients using the following criteria:

- ❖ Condylar head fracture cohort (CHF) 1993–2022:
  - (I) Inclusion criteria from the condylar head fracture cohort (CHF) 1993–2022 were as follows:

(i) Condylar head fractures including minor and/or major fragmented cases, multilevel fractures including a fracture of the condylar head (29,33,34); considered for surgical treatment (defined by presence of clinical symptoms such as malocclusion and/or limited range of motion and pain);
(ii) Surgical treatment with ORIF.

(II) Exclusion criteria were non-surgical fracture treatment and central dislocation of the condyle into the middle cranial fossa.

❖ Condylar fracture dataset (CBF/CNF/CHF) 2007–2022:

(II) Inclusion criteria for the condylar fracture dataset (CBF/CNF/CHF) 2007–2022 were as follows:
(i) Condylar and ramal fractures with displacement or dislocation of any location (condylar base, condylar neck, condylar head and/or condylar multilevel fractures) (34,35);
(ii) Surgical treatment with ORIF;
(iii) Surgeries performed by the same surgeon (control of homogeneity of assessment);
(iv) Documentation of an intraoperative subjective assessment of the surgeon with regard to feasibility of ORIF, defined as absence or presence of major obstacles when performing osteosynthesis (videlicet ORIF procedure within the range of usual challenges or well above, that is, either "borderline feasibility" or impossibility of performance).

(II) Exclusion criteria were non-surgical fracture treatment and central dislocation of the condyle into the middle cranial fossa.

Data parameters recorded were: age; gender; presence or absence of major fragmentation as defined by the AO classification (34) or "comminution" defined as obstacle to perform a standard small fragment positional screw osteosynthesis for CHF (30-34); delay between trauma and ORIF >10–14 days; presence of severe osteoporosis (as noticed during ORIF, severe defined as impeding osteosynthesis); adherence to postoperative physiotherapy; bony complications documented in the postoperative course such as pseudarthrosis, progressive osteoarthrosis, HO with or without ankylosis, and bony ankylosis; indication for a joint replacement (total alloplastic joint, alloplastic hemi-joint and/or autologous replacement) intra- or postoperatively with respective timepoints if performed.

Statistical analysis of potential correlations was performed using two tailed Fisher's exact test (IBM SPSS version 27.0.1, IBM, Armonk, NY, USA), the level of significance was set at $P<0.05$.

Approval of the ethics committee was not required due to the retrospective character of the data analysis performed.

Results

Literature search

A total of 1,781 records were identified in the initial systematic search (*Figure 1*). Subsequent to the screening of titles and abstracts, 1,714 publications were excluded because they did not adhere to the inclusion criteria or fulfilled the exclusion criteria. 65 studies were retrieved for full text analysis. 61 of those articles were excluded due to thematic irrelevance (mostly through applying surgical strategies other than alloplastic reconstruction). Finally, 4 publications were included describing cases with the application of alloplastic reconstruction in the context of a condylar fracture.

The complementary search yielded a total of 254 results. After screening of titles and abstracts, 227 publications were excluded based on the inclusion and exclusion criteria. Twenty-seven papers were retrieved for full text analysis and 24 of those were excluded due to thematic irrelevance (mostly because they did not include a condylar fracture in patient history). Eventually 3 publications were included describing cases with an application of alloplastic reconstruction in the context of a condylar fracture.

Based on the systemic literature search for the German TMJR guideline, the 256 studies included in the guideline were screened for use of TMJR in the context of condylar fractures (*Figure 1*). Subsequent to applying the inclusion, exclusion and selection criteria, 1 additional study was included describing cases with an application of alloplastic reconstruction in the context of a condylar fracture.

The systematic review by Niezen *et al.* yielded 47 studies containing 83 patients with condylar fractures (*Figure 1*) (14). Of these, 5 publications involved cases with an alloplastic reconstruction as a primary or early secondary (<6 months) treatment of condylar fractures and were therefore included in the review.

In summary, a total of 13 publications including 16 patients were identified by the various search approaches and included in the review (*Table 3*) (36-48). Four of the patients received an alloplastic reconstruction other than a

Table 3 Details on included studies (sorted by the alphabetical order of the authors)

Source	Study type/LoE	Patients (n)	Fracture	Prosthesis	Indication/patient history	Follow-up	Outcome
Total alloplastic joint reconstruction as primary treatment option (therefore meeting the PICOTS criteria)							
No studies available							
Other alloplastic joint reconstruction as primary treatment option							
Lindqvist *et al.* 1986 (36)*	Case series/LoE 4	1/2	Unilateral condylar fracture	Condylar reconstruction plate	Severe soft tissue damage and a comminuted fracture of the mandibular condyle, ramus and angle following gunshot injury (shotgun)	6 months	Except of wound infection 2 month after surgery no complications, MIO 29 mm, satisfactory mandibular function
Small *et al.* 1964 (37)*	Case series/LoE 4	2/6	Unilateral condylar fracture	Teflon block	Comminuted condylar fracture	2 years	Good function, slight deviation of the mandible towards the fractured side
			Unilateral condylar fracture	Silastic block	Severe displacement of condylar head with articular surface completely sheared off	1 year	No complications
Terracol 1954 (38)*	Case report/LoE 5	1	Unilateral condylar fracture	Acrylic condylar head as a prosthesis	Severe dislocation	5 years	Satisfactory mandibular function, "normal" MIO, no complications
Total alloplastic joint reconstruction as secondary treatment ≤6 months post fracture (therefore meeting the PICOTS criteria)							
Davis *et al.* 2013 (39)	Case series/LoE 4	1/6	Bilateral condylar neck fracture	Stock TMJR (5 months p.f.)	Left-sided wound infection with rapid proximal segment degeneration following ORIF	5 years	Stable jaw function and MIO 37 mm
Koneru *et al.* 2021 (40)*	Case report/LoE 5	1	Unilateral condylar neck fracture	Custom TMJR (6 months p.f.)	Unilateral Sawhney's Type I ankylosis (Turlington and Durr symptomatic Grade 1) following failed IMF	6 months	MIO 35 mm, minimal deviation towards the left side
Woodbury *et al.* 1998 (41)*	Case series/LoE 4	1/3	Bilateral dislocated subcondylar fracture	Stock TJR (1 month p.f.)	Medial dislocation of an avascular left condyle following ORIF	n.a.	Postoperative MIO 40 mm
Total alloplastic joint reconstruction as secondary treatment >6 months post fracture							
Brierly *et al.* 2022 (42)	Cohort study/LoE 5**	1/151	Unilateral condylar fracture	Custom TMJR	Old displaced condylar fracture	5 years	n.a.
Candirli *et al.* 2014 (43)	Case series/LoE 4	1/9	Condylar fracture n.s.	TMJR n.s.	Displaced condylar fracture	n.a.	No complications using new subparotideomasseteric approach
Davis *et al.* 2013 (39)	Case series/LoE 4	2/6	Unilateral condylar neck fracture	Custom TMJR (1 year p.f.)	Complete resorption of CCG following malunion and resorption after MMF	n.a.	Stable jaw function and MIO 44 mm
			Condylar fracture n.s.	Stock TMJR (>10 years p.f.)	Ankylosed CCG following MMF	6 years	Stable jaw function and MIO 35 mm
Ferreira Pinto *et al.* 2020 (44)	Case report/LoE 5	1	Unilateral condylar fracture	Custom TMJR (13 years p.f.)	Multiple traumata of the condylar region: Condylar plate fracture following ORIF and ankylosis in the sequence of initial condylar fracture	n.a.	Improved jaw function under physical therapy and MIO 38 mm
De Moraes *et al.* 2012 (45)	Case report/LoE 5	1	Unilateral condylar fracture	Custom TMJR (16 months p.f.)	Condylar fracture malunion by failure of the internal fixation	1 year	MIO 35 mm, skeletal and occlusal stability and no pain
Roh *et al.* 2013 (46)	Case series/LoE 4	1/2	Bilateral condylar fracture	Stock TMJR (14 months pf)	Degenerative osteoarthritis at the right condyle and malunion at the left condyle	1 year	MIO 31 mm, pain and joint crepitation resolved
Thiem *et al.* 2021 (47)	Case report/LoE 5	1	Bilateral condylar fracture	Custom TMJRs	Bilateral deforming TMJ arthrosis (Wilkes-V) and unilateral ankylosis from a bilateral condylar fracture.	n.a.	Unilateral aseptic inflammation by broken screw and loosening of the fossa component six weeks after surgery. No complications on the opposite side
Val *et al.* 2022 (48)	Case report/LoE 5	1	Bilateral condylar intracapsular fracture	Custom TMJRs (23 years p.f.)	Bilateral ankylosis (previous therapeutic approaches: non specified surgery, arthrocentesis, interpositional arthroplasty with temporal fascia flap)	1 year	MIO 39 mm and good ability to shred food

*, studies on primary or early secondary TMJR in condylar fractures identified by Niezen *et al.* (14); **, downgraded due to a lack of sufficient data plus TMJR in context of condylar fracture is only mentioned as a case report within the cohort study. CCG, costochondral graft; IMF, intermaxillary fixation; LoE, level of evidence; MIO, maximum interincisal opening; MMF, maxillomandibular fixation; n.a., not available; n.s., not further specified; ORIF, open reduction and internal fixation; TMJR, temporomandibular joint replacement; p.f., post fracture.

total joint replacement as a primary treatment following a condylar fracture (36-38). The application of a total TMJR was found exclusively as a secondary treatment option for condylar fractures. In 9 cases TMJR was done within a time frame greater than 6 months post fracture (39,42-48). Therefore, only three patients (secondarily treated with TMJR within 6 months post fracture) sufficiently met the PICOTS criteria (39-41). No study describing the use of total TMJR as a primary (that is, immediate) treatment option for condylar fractures was identified by the various search approaches.

The overall LoE measured by the Oxford criteria (28) was low, ranging between level 4 (6 studies) and level 5 (7 studies) (*Table 3*). Six studies were case reports, 6 were case series and one study met the criteria for a non-controlled, retrospective cohort study. However, the latter did not report condylar fractures nor trauma as diagnoses in the context of TMJR or as an indication for TMJR. Nonetheless a patient with a history of an initial condylar fracture was described as a case example. Therefore, the LoE of the cohort study was downgraded from level 4 to level 5.

Condylar fracture cohorts

Surgeries for CHFs treated between 1993 and 2007 were performed at the department of OMFS, Technical University Munich, Germany (mostly by first author AN) and since 2007 at the department of OMFS, University Hospital Marburg, Germany, with CHFs exclusively operated by the assessing author AN).

Overall our prospective database of condylar fractures comprises 604 condylar fractures (CHF/CNF/CBF), surgically treated between 1993 and 2022.

There were 405 condylar head fractures (CHF) surgically treated meeting the inclusion criteria (I), of which 220 were operated between 1993 and 2007, and 185 between 2007 and 2022.

Out of the 199 condylar base and neck fractures operated between 2007 and 2022 (CBF/CNF), 85 base and neck fractures were included according to inclusion criteria (II) (that is, ORIF by the same surgeon AN).

Thus a total of 490 condylar fractures were included for further analysis.

Evaluation of the condylar head fracture cohort (CHF)

Major fragmentation in the sense of "comminution" was recorded intraoperatively in 52 fractures (12.8%), whereas fragmentation according to the AO classification, occurred in 172 fractures (42.5%). None of the fractures received a total alloplastic joint replacement as primary or early secondary treatment, nor to the best of our knowledge during the later follow-up period [confer also 5 years long-term follow up data (31)].

Evaluation of the overall CHF and CNF/CBF datasets

Bony complications

The total number of bony complications observed across both datasets was 27 (*Table 4*). Within the CHF collective there were 23 bony complications out of 405 fractures, and in the CBF/CNF subset there were 4 bony complications out of 85 fractures, including revision cases.

The following complications were observed: progressive osteoarthrosis (as a sequel of intraarticular scarring and high grade limitation of joint mobility) in 8 joints (31% of bony complications, overall 1.6%); pseudarthrosis (due to failure of osteosynthesis material) in 7 joints (27% of bony complications, overall 1.4%); bony ankylosis and HO in 6 joints (23.1% of bony complications, overall 1.2%); HO without ankylosis in 3 joints (3.8% of bony complications, overall 0.6%), with HO thus overall observed in 9 joints (34.6% of bony complications, overall 1.8%).

Among the condylar base and neck fractures 2007–2022 (surgeon AN) specifically, there were four bony complications (4/85 videlicet 4.7%) requiring surgical revision. Case 1: bilateral condylar neck fractures with secondary displacement after ORIF in another hospital, revision surgery approximately 2 months later with pseudarthrosis resection and re-osteosynthesis with synthetic bone graft, right hand side fails with redislocation, requiring corrective orthognathic surgery due to persistent malocclusion; Case 2: bilateral high condylar neck fractures, left hand side treated with 1.5 plates, loosening of osteosynthesis material with pseudarthrosis, successful revision surgery with autologous spongious bone graft; Case 3: condylar neck fracture in a patient with bruxism, secondary displacement after ORIF, successful revision surgery with pseudarthrosis resection, re-osteosynthesis with autologous spongious bone graft; Case 4: trifocal fracture with bilateral CNFs side in a severe osteoporosis case, secondary displacement of the CNF with sintering and healing of the condylar process in shortened malposition, requiring prosthodontic occlusal correction. None of the condylar fracture patients of the overall collective of 604 CBFs, CBNs and CHFs (that is, including also those CBF/CNF not meeting the inclusion criteria) underwent a joint replacement (TMJR, alloplastic hemi-joint or autologous

Table 4 Details of bony complications recorded in CHF and CBF/CNF datasets

No. (n=27)	Complications observed	Major fragmentation (yes =1; no =0)	Fracture type p/m (A/B/C)	Delayed treatment (days)	Lack of adherence (yes =1; no =0)	Age ≤16 years (yes =1; no =0)
1	HO/ankylosis	0	p (B)	14	1	1
2	HO/ankylosis	0	p (C)	21	0	0
3	HO/ankylosis	1	p (B)	24	1	0
4	HO/ankylosis	0	m (A)	18	1	0
5	Pseudarthrosis	1	p (B)	12	0	0
6	Pseudarthrosis	0	p (C)	<10	0	0
7	Osteoarthrosis	1	p (B)	<10	0	0
8	Osteoarthrosis	1	p (B)	<10	0	0
9	Pseudarthrosis	1	p (B)	<10	0	0
10	Pseudarthrosis	0	p (B)	<10	0	1
11	Osteoarthritis	0	m (A)	<10	0	0
12	Sintering	1	CNF	<10	0	0
13	Osteoarthritis	1	p (C)	<10	0	0
14	HO	1	p (B)	<10	0	0
15	Osteoarthritis	0	p (B)	<10	0	0
16	Osteoarthritis	1	p (B)	<10	1	0
17	Pseudarthrosis	1	CNF	<10	0	0
18	Pseudarthrosis	0	p (C)	<10	0	0
19	Osteoarthritis	0	p (B)	<10	0	0
20	HO/ankylosis	1	p (B)	12	1	0
21	HO/ankylosis	1	p (C)	12	1	0
22	HO	0	p (B)	<10	0	0
23	Resorption	1	p (B)	<10	0	0
24	Pseudarthrosis	0	CNF	<10	0	0
25	HO	0	p (B)	<10	0	0
26	Osteoarthritis	1	p (B)	<10	1	0
27	Pseudarthrosis	0	CNF	28	0	0

CHF, condylar head fracture; CBF, condylar base fracture; CNF, condylar neck fracture; HO, heterotopic ossification; m, fracture medial to the pole zone AO classification; p, fracture within the pole zone AO classification; A, fracture medial to the pole zone; B, fracture within the lateral pole zone, intracapsular; C, fracture within the pole zone; partially extracapsular; lack of adherence refers to physiotherapy (missing or failed).

transplant such as costochondral grafts etc.).

There was significant correlation (P<0.01), between bony complications overall (n=23, that is, 5.7%). and major fragmentation observed in the CHF group during follow-up.

Fisher's exact test showed a significant correlation between HO and delayed treatment later than 10–14 days after trauma (P<0.01), as well as for ankylosis (P<0.05), whereas for the age, gender, lacking adherence to physiotherapy, subtypes of fractures according to AO classification (fractures type p within the lateral pole zone), and major fragmentation there were no significant correlations with ankylosis and/or HO (*Table 4*).

Table 5 Borderline feasibility documented in the CHF collective 2007–2022 and in the CBF/CNF/CHF collective 2007–2022

Reasons for borderline feasibility (n=23)	Events per fracture sites (n)	Events per fractures sites (%)	P value (Fisher's exact test)
CHF collective (n=185)			
Comminution CHF	9	4.9	0.00275
Multilevel fracture CHF	5	2.7	0.00014
Severe osteoporosis CHF	5	2.7	0.00081
CBF/CNF/CHF collective (n=270)			
Comminution CBF/CNF/CHF	10	3.7	0.00029
Multilevel fracture CBF/CNF/CHF	6	2.2	0.00058
Severe osteoporosis CBF/CNF/CHF	7	2.6	0.00022

CHF, condylar head fracture; CBF, condylar base fracture; CNF, condylar neck fracture.

Subjective assessment of "borderline feasibility" of osteosynthesis in CBF/CNF/CHF 2007–2022 was recorded in 12/270 cases (4.4%), with CHFs in n=11/185 (5.9%); CBF/CNF in n=1/85, (1.2%) or 1/199 (0.5%), respectively, as all revisions surgeries were performed by the assessing surgeon (AN). None of the fractures was rated as "impossible to perform". In 9/270 fractures (3.9%, collective 2007–2022 CBF/CNF/CHF) the proximal fragments could be fixed by osteosynthesis in some malposition only (with rotation/angulation ≤10–15 degrees and or loss of height ≤2–3 mm), however without relevant effect on occlusion (for those rated as bony complications confer above). Among those fractures rated as "borderline feasibility" (n=12), Fisher's exact test showed a significant correlation in CHFs for major fragmentation (P<0.01), severe comminution (P<0.001), multilevel fractures (P<0.01) and severe osteoporosis (P<0.001). For all condylar fractures in the collective CBF/CNF/CHF 2007–2022 the correlation to "borderline feasibility" was even more pronounced, with P<0,001 for major fragmentation, P<0.001 for multilevel fractures and P<0.001 for osteoporosis (*Table 5*). Comparing the 2007–2022 CHF collective and the collective of CBN/CNF 2007–2022 significant interdependence of "comminution" as a parameter for borderline feasibility with CHFs could be established (P<0.01, Fisher's exact test).

Discussion

Whilst there is good evidence that ORIF on condylar fractures reduces complications and produces better anatomical and functional outcomes, dysfunction of the TMJ may still occur either due to the residual deformity, complications of surgery or the soft tissue injury to the joint (7,8,49-53).

Most TMD resulting from trauma, managed non-surgically or with ORIF, should be managed in line with TMD of other causes, by so-called conservative or non-surgical means. Malocclusion and deformity may be managed by orthodontics or compensatory orthognathic procedures (54-57).

Where non-surgical management is ineffective, or there is symptomatic or functional deteriorations, then minimally invasive (arthrocentesis/arthroscopic) interventions may be appropriate. Alternatively open arthroplasty may be considered in limited cases where these have been ineffective (21,58).

Temporomandibular joint replacement may be considered in the management of condylar trauma, in several circumstances however. (I) There may be early significant structural damage and functional disability requiring reconstruction of the joint, or (II) there may be delayed deformity or dysfunction of the TMJ, such as arthritis or ankylosis, which fails to respond to non-surgical or minimally invasive measures and fulfils the criteria for TMJR (22-25). Complications of treatment of condylar trauma, such as infection or avascular necrosis, may create indications for TMJR and be considered as part of the early or the delayed indications depending on what structural and functional problems they produce and the timing.

The detailed indications for TMJR in most instances of "delayed indications" are based on the resultant dysfunction (e.g., ankylosis, arthrosis) and not to the primary aetiology (trauma) and are considered in the chapters of this special issue relating to such indications for TMJR, and not discussed further here.

Although a history of trauma is reported for up to 50%

of TMJR patients (59-63) most of this data relies on self-reported trauma, or lacks details of the type of trauma, its treatment, or the actual indication for TMJR.

According to the systematic review by Niezen *et al.* (14), in as few as 83 out of approximatively 4,600 TMJR (1.8%) could condylar fracture be clearly identified as the indication, with 19 cases described in case reports, 37 in case series and 27 in cohort/clinical studies. The timepoint of TMJR implantation ranged from 1–4 weeks to 30 years after trauma. Reasons for TMJR implantation according to Niezen *et al.* (14) were; ankylosis (n=34), reconstruction of the condyle (n=21, with 10 performed later than 4 years after trauma, that is, late sequelae), malunion (n=6), osteoarthritis (n=3) and condylar resorption, inflammation, fracture of osteosynthesis material, and HO (n=1 each) and the remainder undefined (n=19). Among those 83 patients, 4 underwent TMJR as primary treatment, 13 had undergone failed osteosynthesis (15.7%), 16 conservative (19.3%) or no treatment (3/83; 3.6%) and the remainder was not reported or unclear. It is noteworthy that 16 (19.3%) of the 83 patients had already undergone open joint surgery (gap arthroplasty, costochondral graft, spacers, condylectomy etc.) before TMJR was undertaken. Only 24 (28.9%) of the patients had received no prior corrective temporomandibular joint surgery and no information was available for 43 (51.8%) of the patients.

The first out of the four cases already identified by Niezen *et al.* for primary total joint replacement was performed in 1954—the entire head was removed and replaced by an acrylic head as a prosthesis (38). Another case was a shotgun wound from 1986 due to a suicide attempt with a severe comminution of the condyle, ramus and angle with concomitant tissue defects. This patient received a mandibular reconstruction plate working as an alloplastic hemi-joint (36). In another case series, a comminuted condyle was removed in an edentulous patient suffering a car accident and replaced by a Teflon block. The same authors also removed a sheared off condylar head fragment in another patient and replaced it by a silastic spacer (37).

By virtue of their historical nature, although the indications for primary TMJ reconstruction might still have some applicability, the skills and technology required to undertake ORIF have evolved significantly and the techniques of reconstruction of the TMJ were not aligned to the modern standards for alloplastic TMJR.

Regarding cases considered as having early secondary reconstruction of the TMJ, Woodbury *et al.* reported a gunshot case replaced by a rib graft and a further case with a double sided CHF treated conservatively which after 10 weeks required a vertical ramus osteotomy after removal of the comminuted CHF fragments (41). A third patient received a Christensen total joint early after a failed ORIF in a subcondylar fracture (41), the latter case thus fitting to our PICOTS criteria. A case receiving a customized TMJR with a Sawhney's type I ankylosis reported by Koneru *et al.* again was a secondary TMJR 6 months after failed conservative condylar fracture treatment with a modified total alloplastic joint using a patient specific titanium cap over the shortened condyle with a very flat UHMPWE fossa (40). Other reports including e.g., central dislocation in the middle cranial fossa (39,64) did not meet our inclusion criteria.

Regarding our additional findings, Davis *et al.* described a case where at one week after initial bilateral ORIF following bilateral condylar fracture the patient presented with a left sided wound infection (39). Following intense antibiotic therapy, removal of the osteosynthesis material and the use of a temporary reconstruction plate, a TMJR was inserted once the infection had been eliminated approximately 5 months post fracture, and thus this case also fulfilled our PICOTS criteria.

In summary the systematic literature search adding to those TMJR already identified by Niezen *et al.* (14) yielded 10 additional cases describing TMJR in the context of a condylar fracture. Combining our results with the work by Niezen *et al.* a total of 13 studies with 16 patients were included in the review, with only 4 cases received a TMJR as a primary treatment. The reconstruction however was done using alloplastic materials other than a total joint prosthesis, therefore not fulfilling the PICOTS criteria. Eventually only 3 patients treated by an early secondary total TMJR were identified fulfilling the PICOTS criteria.

When all these cases are put together, certain themes emerge. In most cases identified as receiving some form of "joint replacement" as primary or early secondary treatment, the indication was given as "severe dislocation with no real option to reduce the fracture, or comminution", infection (39) or with central dislocation into the middle cranial fossa (65,66).

The indications for primary TMJ reconstruction after trauma are therefore fairly narrow. Extremely severe comminution, such as found with ballistic injuries, is arguably the only true indication, but is not in itself an absolute indication (67,68). Even then, immediate reconstruction is generally not appropriate due to the compromised soft tissue envelope, and the need to allow healing of the distal mandible to which the reconstruction will be fixed (69-71). In many

countries, ballistic injuries to the face are quite uncommon, including none within our own case series from 1993 to 2022 (72-74).

A major limitation of this systemic literature review was the low LoE. Measured by the Oxford criteria only one of the included studies met the criteria of a cohort study (retrospective, non-controlled), but was downgraded due to the way data was reported. Six of the included studies were identified as case series and 6 as case reports. Therefore, the low LoE also emphasises the rare indication of a TMJR in the direct context of a condylar fracture.

In the context of maxillofacial trauma Mercuri *et al.* reported a history of trauma to be neither a predictor for worse or better outcomes after TMJR, and the same applies for satisfaction of the patients (59,60). Especially in case of trauma, however, aspects of a claim for damages need to be considered, too. This may be an additional reason why e.g., Kanatas *et al.* reported a worse functional outcome after trauma. The authors attributed this worse outcome to the more extensive destruction of the traumatized joints, but their case report (75) included just two patients (one car accident, one external force).

Based on improved evidence by systematic reviews and meta-analyses (50,76-79), ORIF of condylar fractures should be considered with LoE 1 (28) as the gold standard for both displaced or dislocated condylar base (CBF) and neck fractures (CNF) in adults. There is ample evidence that ORIF significantly reduces the risk of asymmetries, malocclusion and posttraumatic pain (9,11,50,76-80). There is furthermore increasing evidence that ORIF of condylar head fractures (CHF) in adults (29-31,53,81-85) and also severely displaced or dislocated CBF and CNF in children and younger adolescents with mixed dentition (86-88) can produce excellent outcomes, which are potentially better than non-surgical management, in carefully selected cases.

There are still many who advocate closed, or non-surgical, treatment of condylar fractures (4,5), however many of the arguments against ORIF can be contested by the lack of homogeneity in much of the data presented, and the use of data from historical series where current best practice for was not used, thus resulting in higher complications rates and poorer functional outcomes.

In contrast, ORIF in condylar fracture has the potential to restore the anatomy and enable normal physiological function of the TMJ if performed well (9,11,50,76-79,81,87,89). Well performed ORIF of condylar fractures, should efficiently reduce complication rates and help to avoid late sequelae such as ankylosis (90) and trauma associated condylar resorption (91,92) (videlicet traditional indications for TMJR), but in the first place could prevent ORIF associated complications such as malunion and secondary displacement due to insufficient osteosynthesis (93). This implies that widespread striving for improvement of skills and expertise in ORIF of condylar traumatology is mandatory (87).

There are a number of considerations in optimizing ORIF: (I) case selection, (II) the surgical approach to enable visualisation and reduction of the fracture whilst minimizing complication, particularly of facial nerve or parotid gland injury, (III) adequate fixation, (IV) addressing of the soft tissue injury (V) post-operative physiotherapy.

(I) With regards to case selection, whilst consensus meetings (77) have provided some guidance on indications for ORIF of condylar fractures, there is still work to be done to determine precise indications (86,94). Simultaneously, clear contra-indications to ORIF may include the inability to adequately reduce or apply fixation to the fractured fragments, but more precise contra-indications remain to be established.

One factor in this is the degree of comminution, or fragmentation, particularly in condylar head fractures (34,35). It is noteworthy, that two decades ago fragmented head fractures were generally considered "not to be amenable to safe and stable osteosynthesis" (2) or at least "to be still experimental" according to a then valid consensus conference (3,87). Publications often exclude or conspicuously do not report on CHF cases with major fragmentation (21,32,81,84,95,96) despite fragmentation being found in as much as 40% of fractures in our series (around 30% minor fragmented and some 10% major fragmented cases) (87,97).

In our data for major fragmented cases during the period 2007–2022, all displaced or dislocated condylar fractures (CB; CN; CH), that is, explicitly including all major fragmented cases, underwent ORIF. Although this may be termed a highly biased collective (videlicet performed in a specialized trauma center), this nevertheless indicates that major fragmented cases ("comminution") are not an a priori contra-indication for surgery, nor substantiate a primary indication for TMJR. Our evaluation showed a significant correlation for feasibility of ORIF according to intraoperative

assessment by the performing surgeon with multilevel fractures and major fragmented fractures (Fisher's exact test, P<0.01). This correlation was even more pronounced in case of "comminution" (Fisher's exact test, P<0.001) and severe osteoporosis cases (Fisher's exact test, P<0.001). Major fragmentation did however correlate with bony complications. Although no cases in our series necessitated early or late secondary reconstruction of the TMJ, some did require surgical intervention, and only extremely long term follow up will confirm that the risk of TMD requiring TMJR in these patients is not higher than a comparable cohort of non-trauma patients.

(II) One factor often quoted as a reason for not considering ORIF of condylar fractures is the complications, including of facial nerve injury and to the parotid gland, of the surgical approach (7,98,99). Refinements in approaches to the condyle (98-104) have clearly demonstrated that there are significant differences in facial nerve injury rates depending on the approach chosen (98,99,101,102). Salivary gland complication can simultaneously be reduced in the approach to the condylar neck/base if approaches are selected which do not breach the parotid capsule (7,98,104).

(III) The biomechanical demands for stability in condylar process fractures were published more than two decades ago (105,106). Inadequate fixation in condylar neck/base fractures can result in pseudarthrosis/malunion (93) and in extreme cases even total loss of joint functionality (87,107), which may ultimately require TMJR to correct (15). In condylar head fractures, some fixation techniques [e.g., plating procedures (30,108)] have a high potential to promote scarification, loosening of osteosynthesis material etc. due to interference with the intracapsular and periarticular soft tissues (32,109) and lack of stability (30,110,111), and may lead to severe osteoarthrosis in the long run, potentially ending up in TMJR.

(IV) The importance of management of the soft tissues of the TMJ when treating condylar fractures is being increasingly recognised and plays a role in optimizing the outcome of ORIF (112-115). The retention of the intra-articular disc in a functioning joint may even be as important as the bony reconstruction in the long term functioning of the TMJ (20,50,81,87,116-118).

(V) The historical use of rigid intermaxillary fixation in the management of condylar fractures is considered now to be a significant risk factor in reduced mobility of the joint and is in most instances contraindicated. Functional rehabilitation is the preferred approach, although the term is used for a heterogenous group of approaches to the mobilisation of the TMJ post injury (5).

Another factor which often goes underreported in condylar trauma and which may substantially contribute to adverse effects in both ORIF and TMJR is HO. In HO, an increased proliferation of osteoblastic cells and an accelerated differentiation of osteoprogenitor cells are considered to be responsible for increased osteogenesis (119-122). Respective studies were able to show the role of a humoral mechanism in enhanced fracture healing and the induction of HO manifesting in genetically susceptible individuals especially after traumatic brain injuries (TBIs) and in trauma cases with prolonged immobilization (119-123). Gautschi *et al.* hypothesized that bone formation may not be limited to cells of the mesenchymal lineage, and circulating cells of hematopoietic origin with osteogenic potential (COP) can also serve as osteogenic precursors and thus may well be involved in HO at remote sites of tissue inflammation or even prolonged immobilization (121,122).

The concept of HO influenced by prolonged immobilisation was basically confirmed by our assessment of complications following condylar trauma, which showed a significant correlation for delayed ORIF of CHFs with HO (Fisher's exact test, P<0.01) and also with ankylosis (Fisher's exact test, P<0.01). Whereas major fragmentation could be shown to be associated with bony complications in general (Fisher's exact test, P<0.01) (such as progressive osteoarthritis, pseudarthrosis, failure of osteosynthesis material and HO/ankylosis), the correlation between major fragmentation, type of fracture, age and insufficient physiotherapy were statistically not significant within the group exhibiting the above complications.

Conclusions

In condylar traumatology, ORIF may be considered the treatment of choice where there is significant displacement of the fracture or dysfunction (although what constitutes significant in this context remains to be clearly defined). Functional rehabilitation is the preferred approach for undisplaced/minimally displaced fractures. Several patient

(age/co-morbidities/osteoporosis), fracture (comminution) and surgeon (expertise/equipment) factors will impact on treatment decisions. ORIF should be considered the treatment of first choice even in major fragmented cases.

TMJ symptoms and dysfunction are not uncommon after trauma and are largely managed in line with well-established protocols for conservative management of TMD, which may include surgical intervention in limited cases.

There are few, if any indications for primary treatment of condylar trauma with TMJR, although it may be indicated in specific circumstances in delayed primary treatment where there is very severe soft or hard tissue destruction (e.g., ballistic injuries), or early TMJR after failed primary treatment (non-union, resorption, ankylosis).

Late sequelae of TMJ trauma, even when managed optimally, include ankylosis, HO, progressive osteoarthritis or condylar resorption and in those situations, in keeping with the same pathologies arising from different aetiologies, TMJR is an important tool in the armamentarium of surgeons, where more conservative measures are not appropriate or successful.

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Appendix 1 External literature searches integrated in this study

The following external literature searches were integrated into our literature search:

(I) The German S3 (that is, evidence and consensus based) guideline on total alloplastic joint replacement, was published in 2020 by the Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften [AWMF (study group of the German scientific medical societies) register number 007-106)] (22,23). For this guideline a literature search was performed in the databases PubMed, PubMed Central, Cochrane and ZBmed and a manual search, last updated November 2019, under the search terms "temporomandibular joint [AND] prosthesis [OR] replacement [OR] reconstruction [OR] implant". National and international guidelines within the databases PubMed and Cochrane, www.guideline.gov., www.nice.org.uk and the websites of the European (EACMFS: European Association of Cranio-Maxillo-Facial Surgery) and American (AAOMS: American Association of Oral and Maxillofacial Surgeons) specialist medical societies for oral and maxillofacial surgery were also searched for relevant evidence. A detailed report on the methodology is presented in the respective guideline report (24).

(II) A recent systematic literature research conducted by Niezen et al. under the title “Temporomandibular Joint Prosthesis as treatment option for mandibular condylar fractures: A systematic review and meta-analysis” (14). This systematic review was registered under PROSPERO, Number CRD42020158164 and comprised around 13,093 patients and 20,860 prostheses. The methodology used for this systematic review according to The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (26) is described there in detail and included studies published till December 2020. The authors kindly permitted us to cite their work and refer to their data after acceptance of their paper for publication.

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