Int. J. Oral Maxillofac. Surg. 2025; 54: 598–606
https://doi.org/10.1016/j.ijom.2025.01.018, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Clinical Paper
Trauma

Long-term outcomes of open treatment of condylar head fractures using cannulated headless bone screws—a retrospective analysis

A. Franke[a,1], J.B. Matschke[a,2], P. Sembdner[b,3], A. Seidler[b], N.M.H. McLeod[c,4], H. Leonhardt[a,5]

[a]Department of Oral and Maxillofacial Surgery, University Hospital Carl Gustav Carus Dresden, Technische Universität Dresden, Dresden, Germany; [b]Virtual Product Development, Institute of Machine Elements and Machine Design, TU Dresden, Dresden, Germany; [c]Oral and Maxillofacial Surgery, University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK

A. Franke, J. B. Matschke, P. Sembdner, A. Seidler, N. M.H. McLeod, H. Leonhardt: Long-term outcomes of open treatment of condylar head fractures using cannulated headless bone screws—a retrospective analysis. Int. J. Oral Maxillofac. Surg. 2025; 54: 598–606.

Abstract. The treatment of mandibular fractures affecting the condylar head (CHF) can be either closed or open. In the case of an open approach, the headless bone screw (HBS) is an option. This study was performed to investigate the efficacy of osteosynthesis with HBS using three-dimensional radiographic imaging and clinical evaluation over long-term follow-up. This was a single-centre retrospective study. Clinical parameters and three-dimensional radiographic scans were collected during follow-up, DICOM datasets were segmented, and model analysis was conducted. Forty-five patients who received a HBS and met the eligibility criteria were included. There were significant improvements in all clinical parameters (mouth opening, protrusion, laterotrusion; all $P < 0.05$) except for the laterotrusion of the unaffected side ($P = 0.071$). Mean volume and surface area changes (from postoperative (mean 1.9 days) to final follow-up (mean 1675 days)) were 127.2 mm^3 and −22.4 mm^2, respectively, and were not statistically significant ($P = 0.18$ and $P = 0.51$). There were radiographic signs of condylar remodelling. Nine HBS in nine patients required removal due to the screw penetrating the articular surface of the healing condylar head. This single-centre retrospective study found good functional outcomes using HBS for CHF, with a screw removal rate of 20%.

Keywords: Mandibular fractures; Mandibular condyle; Three-dimensional imaging; Bone screws; Traumatology; Open fracture reduction; Internal fracture fixation.

Accepted for publication 31 January 2025
Available online 14 February 2025

Mandibular fractures are a common type of facial trauma[1,2], with the condylar neck and base, and the condylar head being particularly affected[3]. These structures are among the most frequently fractured areas of the mandible, and their injury can result in impaired

[1] ORCID: 0000-0001-9324-9574.
[2] ORCID: 0000-0002-8713-8728
[3] ORCID: 0000-0003-0706-371X
[4] ORCID: 0000-0001-5795-6482
[5] ORCID: 0000-0003-1412-0276

0901-5027/540598 + 9

mandibular mobility, occlusion, and food intake.

The treatment of mandibular fractures by reduction is a subject of ongoing debate, with proponents of closed and open reduction presenting compelling arguments. Closed treatment refers to the use of non-surgical methods to regain the normal occlusion, which can be achieved by guiding elastics via arch bars, orthodontic braces, or intermaxillary fixation (IMF) screws. The application of maxillomandibular fixation (MMF) is not evidence-based, although some argue that MMF may be beneficial to reduce post-trauma temporomandibular joint pain. In contrast, surgical treatment via internal fixation may involve only intraoperative or brief postoperative MMF[4]. Proponents of closed treatment report it to be a simple, efficient, and cheap method to restore the occlusion, with reduced morbidity, and emphasize the elimination of surgical complications such as facial nerve damage and scarring, as well as the requirement for general anaesthesia or secondary surgery[5,6]. On the other hand, proponents of open reduction and internal fixation (ORIF) argue that closed treatment can restrict sufficient nutritional intake, make it challenging to maintain oral hygiene, and increase the risk of post-treatment respiratory problems such as aspiration and asphyxia[6]. They also point to long-term complications such as inadequate restoration of the mandibular ramus height and the potential risk for ankylosis[7]. For bilateral fractures of the condylar head with a reduction in ramus height, closed treatment usually leads to functionally adverse results, i.e., open bite.

Surgical treatment by ORIF is recommended for condylar head fractures (CHF) associated with a loss of mandibular ramus height[8]. An appropriate and uniform classification system is necessary to allow studies on CHF to be compared adequately[9]. The AOCMF (AO Foundation) is a detailed system for classifying facial skeleton fractures. The level 2 classification of mandibular fractures defines the boundaries of the condyle, while the level 3 classification of condylar fractures further defines condylar head and neck fractures, their fragmentation and displacement[10].

A recent meta-analysis on the management of condylar fractures suggested that closed treatment provides superior outcomes for maximum interincisal opening, laterotrusion, and protrusion when compared to ORIF[11]. In contrast, a prospective randomized multi-centre study reported that closed and open treatment options for CHF yielded acceptable results; however, ORIF, irrespective of the osteosynthesis technique, was superior for all objective and subjective functional parameters[12].

Various techniques for osteosynthesis have been proposed for the surgical treatment of CHF, ranging from miniplates and microplates[13–15] to various types of screw[16–20] and resorbable polylactide pins[21,22]. Titanium-based cannulated headless bone screws (HBS) are another alternative for the fixation of fractures of small bones and have been proposed for the treatment of CHF[23].

No long-term evaluation of the efficacy of osteosynthesis of CHF with HBS has been conducted to date. The aim of this study was to determine mandibular functional outcomes through the analysis of clinical parameters and morphological changes of the healing condylar head on three-dimensional (3D) radiographic imaging, in patients treated by ORIF with a HBS.

Materials and methods

Study design

The Ethics and Institutional Review Board of the University Hospital Carl Gustav Carus at the Technical University of Dresden (institutional review board number IRB00001473) registered at the Office for Human Research Protections (IORG0001076) approved the study (internal ethics committee ID number: EK 170042015).

This was a single-centre retrospective cohort study. All consecutive patients with a CHF who received treatment in the Clinic for Oral and Maxillofacial Surgery of Carl Gustav Carus University Hospital in Dresden between May 2012 and October 2018 were considered for inclusion. ORIF was performed in patients with fractures that led to a reduction in mandibular ramus height of ≥2 mm, for whom a subjective disturbance of the occlusion was present, and when there were no contraindications to general anaesthesia. To be eligible for inclusion in the study, the patients had to have undergone a surgical intervention by ORIF with a cannulated titanium HBS 2 mini short thread screw from KLS Martin GmbH & Co. KG (Tuttlingen, Germany). Exclusion criteria were age < 18 years and patients who had not received surgical intervention by ORIF using a cannulated titanium HBS 2 screw. For the radiographic assessment, the patients had to have at least two postoperative cone beam computed tomography (CBCT) scans (early postoperative and follow-up) of sufficient imaging quality to permit comparison.

For better comparability, the fractures were classified according to the comprehensive AOCMF classification system for mandibular condylar fractures level 3[10]: the letter ‘H′ indicates a fracture of the condylar head, the letters ‘m′ and ‘p′ represent the medial and pole regions of the head, respectively, and numbers 0, 1, and 2 indicate the degree of fragmentation.

Headless bone screws

A titanium alloy HBS (HBS 2 mini short thread, number 26-820-XX-71; KLS Martin GmbH & Co. KG) was utilized to secure the reduced fractures. This screw has a cannulated design that enables prefixation of the reduced fracture using a Kirschner wire; the screw can then slide over the wire to be positioned precisely where the wire is located. With varying tip and head thread pitches, the screw can compress the fracture after each thread grips its fragment, resulting in stable osteosynthesis in a relatively small region of bone (Fig. 1).

Surgical method

The surgical approach was preauricular in every patient. Surgery was performed with at least one experienced consultant in oral and maxillofacial surgery traumatology present. The method used was that described by Loukota[23]. Postoperatively, the patients received rigid IMF for 2 days to prevent joint effusion. Following this, elastics were employed if the occlusion was unsatisfactory until an adequate occlusion was achieved. One month after surgery, the patients were instructed on exercises to improve their active and passive range of motion by actively opening their mouths and performing protrusive and laterotrusive excursions at least three times daily.

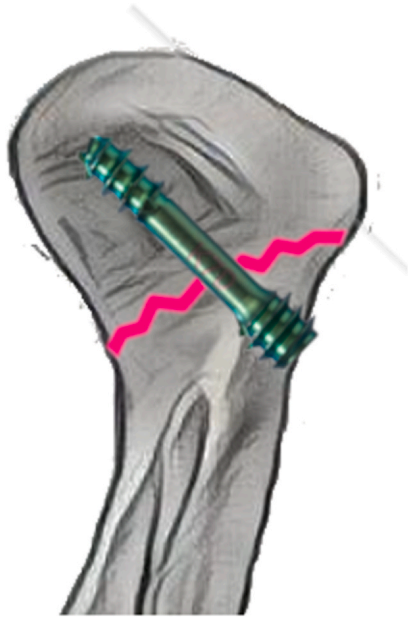

Fig. 1. Anterior view of the mandibular condyle. The fracture line is depicted in magenta (Hp-type); the HBS is shown in green. Compression is exerted across the magenta-coloured line.

Follow-up

Patients were assessed at routine follow-up appointments, which were categorized into clusters based on predetermined time intervals. In cluster 1, the duration of follow-up ranged from 0 to 50 days, in cluster 2 from 51 to 100 days, in cluster 3 from 101 to 200 days, in cluster 4 from 201 to 400 days, and in cluster 5 from 401 days onwards (Table 1). Allocating follow-ups to the respective clusters accounted for unavoidable variability in postoperative appointments.

Assessments included the following parameters as primary clinical outcome variables: mouth opening, mandibular articulation (protrusion, laterotrusion), and the occlusion. Secondary clinical outcome variables were subjective complaints (including pain, discomfort, difficulty eating, and unfavourable scarring) and complications (including facial nerve palsy, salivary fistula, and hypesthesia). During the follow-up appointments, radiographic scans were performed whenever possible to ensure appropriate bone healing and screen for mechanical complications.

A caliper was used to obtain mandibular excursion and inter-incisal distance measurements; values were recorded in millimetres. Missing teeth were recorded, excluding the third molars of the upper and lower jaws. A metalized polyester foil (Arti-Fol 8 µm; Dr. Jean Bausch GmbH & Co. KG, Cologne, Germany) was applied between all occluding pairs of teeth to assess the occlusion. If all occluding pairs of teeth gripped onto the foil distal to the canines, the occlusion was considered satisfactory. Conversely, the occlusion was deemed unsatisfactory if the foil could be withdrawn without encountering resistance.

Table 1. Time clusters used for allocation of the follow-up intervals.

Cluster	Time interval
1	0–50 days
2	51–100 days
3	101–200 days
4	201–400 days
5	401+ days

Radiological examination

Postoperative radiographic data were obtained using a 3D Accuitomo EX-2F8 CBCT scanner (J. Morita Europe GmbH, Dietzenbach, Germany). Patients were only included if they had at least one additional radiograph taken during follow-up for further evaluation at least 6 months after the initial treatment.

DICOM datasets of the radiographic images were segmented using Elements Contouring 4.5 (Brainlab AG, Munich, Germany) to obtain temporomandibular joint process segmentations. Artec Studio 15 Professional x64 version 15.1.2.60 (Artec 3D, Findel Senningerberg, Luxembourg) was used to process the segmentations further. Matching was done by superimposing the segments ideally in the ramus region while excluding the condylar head. The A-line was then used to isolate the condylar head and neck from the remaining segment[24]. The volumes and surfaces of these segments were recorded for each time point, and the measurements were recorded as the primary radiographic outcome variables. The segments from the initial and final CBCT scans were compared using the parameter root mean square error (RMSE) to determine the 3D congruency between these time points; the RMSE was another primary radiographic outcome variable.

Statistical analysis

All collected data were analysed using Prism 10 version 10.2.2 (GraphPad Software Inc., San Diego, CA, USA), and the mean ± standard deviation and confidence intervals (95% CI) were documented. Descriptive evaluations and graphical representations were also performed. After applying the Shapiro–Wilk test to determine whether the data followed a normal distribution, the clinical data and radiographic measurements were compared between the groups using parametric and non-parametric statistical tests as appropriate. Parametric tests included paired and unpaired *t*-tests and repeated measures for changes over time. A mixed-effects analysis using the Greenhouse–Geisser correction was employed. Holm–Šídák multiple comparison tests were computed for each cluster (time-interval) comparison to account for matched data over time. Non-parametric tests included the Mann–Whitney test, Wilcoxon test, or Kruskal–Wallis test. The significance level was set at $\alpha = 0.05$.

Results

Patients

Forty-five patients were treated: 33 male (73.3%) and 12 female (26.7%). The youngest patient in the cohort was 19 years old and the oldest patient was 86 years old. Mean age was 42.9 ± 18.8 years (95% CI 37.3–48.6 years); 41.3 ± 17.8 years (95% CI 35.0–47.6 years) for the male patients and 47.3 ± 21.6 years (95% CI 33.5–61.0 years) for the female patients. There was no statistically significant difference in age between the male and female patients (Mann–Whitney test, $P = 0.44$).

The main reason for admission was road traffic accidents ($n = 23$, 51.1%), followed by falls without external influence ($n = 18$, 40%), work-related accidents ($n = 2$, 4.4%), and assault ($n = 1$, 2.2%) and leisure accidents ($n = 1$, 2.2%).

Fractures

The 45 patients had suffered 61 CHF; 16 patients (35.6%) had bilateral fractures. Of the 61 CHF, 33 were on the right side (54.1%) and 28 on the left (45.9%). Surgical treatment by preauricular approach was applied for 50 fractures, whilst closed reduction through MMF for 10 days was applied for the remaining 11 fractures. According to AOCMF level 3, 21 of the 50 fractures (42%) that received ORIF

Table 2. Concomitant mandibular fractures in the study population (N = 45).

Concomitant fracture location	Patients	
	n	%
Condylar head	16	35.6
Condylar neck	1	2.2
Condylar base	4	8.9
Mandibular body	28	62.2
Lateral midface, unilateral	3	6.7
Lateral midface, bilateral	1	2.2
Central midface, unilateral	1	2.2
Central midface, bilateral	5	11.1
Naso-orbito-ethmoidal	3	6.7
External acoustic meatus	8	17.8
Skull base	1	2.2

with a HBS were type Hp0, 23 (46%) were type Hp1, and six (12%) were type Hp2. Concomitant fractures of the mandible are listed in Table 2.

The 50 CHF were treated with 51 HBS. The most commonly used length of screw was 13 mm (n = 21, 41.2%), followed by 15 mm (n = 12, 23.5%), 14 mm (n = 8, 15.7%), 16 mm (n = 7, 13.7%), and 11, 12, and 17 mm (each n = 1, each 2.0%). Figs. 2 and 3 show postoperative CBCT scans depicting the use of different length HBS in two patients.

Follow-up

The overall follow-up rate of patients was 75.6% (n = 34) in cluster 1, 55.6% (n = 25) in cluster 2, 53.3% (n = 24) in cluster 3, 37.8% (n = 17) in cluster 4%, and 37.8% (n = 17) in cluster 5. Cluster 5 included all patients followed up for 400 days or more.

The mean long-term follow-up period was 2484 ± 906 days (median 2861 days, 95% CI of the mean 2018–2950 days), or 81.7 ± 29.8 months (median 94.1 months, 95% CI of the mean 66.3–97.0 months).

Clinical data

A mean 5.3 ± 8.2 teeth were missing (median 2.0, 95% CI of the mean 2.8–7.8). The occlusion was satisfactory in 33/34 patients (97.1%) in cluster 1 and all patients examined thereafter. A statistically significant improvement in mouth opening (mixed-effects analysis; F = 47.250, df = 2.390, P < 0.001) and protrusion (mixed-effects analysis; F = 20.570, df = 1.435, P < 0.001) was observed in all patients between the different examination intervals (Table 3). Over time, there was no statistically significant increase in excursive distance on the healthy side (mixed-effects analysis; F = 8.761, df = 0.518, P = 0.071), but there was a statistically significant improvement in laterotrusion for the condylar head that received ORIF (mixed-effects analysis; F =

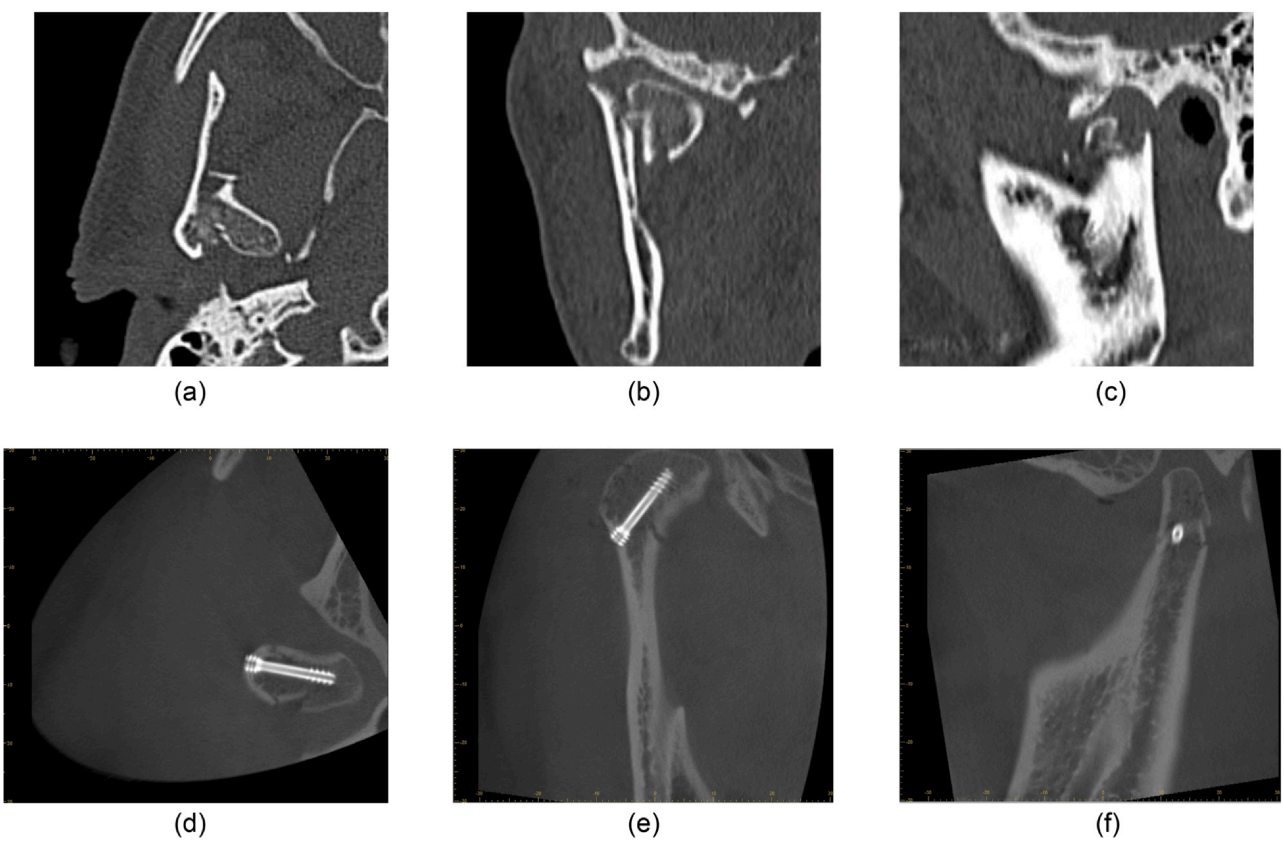

Fig. 2. CT and CBCT scans of patient A (16-mm headless bone screw). Preoperative: (A) axial plane, (B) coronal plane, (C) sagittal plane. Postoperative: (D) axial plane, (E) coronal plane, (F) sagittal plane.

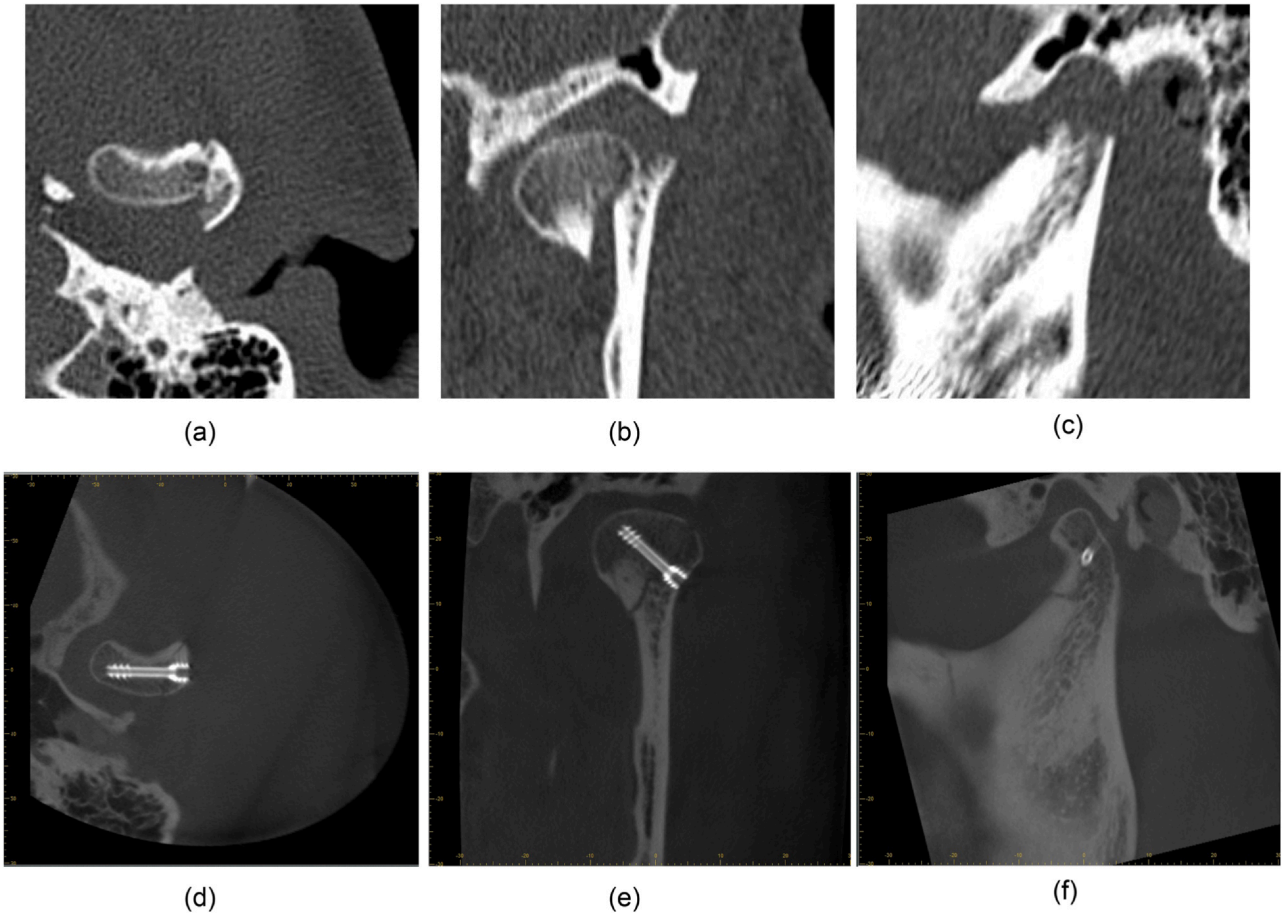

Fig. 3. CT and CBCT scans of patient B (13-mm headless bone screw). Preoperative: (A) axial plane, (B) coronal plane, (C) sagittal plane. Postoperative: (D) axial plane, (E) coronal plane, (F) sagittal plane.

6.700, df = 1.060, P = 0.045). Among all clusters except clusters 1 and 4, there was a statistically significant difference in laterotrusion between the fractured and healthy sides (Table 4).

During the follow-up examinations, paraesthesia of the preauricular skin was recorded in six of the 34 patients in cluster 1. None of the patients complained about paraesthesia in cluster 5. One of 17 patients reported hyperesthesia in cluster 5.

At most, only transient facial nerve paresis occurred after ORIF. However, one of nine patients who underwent HBS removal had persistent palsy of the frontal branch. Additionally, one of 17 patients in cluster 5 showed signs of craniomandibular dysfunction that required treatment by physiotherapy.

Routine removal of the HBS was not performed; however, nine patients (20%) underwent a second surgery to remove the screw. The reason for removal was signs of screw loosening or penetration of the screw through the articular surface. The time between insertion and HBS removal ranged from 31 to 3077 days, averaging 593.8 ± 982.4 days (median 213 days, 95% CI of the mean −161.4 to 1349.0 days).

Table 3. Overview of mouth opening and protrusion (in millimetres).

Clinical parameter	Mean ± SD	95% CI
Mouth opening		
Cluster 1	26.0 ± 8.4	23.1–28.8
Cluster 2	35.8 ± 9.5	31.9–39.7
Cluster 3	40.2 ± 7.1	37.2–43.2
Cluster 4	42.4 ± 6.5	39.1–45.8
Cluster 5	43.4 ± 5.6	40.6–46.4
Mixed-effects analysis	$P < 0.001$	
Protrusion		
Cluster 1	4.3 ± 2.2	3.1–5.5
Cluster 2	5.5 ± 2.4	4.3–6.7
Cluster 3	6.4 ± 1.8	5.5–7.2
Cluster 4	7.9 ± 2.5	6.5–9.3
Cluster 5	6.8 ± 1.4	6.0–7.5
Mixed-effects analysis	$P < 0.001$	

CI, confidence interval; SD, standard deviation.

Radiographic data

The time interval between the operation and the initial eligible postoperative CBCT scan was 1.9 ± 1.5 days (median 1 day, 95% CI of the mean 1.2–2.5 days), and the mean time interval between the first and final CBCT scan was 1675 ± 263 days.

The mean volume measured in the initial postoperative CBCT (n = 26) was 1966 ± 559 mm^3 (median 1907 mm^3, 95% CI of the mean

Table 4. Overview of the laterotrusion to the healthy non-fractured side and to the surgically treated side (in millimetres).

	Laterotrusion with the healthy condylar head towards the fracture side		Laterotrusion with the fractured surgically treated condylar head away from the fracture side		P-value[a]	Mean of the differences ± SD (95% CI)
	Mean ± SD	95% CI	Mean ± SD	95% CI		
Cluster 1	4.4 ± 2.1	2.9–6.0	3.9 ± 1.9	2.4–5.4	0.55	0.6 ± 2.7 (−1.5 to 2.6)
Cluster 2	7.0 ± 1.5	5.7–8.3	4.8 ± 2.6	2.6–6.9	0.020*	2.3 ± 2.1 (0.5–4.0)
Cluster 3	7.3 ± 2.5	5.2–9.3	5.4 ± 1.2	4.4–6.4	0.039*	1.9 ± 2.1 (0.1–3.6)
Cluster 4	8.5 ± 3.8	5.3–11.7	6.5 ± 2.2	4.7–8.3	0.19	2.8 ± 4.5 (−1.9 to 7.6)
Cluster 5	10.9 ± 3.0	8.6–13.2	6.6 ± 3.2	4.1–9.0	0.004*	4.3 ± 3.2 (1.9–6.8)
Mixed-effects analysis	F = 8.761, df = 0.518 P = 0.071		F = 6.700, df = 1.060 P = 0.045*			

CI, confidence interval; SD, standard deviation.
*Significant.
[a]Paired t-test.

1740–2191 mm^3), while it was 2093 ± 761 mm^3 (median 2049 mm^3, 95% CI of the mean 1786–2400 mm^3) for the final CBCT (n = 26). There was no significant difference between these two volumes (paired t-test, P = 0.18; mean of the differences 127.2 ± 465.0 mm^3, 95% CI −60.6 to 315.0 mm^3). The volumes increased and decreased relative to the initial situation. The overall relative change in volume was 15.9 ± 19.3% (median 8.8%, 95% CI of the mean 8.1–23.7%).

The surface area was determined to be 1063 ± 228 mm^2 (median 1036 mm^2, 95% CI of the mean 971–1155 mm^2) for the initial postoperative CBCT (n = 26) and 1041 ± 269 mm^2 (median 991 mm^2, 95% CI of the mean 932–1149 mm^2) for the last examination (n = 26). There was no significant difference between these two surface areas (paired t-test, P = 0.51; mean of the differences −22.4 ± 172.3 mm^2, 95% CI −47.2 to 92.0 mm^2). As found for the volume, the surface areas increased and decreased relative to the initial situation. The overall relative change in surface area was 12.2 ± 9.7% (median 10.2%, 95% CI of the mean 8.3–16.2%).

The 3D congruency was determined by matching the two 3D digital models. The mean computed difference in the surfaces of the condylar heads between the initial and final CBCT scan was 1.6 ± 0.8 mm (median 1.4 mm, 95% CI of the mean 1.2–1.9 mm). No statistical comparison could be performed since these values already reflect the difference between the two models at two different time points.

Discussion

This single-centre retrospective study found good functional outcomes with few complications after ORIF of CHF using HBS. Although laterotrusion of the treated mandibular condyle was significantly less than that of the healthy side, there was no subjective complaint of impaired function by any of the patients at the final follow-up. There were changes in the volume and surface area of the treated condylar head, but without statistical significance. However, there was a strong indication of condylar head remodelling during the healing process, suggested by the need for screw removal in some cases and by the comparison of the initial and final 3D CBCT models of the condylar head.

There may be a reasonable acceptance that ORIF should be the preferred option for fractures of the base and neck of the mandibular condyle[4,25,26]. However, much controversy remains about treating fractures of the condylar head, particularly regarding the osteosynthesis material used[25]. ORIF of CHF is challenging, as the topographic anatomy around the temporomandibular joint is complex, and surgical treatment requires an experienced surgeon[25,27]. The configuration of the condylar head is also distinctive and puts high mechanical demands on the material used for osteosynthesis[25,28].

An essential part of successful clinical treatment of any fracture of the mandible is restoring a normal occlusion. There are reports of occlusal disturbances after ORIF of CHF, with a frequency ranging from 0% to 10%[15,22,29–31]. This is in line with the absence of any permanent malocclusion observed in the current study.

Another essential parameter for normal mandibular excursion is mouth opening. The current literature reports mean inter-incisal distances between 37.8 ± 4.2 mm and 50.5 ± 5.1 mm[19,22,30–32]. Again, the results of the current study align with these previously reported values, showing acceptable clinical results achieved with HBS fixation.

Lateral and protrusive movements of the mandible are paramount when investigating mandibular excursion in more detail. Reported studies examining these articulations after ORIF of CHF are scarce. A well-performed study measuring lateral mandibular movement by linear measurements and axiography demonstrated results for the healthy and fractured sides that are on par with those presented in the present work[19]. Other groups have reported similar results for lateral movement of the mandible after the surgical treatment of CHF[31,33].

Facial nerve palsy is a complication of the surgical treatment of CHF that can severely affect the patient both functionally and aesthetically. A systematic review published in 2014 that examined CHF and included preauricular, retroauricular, and endaural approaches, reported rates of facial nerve weakness ranging from 0.5% to 20.8%[28]. Another systematic review and meta-analysis examined the occurrence of facial nerve palsy in the surgical therapy of all mandibular fracture treatments regardless of the approach. Temporary nerve damage was found in 0–10.0% of cases and permanent nerve damage in 0.3% following preauricular approaches[27]. With only temporary facial nerve paralysis in complete remission at the final examination, the present study results align with these reports in the current literature.

A second approach for material removal is thought to be associated with a higher risk of facial nerve palsy due to scarring of the tissue and more difficult dissection of the nerve[34,35]. Persistent facial nerve palsy caused by surgery for material removal was observed in one of the current study patients, which supports the findings of these previous studies.

Since the capsule as a disc–condyle unit must physiologically perform a relative movement against the lateral ligament during translation of the head, scar-related fusion in the area of the lateral ligament will inevitably lead to a limitation of disc mobility. Especially when using plate osteosynthesis, the material interferes directly with the capsular attachment[20]. Hence, the importance of the design of the screw heads, whose positions are extra-articular but may have direct contact with the lateral ligament, becomes apparent. A screw head that is as flat as possible, as seen in the design of the small fragment screws used by some authors[30,32,36], is advantageous here to avoid irritation and traumatization of both the capsular ligament apparatus and the delicate local bone itself. The HBS used in the present study offers the opportunity to insert a K-wire first, facilitating handling via prefixation of the fracture and only fixing the fracture with the screw once the reduction is satisfactory. In addition, the headless portion is on a level with or just below the bone surface after insertion. The absence of a protruding head, or a head that rests on the bony surface, may result in less irritation of the capsular attachment and, ultimately, less need to remove the screw due to soft tissue alterations.

Finally, lag screw fixation provides functional stability by exerting moderate pressure on the bone ends at the fracture site due to the pitch differential between the leading and trailing threads, which in turn reduces the formation of connective tissue and callus. These threads are coarse enough to allow sufficient grip in the cancellous bone of the condylar head, rendering the screws ideal for the indication of ORIF of CHF. Additionally, the relatively small size of the HBS minimizes the amount of material incorporated into the bone. An adequate restoration of mouth opening and excursive movements of the mandible, as revealed by the results of the present study, could also indicate reduced irritation of the capsular attachment. In summary, the functional results of the HBS are comparable to those reported by other groups using small fragment repositioning screws for ORIF of CHF, rendering it a genuine alternative technique for the surgical treatment of CHF.

A certain degree of remodelling of the healing condylar head was noted, and this has also been observed by other authors[25]. The most unfavourable mechanical problem of protruding screws is at the tip side of the screws, when the articular surface is penetrated; this can even lead to destruction of the skull base. The primary reason for implant removal in the current study was mechanical complications, i.e., screw loosening or penetration of the screw through the articular surface. The necessity to remove the screw due to penetration may well be due to the shrinking volume of the healing condylar head. The fact that screw removal was not necessary for all patients can undoubtedly be explained by the fact that volume shrinkage was not detected in all condylar heads. Over the time frame of this study (2012–2018), screws of shorter lengths were gradually selected for ORIF to minimize the risk of extrusion, and this had no apparent adverse effect on the stability of the fixation. Interestingly, most screws that had to be removed during the study showed a protrusion of the head of the HBS on the lateral aspect of the condylar head.

3D analysis of the condylar head dates back to 2010[37]. Since then, studies have attempted to describe the volume of the condylar head; however, there have been no reports of absolute values. Instead, the volume has been reported relative to the total volume of the entire mandible[38]. Some research works have been concerned with the volume of the condylar head in the context of traumatology or surgical treatment of the mandibular condyle and head itself[30,32,36]. While Skroch et al.[32] did not provide absolute values of the volumes of the condylar head but only reported the postoperative volume loss, Johner et al.[36] and Neuhaus et al.[30] also made statements on the absolute values at the respective examination times. These absolute values are significantly higher than those measured in the present study. The higher volumes may be due to the different planes used to segment the condylar heads. Whilst the absolute value of volume change in this study (mean 127.2 mm^3) is less than the 270 mm^3 and 348 mm^3 reported in the recent literature, the relative difference in volume (mean 15.9%) is within the range of the previously reported values (15.3–16.0%)[32,36]. The changes in volume observed in the literature and the present study indicate a certain plasticity of the healing condylar head.

Similarly, few reports in the literature have examined the surface of the condylar head. A previous study examined the surface area of the condylar head, but the cut-off plane to define the condylar head was set more cranially than that in the current study[37]. Another group of authors, who examined structural changes in the condylar head after ORIF, attempted to measure the change in the surface of the joint by measuring the distance between the osteosynthesis screws and the joint surface using 3D data, resulting in a two-dimensional analysis in three planes; however, they did not determine the actual surface of the condylar head[33]. Therefore, a comparison of the results presented here with the current literature is not possible. A reduction in the surface area of the condyle was demonstrated (mean −22.4 mm^2). An explanation for this could be that the surface area is initially high due to indentations and protrusions of the individual bone fragments. In the course of healing, remodelling occurs in which the body fills the indentations, and the protrusions and indentations smoothen, resulting in a less fissured surface and a smaller surface area. This parameter can, therefore, be assumed as an indicator of a 3D change, i.e., remodelling of the articular surface.

A recent meta-analysis favours 3D methods over linear distances or angles for evaluating the symmetry of anatomical structures[39]. Hence, 3D analysis might also be used to screen for changes in the same anatomical structure over time. However, it appears that there is no published report of RMSE or similar 3D parameters to screen for changes in the condylar head.

This study has some limitations. While the number of patients receiving ORIF included in this study was relatively large, given the prevalence of CHF, the sample size was relatively small in the last follow-up cluster due to patient compliance. The reasons for the increase or decrease in volume and surface area could not be elucidated. The total number of CBCT scans was too small to provide a detailed description of the 3D change, leading to a lack of adequate verification of the plasticity of the condylar head. Further studies with more frequent CBCT scans are needed to describe the 3D changes in the condylar head. Despite no subjective patient complaints, patient-reported outcome measures (PROMS) could have improved the quality of the evaluation.

In conclusion, surgical therapy by open reduction and internal fixation for condylar head fractures is a controversial topic. All methods applied for the treatment of the patients in this study were state-of-the-art, and virtually all fracture patterns of the condylar head were treated. Even though the screw had to be removed in 20% of the patients, the clinical outcomes were good, and there were few complications associated with the surgical intervention. Consequently, it can be concluded that headless bone screws provide a satisfactory alternative osteosynthesis method for open reduction and internal fixation of condylar head fractures.

Ethical approval

Technical University of Dresden (Institutional Review Board no. IRB00001473).

Patient consent

Consent obtained for publication of the images.

Funding

None.

Availability of data and materials

The datasets generated and analysed during this study are available from the corresponding author upon reasonable request.

Competing interests

None.

References

1. Hassanein AG. Trends and outcomes of management of mandibular fractures. *J Craniofac Surg* 2019;**30**:1245–51. https://doi.org/10.1097/SCS.0000000000005469
2. Nogami S, Yamauchi K, Bottini GB, Otake Y, Sai Y, Morishima H, Higuchi K, Ito K, Gaggl A, Takahashi T. Fall-related mandible fractures in a Japanese population: a retrospective study. *Dent Traumatol* 2019;**35**:194–8. https://doi.org/10.1111/edt.12471
3. Afrooz PN, Bykowski MR, James IB, Daniali LN, Clavijo-Alvarez JA. The epidemiology of mandibular fractures in the United States, Part 1: a review of 13,142 cases from the US National Trauma Data Bank. *J Oral Maxillofac Surg* 2015;**73**:2361–6. https://doi.org/10.1016/j.joms.2015.04.032
4. Al-Moraissi EA, Neff A, Kaur A, Falci SGM, Maria De Souza G, Ellis E. Treatment for adult mandibular condylar process fractures: a network meta-analysis of randomized clinical trials. *J Oral Maxillofac Surg* 2023;**81**:1252–69. https://doi.org/10.1016/j.joms.2023.06.006
5. Kommers SC, Van Den Bergh B, Forouzanfar T. Quality of life after open versus closed treatment for mandibular condyle fractures: a review of literature. *J Craniomaxillofac Surg* 2013;**41**:e221–5. https://doi.org/10.1016/j.jcms.2013.01.022
6. Landes CA, Day K, Glasl B, Ludwig B, Sader R, Kovács AF. Prospective evaluation of closed treatment of nondisplaced and nondislocated mandibular condyle fractures versus open reposition and rigid fixation of displaced and dislocated fractures in children. *J Oral Maxillofac Surg* 2008;**66**:1184–93. https://doi.org/10.1016/j.joms.2007.06.667
7. Suzuki T, Kawamura H, Kasahara T, Nagasaka H. Resorbable poly-L-lactide plates and screws for the treatment of mandibular condylar process fractures: a clinical and radiologic follow-up study. *J Oral Maxillofac Surg* 2004;**62**:919–24. https://doi.org/10.1016/j.joms.2004.01.016
8. Schneider M, Erasmus F, Gerlach KL, Kuhlisch E, Loukota RA, Rasse M, Schubert J, Terheyden H, Eckelt U. Open reduction and internal fixation versus closed treatment and mandibulomaxillary fixation of fractures of the mandibular condylar process: a randomized, prospective, multicenter study with special evaluation of fracture level. *J Oral Maxillofac Surg* 2008;**66**:2537–44. https://doi.org/10.1016/j.joms.2008.06.107
9. McLeod NMH, Keenan M. Towards a consensus for classification of mandibular condyle fractures. *J Craniomaxillofac Surg* 2021;**49**:251–5. https://doi.org/10.1016/j.jcms.2021.01.017
10. Neff A, Cornelius CP, Rasse M, Torre D, Audigé L. The comprehensive AOCMF classification system: condylar process fractures – level 3 tutorial. *Craniomaxillofac Trauma Reconstr* 2014;**7**(1_):44–58. https://doi.org/10.1055/s-0034-1389559
11. Shobha ES, Nainoor N, Prashanth NT, Rangan V, Malick R, Shetty S. Comparative evaluation of open reduction with internal fixation against closed reduction methods for condylar fracture management: a systematic review and meta-analysis. *J Maxillofac Oral Surg* 2024;**23**:475–87. https://doi.org/10.1007/s12663-024-02125-4
12. Eckelt U, Schneider M, Erasmus F, Gerlach KL, Kuhlisch E, Loukota R, Rasse M, Schubert J, Terheyden H. Open versus closed treatment of fractures of the mandibular condylar process—a prospective randomized multi-centre study. *J Craniomaxillofac Surg* 2006;**34**:306–14. https://doi.org/10.1016/j.jcms.2006.03.003
13. Feng Z, Chen X, Cao F, Lin Q, Lai R. Mini titanium plate for treatment of intracapsular condylar fractures. [Article in Chinese]. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi* 2016;**30**:348–52.
14. Lai BR, Liao HT. Functional outcomes of surgical management of mandibular condylar head fractures. *Ann Plast Surg* 2020;**84**(1S):S69–73. https://doi.org/10.1097/SAP.0000000000002172
15. Xie ST, Singhal D, Chen CT, Chen YR. Functional and radiologic outcome of open reduction and internal fixation of condylar head and neck fractures using miniplate or microplate system. *Ann Plast Surg* 2013;**71**(1):S61–6. https://doi.org/10.1097/SAP.0000000000000040
16. Omezli MM, Torul D, Polat ME, Dayi E. Biomechanical comparison of osteosynthesis with poly-L-lactic acid and titanium screw in intracapsular condylar fracture fixation: an experimental study. *Niger J Clin Pract* 2015;**18**:589–93. https://doi.org/10.4103/1119-3077.158946
17. Xin P, Jiang B, Dai J, Hu G, Wang X, Xu B, Shen SG. Finite element analysis of type B condylar head fractures and osteosynthesis using two positional screws. *J Craniomaxillofac Surg* 2014;**42**:482–8. https://doi.org/10.1016/j.jcms.2013.06.006
18. Yang M, Zhang B, Zhou Q, Gao X, Liu Q, Lu L. Minimally-invasive open reduction of intracapsular condylar fractures with preoperative simulation using computer-aided design. *Br J Oral*

Maxillofac Surg 2013;**51**:e29–33. https://doi.org/10.1016/j.bjoms.2012.03.005

19. Kolk A, Neff A. Long-term results of ORIF of condylar head fractures of the mandible: a prospective 5-year follow-up study of small-fragment positional-screw osteosynthesis (SFPSO). *J Craniomaxillofac Surg* 2015;**43**:452–61. https://doi.org/10.1016/j.jcms.2015.02.004
20. Neff A, Mühlberger G, Karoglan M, Kolk A, Mittelmeier W, Scheruhn D, Horch HH, Kock S, Schieferstein H. Stabilität der Osteosynthese bei Gelenkwalzenfrakturen in Klinik und biomechanischer Simulation. [Stability of osteosyntheses for condylar head fractures in the clinic and biomechanical simulation]. [Article in German]. *Mund Kiefer Gesichtschir* 2004;**8**:63–74. https://doi.org/10.1007/s10006-004-0529-9
21. Wang WH, Deng JY, Zhu J, Li M, Xia B, Xu B. Computer-assisted virtual technology in intracapsular condylar fracture with two resorbable long-screws. *Br J Oral Maxillofac Surg* 2013;**51**:138–43. https://doi.org/10.1016/j.bjoms.2012.04.005
22. McLeod NMH, Saeed NR. Treatment of fractures of the mandibular condylar head with ultrasound-activated resorbable pins: early clinical experience. *Br J Oral Maxillofac Surg* 2016;**54**:872–7. https://doi.org/10.1016/j.bjoms.2016.05.027
23. Loukota RA. Fixation of dicapitular fractures of the mandibular condyle with a headless bone screw. *Br J Oral Maxillofac Surg* 2007;**45**:399–401. https://doi.org/10.1016/j.bjoms.2005.12.002
24. Loukota RA, Eckelt U, De Bont L, Rasse M. Subclassification of fractures of the condylar process of the mandible. *Br J Oral Maxillofac Surg* 2005;**43**:72–3. https://doi.org/10.1016/j.bjoms.2004.08.018
25. Neff A. Open reduction and internal fixation in temporomandibular joint traumatology: current concepts and future perspectives. *Stomatol Dis Sci* 2019;**3**:2. https://doi.org/10.20517/2573-0002.2018.27
26. Al-Moraissi EA, Ellis E. Surgical treatment of adult mandibular condylar fractures provides better outcomes than closed treatment: a systematic review and meta-analysis. *J Oral Maxillofac Surg* 2015;**73**:482–93. https://doi.org/10.1016/j.joms.2014.09.027
27. Al-Moraissi EA, Louvrier A, Colletti G, Wolford LM, Biglioli F, Ragaey M, Meyer C, Ellis E. 3rd. Does the surgical approach for treating mandibular condylar fractures affect the rate of seventh cranial nerve injuries? A systematic review and meta-analysis based on a new classification for surgical approaches. *J Craniomaxillofac Surg* 2018;**46**:398–412. https://doi.org/10.1016/j.jcms.2017.10.024
28. Boffano P, Benech R, Gallesio C, Arcuri F, Benech A. Current opinions on surgical treatment of fractures of the condylar head. *Craniomaxillofac Trauma Reconstr* 2014;**7**:92–100. https://doi.org/10.1055/s-0034-1371772
29. Li H, Zhang G, Cui J, Liu W, Dilxat D, Liu L. A modified preauricular approach for treating intracapsular condylar fractures to prevent facial nerve injury: the supratemporalis approach. *J Oral Maxillofac Surg* 2016;**74**:1013–22. https://doi.org/10.1016/j.joms.2015.12.013
30. Neuhaus MT, Gellrich NC, Zeller AN, Bartella AKH, Sander AK, Lethaus B, Halama D, Zimmerer R. Minimal bone resorption after open treatment of mandibular condylar head fractures; Preprint, posted October 11, 2021. ⟨https://doi.org/10.21203/rs.3.rs-958849/v1⟩. ⟨https://www.researchsquare.com/article/rs-958849/v1⟩ [Accessibility verified 28 January 2025].
31. Kozakiewicz M, Gabryelczak I, Bielecki-Kowalski B. Clinical evaluation of magnesium alloy osteosynthesis in the mandibular head. *Materials* 2022;**15**:711. https://doi.org/10.3390/ma15030711
32. Skroch L, Fischer I, Meisgeier A, Kozolka F, Apitzsch J, Neff A. Condylar remodeling after osteosynthesis of fractures of the condylar head or close to the temporomandibular joint. *J Craniomaxillofac Surg* 2020;**48**:413–20. https://doi.org/10.1016/j.jcms.2020.02.005
33. Smolka W, Cornelius CP, Lechler C. Resorption behaviour of the articular surface dome and functional outcome after open reduction and internal fixation of mandibular condylar head fractures using small-fragment positional screws. *J Craniomaxillofac Surg* 2018;**46**:1953–9. https://doi.org/10.1016/j.jcms.2018.09.008
34. Moin A, Shetty AD, Archana TS, Kale SG. Facial nerve injury in temporomandibular joint approaches. *Ann Maxillofac Surg* 2018;**8**:51. https://doi.org/10.4103/ams.ams_200_17
35. Weinberg S, Kryshtalskyj B. Facial nerve function following temporomandibular joint surgery using the preauricular approach. *J Oral Maxillofac Surg* 1992;**50**:1048–51. https://doi.org/10.1016/0278-2391(92)90488-L
36. Johner JP, Essig H, Neff A, Wagner MEH, Blumer M, Gander T. Volumetric evaluated bone resorption after open reduction and internal fixation of condylar head fractures of the mandible. *J Oral Maxillofac Surg* 2021;**79**:1902–13. https://doi.org/10.1016/j.joms.2021.04.018
37. Tecco S, Saccucci M, Nucera R, Polimeni A, Pagnoni M, Cordasco G, Festa F, Iannetti G. Condylar volume and surface in Caucasian young adult subjects. *BMC Med Imaging* 2010;**10**:28. https://doi.org/10.1186/1471-2342-10-28
38. Santander P, Quast A, Olbrisch C, Rose M, Moser N, Schliephake H, Meyer-Marcotty P. Comprehensive 3D analysis of condylar morphology in adults with different skeletal patterns—a cross-sectional study. *Head Face Med* 2020;**16**:33. https://doi.org/10.1186/s13005-020-00245-z
39. Morgan N, Suryani I, Shujaat S, Jacobs R. Three-dimensional facial hard tissue symmetry in a healthy Caucasian population group: a systematic review. *Clin Oral Investig* 2021;**25**:6081–92. https://doi.org/10.1007/s00784-021-04126-w

Correspondence to: Klinik und Poliklinik für Mund-
Kiefer- und Gesichtschirurgie
Universitätsklinikum Carl Gustav Carus
an der Technischen Universität Dresden
Fetscherstraße 74
01307 Dresden
Germany. Tel.: +49 351 458 18150.
Fax: +49 351 4585348.
E-mail:
adrian.franke@uniklinikum-dresden.de