Zygomatico-Orbital Fracture-Dislocation in Surgical Treatment : Novel 3-Dimensional Software Automated Analysis

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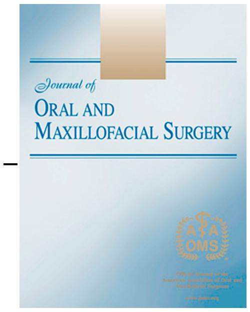

ZYGOMATICO-ORBITAL FRACTURE DISLOCATION IN SURGICAL TREATMENT – NOVEL 3D SOFTWARE AUTOMATED ANALYSIS

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ABSTRACT

Purpose

The human capability to detect the degree of zygomatico-orbital (ZMO) fracture dislocation in surgical treatment is unknown. The aim of the study was to examine the association between ZMO fracture dislocation and injury etiology and treatment.

Methods

The investigators implemented a retrospective cross-sectional study and enrolled a sample composed of patients with an isolated unilateral ZMO fracture and analyzed fracture dislocation from computed tomography (CT) images with an automatic algorithm. The primary predictor variable was mean surface point-to-point dislocation (the mean distance of dislocation for all surface points in isolated ZMO fracture segments between the original position and after virtual repositioning). The primary outcome was the treatment choice (operative versus nonoperative). Other studied variables were gender, age group, injury mechanism, clinical asymmetry, and human-evaluated dislocation in CT images. Descriptive and bivariate statistics were computed, and the threshold for statistical significance was set at $P < .05$.

Results

The sample consisted of 115 subjects with a mean age of 66.3 years, 66.1% of whom were male, and the most common cause of injury was falling on the ground (49.6%). Operative treatment was required for 58 (50.4%) subjects. There was a significant association between mean dislocation and operative treatment. The mean dislocation of operatively vs. nonoperatively treated fractures was 2.39 vs. 1.05 mm ($P < .001$). Mean fracture dislocation was greatest in injuries caused by assault (2.41 mm) and smallest in MVAs (1.08 mm) and ground-level falls (1.25 mm). The threshold of human eye detection for ZMO fracture dislocation was 1.97 mm.

Conclusion

The results of the present study demonstrate that the threshold for operative treatment of ZMO fracture dislocation is over 2 mm, which the human eye is able to detect. True dislocation is greater in younger than elderly patients and in injuries caused by assault compared to falling.

INTRODUCTION

Zygomatico-orbital (ZMO) fractures are among the most common types of facial fractures (11–24%)[1,2] and are most frequently caused by interpersonal violence (15–64%), falls (12–31%), motor vehicle accidents (11–44%), and sports injuries (6–11%)[1,3–5]

The zygomatic bone is a complex tripod-shaped bone forming the lateral wall and floor of the orbit, as well as the outer zygomatic prominence of the mid-facial region. A fracture can result in both malfunction (e.g. restricted mandibular opening or lateral movement) and asymmetry of the mid-face. The main objective of the surgical treatment of ZMO fractures is the reduction and additionally as needed the fixation of the displaced malar bone to enable normal ocular function and mandibular movement, and to restore a symmetrical facial appearance[6]

For corrective surgery, various classifications of ZMO fractures have been suggested based on different fracture patterns[7–9], and numerous studies assessing surgical methods for treating ZMO fractures have been published[10–13] . However, only a few studies have quantitatively analyzed the dislocation patterns of these fractures in three dimensions[14,15]. Fracture dislocation and the direction of dislocation form the basis of classifications and are also essential in clinical decision making.

The purpose of this study was to investigate the extent of ZMO fracture dislocation in relation to operative treatment and etiological factors, as the precise extent of dislocation in ZMO fracture management is unknown. The hypotheses were that a clear ZMO dislocation threshold for operative treatment and human eye detection can be defined, and that dislocation is greater in younger than elderly patients with adjuvant etiologies. The specific aims were to analyze the extent of ZMO fracture dislocation and operative treatment and to compare these between patients differing in age, gender, and injury mechanism. An additional study aim was to clarify the extent of dislocation detectable by the human eye.

MATERIALS AND METHODS

Study design and data collection methods

A retrospective cross-sectional study was designed and performed to address the study aims. Patients diagnosed with a unilateral isolated ZMO fracture during a 7-year period from January 1, 2010 to December 31, 2016 were identified and included from a previously published data set[16]. Patients with an isolated ZMO arch fracture, inaccurate computed tomography (CT) data (slice thickness > 2 mm and/or absence of axial images), or those for whom CT-assisted ZMO fracture reposition was unpractical due to a previous fracture of the side to be compared or significant congenital/developmental facial asymmetry were excluded from the study.

Study variables

The primary predictor was the mean point-to-point distance (mm) (the mean Euclidean distance of dislocation for all surface points in isolated ZMO fracture segments between the original position and after virtual repositioning). Secondary predictor variables were the extent of linear dislocation of the ZMO fracture in millimeters (mm) in 3 axes (mediolateral, anteroposterior, and craniocaudal) and the extent of rotation in degrees around the same axes. The primary outcome was the method of treatment the patient had received, i.e. operative treatment or non-surgical follow-up.

The other variables were gender (male or female), age group (geriatric patients aged at least 65 years or younger adults aged 20 to 30 years), the trauma mechanism [classified as one of the following: 1) assault, 2) fall on the ground, 3) bicycle, 4) sports, 5) hit by a blunt object, 6) fall from height, 7) MVA (motor vehicle accident)], the presence of clinical asymmetry in the primary post-traumatic condition after the trauma (i.e. present or absent), and human-evaluated dislocation in CT (present or absent, evaluated by two human observers).

Human Observer Analysis of CT Imaging

CT images were retrospectively analyzed by two independent observers (M.T. and S.A.) for fracture dislocation and the fracture type. Human-evaluated dislocation was considered as present if a human observer was able to detect translation or rotation in CT imaging studies. In the case of disagreement, a final classification was achieved by consensus reading.

Computed tomographic analysis

All patients underwent CT using multidetector scanners (GE Healthcare, Milwaukee WI) with a bone algorithm. The data were reformatted into 1.0-, 1.5-, or 2.0-mm-thick axial, coronal, and sagittal images.

Computer-Assisted Analysis of CT Imaging:

Computer-assisted analysis of ZMO fracture dislocation was conducted by using Bonelogic CMF Zygoma software (Disior Ltd Helsinki). Figure 1 illustrates the software-assisted reduction of an isolated ZMO fracture. From the axial CT data (DICOM format), a surface model of facial bones (threshold of 300 HU) was automatically created. Removal of the mandible and cervical vertebrae from the model and segmentation of the ZMO fracture fragments was conducted manually. The central sagittal plane was determined using a modified algorithm presented by Sun[17], and 3D models were automatically aligned to neutral rotation and lateral flexion by using this plane. The position of a ZMO fragment after virtual repositioning was determined by comparing the ZMO fragment position with the unaffected (healthy) side using a modified affine registration algorithm.

Figure 2 illustrates the direction of dislocation and rotation around a ZMO fracture. Fracture dislocation analysis was performed using a modified rigid-body iterative closest point (ICP) algorithm between the initial ZMO fragment position and that after virtual repositioning, and the translation (mm) and rotation (°) were computed along three axes relative to the fragment centroid.

The mean point-to-point distance was determined by calculating the minimum Euclidean distance for each vertex between its original and repositioned location and then calculating the mean value for each case modified from the model presented by Gibelli et al.[18]. The final decision on successful repositioning (<1-mm steps in orbital rims or malar fracture lines) was reached visually by consensus of the authors (V.L., M.T., and J.S.).

Statistical analysis

All computer-assisted dislocation analysis results were normalized on the same side to enable statistical comparison. Descriptive statistics (mean, range, SD where applicable) were computed for all study variables.

The differences in the mean or distribution of continuous dislocation analysis parameters (i.e. degree of rotation and translation), as well as the mean point-to-point distance, were compared using the Student's T-test for independent samples for variables that followed a normal distribution and the Mann-Whitney U-test for independent samples for those variables not following a normal distribution, while the Kruskal-Wallis test for independent samples was used to compare means across multiple groups.

The confidence levels were adjusted with Bonferroni correction to compensate for multiple comparisons. The effect of primary and secondary predictor variables (mean point-to-point dislocation and translation and rotation in three dimensions, respectively) on the choice of treatment was assessed using binary logistic regression.

Ethical considerations

The study was approved by the Internal Review Board of the Head and Neck Center, Helsinki University Hospital, Helsinki, Finland (356/2017). Patient consent was not required because of the retrospective nature of the study. The guidelines of the Declaration of Helsinki were followed in this study.

RESULTS

In total, 115 patients were identified for the present study (Figure 3). Of these, 58 (50.4%) received operative treatment: 44/58 (75.9%) were treated with fracture reduction and plate fixation, while the remaining 14/58 (24.1%) were treated with closed reduction without plate fixation.

Table 1 presents the association between gender, age, trauma mechanism, clinical asymmetry, human-evaluated dislocation in CT, the degree of dislocation and rotation, and software-calculated mean point-to-point ZMO fracture dislocation. The difference in the extent of the measured dislocation was statistically significant in relation to gender, age group, cause of injury, and the presence of asymmetry in clinical and radiological evaluation ($P < .001$). The software-calculated mean dislocation was greatest among males (1.98 mm), younger adults (2.30 mm), in injuries caused by sports (2.53 mm), when asymmetry was present either in clinical (2.44 mm) or radiological evaluation (1.97 mm) by a human observer. The Pearson correlation was significant between medial dislocation, mediolateral and anteroposterior rotation, and mean dislocation.

Table 2 summarizes the association between gender, age, trauma mechanism, clinical asymmetry, human-evaluated fracture dislocation in facial bone CT, the degree of dislocation and rotation, and the selected surgical treatment. Operative treatment was needed significantly more often among males (60.5%) than females (30.8%, P = .003), and among younger adults (77.1%) than geriatric patients (31.3%, P < .001). The significant predictors for corrective surgery were ZMO fractures caused by being hit by a blunt object (100.0%, P = .044) and assault (80.0%, P < .001), whereas injuries caused by falling on the ground did not require surgical intervention (70.2%, P < .001). Dislocation in a medial direction (2.21 mm) and counterclockwise rotation (3.60°) were the most significant software-calculated parameters predicting surgical treatment (P < .001). The zygomatic bone was registered as asymmetric based on clinical survey for 55 and based on radiological revaluation for 95 patients, and 89.1% of clinically and 61.1% of radiologically asymmetric patients received operative treatment (P < .001).

Table 3 presents the bivariate association between software-calculated mean point-to-point dislocation and surgical treatment. There was a significant difference in mean ZMO fracture dislocation between patients treated with corrective surgery (2.39 mm) and those who underwent non-operative follow-up (1.05 mm, P < .001).

Table 4 presents the regression model between fracture dislocation variables and treatment adjusted for age, sex, and clinical asymmetry. Mean surface point-to-point dislocation was significantly correlated with surgical treatment when adjusted for age group, gender, and primary clinical asymmetry (OR 2.83, CI 1.16–6.93).

Table 5 presents the logistic regression analysis for secondary predictors, age group, gender, primary clinical asymmetry, and operative treatment. Dislocation in a medial direction was the only software-calculated parameter that significantly correlated with operative treatment (OR =

1.92 when unadjusted (P < .001) and OR = 2.26 (P = .026) when adjusted for age group, gender, and primary clinical asymmetry).

DISCUSSION

The purpose of the study was to investigate the extent of ZMO fracture dislocation in relation to operative treatment and etiological factors, as the precise extent of dislocation in ZMO fracture management is unknown. The hypotheses were that a clear ZMO dislocation threshold for operative treatment and human eye detection can be defined, and that dislocation is greater in younger than elderly patients with adjuvant etiologies. The specific aims were to analyze the extent of ZMO fracture dislocation in relation to operative treatment and to compare patients differing in age, gender, and injury mechanism, clinical asymmetry, and human eye detection of the presence of dislocation.

Both hypotheses were confirmed. Mean point-to-point fracture dislocation was greater in surgically treated patients (2.39 mm) than those who did not undergo surgery (1.05 mm) (P < .001). Mean dislocation was also greater when dislocation was detected by the human eye (1.97 mm) compared to when it was not detected (0.58 mm) (P < .001). Patients who were treated operatively and who had greater mean fracture dislocation were more often males, younger, and had been assaulted, hit with a blunt object, or suffered sports injuries. Dislocation in the medial direction and counterclockwise rotation around the mediolateral axis (see Fig. 2 for directions) predicted surgery.

Our findings regarding the injury mechanisms, age groups, and gender distribution among patients with ZMO fractures are in line with several previous findings. Salentijn et al. and Olate et al. both reported that ZMO fracture patients treated with surgery were more often male and younger, and had more often sustained their injuries due to violence[19–21]. However, in the present logistic regression analyses, only medial translation was found to correlate significantly with surgical treatment (OR 2.98, $P < 0.001$). Our results reveal that more common operative treatment in men, in younger patients, and in other injury mechanisms than falling is explained by the higher fracture dislocation rates in these groups. Thus, dislocation is the main factor indicating ZMO fracture surgery.

According to our results, elderly patients receive corrective surgery for ZMO fracture surgery less often than younger patients, and this is not only due to ineligibility for surgical treatment or a less pronounced esthetic disadvantage, but also because of age-related differences in typical injury mechanisms causing different types of fractures. Slow falling on the ground, which is the main cause of ZMO fractures in elderly patients[4,20], might lead to a more even distribution of injury forces to the facial bones, resulting in minor ZMO fracture dislocation. Despite older people being more prone to fractures in general, ZMO fractures in the elderly are less dislocated than in younger patients.

The mean point-to-point dislocation was 2.44 mm in fractures where facial asymmetry was recorded in the primary clinical situation. The great majority of the patients treated surgically (89%) had clinically detectable asymmetry in the primary state, and radiologically confirmed dislocation was present in all operatively treated patients. Clinically detected and radiologically confirmed dislocation of the fracture is often cited as an indication for surgery, in addition to functional deficit[6,22]. In the present study, asymmetry was evaluated by a consultant or resident of maxillofacial surgery, i.e., a physician with experience of facial fractures. The present radiological findings might have confirmed the clinical interpretation. The decision to perform operative treatment was consistent, and none of the patients not undergoing surgery required secondary surgery. Experienced clinical evaluation in the primary state was thus found to be reliable when detecting significant asymmetry, despite swelling and possible hematoma in the early stage.

Similarly to our findings, Pau et al. observed that patients treated surgically more often had severe medial dislocation[15]. Toriumi et al. reported the largest translation in the posterior direction[14], in contrast to medial translation in our study. Consistently with Toriumi et al., the most common rotation around the mediolateral axis in our study was anti-clockwise (positive direction in Fig. 2). While Toriumi et al. reported rotation around the anteroposterior axis solely in an anti-clockwise direction, the most common rotation direction in our study was clockwise (positive direction in Fig. 2). In addition to individual movement components, we calculated a mean point-to-point dislocation value for all surface points of dislocated fragments. All the subjects in our study had a mean point-to-point distance that was several orders of magnitude greater than the healthy subjects in the study of Gibelli et al., although their methodology for segmenting and registering the zygomatic bone was slightly different from ours[18]. The mean point-to-point distance was also significantly larger in those patients diagnosed as having a dislocated versus a non-dislocated fracture following the CT scan and in those having primary clinical asymmetry versus those without. This might imply that mean point-to-point dislocation could potentially be used as an indicator of the severity of dislocation in a ZMO fracture. However, in addition to bony symmetry, studies focusing on long-term aesthetic deficits and patient satisfaction are required.

The main limitation of the present study was that our method relied on using the nonaffected facial side as a reference and could not therefore be applied to bilateral ZMO fractures or in facial deformities. In most cases, however, a symmetric zygomatic position can still be considered as a gold standard to determine the pre-traumatic position[23–25]. The strength of the present study was the ability to detect and quantify the individual movement components related to a particular fracture.

CONCLUSION

In the present study, operative treatment was selected significantly more often in younger than geriatric patients ($P < .001$), in males than females ($P = .003$), when clinical post-traumatic asymmetry was present ($P < .001$), and in injuries caused by assault ($P < .001$). Dislocation was greatest in younger patients (2.4 mm), in injuries caused by sports (2.5 mm) and when hit by a blunt object or following assault (2.4 mm), and when clinical asymmetry was present (2.4 mm).

The threshold of ZMO fracture dislocation for operative treatment was 2.4 mm, which was within the limits of human eye detection of true dislocation (1.97 mm). Logistic regression analysis revealed that the *risk* of operative treatment was significantly higher in the medial direction (OR 1.92 when unadjusted, and OR 2.26 when adjusted for age, gender, and primary clinical asymmetry; $P = .026$).

A prospective study with even larger patient groups could determine the threshold for recommending or avoiding a surgical approach in different age groups.

DUAL COMMITMENTS

Disior® Ltd did not take part in any way in data selection, manuscript preparation, or the publication process. The data and article were not pre-reviewed by Disior® Ltd before publication. One of the authors (V.L.) was an employee of Disior® during the analysis process. No other financial engagements existed between the authors and Disior® Ltd.

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REFERENCES

1. Boffano P, Roccia F, Zavattero E, Dediol E, Uglešić V, Kovačič Ž, Vesnaver A, Konstantinović VS, Petrović M, Stephens J, Kanzaria A, Bhatti N, Holmes S, Pechalova PF, Bakardjiev AG, Malanchuk VA, Kopchak A V., Galteland P, Mjøen E, Skjelbred P, Koudougou C, Mouallem G, Corre P, Løes S, Lekven N, Laverick S, Gordon P, Tamme T, Akermann S, Karagozoglu KH, Kommers SC, Forouzanfar T: European Maxillofacial Trauma (EURMAT) project: A multicentre and prospective study. J Cranio-Maxillofacial Surg 43: 62, 2015.
2. Al-Khateeb T, Abdullah FM: Craniomaxillofacial Injuries in the United Arab Emirates: A Retrospective Study. J Oral Maxillofac Surg 65: 1094, 2007.
3. Bogusiak K, Arkuszewski P: Characteristics and epidemiology of zygomaticomaxillary complex fractures. J Craniofac Surg 21: 1018, 2010.
4. Ellis E, El-Attar A, Moos KF: An Analysis of 2,067 cases of zygomatico-orbital fracture. J Oral Maxillofac Surg 43: 417, 1985.
5. Calderoni DR, Guidi MDC, Kharmandayan P, Nunes PHF: Seven-year institutional experience in the surgical treatment of orbito-zygomatic fractures. J Cranio-Maxillofacial Surg 39: 593, 2011.
6. Moreira Marinho RO, Freire-Maia B: Management of fractures of the zygomaticomaxillary complex. Oral Maxillofac Surg Clin North Am 25: 617, 2013.
7. Knight JS, North JF: The classification of malar fractures: An analysis of displacement as a guide to treatment. Br J Plast Surg 13: 325, 1960.
8. Zingg M, Laedrach K, Chen J, Chowdhury K, Vuillemin T, Sutter F, Raveh J: Classification and Treatment of Zygomatic Fractures: A Review of 1,025 Cases. J Oral Maxillofac Surg 50: 778, 1992.
9. Fujii N, Yamashiro M: Classification of malar complex fractures using computed tomography. J Oral Maxillofac Surg 41: 562, 1983.
10. Olate S, Lima SM, Sawazaki R, Moreira RWF, Moraes M De: Surgical approaches and

fixation patterns in zygomatic complex fractures. J Craniofac Surg 21: 1213, 2010.

11. Kelley P, Hopper R, Gruss J: Evaluation and treatment of zygomatic fractures. Plast Reconstr Surg 120: 5, 2007.

12. Kurita M, Okazaki M, Ozaki M, Tanaka Y, Tsuji N, Takushima A, Harii K: Patient satisfaction after open reduction and internal fixation of zygomatic bone fractures. J Craniofac Surg 21: 45, 2010.

13. Hwang K: One-point fixation of tripod fractures of zygoma through a lateral brow incision. J Craniofac Surg 21: 1042, 2010.

14. Toriumi M, Nagasao T, Itamiya T, Shimizu Y, Yasudo H, Sakamoto Y, Ogata H, Kishi K: 3-D analysis of dislocation in zygoma fractures. J Cranio-Maxillofacial Surg 42: 397, 2014.

15. Pau CY, Barrera JE, Kwon J, Most SP: Three-Dimensional Analysis of Zygomatic-Maxillary Complex Fracture Patterns. Craniomaxillofac Trauma Reconstr 3: 167, 2010.

16. Toivari M, Snäll J, Suominen AL, Apajalahti S, Lindqvist C, Thorén H: Associated Injuries Are Frequent and Severe Among Geriatric Patients With Zygomatico-Orbital Fractures. J Oral Maxillofac Surg 77: 565, 2019.

17. Sun C: Symmetry detection using gradient information. Pattern Recognit Lett 16: 987, 1995.

18. Gibelli D, Cellina M, Gibelli S, Oliva AG, Termine G, Pucciarelli V, Dolci C, Sforza C: Assessing symmetry of zygomatic bone through three-dimensional segmentation on computed tomography scan and “mirroring” procedure: A contribution for reconstructive maxillofacial surgery. J Cranio-Maxillofacial Surg 46: 600, 2018.

19. Salentijn EG, Boverhoff J, Heymans MW, Bergh B Van Den, Forouzanfar T: The clinical and radiographical characteristics of zygomatic complex fractures: A comparison between the surgically and non-surgically treated patients. J Cranio-Maxillofacial Surg 42: 492, 2014.

20. Salentijn E, Bergh B den, Boffano P, Boverhoff J, Forouzanfar T: The epidemiological

characteristics of zygomatic complex fractures: A comparison between the surgically and non-surgically treated patients. Natl J Maxillofac Surg 4: 214, 2013.

21. Olate S, Lima SM, Sawazaki R, Moreira RWF, Moraes M De: Variables related to surgical and nonsurgical treatment of zygomatic complex fracture. J Craniofac Surg 22: 1200, 2011.

22. Kaufman Y, Stal D, Cole P, Hollier L: Orbitozygomatic fracture management. Plast Reconstr Surg 121: 1370, 2008.

23. Feng F, Wang H, Guan X, Tian W, Jing W, Long J, Tang W, Liu L: Mirror imaging and preshaped titanium plates in the treatment of unilateral malar and zygomatic arch fractures. Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology, 2011.

24. Lerhe B, Alshehri S, Ferachon D, Dejean S, Salabert AS, Lopez R: Tomographic osteometry of the zygomatic bone applied to traumatology of facial bones: Preliminary retrospective study of zygomatic summit in 28 patients. J Cranio-Maxillofacial Surg 45: 150, 2017.

25. Khaqani MS, Tavosi F, Gholami M, Eftekharian HR, Khojastepour L: Analysis of Facial Symmetry After Zygomatic Bone Fracture Management. J Oral Maxillofac Surg 76: 595, 2018.

Table 1. The association between gender, age, trauma mechanism, clinical asymmetry, human-evaluated dislocation in CT, and software-calculated dislocation of ZMO fractures.

	Software calculated dislocation		
	n	**Mean surface point-to-point dislocation (mm ± SD)**	***P*-value**
Gender			
Male	76	1.98 (±1.24)	<.001***
Female	39	1.23 (±0.79)	
Age group			
Younger adults	48	2.30 (±1.34)	<.001*
Geriatric patients	67	1.31 (±0.79)	
Trauma mechanism			
Assault	25	2.41 (±1.50)	<.001**
Fall on the ground	57	1.25 (±0.73)	
Bicycle	11	1.91 (±1.11)	
Sports	9	2.53 (±1.26)	
Hit by a blunt object	4	2.39 (±0.97)	
Fall from height	3	2.24 (±0.96)	
MVA	6	1.08 (±0.82)	
Clinical asymmetry #			
Present	55	2.44 (±1.54)	<.001***
Undetected or absent	60	1.07 (±0.68)	
Human-evaluated dislocation in CT §			
Present	95	1.97 (±1.13)	<.001*
Absent	20	0.58 (±0.26)	
Degree of dislocation		**Correlation with mean surface point-to-point dislocation**	
Mediolateral	115	-0.876	<.001 ƒ
Anteroposterior	115	-0.231	.078 ƒ
Cranio-caudal	115	0.136	0.876 ƒ
Degree of rotation (deg°)			
Mediolateral	115	-0.335	.002 ƒ
Anteroposterior	115	0.365	<.001 ƒ
Cranio-caudal	115	0.014	5.298 ƒ

Abbreviations: *, 2-tailed, Mann-Whitney U-test for independent samples, Bonferroni adjustment for multiple comparisons; **, 2-tailed, Kruskal-Wallis test for independent samples; ***, 2-tailed, Student's T-test for independent samples, Bonferroni adjustment for multiple comparisons; ƒ, Pearson correlation coefficient, 2-tailed significance, Bonferroni adjustment for multiple comparisons; #, primary post-traumatic condition after the trauma; CT, computed tomography; §, evaluated unaware of the clinical condition; mm, millimeters; deg°, degrees; SD, standard deviation

Table 2. The association between gender, age, trauma mechanism, registered clinical asymmetry, human-evaluated ZMO fracture dislocation in facial bone CT, and surgical treatment.

		Treatment				
		Operative		Non-surgical		
		n	%	n	%	***P*-value**
Gender						
Male	(n = 76)	46	60.5	30	39.5	.003*
Female	(n = 39)	12	30.8	27	69.2	
Age group						
Younger adults	(n = 48)	37	77.1	11	22.9	<.001*
Geriatric patients	(n = 67)	21	31.3	46	68.7	
Trauma mechanism						<.001*
Assault	(n =25)	20	80.0	5	20.0	
Fall on the ground	(n = 57)	17	29.8	40	70.2	
Bicycle	(n = 11)	7	63.6	4	36.4	
Sports	(n = 9)	7	77.8	2	22.2	
Hit by a blunt object	(n = 4)	4	100.0	0	0.0	
Fall from height	(n = 3)	2	66.7	1	33.3	
MVA	(n = 6)	1	16.7	5	83.3	
Clinical asymmetry #						
Present	(n = 55)	49	89.1	6	10.9	<.001*
Undetected or absent	(n = 60)	9	15.0	51	85.0	
Human-evaluated dislocation in CT §						
Present	(n = 95)	58	61.1	37	38.9	<.001*
Absent	(n = 20)	0	0.0	20	100.0	
Degree of dislocation		mm (±SD)		mm (±SD)		
Mediolateral	(n = 115)	-2.21 (±1.40)	-	-0.53 (±1.04)	-	<.001**
Anteroposterior	(n = 115)	-1.42 (±1.52)	-	-0.80 (±1.23)	-	.078**
Cranio-caudal	(n = 114)	-0.27 (±1.07)	-	-0.34 (±1.09)	-	5.730**
Degree of rotation		deg° (±SD)		deg° (±SD)		
Mediolateral	(n = 115)	-3.60 (±2.69)	-	-1.52 (±2.50)	-	<.001**
Anteroposterior	(n = 115)	3.71 (±3.90)	-	1.57 (±3.13)	-	.006**
Cranio-caudal	(n = 114)	-1.78 (±7.86)		-1.39 (±3.64)	-	2.136**

Abbreviations: *, Pearson's chi-square; : **, 2-tailed, Mann-Whitney U-test for independent samples, Bonferroni adjustment for multiple comparisons, #, primary post-traumatic condition after the trauma; MVA, motor vehicle accident; CT, computed tomography; §, evaluated unaware of the clinical condition; mm, millimeters; deg°, degrees; SD, standard deviation

Table 3. The association between software-calculated dislocation, the degree and direction of dislocation, and surgical treatment.

		Treatment		
	All subjects (n = 115)	**Operative (n = 58)**	**Non-surgical (n = 57)**	***P*-value***
Software-calculated dislocation				
Mean surface point-to-point dislocation (mm ±SD)	1.72	2.39 (±1.15)	1.05 (±0.69)	< .001

Abbreviations: *Bivariate analysis for difference in means (Student's T-test), Bonferroni adjustment for multiple comparisons; SD, standard deviation

Table 4. Logistic regression analysis for operative treatment, primary predictor and explanatory variables.

Study Variable	Reference for categorical variables	OR	95% CI	β coefficient	*P*-value
Unadjusted					
Mean surface point-to-point dislocation		6.31	3.22 - 12.33	1.841	.150
Adjusted					
Mean surface point-to-point dislocation		2.83	1.16 - 6.93	1.04	.023
Gender	female	1.03	0.26 - 4.00	0.025	.97
Age group (young versus geriatric)	geriatric	6.35	1.52 - 26.42	1.848	.011
Primary clinical asymmetry	none	23.57	6.14 - 90.51	3.16	< .001

Abbreviations: *adjusted for age group, gender, primary clinical asymmetry; for reference OR 1.0

Table 5. Logistic regression analysis for secondary predictors, age, gender, primary clinical asymmetry, and operative treatment.

Study Variable		Reference for categorical variables	OR	95% CI	β coefficient	*P*-value
Unadjusted						
Direction of translation						
Medial	(X-axis)		1.92	1.87 - 4.77	1.095	< .001
Posterior	(Y-axis)		1.06	0.7 - 1.617	0.062	.773
Caudal	(Z-axis)		1.10	0.70 - 1.73	0.094	.684
Direction of rotation						
Mediolateral	(X-axis), CW		1.21	0.95 - 1.54	0.192	.120
Anteroposterior	(Y-axis), CW		0.98	0.83 - 1.15	-0.024	.773
Cranio-caudal	(Z-axis), CCW		0.99	0.91 - 1.08	-0.010	.836
Adjusted*						
Direction of translation						
Medial	(X-axis)		2.26	1.1 - 4.66	0.820	.026
Posterior	(Y-axis)		1.19	0.64 - 2.21	0.180	.580
Caudal	(Z-axis)		1.52	0.77 - 3.01	0.420	.230
Direction of rotation						
Mediolateral	(X-axis), CW		1.13	0.82 - 1.57	0.130	.444
Anteroposterior	(Y-axis), CW		1	0.80 - 1.25	0.000	.997
Cranio-caudal	(Z-axis), CCW		1	0.88 - 1.14	0.000	.995
Gender		female	1.13	0.26 - 4.93	0.120	.870
Age group (young versus geriatric)		geriatric	12.12	2.29 -65.02	2.500	.003
Primary clinical asymmetry		none	27.02	6.49 - 112.46	3.300	< .001

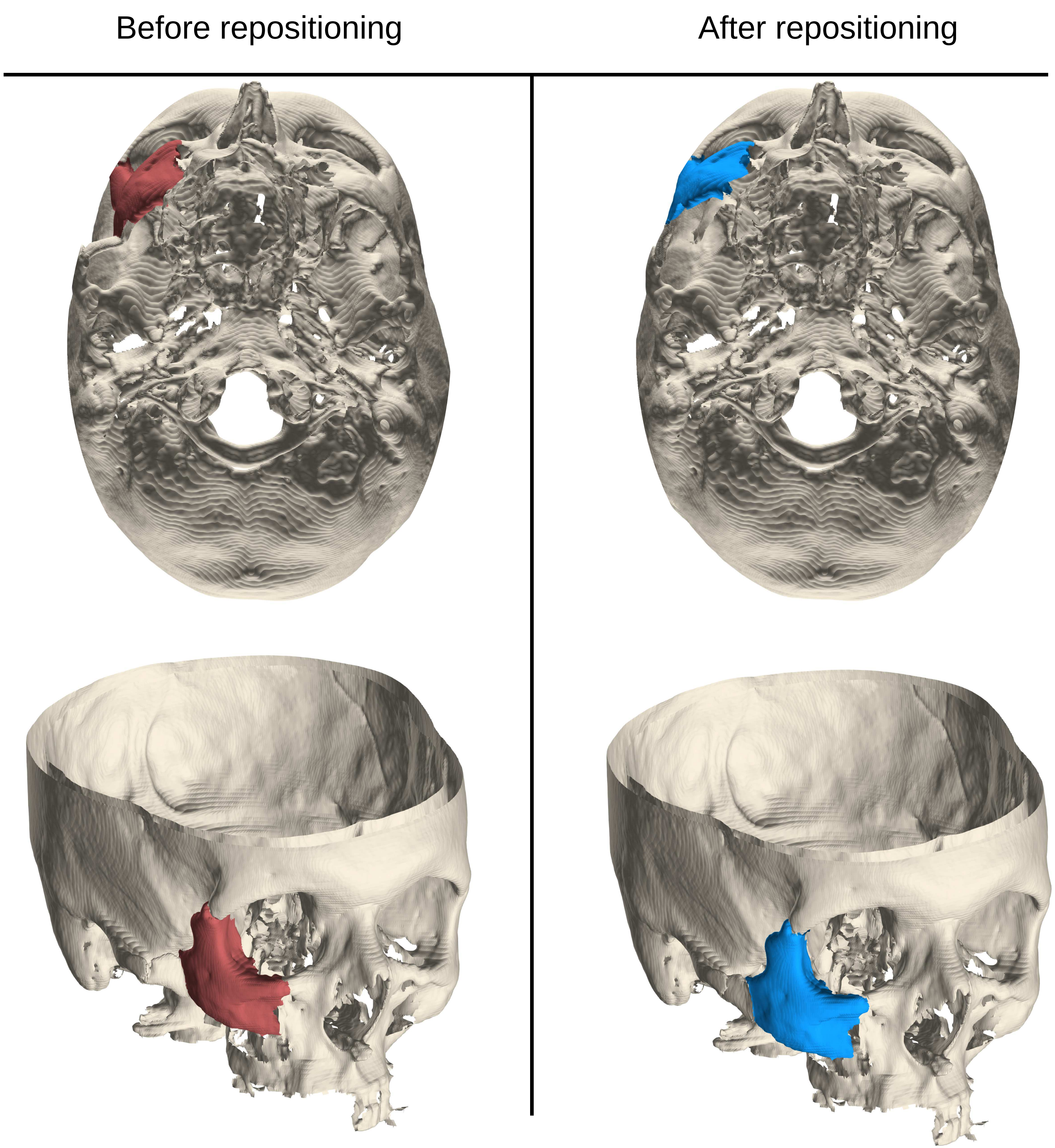
Abbreviations: *adjusted for age group, gender, and primary clinical asymmetry; CW, clockwise; CCW, counterclockwise; for reference OR 1.0

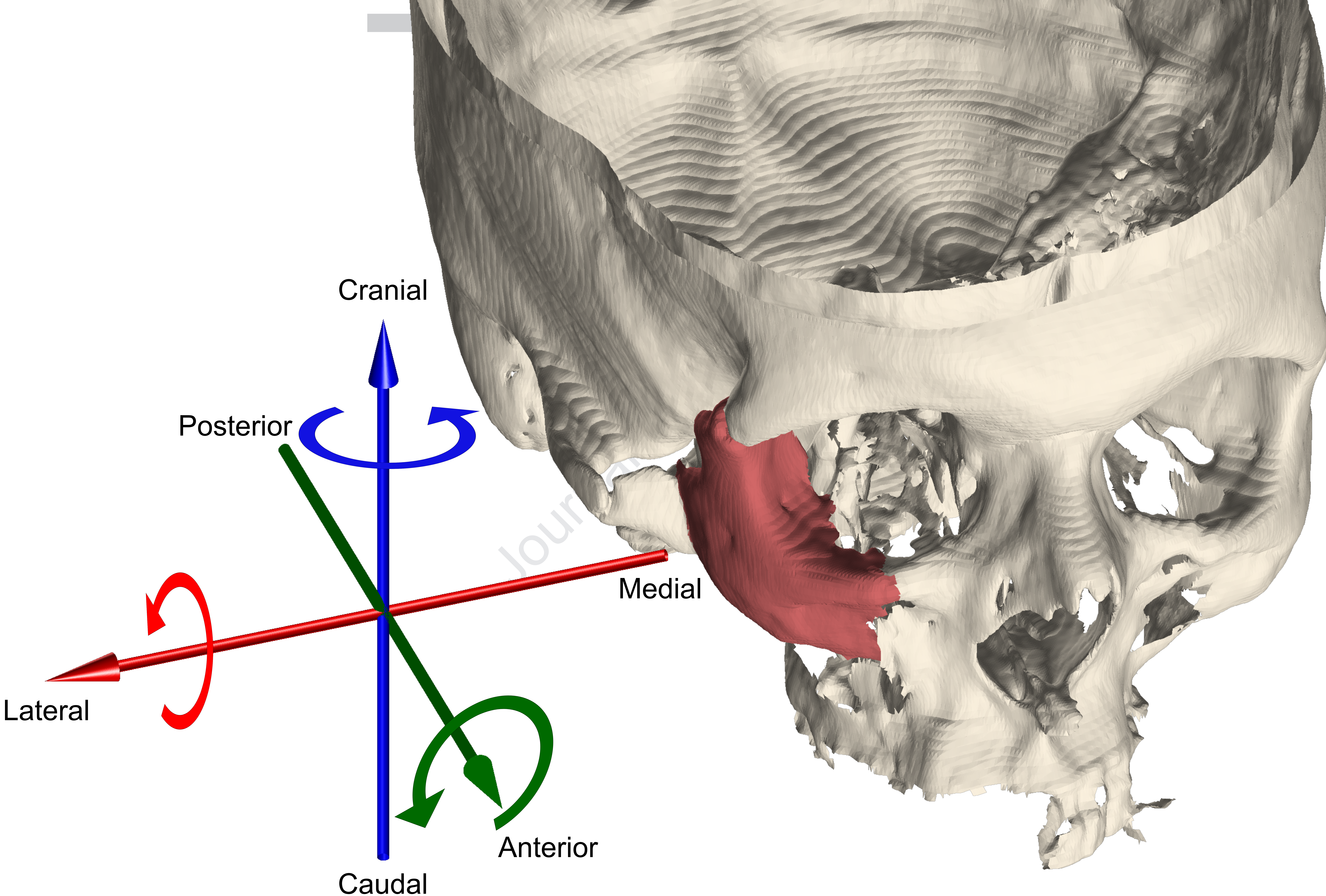
Legends to Figures 1–3

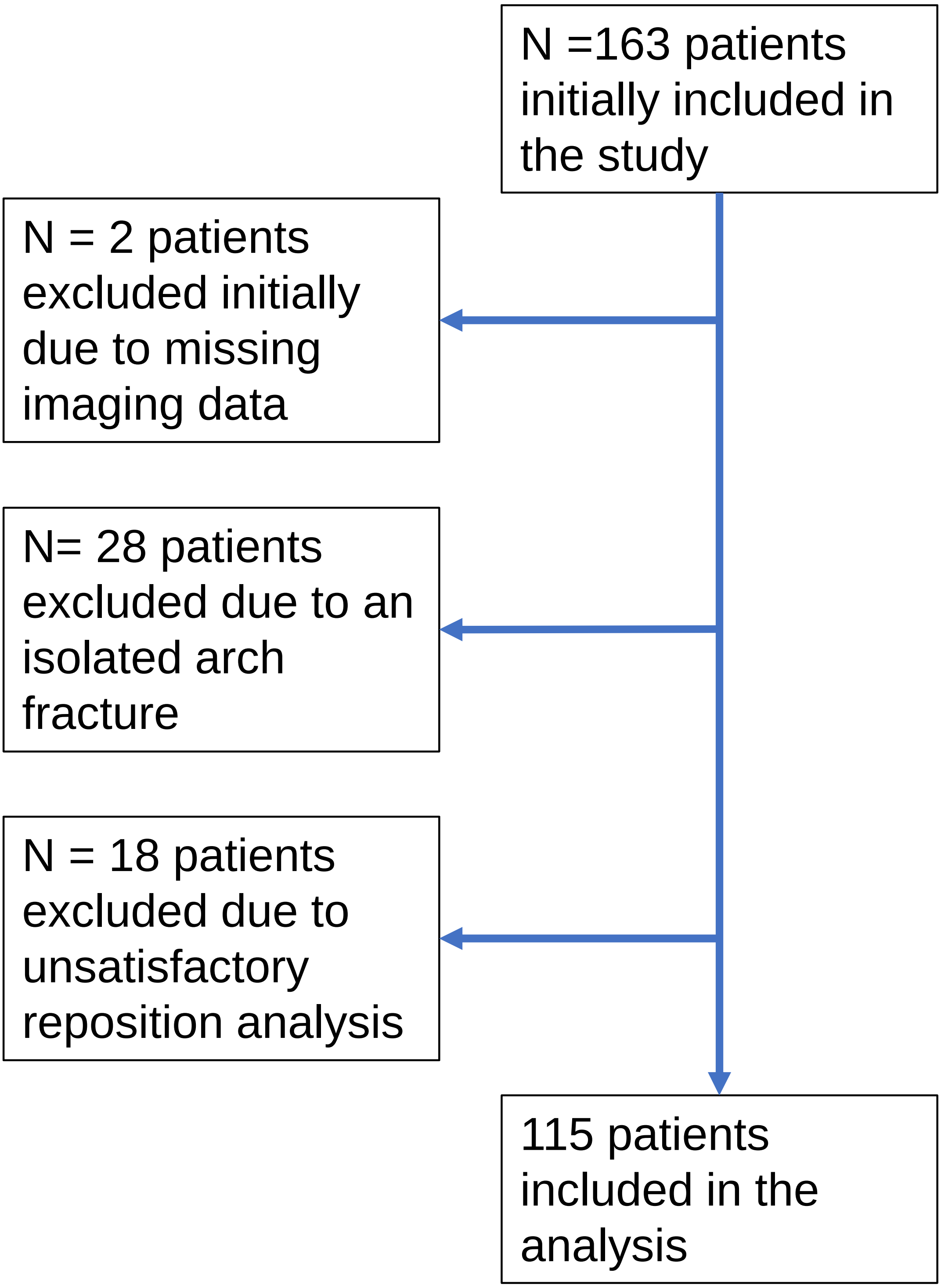
Figure 1. Visualization of the surface mesh before (left) and after software-assisted virtual repositioning of an isolated ZMO fracture (right).

Figure 2. The direction and rotation of a ZMO fracture. Arrows indicate positive direction for translation and clockwise rotation around the axes.

Figure 3.Study design.


Before repositioning
After repositioning


Cranial
Posterior
Medial
Lateral
Anterior
Caudal


N =163 patients initially included in the study
N = 2 patients excluded initially due to missing imaging data
N= 28 patients excluded due to an isolated arch fracture
N = 18 patients excluded due to unsatisfactory reposition analysis
115 patients included in the analysis