The Role of Intraoperative Navigation in Surgical Treatment of Unilateral Zygomatic Complex Fractures: A Systematic Review and Meta-Analysis

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Purpose: The application of a computer-aided navigation system (CANS) in zygomatic complex (ZMC) fractures has been extensively reported, but individual results are heterogeneous. The purpose of this systematic review was to evaluate the role of CANS in the surgical treatment of unilateral ZMC fractures.

Methods: Electronic retrieval of MEDLINE, Embase, and Cochrane Library (CENTRAL) and manual searching until November 1, 2022 were used to identify cohort studies and randomized controlled trials employing CANS in the surgical treatment of ZMC fractures. The identified reports contained at least 1 of the following outcome variables: accuracy of reduction, total treatment time, amount of bleeding, postoperative complications, satisfaction, and cost. Weighted or mean differences (MD), risk ratios, and corresponding 95% confidence intervals (CI) were calculated, where $P < .05$ and $I^2 > 50\%$ random-effect model was adopted, and a vice versa fixed-effect model was adopted. Descriptive analysis was applied to qualitative statistics. The protocol was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and prospectively registered with PROSPERO (CRD42022373135).

Results: A total of 562 studies were identified, of which 2 cohort studies and 3 randomized controlled trials with 189 participants were included. Meta-analysis indicated that employing CANS significantly decreased the reduction error (MD = −0.86, 95% CI −1.58 to −0.14; *P* = .02, random-effect model) compared with conventional surgery without using CANS. The differences in total treatment time (preoperative planning time: MD = 1.44, 95% CI −3.55 to 6.43; *P* = .57 and operative time: MD = 3.02, 95% CI −9.21 to 15.26; *P* = .63, fixed-effect model) and amount of bleeding (MD = 14.86, 95% CI −8.86 to 38.58; *P* = .22, fixed-effect model) were not statistically significant between the two groups. Descriptive analysis suggested that postoperative complications, postoperative satisfaction, and cost were also similar with or without CANS.

Conclusion: Within the limitations of the present review, the reduction accuracy of unilateral ZMC fractures using CANS is superior to that of conventional surgery. CANS presents limited influence on operation time, amount of bleeding, postoperative complications, postoperative satisfaction, and cost.

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The zygomatic complex (ZMC), a prominent structure in the maxillofacial region, is prone to fracture when traumatized.[1] The incidence of ZMC fractures has been reported to be approximately 28.3 to 40%,[2,3] second only to mandibular fractures (56%) among maxillofacial traumas.[4] ZMC fractures may lead to zygomatic transposition, diplopia, restriction in mouth-opening, infraorbital nerve injury, and facial deformities.[5] Due to proximity to important anatomical structures and limited surgical field, accurate surgical reduction is challenging for oral and maxillofacial surgeons.[6]

The goal of surgical treatment for ZMC fractures is precise repositioning and rigid internal fixation to ensure optimal functional and aesthetic results.[2] Traditionally, the reduction of the ZMC has primarily depended on the subjective visual and tactile evaluation of surgeons.[7] The interference of soft tissue swelling and a limited visual field increases the risk of intraoperative over or undercorrection, resulting in postoperative midface deformity and asymmetry.[8]

Computer-aided navigation systems (CANSs) have shown great potential in oral and maxillofacial surgery,[1,8] especially in the process of accurately locating anatomical markers and implanting instruments. Currently, CANSs can help surgeons to achieve real-time positioning of the ZMC, visualize the matching between the fractured bone and the predesigned position, and thus decrease the reduction deviation during surgery.[1,9,10] The accuracy of navigation is based on point-to-point confirmation, instead of providing the most updated architecture of bone. Although several studies[8,10-16] have described the application of CANSs in the reduction of ZMC fractures, most of these studies were retrospective in nature or no-control trials, making comprehensively assessing the superiority of CANSs over conventional surgery (CS) without using CANS difficult. Furthermore, the indication for CANS remains poorly defined in terms of fracture type, reduction accuracy, and additional burden.[17-19]

Hence, the purpose of this study was to evaluate the multifaceted manifestations of the CANS in ZMC fracture reconstruction and to explore the clinical guidelines for employing a CANS to serve patients more reliably and reduce costs. The null hypothesis was that the reduction of ZMC fractures did not differ between the application of a CANS and the use of CS.

Materials and Methods

PROTOCOL

This systematic review complied with the PRISMA statement[20] and Cochrane collaboration guidelines.[21] The protocol was prospectively registered in PROSPERO (CRD42022373135).

SEARCH STRATEGY

A systematic search of electronic databases, including MEDLINE, Embase, and Cochrane Library (CENTRAL), was undertaken until November 1, 2022; only publications in English were searched using the following search terms: (zygomatic fracture OR zygomatic complex fracture OR zygomaticomaxillary complex fracture OR orbitozygomatic complex fracture) AND (navigation OR navigation system OR computer-assisted OR navigation-assisted OR surgical navigation) AND (human).

The results of the retrieval were managed using NoteExpress software (Aegean Music Technology Co, LTD, China). Duplicates and publications in other languages were removed, and the titles, abstracts, and full texts of the remaining publications were screened independently by two reviewers (Zhao R and Wang B). Any disagreements between the two reviewers were resolved by discussion, and if no agreement was reached, a third reviewer (Zhang W) participated until a consensus was reached.

Furthermore, a manual search of professional journals in the domain of oral and maxillofacial surgery from January 1, 2010 to November 1, 2022 was supplemented. Based on the preliminary publication information, the journals included *Journal of Oral and Maxillofacial Surgery, International Journal of Oral and Maxillofacial Surgery, Oral and Maxillofacial Surgery Clinics of North America, Atlas of The Oral and Maxillofacial Surgery Clinics of North America, British Journal of Oral and Maxillofacial Surgery, Journal of Craniofacial Surgery, Journal of Maxillofacial and Oral Surgery, Annals of Maxillofacial Surgery, Journal of Cranio-Maxillofacial Surgery, Journal of Stomatology, and Oral and Maxillofacial Surgery.*

FOCUS QUESTION

The following primary research question was investigated: what is the difference in efficacy between a CANS and CS for the treatment of patients with unilateral ZMC fractures?

SELECTION CRITERIA

Publications were included if they matched the following PICOS criteria: (P) Population: Patients with ZMC fractures. (I) Intervention: The reduction of ZMC fractures was verified by an intraoperative CANS. (C) Control: The reduction of ZMC fractures was verified by CS. (O) Outcomes: The primary outcome was to determine the reduction accuracy of ZMC fractures. The secondary outcomes included the total treatment time (preoperative planning and postoperative time), amount of bleeding, postoperative complications, postoperative satisfaction, and cost.

(S) Study design: Retrospective or prospective cohort studies and randomized controlled trials (RCTs).

Publications were excluded if they met the following criteria: 1) animal studies or in vitro studies; 2) lack of outcome or data of interest; and 3) case (series) report, conference article, review, and protocol.

DATA EXTRACTION

Two professional reviewers (Zhao R and Wang B) independently extracted the following information from the identified studies and recorded them in a predesigned spreadsheet: author, year of publication, study design, country, population, male/female, age, category of fractures, fracture time, preoperative design software, computerized tomography (CT) slices, navigation system, postoperative evaluation time, duration of follow-up, and outcomes. Incomplete information concerning requirements were supplemented by contacting the corresponding author via email.

VARIABLES

The analysis was based on six different outcome variables for which the original protocols needed to be transformed and pooled:

The status of the ZMC fracture was assessed by preoperative CT in all included studies. The selected landmarks on the healthy side were mirrored to the affected side through the midsagittal plane as the landmarks for reduction. Postoperative CT was used to verify the distance difference between the fracture reduction point and the landmark point. Regarding the measurement methodology, heterogeneity was observed in 1-dimensional and three-dimensional directions among different studies. The 1-dimensional direction was defined as the difference between the horizontal distance of the reduction point and the landmark to the midsagittal plane. The three-dimensional direction was defined as the difference in the synthetic distance between the reduction points and the landmarks.

The total treatment time was defined as the sum of the preoperative planning and intraoperative operative times. The amount of bleeding was the total bleeding volume of patients during the reduction surgery. Postoperative complications were defined as new adverse events reported after surgery by the attending physician or by the patients. The cost was defined as the total expenditure incurred by patients during the entire surgical phase. Weighted means and standard deviations were calculated for the above parameters. If the outcome variables were published as ranges of quartiles, they were converted to their respective means and standard deviations according to the Box-Cox model of McGrath et al[22]

The differences in postoperative satisfaction result from the evaluation criteria of each study and involve the evaluation of different identities (patients and doctors). Higher scores represented patients' recognition of facial symmetry and aesthetics.

METHODOLOGICAL EVALUATION

A professional evaluator (evidence-based medicine expert from Lanzhou University, irrelevant to this study) assessed the methodological quality of the cohort studies according to the Newcastle-Ottawa Scale (NOS).[23] Eight prominent areas of each study were judged by scoring (the area of comparability scored 2 and the remaining seven areas scored 1). The highest score for a single study was 9. A score greater than 7 was considered high quality, while a score less than 6 was considered low methodological quality.

The methodological quality of RCTs was evaluated using the Cochrane Collaboration risk of bias tool,[24] which consists of seven domains (sequence generation, allocation concealment, blinding of participants and investigators, blinding of outcome assessment, incomplete data outcome, selective outcome reporting, and potential sources of bias). These areas are graded as "high risk," "low risk," and "unclear."

DATA SYNTHESIS

The relevant results were analyzed using Review Manager 5.4 (The Cochrane Collaboration). The relative risk and the mean difference (MD) were used as the effect indices of binary variables and continuous variables, respectively. The statistical setting of the results was a 95% confidence interval (CI), and $P < .05$ was considered statistically significant. Q and I^2 tests were performed to evaluate the heterogeneity of the results. When $P < .05$ and $I^2 > 50\%$, significant heterogeneity existed between the studies, and a random-effects model was used. Otherwise, a fixed-effect model was used. Indicators of insufficient data were evaluated using descriptive statistics.

Results

SELECTION AND CHARACTERISTICS OF STUDIES

A total of 562 studies were retrieved from the database (Fig 1). The preliminary screening of titles and abstracts was conducted independently, and 9 studies were eligible for full-text review. Four studies[25-28] were subsequently excluded according to our criteria, and as a result, 5 studies[29-33] were included in this review (Table 1). All included clinical trials were conducted in China (four from different centers in mainland Chinese, and the other from Taipei[32]), two of which were funded by the Chinese government,[30,31] while the rest did not disclose the funding source.

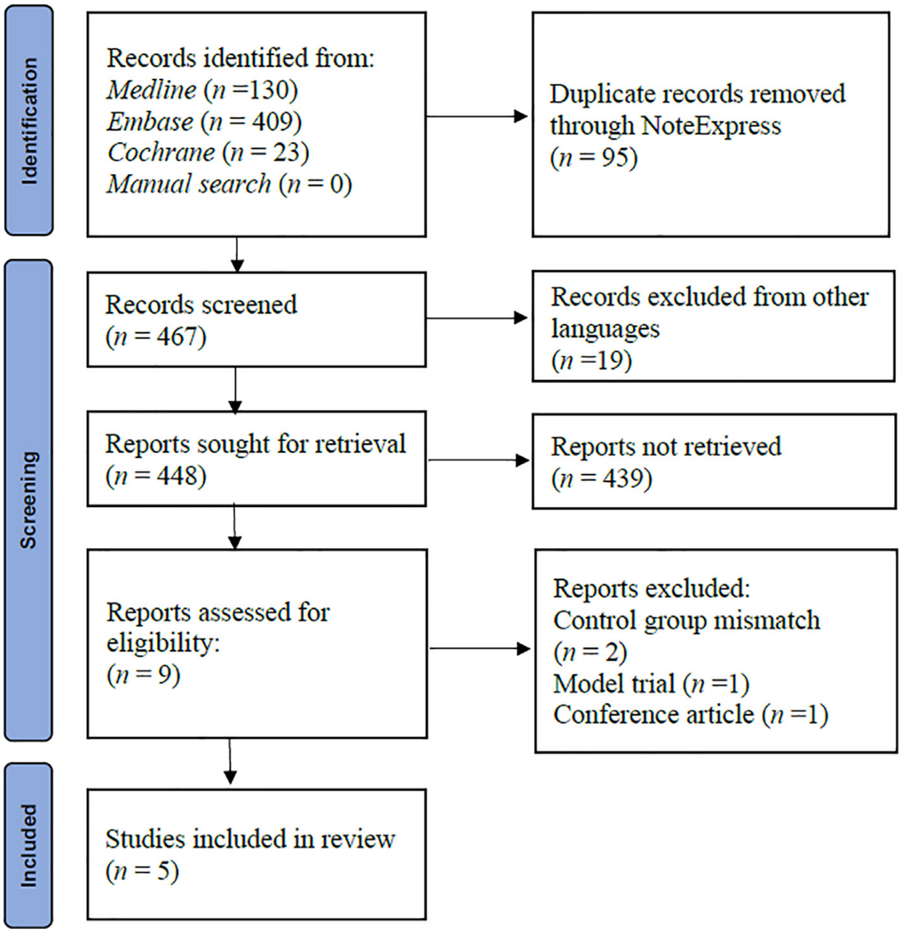

FIGURE 1. PRISMA flowchart of the search process.

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QUALITY ASSESSMENT

Two retrospective studies,[29,32] being eligible for all items of the Newcastle-Ottawa Scale, were considered to be at low risk of bias. Three RCTs[30,31,33] conformed to most of the items of the Cochrane collaboration tool, including random sequence, blinding methodology, attribution, and selection. All studies were judged to have a low risk of bias, although clarifying if other biases existed was difficult (Table 2).

OUTCOMES

In total, 189 participants with unilateral ZMC fractures were included in the present review. After preoperative design with professional software, 97 patients underwent surgery with the assistance of a CANS. The remaining patients were treated with the traditional free-hand method (Table 3).

ACCURACY OF REDUCTION

In all five studies,[29-33] the healthy side was mirrored to the fractured side to anchor the landmarks. Bao et al[29] evaluated reduction outcomes by chromatographic analysis and the symmetry index. In the other four studies,[30-33] Cheng et al[30] used the 3D coordinate system to measure the X, Y, and Z distances between the reduction points and the landmarks in the midsagittal plane, and the X-axis effect was consistent with the linear 1-dimensional distance adopted by Gong et al[31]; Both Yang et al[32] and Zhang et al[33] counted the integrated value of the 3D distance between the reduction point and the landmark. When the measurement dimensions were analyzed as subgroups, less error was observed among patients in the CANS group than among those in the CS group. This difference was statistically significant (MD = −0.86; 95% CI −1.58 to −0.14; P = .02, random-effect model; Fig 2). Substantial heterogeneity was detected (χ^2 = 16.51, df = 3 [P = .0009]; I^2 = 82%).

TOTAL TREATMENT TIME

The preoperative planning time was documented in two studies,[30,33] and meta-analysis showed no

Table 1. CHARACTERISTICS OF THE INCLUDED STUDIES

Authors, years	Study Design	Country	Population (Male/Female)	Age (years)	Category of Fractures	Fractured Time (days)	Preoperative Design Software	CT Slice (mm)	Navigation System	Postoperative Evaluation Time	Duration of Follow-Up
Bao et al 2018[29]	Retrospective	China	CANS: 15 (10/5)	CANS: 41.06 ± 11.78	Unilateral ZMC fractures (Zingg type C)	<14	iPlan 3.0 (BrainLAB, Feldkirchen, Germany)	0.67	BrainLAB	2 wk	18 mo
			CS: 10 (7/3)	CS: 39.4 ± 10.62					-		
Cheng et al 2022[30]	RCT	China	CANS: 19 (14/5)	CANS: 38.5 ± 13.0	Unilateral ZMC fractures (Zingg type B)	CANS: 17.0 ± 9.4	ProPlan CMF 3.0 software (Materialise, Leuven, Belgium)	NR	Acc-Navi system	3 days	NR
			CS: 19 (11/8)	CS: 33.5 ± 8.1		CS: 14.2 ± 12.5			-		
Gong et al 2016[31]	RCT	China	CANS: 39 (30/9)	CANS: 31.35 ± 10.00$	Unilateral ZMC fractures (Zingg type B/C)	≥21	SurgiCase CMF 5.0 (Materialise, Leuven, Belgium) and iPlan CMF (BrainLAB, Feldkirchen, Germany)	1.25	BrainLAB	48 to 72 hours	6 mo
			CS: 39 (32/7)	CS: 32.65 ± 13.08$					-		
Yang et al 2019[32]	Retrospective	China (Taipei)	CANS: 14 (5/9)	CANS: 38.9 ± 14.6	Unilateral zygomatic fracture (Zingg type B)	CANS: 10.0 ± 4.7	iPlan CMF (BrainLAB AG, Munich, Germany)	0.65	BrainLAB	≥3 mo	311.1 ± 228.8 days
			CS: 14 (5/9)	CS: 37.3 ± 11.5		CS: 8.6 ± 5.1			-		357.9 ± 169.9 days
Zhang et al 2018[33]	RCT	China	CANS: 10 (7/3)	CANS: 33.60 ± 11.36	Unilateral ZMC fractures (Zingg type B/C)	NR	Geomagic Studio 11 software (Geomagic, NC State, USA)	1	BrainLAB	2 wk	1 yr
			CS: 10 (6/4)	CS: 35.50 ± 11.39					-		

Abbreviations: CS, control group; CANS, navigation group; NR, not report; RCT, randomized controlled trial; $, quartile conversion (Box-Cox model).

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Table 2. RISK OF BIAS ASSESSMENT FOR RETROSPECTIVE STUDIES AND RCTS

	Cochrane Collaboration Tool							Newcastle-Ottawa Scale							
Author (years)	Random Sequence Generation (selction bias)	Allocation Conceal ment (selection bias)	Blinding of Participants and Personnel (performance bias)	Blinding of Outcome Assessment	Incomplete Outcome Data (attrition bias)	Selective Reporting (reporting bias)	Other Bias	Represent-ativeness of the Exposed Cohort	Selection of the Non-exposed Cohort	Ascertainment of Exposure	Demonstration that Outcome of Interest was not Present at Start of Study	Comparability of Cohorts on the Basis of the Design or Analysis	Assessment of Outcome	Was Follow-Up Long Enough for Outcomes to Occur	Adequacy of Follow-Up of Cohorts
Randomised controlled trials															
Cheng et al 2022[30]	Unclear	Unclear	Low	Low	Low	Low	Unclear								
Gong et al 2016[31]	Low	Unclear	Low	Low	Low	Low	Unclear								
Zhang et al 2018[33]	Low	Low	Low	Low	Low	Low	Unclear								
Retrospective cohort studies															
Bao et al 2018[29]								1	1	1	1	2	1	1	1
Yang et al 2019[32]								1	1	1	1	2	1	1	1

Abbreviations: Low, low risk of bias; Unclear, unclear risk of bias.

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Table 3. OUTCOMES OF THE INCLUDED STUDIES

Authors, years	Accuracy of Reduction (mm)	Preoperative Planning Time (minutes)	Operation Time (minutes)	Amount of Bleeding (ml)	Postoperative Complication (Number)	Satisfaction Evaluation	Cost (RMB)
Bao et al 2018[29]	Chromatographic analysis, symmetry index	NR	NR	NR	CANS: temporary facial nerve injury (3)	NR	CANS: No extra cost
					CS: temporary facial nerve injury (2)		-
Cheng et al 2022[30]	CANS: X (0.97 ± 0.70)$^{\$}$, Y (0.46 ± 0.43)$^{\$}$, Z (0.93 ± 0.77)$^{\$}$	CANS: 55.8 ± 9.9	CANS: 85.6 ± 32.4	CANS: 71.7 ± 43.1	0	NR	NR
	CS: X (0.80 ± 1.15)$^{\$}$, Y (0.97, 0.23~1.80), Z (0.83,0.44~1.37)	CS: 54.2 ± 10.3	CS: 86.1 ± 25.4	CS: 55.7 ± 32.4			
Gong et al 2016[31]	CANS: 1.29 ± 1.54$^{\$}$	NR	CANS: 379.35 ± 207.81$^{\$}$	CANS: 317.75 ± 269.38$^{\$}$	0	CANS: VAS for self-appearance satisfaction 9 (8~9), for doctors 8 (6~9)	CANS: 42,417.70 ± 18,574.08$^{\$}$
	CS: 2.65 ± 2.08$^{\$}$		CS: 349.85 ± 169.32$^{\$}$	CS: 328.4 ± 246.29$^{\$}$		CS: VAS for self-appearance satisfaction 8 (8~9), for doctors 7 (5~9)	CS: 44,852 ± 20,254.24$^{\$}$
Yang et al 2019[32]	CANS: 0.53 ± 1.14	NR	CANS: 158.1 ± 29.0	NR	0	CANS: self-appearance satisfaction (1-10): 8.9 ± 1.1	NR
	CS: 2.93 ± 2.15		CS: 153.0 ± 46.2		CS: eyelid scar (1)	CS: self-appearance satisfaction (1-10): 9.1 ± 0.8	
Zhang et al 2018[33]	CANS: 0.59 ± 0.14	CANS: 48.00 ± 8.31	CANS: 183.70 ± 25.33	NR	0	NR	CANS: Extra 1000RMB
	CS: 1.23 ± 0.27	CS: 46.80 ± 9.69	CS: 179.00 ± 21.15				-

Abbreviations: CANS, navigation group; CS, control group; NR, not report; $^{\$}$, quartile conversion (Box-Cox model); RMB, Renminbi; VAS, visual analogue score.

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Study or Subgroup	CANS Mean	CANS SD	CANS Total	CS Mean	CS SD	CS Total	Weight	Mean Difference IV, Random, 95% CI
One-dimensional direction								
Cheng et al. 2022	0.97	0.7	19	0.8	1.15	19	27.2%	0.17 [-0.44, 0.78]
Gong et al. 2016	1.29	1.54	39	2.56	2.08	39	23.6%	-1.27 [-2.08, -0.46]
Subtotal (95% CI)			**58**			**58**	**50.7%**	**-0.52 [-1.93, 0.89]**
Heterogeneity: Tau² = 0.90; Chi² = 7.76, df = 1 (P = 0.005); I² = 87%								
Test for overall effect: Z = 0.73 (P = 0.47)								
Three-dimensional direction								
Yang et al. 2019	0.53	1.14	14	2.93	2.15	14	16.4%	-2.40 [-3.67, -1.13]
Zhang et al. 2018	0.59	0.14	10	1.23	0.27	10	32.8%	-0.64 [-0.83, -0.45]
Subtotal (95% CI)			**24**			**24**	**49.3%**	**-1.40 [-3.11, 0.31]**
Heterogeneity: Tau² = 1.33; Chi² = 7.17, df = 1 (P = 0.007); I² = 86%								
Test for overall effect: Z = 1.61 (P = 0.11)								
Total (95% CI)			**82**			**82**	**100.0%**	**-0.86 [-1.58, -0.14]**
Heterogeneity: Tau² = 0.40; Chi² = 16.51, df = 3 (P = 0.0009); I² = 82%								
Test for overall effect: Z = 2.33 (P = 0.02)								
Test for subgroup differences: Chi² = 0.60, df = 1 (P = 0.44), I² = 0%								

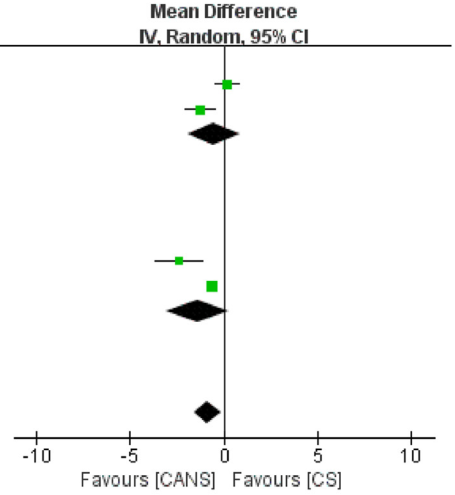

FIGURE 2. Forest plot of accuracy of reduction.

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significant difference between CANS and CS (MD = 1.44; 95% CI −3.55 to 6.43; *P* = .57, fixed-effect model; Fig 3). Heterogeneity was not detected (χ^2 = 0.01, df = 1 [*P* = .94]; I^2 = 0%).

Four studies[30-33] recorded the operative time of ZMC fracture reduction. Meta-analysis showed that the operative time was slightly longer for navigation than for non-navigated cases, but the result did not reach statistical significance (MD = 3.02; 95%CI −9.21 to 15.26; *P* = .63, fixed-effect model; Fig 4). Homogeneity was detected between studies (χ^2 = 0.57, df = 3 [*P* = .90]; I^2 = 0%).

AMOUNT OF BLEEDING

Two studies[30,31] reported the estimated amount of intraoperative bleeding. Meta-analysis showed no significant difference between them (MD = 14.86; 95% CI −8.86 to 38.58; *P* = .22, fixed-effect model; Fig 5). Heterogeneity was also not detected (χ^2 = 0.20, df = 1 [*P* = .66]; I^2 = 0%).

POSTOPERATIVE COMPLICATIONS

All five studies[29-33] described the occurrence of postoperative complications in participants. Of these, Bao et al[29] recorded 3 cases of temporary facial nerve injury in the CANS group and 2 cases in the CS group. Yang et al[32] reported 8 cases of mild cheek numbness in the CANS group and 6 cases of mild cheek numbness and 1 eyelid scar in the CS group.

POSTOPERATIVE SATISFACTION

Two studies assessed patients' postoperative satisfaction. Inconsistent evaluation criteria led to the use of descriptive analysis. Gong et al[31] used the visual analog scale to evaluate the symmetrical satisfaction 6 months after surgery, and no significant difference in the patient's own perspective was detected (*P* = .328), whereas the symmetrical satisfaction of the CANS group was better from the doctor's perspective (*P* = .043). Yang et al[32] designed a satisfaction scale to assess self-appearance satisfaction, and this parameter also did not differ between groups (*P* = .847).

COST

Three studies[29,31,33] introduced the cost of fracture surgery with or without using a CANS. Specifically, the application of CANS was free in Bao et al's[29] trial. In Gong et al's study,[31] no significant difference was

Study or Subgroup	CANS Mean	CANS SD	CANS Total	CS Mean	CS SD	CS Total	Weight	Mean Difference IV, Fixed, 95% CI
Cheng et al. 2022	55.8	9.9	19	54.2	10.3	19	60.3%	1.60 [-4.82, 8.02]
Zhang et al. 2018	48	8.31	10	46.8	9.69	10	39.7%	1.20 [-6.71, 9.11]
Total (95% CI)			**29**			**29**	**100.0%**	**1.44 [-3.55, 6.43]**
Heterogeneity: Chi² = 0.01, df = 1 (P = 0.94); I² = 0%								
Test for overall effect: Z = 0.57 (P = 0.57)								

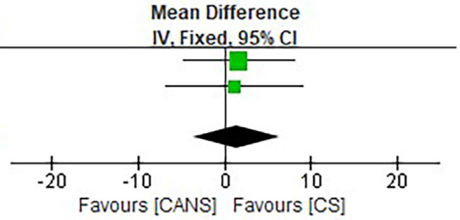

FIGURE 3. Forest plot of preoperative planning time.

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Study or Subgroup	CANS Mean	CANS SD	CANS Total	CS Mean	CS SD	CS Total	Weight	Mean Difference IV, Fixed, 95% CI
Cheng et al. 2022	85.6	32.4	19	86.1	25.4	19	43.7%	-0.50 [-19.01, 18.01]
Gong et al. 2016	379.35	207.81	39	349.85	169.32	39	2.1%	29.50 [-54.63, 113.63]
Yang et al. 2019	158.1	29	14	153	46.2	14	18.4%	5.10 [-23.47, 33.67]
Zhang et al. 2018	183.7	25.33	10	179	21.15	10	35.8%	4.70 [-15.75, 25.15]
Total (95% CI)			**82**			**82**	**100.0%**	**3.02 [-9.21, 15.26]**

Heterogeneity: Chi² = 0.57, df = 3 (P = 0.90); I² = 0%
Test for overall effect: Z = 0.48 (P = 0.63)

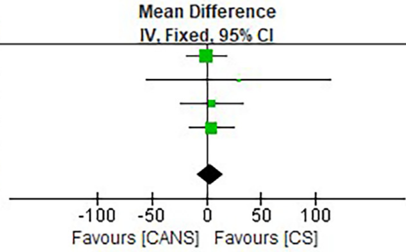

FIGURE 4. Forest plot of operation time.

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detected between the two groups (CANS: 42,417.70 ± 18,574.08-Yuan VS CS: 44,852 ± 20,254.24 -Yuan, P = .614). In the study by Zhang et al,[33] each instance of CANS uses costs 1000 yuan.

Discussion

This systematic review included 2 cohort studies and 3 RCTs that compared the consequences of intraoperative ZMC fracture reduction with and without using a CANS. Our results refuted the null hypothesis that CANS has a positive effect on the accuracy of ZMC fracture reduction, which is characterized by a smaller distance error from the landmarks. Overall, the use of a CANS does not seem to significantly influence total treatment time, amount of bleeding, postoperative complications, satisfaction, or cost.

In terms of the accuracy of fracture reduction, using a CANS results in more satisfactory symmetry of the facial contour. A recent systematic review by Dubron et al[9] supported this finding because CANS accurately identifies surgical instruments and anatomical structures, provides cooperative guidance to anastomose the end of the fracture during the surgery, directly verifies the effect of fitting with the landmarks, and then adjusts intraoperatively.[34] Instead of bilateral ZMC fractures, all of the included studies involved the treatment of unilateral ZMC fractures, which made it easier to determine the patient's landmarks by symmetrically flipping the imaging findings.[34,35] Although the landmarks are diverse (such as infraorbital rim, zygomaticofrontal, zygomaticosphenoid, zygomaticotemporal, etc), they are all characterized by proximity, maneuverability, and repeatability of the operation because of the subjective choices before surgery, which helps to calculate the distance between the reduction position and these landmarks.

The included studies showed that the average errors of the CANS were less than 1.5 mm, which is consistent with previous reports.[16,31] Notably, our results were synthesized by subgroup analysis in both the 1-dimensional and three-dimensional directions. Although a smaller distance represents a more accurate reduction, a zero distance in the 1-dimensional direction does not imply complete symmetry of the ZMC since it omits the deviation positions in the coronal and sagittal directions. Nevertheless, the comprehensive three-dimensional deviation between the landmarks and the reduction points avoids the potential deviation of linear measurement. In contrast, Bao et al[29] evaluated the three-dimensional symmetry of comminuted ZMC fractures by visually stratified chromatographic analysis and the symmetry index, respectively, and unanimously confirmed the reliability of CANS. Notably, the change in orbital volume that may be accompanied by ZMC fractures is easily ignored. Four of these studies[29,31-33] reported cases with orbital injury, but only 1 study[29] compared changes in orbital volume before and after surgery. In that study, the preoperative orbital volume was similar between the two groups, but the restoration of orbital volume employing CANS was better after surgical reduction (CANS: 2.15 ± 1.4 cm^3 vs CS: 1.6 ± 0.64 cm^3; P = .011). In this sense, the reduction accuracy needs to be evaluated in multiple aspects, but guidelines to standardize the methodology are lacking.

Study or Subgroup	CANS Mean	CANS SD	CANS Total	CS Mean	CS SD	CS Total	Weight	Mean Difference IV, Fixed, 95% CI
Cheng et al. 2022	71.7	43.1	19	55.7	32.4	19	95.7%	16.00 [-8.24, 40.24]
Gong et al. 2016	317.75	269.38	39	328.4	246.29	39	4.3%	-10.65 [-125.20, 103.90]
Total (95% CI)			**58**			**58**	**100.0%**	**14.86 [-8.86, 38.58]**

Heterogeneity: Chi² = 0.20, df = 1 (P = 0.66); I² = 0%
Test for overall effect: Z = 1.23 (P = 0.22)

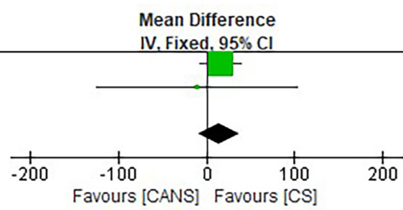

FIGURE 5. Forest plot of amount of bleeding.

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The reasons for higher heterogeneity may be related to the ZMC fracture types, surgical incision, software, and hardware products.[33,36] First, all participants in the five included studies were classified according to Zingg's classification.[37] Of them, 2 included type B fractures,[30,32] 2 included both type B and C fractures,[31,33] and 1 was a type C fracture.[29] Unlike complete monofragment zygomatic fracture of type B, multifragment zygomatic fracture of type C indicates that maintaining the correct angulation and inclination is more difficult.[37] Second, the number and location of surgical incisions were diverse in the included studies and were mostly confined to the maxillary vestibular sulcus, inferior eyelid, coronary valve, and exterior superciliary arch. Inappropriate approaches undoubtedly interfere with the surgeons' field of vision and exacerbate intraoperative bleeding, especially in the case of free-hand manipulation without a CANS. Third, more user-friendly software and hardware products (such as thinner CT slices, faster data conversion, and data registration) result in finer anatomical reconstruction and less error, which is of great importance for device-dependent CANS.[9,38] These differences may potentially affect the interstudy homogeneity.

Based on our results, the application of CANS did not significantly prolong the total treatment time. Cheng et al[30] and Zhang et al[33] reported that the mean preoperative planning time of CANS is slightly longer than that of CS. Fixing registration references and selecting landmarks for the navigation system is expected to require additional time. Although the use of navigation adds additional processes, interestingly, it seems to have little impact on the total treatment time compared to CS, which may be attributed to the following: the increased time of CANS might be offset by the time needed to evaluate the reduction result based on the surgeon's limited visualization of the fracture site in CS.[9,31] The average operation time exceeded 300 minutes in the study reported by Gong et al,[31] which was significantly higher than that in the other three studies. Thus, their participants evidently suffered from delayed fractures (≥21 days), in which the dislocation healing of the fracture segments obscured the anatomical structure, requiring a more time-consuming procedure for discrimination and reduction. Notably, the time advantage of the CANS is associated with a steep learning curve for operators prior to its use, which was not considered.

Meta-analysis indicated that the amount of intraoperative bleeding did not increase with the use of navigation. Cheng et al[30] reported an average blood loss of less than 100 ml, whereas Gong et al[31] reported a blood loss of nearly 300 ml in the treatment of delayed zygomatic fractures. Increased bleeding was also consistent with the extended operation time. Conceivably, nonfresh fracture reduction requires the reconstruction of poorly healed fracture segments and thus prolongs the bleeding time.[32] Therefore, ZMC fractures should be treated as soon as possible.[39]

Descriptive analysis revealed a low incidence of postoperative complications in reduction surgery. Only Bao et al[29] reported temporary facial nerve injury, 3 cases in the CANS group and 2 cases in the CS group, which were mainly related to an invasive operation and operator experience. Several studies[32,33] recorded preoperative clinical symptoms, including limited opening, enophthalmos, infraorbital numbness, and cheek numbness. Symptoms improved after reduction surgery in patients both with or without using CANS, making the assessment of the impact of CANS on these symptoms difficult.

To the best of our knowledge, no study has found a positive effect of the CANS on the deceleration of postoperative complications. Instead, several included studies[29,31,33] indicated that the registration frame must be installed in the patient's forehead, and additional devices might be inserted to act as landmarks in comminuted fractures. These additional injuries have been confirmed to be associated with risks such as scarring, infection, and craniocerebral trauma.[13,33] The use of CANSs needs to be improved in the future to minimize these complications.

Studies have indicated that the alignment error of ZMC fractures exceeds 2 mm, which can make facial asymmetry and deviation visible to the naked eye.[40] An analysis of the reduction accuracy showed that the reset error of using CANS is less than 2 mm, whereas that of CS exceeds 2 mm, resulting a higher risk of dissatisfaction among patients.[31] Notable, symmetry compensation in the process of soft tissue coverage and healing will decrease errors in the reduction of fracture segments,[40] which explains the findings of two studies[31,32] that reported acceptable facial morphologies from participants at least half a year after surgery. Interestingly, physicians perceived the use of a CANS as advantageous for facial symmetry, which Gong et al interpreted as a function of the Hawthorne effect.[31]

The necessity and rationality of using a CANS in the treatment of ZMC fractures need to be carefully appraised to avoid placing an additional financial burden on patients. In principle, the unfavorable factors of ZMC fracture reduction (such as fracture types, the timing of surgery, number of fixation points, adjacent critical anatomical structures, etc) increase the risk of undesirable results, which supports the use of a CANS.[34] Based on the current results, we cautiously recommend that the use of a CANS for the real-time location of fracture segments and reduction in the case of Zingg's classification types B and C.[37] However, the use of a CANS is not justified in the case of type A fractures because experienced surgeons can successfully reduce fractures with the free-hand approach.

The main limitation of this systematic review is that the heterogeneity of the evaluation methods for the reduction accuracy of CANS is based on the distance difference in 1-dimensional and three-dimensional directions, which is not sufficient to perform a meta-analysis of the angle and volume of ZMC fractures. Furthermore, available evidence is still insufficient to confirm the comprehensive performance of CANS. Future clinical trials will have to address important issues, including fracture type, the timing of surgery (immediate or delayed), the number of fixation points, and cost-effectiveness analysis. Extended follow-up will allow the evaluation of soft tissue atrophy, muscle traction, and long-term treatment efficacy.

Within the limitations of this study, the use of CANS improves the reduction accuracy compared with CS for the treatment of unilateral ZMC fractures, and the real-time anatomical positioning and segment-end anastomosis afforded by a CANS can compensate for additional installation time. The influence of a CANS on indications, safety, efficacy, patient satisfaction, and cost was limited. Further evidence from homogenous RCTs is needed to substantiate the performance of CANS.

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