Original Articles

Floating Elbow in Adults: A Systematic Review and Meta-Analysis

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Background

We aimed to systematically review all papers examining floating elbow injuries in adults.

Material and Methods

MEDLINE, Cochrane Bone, Joint and Muscle Trauma, PROSPERO, and Scopus databases were searched up to August 31, 2020. Included studies had as a primary or secondary outcome the functional outcomes after a floating elbow injury on patients aged 17 or older. Methodological quality of the included studies was assessed.

Results

Thirty-two studies met the inclusion criteria. Patients were male at 73,1%. Median age of the patients was 33,0 years and median time of follow-up was 19,5 months. Articular surfaces were affected at 24,4%, whereas 51,2% of the fractures was open. Approximately, 34,9% of the patients suffered neural injury. Ipsilateral and multiple-system injuries were present in 34,8% and 76,3 % of the cases, respectively. Multivariate analysis showed that intra-articular and nerve damage, open fractures and multi-system injuries affected range of motion, union and complications. Sex, age, vascular damage and ipsilateral injuries of the patient did not adversely impact the outcome. All of the included studies were classified as very-low quality of evidence.

Conclusions

The current knowledge regarding the characteristics of floating elbow in adults is limited, albeit we were able to provide possible pre-operative predictor outcomes.

INTRODUCTION

Floating elbow, the combination of ipsilateral fractures of the humerus and forearm which creates an unstable intermediate articulation, is a relatively rare lesion.^{1,2} Stanitski and Micheli³ introduced the term 'floating elbow' to describe this injury pattern in children and since then the description was extended to adults who sustain concomitant fractures of the humerus and forearm in the same limb (Fig. 1&2).^{2,4,5} This injury usually is the result of high-energy trauma and can be combined with severe soft tissue

damage and open fractures along with neurovascular compromise.^{2,4,5}

Although literature describing functional outcomes in patients with floating elbow is limited, surgical treatment has been widely accepted and there is evidence that these injuries are treated most effectively with surgical stabilization of the humerus and the forearm using a plate or intramedullary nail.^{2,4,6-8} There is, however, controversy in the literature regarding the most appropriate classification, functional outcomes and prognostic factors of this type of injury.

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Figure 1. Floating elbow injuries are complex injuries involving concomitant fractures of the humerus and forearm in the same limb.

Figure 2. The treatment of floating elbow injuries is surgical. Most patients are treated with ORIF for both fractures, albeit intramedullary nail in certain cases is a valid option.

Case series from Solomon,¹ Jockel⁵ and Ditsios⁴ and Diaz et al.,⁹ notice that development of residual nerve palsy associates with worse results in functional scales. Patients with extra-articular injuries seem to obtain a higher degree

of range of motion and better scores in functional scales.^{1,4,5,9} Diaz,⁹ Pierce,⁶ and Yokoyama et al.¹⁰ in their respective series did not find a clear risk factor for poor prognosis of these injuries among multiple factors, such as open fracture, vascular injury, time to fixation, injury severity score, and nerve injury. Yokoyama et al. concluded that these injuries potentially have many complications, such as infection, nonunion, and neurovascular damage, which led to long-term functional disability of affected limb.¹⁰

The primary objective of the study is to summarize the current knowledge reported in the literature surrounding floating elbow injuries. The secondary objective of the study is to identify possible outcome predictors of this type of injury.

MATERIAL AND METHODS

SEARCH STRATEGY AND SELECTION CRITERIA

The systematic review and meta-analysis adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for meta-analyses of interventional studies.¹¹ We searched PubMed through MEDLINE, Cochrane Bone, Joint and Muscle Trauma, PROSPERO and Scopus databases with the following key phrases: (((“float”[All Fields] OR “floated”[All Fields]) OR “floating”[All Fields]) OR “floats”[All Fields]) AND ((((((“elbow”[MeSH Terms] OR “elbow”[All Fields]) OR “elbow joint”[MeSH Terms]) OR (“elbow”[All Fields] AND “joint”[All Fields])) OR “elbow joint”[All Fields]) OR “elbow s”[All Fields]) OR “elbows”[All Fields]). We did not apply any language restrictions and included all relevant articles up to August 31, 2020. We also hand-searched the reference lists of identified trials and reviews, for further references, including those published in grey literature and unpublished trials. This study is registered with PROSPERO, number CRD42021229347.

ELIGIBILITY CRITERIA

TYPES OF STUDIES

Included studies were either randomized or nonrandomized, either prospective or retrospective cohort, case series or case control, all of them having as primary or secondary outcome the functional outcomes after an floating elbow injury. Reviews, scientific meeting abstracts, animal studies, commentary were excluded. Studies published in a language other than English were translated. Because of the nature of the condition treated, randomised trials might be arduous to be undertaken. Thus, the best available level of evidence on this subject may be provided by a systematic review and meta-analysis of the observational studies, which we present here.

TYPES OF PATIENTS

Patients aged 17 or older, of any gender or race, diagnosed with a floating elbow injury. Floating elbow is the term used

to describe adults who sustain concomitant fractures of the humerus and forearm in the same limb,^{2,4} first described by Stanitski and Micheli.³

TYPES OF INTERVENTIONS

All patients included were treated conservatively or surgically.

TYPES OF OUTCOME MEASURES

Primary outcomes of the systematic review were range of motion (flexion/extension/pronation/supination), grip and elbow strength and functional outcomes assessed by Mayo Elbow Performance Score (MEPS), Khalfayan score, American Shoulder and Elbow Surgeons Shoulder Score (ASES), Visual Analog Score (VAS), Liverpool elbow Score (LES), Disabilities of the Arm, Shoulder and Hand (DASH). Secondary outcomes were union and the presence of complications such as infection, pain, compartment syndrome, heterotopic ossification.

DATA ANALYSIS

Two independent researchers (PC and GC) screened all abstracts identified in the initial search, excluded studies in violation of the inclusion criteria and assessed the risk of bias. Full-text articles were subsequently reviewed in duplicate and, in cases of disagreement, consensus was achieved through discussion or referral to a third reviewer (KD). We transferred all relevant titles and abstracts to Mendeley Desktop Version 1.19.4 for further assessment. An electronic, predesigned data abstraction form, designed in Microsoft Excel 2020, was used to record patient and study characteristics, including authors' name, year of publication, number of patients, age and gender of patients, hand dominance, type of injury, follow-up interval, classification, open or closed fractures, intra- or extra-articular fractures, whether external fixation was used or not, duration of external fixation, time to fixation, type of humerus and forearm treatment, nerve and vascular injuries, associated injuries, head injury, infection, amputation, compartment syndrome, pain, heterotopic ossification, re-operation, union and time to union, time to mobilization, range of motion (flexion/extension/pronation/supination) and functional outcome measures. Associated injuries were categorized in two groups and are presented independently: a) injuries on the ipsilateral upper limb and, b) injuries on multiple organs termed polytrauma patients. If not reported, corresponding authors were contacted to obtain these baseline characteristics.

QUALITY ASSESSMENT

The methodological quality of the included studies was evaluated according to the Newcastle-Ottawa Scale (NOS). NOS is recommended by the Cochrane Collaboration for observational, non-randomised clinical studies.¹² NOS uses a "star system" for cohort or case-control studies.^{13,14} The tool gives a maximum of one star for each numbered ele-

ment of "selection" and "outcome" domains. A maximum of two stars are attributed for the "outcome" domain. However, the studies are case series (ie, no controls); therefore, grading thresholds for converting the Newcastle-Ottawa scales to Agency for Healthcare Research and Quality (AHRQ) standards (good, fair, and poor) was difficult to establish. Representativeness of exposed cohort, selection of nonexposed cohort, and cohort comparability did not apply. We used the methodology described by Reus et al.¹⁵ We therefore implemented the NIH study Quality Assessment Tool for case series (<https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools>). The grades were attributed based on questions 1–9: "good" if questions 1, 6, and 7 (principal factors) were present; "fair" if two factors were present; and "poor" or "insufficient quality" if one factor was present. Case report studies were evaluated with the Joanna Briggs Institute Critical Appraisal Checklist for Case Reports. (https://joannabriggs.org/sites/default/files/2020-08/Checklist_for_Case_Reports.pdf). Additionally, we assessed the external validity of the main clinically relevant outcome measures with the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework.¹⁶

STATISTICAL ANALYSIS

Statistical analysis was performed using Jamovi Version 1.2.27.0. We presented quantitative normally distributed variables with mean±SD, whereas quantitative non-normally distributed variables are presented with median (interquartile). For nominal and ordinal variables, we used frequencies and percentages. Normality was checked with the Shapiro-Wilk test. We assumed a p-value less 0.05 to be statistically significant.

The outcome measures in our study were union, flexion/extension, pronation/supination and complications (infection, pain, heterotopic ossification, compartment syndrome). For the outcome measures odds ratio estimates were obtained for the eight individual baseline variables (age, sex, open/closed fractures, intra-articular fractures, ipsilateral and multi-system injuries, nerve and vascular damage).

Multivariate models were derived to determine predictors of outcome. All outcome measures were treated as binomial variables (yes/no). Flexion/extension and pronation/supination were transformed to binomial variables after we identified whether there was a restriction in the range on movement. Functional range of motion (ROM) of the elbow for daily activity was set at 30°–130° of flexion-extension and 50° of pronation-supination in either direction, as stated by Morrey et al.¹⁷ As all outcome measures were binomial, logistic regression methods were used to derive the predictive models.

RESULTS

The search of PubMed, Cochrane Bone, Joint and Muscle Trauma, PROSPERO and SCOPUS databases produced a total of 282 publications. The [ClinicalTrials.gov](https://www.clinicaltrials.gov) register re-

Figure 3. Study selection process and PRISMA flowchart.

ported no randomized controlled studies on floating shoulder injuries. Twenty additional studies were identified for review of references. After exclusion of 94 duplicate titles, 208 abstracts were selected for review. Of these, 55 full-text articles were selected for formal review. Following review of full-text articles, 32 studies^{1,2,4-10,18-40} met the inclusion criteria for qualitative analysis [19 case series^{1,2,4-10,19,24,28,30-33,35,38,39} and 13 case reports^{18,20-23,25-27,29,34,36,37,40}]. Respective studies and their reasons for exclusion are presented on Supplementary File-Table 1. Finally, 24 articles reported on PROs and were included in the quantitative analysis. For details on the study selection process and the PRISMA flowchart, see [Fig. 3](#).

STUDY CHARACTERISTICS AND QUALITY ASSESSMENT

The literature on this topic mostly consists of small uncontrolled case series, which are consequently of very-low quality of evidence according to GRADE guidelines.⁴¹ As such, no sensitivity analysis was performed. All of the included studies were classified as Level IV evidence,⁴² with all being retrospective case series and reports. [Table 1](#) summarizes the characteristics of the studies selected for review. Risk of bias assessment (RoB) for case series, according to the NIH study Quality Assessment Tool, is presented on the Supplementary File-Table 2. RoB for the case reports, according to the Joanna Briggs Institute Critical Appraisal Checklist for Case Reports, is depicted on the Supplementary File-Table 3.

PATIENT DEMOGRAPHICS

A male predominance was noted with 73,1% of the patients being male and 26,9% being female. Median age of the patients was 33,0 years and median time of follow-up was 19,5 months. Sixteen studies did not mention classification of the injury (six case-series and ten case reports) and there was heterogeneity on the preferred classification system. Dominant hand was affected on 53 out of 104 cases. Patients' descriptive statistics are presented on [Table 2](#).

INJURY MECHANISM

All but two (30/32) studies reported a mechanism of injury. Motor vehicle accidents was the most common mechanism in all series, with 122/210 (58,1%) patients. Falling and industrial accidents, with 40/210 (19,0%) and 26/210 (12,4%), were the second and third-most-common mechanism of injury, respectively.

INJURY CHARACTERISTICS

Most of the injuries did not involve the articular surfaces 195/258 (75,6%), however, more than half of the fractures were open 132/258 (51,2%). Ninety patients (34,9%) suffered neural injury, with damage to the radial nerve being the most prominent one 47/90 (52,2%), followed by damage to multiple nerves 18/90 (20,0%) and the ulnar nerve 14/90 (15,6%). Vascular damage was not common presenting to 7,9% (19/240) of the patients, although laceration of the brachial artery was prominent 12/19 (63,2%) among them. Ipsilateral injuries were present in 34,8% (47/135) of the cases and the patients suffered damage to multiple organs in 76,3% (103/135).

Table 1. Studies' descriptive characteristics

year	study	no	classification	age (y)	cause of injury	sex (m:f)	hand (d:nd)	follow-up (mo)	Type of functional evaluation
1979	Pierce <i>et al.</i>	18	n/m	36,7	13mva, 1fall, 7unknown	13m, 8f	n/m	63,6 (r, 8-120)	objective & functional evaluation
1984	Rogers <i>et al.</i>	19	Rogers classification	31,0+/-10,87	10mva, 3industrial, 2fall, 1gsw	16m, 3f	n/m	21,84+/-7,37	ROM
1985	Lange <i>et al.</i>	9	n/m	27,33+/-10,45	7mva, 2industrial	n/m	n/m	22,33+/-19,03	Lange & Foster classification, ROM
1998	Sohn <i>et al.</i>	13	n/m	38,92+/-13,59	6mva, 4fall, 3industrial	7m, 6f	n/m	18,08+/-6,44	ROM, Lange & Foster classification
1998	Yokoyama <i>et al.</i>	15	AO/OTA classification	32,87+/-14,41	7mva, 2fall, 6industrial	13m, 2f	n/m	45,67+/-31,73	ROM, Khalfayan score
2000	Capomassi <i>et al.</i>	10	Capomassi classification	27,4+/-15,85	6mva, 3industrial, 1fall	9m, 1f	7d, 7nd	33,5 (r, 13-58)	Khalfayan score
2000	Lerner <i>et al.</i>	6	n/m	30,17+/-16,4	4blast, 2gsw	7m	n/m	n/m	ROM, Khalfayan score, grip strength
2003	Solomon <i>et al.</i>	26	AO/ASIF classification	36,92+/-15,14	n/m	15m, 11f	n/m	24,33+/-13/01	ROM, Khalfayan score, grip strength
2006	Anomou <i>et al.</i>	7	Gleizes classification	39,14 (r, 15-57)	3mva, 3industrial	6m, 1f	n/m	13,85 (r, 6-25)	Lange & Foster classification
2007	Stoik <i>et al.</i>	7	AO/ASIF classification	52,86+/-30,60	5mva, 1blast, 1fall	2m, 5f	n/m	12 (r, 2-22)	ROM
2012	El Ibrahim <i>et al.</i>	12	Agarwal and Chadha classification	31,5+/-15,49	9fall, 3mva	8m, 4f	n/m	n/m	Lange & Foster classification
2013	Lamah <i>et al.</i>	8	n/m	n/m	8mva	5m, 3f	3d, 5nd	10 (r, 6-18)	MEPS
2013	Jockel <i>et al.</i>	19	Jockel classification	41,53+/-15,42	n/m	14m, 5f	10d, 9nd	80,46+/-38,45	ROM, ASES, VAS
2013	Ditsios <i>et al.</i>	19	Ditsios classification	33,68+/-9,05	15mva, 2industrial, 2fall	16m, 3f	17d, 2nd	26 (r, 1-40)	ROM, MEPS, Khalfayan score, grip & elbow strength
2015	Cho <i>et al.</i>	6	n/m	45,17+/-14,19	5roller, 1mva	5m, 1f	2d, 4nd	37,00+/-32,96	MEPS, ASES, VAS
2016	Jimenez-Diaz <i>et al.</i>	23	AO/OTA & Ditsios classification	35,87+/-13,18	16mva, 5fall, 1gsw, 1blast	19m, 4f	4d, 19nd	19,53+/-11,05	ROM, MEPS
2018	Trigui <i>et al.</i>	14	Rogers classification	32,07+/-11,52	11mva, 2industrial, 1fall	11m, 3f	n/m	21,79+/-14,33	Stewart & Hundley classification modified by Diémé
2018	Langshong <i>et al.</i>	10	n/m	37,80+/-14,93	6mva, 3fall, 1building collapse	7m, 3f	6d, 4nd	5,15+/-0,58	DASH score
2020	Marius <i>et al.</i>	4	n/m	31	4xmva	3m, 1f	3d,	n/m	MEPS

year	study	no	classification	age (y)	cause of injury	sex (m:f)	hand (d:nd)	follow-up (mo)	Type of functional evaluation
							1nd		
2019	<i>Pari et al.</i>	1	n/m	53	fall	m	n/m	24	ROM
2018	<i>Badia et al.</i>	1	n/m	30	mva	m	yes	48	ROM
2018	<i>Lee et al.</i>	1	n/m	21	fall	f	n/m	12	ROM
2017	<i>Ayoubi et al.</i>	1	n/m	24	fall	m	n/m	6	ROM, MEPS
2017	<i>Kafadar et al.</i>	1	n/m	52	industrial	m	n/m	6	ROM
2015	<i>Bettuzzi et al.</i>	1	n/m	42	fall	m	n/m	12	ROM, MEPS
2015	<i>Goni et al.</i>	1	n/m	44	mva	f	n/m	24	ROM
2015	<i>Bisinella et al.</i>	1	AO/OTA classification	22	mva	m	n/m	8	ROM
2011	<i>Galasso et al.</i>	1	Rogers & Simpson classification	28	mva	m	n/m	18	ROM, grip strength, LES
2006	<i>De Carli et al.</i>	1	Rogers & Simpson classification	25	mva	f	n/m	24	ROM
1997	<i>Sarup et al.</i>	1	n/m	35	fall	f	n/m	5	ROM
1995	<i>Al-Zahrani et al.</i>	1	n/m	45	mva	f	n/m	18	ROM
1989	<i>Viegas et al.</i>	1	n/m	59	industrial	m	n/m	2	ROM

n/m=not mentioned; AO/OTA= Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; AO/ASIF= Arbeitsgemeinschaft für Osteosynthesefragen/Association of the Study of Internal Fixation; mva=motor vehicle accident; gsw=gunshot wound; m=male; f=female; ROM=range of motion; MEPS= Mayo Elbow Performance Score; ASES=American Shoulder and Elbow Surgeons Shoulder Score; VAS= Visual Analog Score; DASH= Disabilities of the Arm, Shoulder and Hand; LES= Liverpool elbow Score

MANAGEMENT

Regarding humerus fractures, more than half of those were treated with ORIF 55,4% (143/258), with the intramedullary nail being the second most preferred treatment of choice 18,6% (48/258). About 11,6% (30/258) of those injuries were treated with immobilization, however cast was an option used mostly in older studies. The majority of forearm fractures were treated with ORIF 79,9% (183/258), however external fixation 8,9% (23/258) and immobilization 8,5% (22/258) were also valid options and were utilized more often than intramedullary nail 4,7% (12/258). There were twenty-nine cases (29/196=14,8%), where ExFix was used prior to definitive treatment.

OUTCOME MEASURES

Outcome measures were diversified. Twenty-three studies reported on ROM, seven on MEPS, five on Khalfayan score and four on the Lange classification ([Table 1](#)). Median ROM, overall, was normal (120°, 0°, 80°, 70° for flexion, extension supination and pronation, respectively). There were fifteen cases evaluated as excellent in MEPS score, seven as good, fourteen as fair and five as poor. With regards to the Khalfayan score twenty-two cases were assessed as excellent, fifteen as good, sixteen as fair and sixteen as poor.

COMPLICATIONS

Despite the fact that floating elbows is usually the result of high-energy trauma and could be combined with severe soft tissue damage, only thirty patients (30/240=12,5%) developed infection. Compartment syndrome and amputation were rare (three and six cases, respectively). Approximately, one out of five patients had issue with the union of the broken bones, with the majority of those 33/54 (61,1%) developing non-union. There were eight cases with mal-union and nine with development of pseudoarthrosis. Heterotopic ossification affected elbow joint in forty-four cases (44/252=17,5%). Patients' descriptive statistics are presented on [Table 2](#).

REGRESSION ANALYSIS

Multivariate analysis ([Table 3](#)) of the findings in 252 of our patients was done to determine predictors of outcome. The patients (n=6) who had amputation were excluded from the analysis. This analysis showed that nerve damage ($OR=2.358$; $CI: 1.065-5.224$; $p=0.034$) and multi-system injuries ($OR=0.399$; $CI: 0.172-0.923$; $p=0.032$) at the time of event affected union. Intra-articular damage was associated with impaired pronation/supination ($OR=6.994$; $CI: 1.4606-33.49$; $p=0.015$), whereas we were unable to identify any predictors of flexion/extension. The presence of open fractures predicted the rate of complications such as infection, heterotopic ossification, pain and compartment syndrome ($OR=3.557$; $CI: 1.571-8.05$; $p=0.002$). Sex, age, vascular damage and ipsilateral injuries of the patient did not adversely affect the outcome. No subgroup analysis was performed.

DISCUSSION

Ipsilateral fractures of the humerus and forearm, also known as the floating elbow, are rare injuries that typically occur in the polytrauma patient. In this systematic review, we identified the descriptive characteristics of adult patients with this type of injury. We also report pre-operative predictors of floating elbow injury outcome using multivariate models. We identified that open and intra-articular fractures, multi-organ system injuries and nerve damage were associated with poor outcome.

Floating elbow injuries in adults have certain descriptive characteristics. Three out of four patients were male, with median age of 33,0 years. Dominant hand was affected on half of these cases, while motor vehicle accidents was the most common mechanism of injury (58,1%). Articular surfaces were affected one out of the four times, whereas more than half of the fractures were open. Approximately, one third of the patients suffered neural injury (34,9%), with damage to the radial nerve being the most prominent one, albeit vascular compromise was uncommon. Ipsilateral and multiple-system injuries were present in 34,8% and 76,3 % of the cases, respectively. Infection rate was at 12,5% of the cases. Compartment syndrome and amputation were rare (three and six cases, respectively). Approximately, one out of five patients presented with non/mal/delayed union and heterotopic ossification affected elbow joint in forty-four cases. The preferred treatment option for the majority of the cases was ORIF for humerus and forearm (55,4% and 79,9%, respectively). Reported patients' descriptive statistics are presented on [Table 2](#).

All of the included studies were classified as very-low quality of evidence according to GRADE guidelines.⁴¹ This restricts the reliability of our results but also emphasizes the low level of published studies performed and the need for further prospective RCTs. The literature on this topic mostly consists of single-center, retrospective, descriptive case series, while the largest series reported in the literature was of 26 patients with a 2-year-period-follow-up.

Several reports have dealt with the complications and functional results after treatment of these fractures, few on the possible predictors of poor functional outcome (investigating statistical significance between different groups) and none using regression models. Multivariate analysis dictated that open and intra-articular fractures, multi-organ system injuries and nerve damage were associated with poor outcomes. Intra-articular injury affected pronation and supination ($OR=6,994$; $CI: 1,4606-33,49$; $p=0,015$), but not flexion and extension ($OR=3,039$; $CI: 0,97730- 9,45$; $p=0,055$). Our findings agree with Ditsios et al. who demonstrated that mean arc of motion was superior in diaphyseal fractured compared to articular ones (97,5° vs 79,4°; $p=0,05$), without distinguishing between the components of ROM.⁴ Diaz et al., in a case series of 23 patients, discovered that articular involvement affected only extension ($p=0,0278$) not flexion, pronation or supination.⁹ Previous studies demonstrated that nerve involvement affected functional outcomes, however in our analysis only union was affected by nerve damage.²³ Jockel et al. revealed that

Table 2. Patients' descriptive characteristics.

Patients characteristics (N=258)				
Age (y), median(iqr)			33,0(21,0)	
Follow-up (m), median(iqr)			19,5(22,0)	
Gender, n%	Male	182/ 249(73,1%)		
	Female	67/ 249(26,9%)		
Hand dominance, n%	Non-dominant	51/ 104(49,4%)		
	Dominant	53/ 104(50,6%)		
Intra-articular, n%	No	195/ 258(75,6%)		
	Yes	63/ 258(24,4%)		
Type of injury, n%	Blast	6/210(2,9%)		
	Building collapse	1/210(0,5%)		
	Fall	40/ 210(19,0%)		
	GSW	4/210(1,9%)		
	Industrial	26/ 210(12,4%)		
	MVA	122/ 210(58,1%)		
	Roller	5/210(2,4%)		
	Unknown	6/210(2,9%)		
Type of fracture, n%	Open	132/ 258(51,2%)		
	Closed	126/ 258(48,8%)		
Nerve damage, n%	No	168/ 258(65,1%)		
	Yes	90/ 258(34,9%)		
		Radial	47/ 90(52,2%)	
		Ulnar	14/ 90(15,6%)	
		Median	4/90(4,4%)	
		Brachial	7/90(7,8%)	
		Multiple	18/ 90(20,0%)	
Vascular damage, n%	No	221/ 240(92,1%)		
	Yes	19/240(7,9%)		
		Brachial	12/ 19(63,2%)	
		Axillary	1/19(5,2%)	
		Radial	2/19(10,2%)	
		Ulnar	2/19(10,2%)	
		Multiple	2/19(10,2%)	
Time to fixation (h), median(iqr)			19,0(137,0)	

Use of ExFix, n%	No	167/ 196(85,2%)		
	Yes	29/ 196(14,8%)		
Duration of Exfix (m), median(iqr)			0,5(0,87)	
Treatment of humerus fx	Amputation	5/258(1,9%)		
	Arthroplasty	2/258(0,8%)		
	CRPP	11/258(4,3%)		
	ExFix	19/258(7,4%)		
	Immobilization	30/ 258(11,6%)		
	Intramedullary Nail	48/ 258(18,6%)		
	ORIF	143/ 258(55,4%)		
Treatment of forearm fx	Amputation	5/258(1,9%)		
	Arthroplasty	3/258(1,2%)		
	CRPP	10/258(3,4%)		
	ExFix	23/258(8,9%)		
	Immobilization	22/258(8,5%)		
	Intramedullary Nail	12/258(4,7%)		
	ORIF	183/ 258(70,9%)		
Associated injuries, n%	No	80/ 215(37,2%)		
	Yes	135/ 215(62,8%)		
			Ipsilateral injury	32/ 135(23,7%)
			Polytrauma	88/ 135(65,2%)
			Both	15/ 135(11,1%)
Head injury, n%	No	80/ 108(74,1%)		
	Yes	28/ 108(25,9%)		
Infection, n%	No	210/ 240(87,5%)		
	Yes	30/ 240(12,5%)		
Compartment syndrome, n%	No	255/ 258(98,8%)		
	Yes	3/258(1,2%)		
Amputation, n%	No	252/ 258(97,7%)		
	Yes	6/258(2,3%)		
Union, n%	No	54/ 258(20,9%)		
			Non-union	33/ 54(61,1%)
			Delayed union	9/54(16,7%)
			Mal union	3/54(5,6%)

		Pseudo	8/54(14,8%)
		Re-fracture	1/54(1,8%)
	Yes	204/ 258(79,1%)	
Time to union (m), median(iqr)			4,00(4,18)
Heterotopic ossification, n%	No	208/ 252(82,5%)	
	Yes	44/ 252(17,5%)	
Re-operation, n%	No	147/ 214(68,7%)	
	Yes	67/ 214(31,3%)	
Pain, n%	No	83/ 116(71,6%)	
	Yes	33/ 116(28,4%)	
Mobilization, w			2,0(2,0)
Flexion (°), median(iqr)			120,0(40,0)
Extension (°), median(iqr)			0,0(15,0)
Supination (°), median(iqr)			80,0(55,0)
Pronation (°), median(iqr)			70,0(52,5)
MEPS score			75,0(25,75)*
	Excellent	22/69(31,9%)	
	Good	15/69(21,7%)	
	Fair	16/69(23,2%)	
	Poor	16/69(23,2%)	
Khalfayan score			80,5(23,0)*
	Excellent	15/41(36,6%)	
	Good	7/41(17,1%)	
	Fair	14/41(34,1%)	
	Poor	5/41(12,2%)	

iqr=interquartile; y=years; m=months; w=weeks; h=hours; mva=motor vehicle accident; gsw=gunshot wound; fx=fracture; exfix=external fixation; *=overall score

nerve injury was associated with lower ASES elbow scores ($p=0,03$)⁵ and Diaz et al. argued that patients with residual nerve palsy have statistically significant differences in flexion ($p=0,04$), extension ($p=0,04$) and prono-supination ($p=0,02$).⁹

A floating elbow injury, usually, is the result of high-energy trauma and as such is combined with serious soft-tissue and multi-system organ involvement that takes precedent over the elbow with regards to treatment. Trauma patients with systemic injuries or extended soft tissues damage are not candidates for early fixation.²³ This potential delay in treatment is reflected on union of the fractures. Regression models showed that multisystem injuries prohibited union ($OR=0,399$; $CI: 0,172-0,923$; $p=0,032$). In addition, open fractures increase the rate of infection, heterotopic ossification, pain and compartment syndrome ($OR=3,557$; $CI: 1,571-8,05$; $p=0,002$). These results contradict previous reports from Yokoyama et al., who argued that open fractures, multi-system injuries or neuro-vascular involvement did not affect the final outcome of these injuries.¹⁰

Despite the seriousness of the injury, most patients had good overall elbow function, as documented by the various functional outcome measures. Median ROM, overall, was all normal (120° , 0° , 80° , 70° for flexion, extension supination and pronation, respectively). Although outcome measures were diversified, more than half of the reported patients had good or higher MEPS score (22/41) and Khalfayan score (37/69). Those results partly could be explained by the findings of Solomon et al., who demonstrated that open fractures, intra-articular and major skeletal injuries did not affect the Khalfayan score,¹ albeit nerve damage did. In the contrary, Diaz et al. suggested that although articular involvement impaired elbow's functional outcomes ($p=0,0108$), neural palsy did not affect their patients' Khalfayan scores.⁹ Finally, Ditsios et al. showed that Khalfayan and MEPS score are negatively affected by intra-articular involvement ($p<0,005$).⁴

The heterogeneity of the included studies can be contributed partly to the variants of floating elbow and its various classification system. Although classical definition of floating elbow is about ipsilateral diaphyseal fracture of

Table 3. Multivariate analysis of the pre-operative factor predicting outcome measures.

Variable (N=254)	Odds ratio	95% CI	p-value
Flexion/extension			
age	0,979	(0,94135- 1,02)	0,302
sex	0,799	(0,22308- 2,86)	0,730
open fx	2,664	(0,88782- 7,99)	0,081
intra-articular fx	3,039	(0,97730- 9,45)	0,055
nerve injury	1,993	(0,64686- 6,14)	0,230
vascular injury	2,958	(0,29495- 29,66)	0,357
ipsilateral injury	0,331	(0,10782- 1,02)	0,053
multi-system injury	1,972	(0,62862- 6,18)	0,245
Pronation/supination			
age	0,980	(0,9380-1,02)	0,355
sex	0,333	(0,0645-1,72)	0,189
open fx	0,289	(0,0614-1,36)	0,115
intra-articular fx	6,994	(1,4606-33,49)	0,015
nerve injury	1,902	(0,4328-8,36)	0,395
vascular injury	1,35e ⁸	(0,00-Inf)	0,991
ipsilateral injury	0,437	(0,0973-1,96)	0,280
multi-system injury	3,226	(0,7481-13,91)	0,116
Union			
age	0,994	(0,967-1,022)	0,665
sex	0,543	(0,194-1,520)	0,245
open fx	1,144	(0,490-2,671)	0,755
intra-articular fx	0,773	(0,329-1,818)	0,555
nerve injury	2,358	(1,065-5,224)	0,034
vascular injury	2,486	(0,734-8,421)	0,144
ipsilateral injury	0,675	(0,247-1,847)	0,444
multi-system injury	0,399	(0,172-0,923)	0,032
Complications			
age	0,984	(0,960-1,01)	0,197
sex	0,640	(0,261-1,57)	0,331
open fx	3,557	(1,571-8,05)	0,002
intra-articular fx	1,172	(0,555-2,48)	0,677
nerve injury	1,335	(0,629-2,83)	0,451
vascular injury	1,572	(0,496-4,99)	0,442
ipsilateral injury	0,880	(0,344-2,25)	0,790
multi-system injury	1,608	(0,785-3,29)	0,194

CI: Confidence Intervals; Inf: Infinity; Complication variable included infection, compartment syndrome, pain and heterotopic ossification,

humerus and forearm, several variants have been described. These variants incorporate fracture patterns of the humeral and/or forearm along with ipsilateral injuries to the upper extremity such as elbow/shoulder dislocation, disruption of the proximal and distal radioulnar joints.^{23,24,27,36,43} The complexity of the injury and its variants lead to the development of various classifications. Our review identified at least seven different classification systems. Ditsios et al. proposed a system based upon the articular surfaces of the elbow joint involved,⁴ Rogers et al. investigated fractures pattern with elbow dislocation,⁷ Agarwal and Chadha proposed a universal classification for floating trauma of

the extremities incorporating fractures along with articular surfaces and soft tissue involvement.²⁴

Treatment strategies have changed over time. In 1984, Rogers et al. reported a 100% nonunion rate in the humerus without rigid fixation.⁷ Since then, stable internal or external fixation of all fractures has been accepted as the treatment of choice for floating elbow injuries in adults.^{4,43} To avoid underestimating injury severity, the fractures should not be assessed individually, but as combinations, as described in the literature.^{2,4,6-8,38,43-45} It is generally accepted that patients with a floating elbow injury should undergo surgical stabilisation at the earliest safe oppor-

tunity,^{46–49} observation and conservative treatment may be used in the short-term whilst the patient is haemodynamically unstable or if other contraindications to surgery exist.³⁸ Consideration of concomitant injuries should take place and careful planning should be made in terms of the timing and surgical strategy. Such an approach will reduce the risk of complications and lead to a good functional outcome.²²

Regarding the sequence of fixation many authors recommend to osteosynthesize the humeral fracture first and then stabilize the distal fracture in one operation.^{24,38} More incidentally, for the sake of technical simplicity, the same method of osteosynthesis is, if possible, preferred for all the brachial and antebrachial foci.³⁸ Shaft fractures associated with adjacent joint dislocations, should be addressed first, to avert additional iatrogenic nerve injury during reduction and to facilitate the joint reduction.²¹ Preoperative CT imaging is a useful tool for ensuring that the correct diagnosis is not missed. Nevertheless, if a CT scan is not performed, careful radiographic examination of the adjacent joint is highly recommended.²¹

There are several limitations to this study. The quality of this study is limited by the quality of the studies included in the review as there were no level I to III studies available, and we were limited to retrospective case series with small numbers of patients. Nevertheless, this is the first meta-analysis performed according to PRISMA guidelines studying the potential impact of floating elbow in adults. Additionally, because of the presence of multiple confounding variables among the included studies such as different classification systems, definition of floating elbow, and variability in reported outcome measures, there was not enough homogeneous data, which makes meaningful comparison between studies challenging. No data regarding smoking status and comminution of the fractures sustained was retrieved. Finally, selection bias may have been present in several studies in which concomitant injuries and the health status of the patient may have played into whether the patient received surgical or nonoperative treatment.

In this systematic review we were able to summarize the current knowledge regarding the descriptive characteristics of floating elbow in adults and provide possible predictor outcomes (open fractures, intra-articular fractures, nerve

injury, multi-system damage). Larger, multicenter studies in the future could improve our understanding of these uncommon injuries, and provide insight into which factors contribute to unfavorable results in these fractures.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors made a substantial contribution and reviewed the document carefully prior to submission. KD, PC, TD, and IP designed and coordinated the research. KD, PC, and GC performed the quality assessment. PC, GC, PK and LK analyzed the data and performed statistical analysis. All aforementioned authors along with TK, KC and PP performed the authorship of initial draft. KD, PC, PK, IP, GC, TD, LK, TK, KC and PP offered significantly contributed to the linguistic formatting and correction of the manuscript, revised it critically for important intellectual content, and were responsible for final proof reading of the article.

DATA AVAILABILITY STATEMENT

Information and datasets analyzed during the current study available from the corresponding author on reasonable request.

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SUPPLEMENTARY MATERIALS

Supplementary Table 1.

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