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Anterior-posterior glenohumeral translation in shoulders with traumatic anterior instability: a systematic review of the literature

Catarina Malmberg, MD[a,*], Kristine Rask Andreasen, MD[a], Jesper Bencke, MSc, PhD[a,b], Per Hölmich, MD, DMSc[a], Kristoffer Weisskirchner Barfod, MD, PhD[a]

[a]Department of Orthopedic Surgery, Sports Orthopedic Research Center – Copenhagen (SORC-C), Copenhagen University Hospital Amager & Hvidovre, Hvidovre, Denmark

[b]Human Movement Analysis Laboratory, Department of Orthopedic Surgery, Copenhagen University Hospital Amager & Hvidovre, Hvidovre, Denmark

A R T I C L E I N F O

Keywords:
Glenohumeral translation
Shoulder kinematics
Shoulder biomechanics
Shoulder instability
Glenohumeral instability
Anterior shoulder instability

Level of evidence: Level IV; Systematic Review

Background: Reports of glenohumeral translation in shoulders with traumatic anterior instability have been presented. The aim of this systematic review was to investigate anterior-posterior translation in shoulders with traumatic anterior instability.

Methods: This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Studies including patients aged ≥15 years with previous traumatic anterior shoulder dislocation or subluxation were included. The outcome was anterior-posterior glenohumeral translation. A search of PubMed, Embase, and Cochrane library was performed on July 17, 2022. Two reviewers individually screened titles and abstracts, reviewed full text, extracted data, and performed quality assessment.

Results: Twenty studies (582 unstable shoulders in total) of varying quality were included. There was a lack of standardization and unity across studies. Radiography, ultrasound, computed tomography, magnetic resonance imaging, motion tracking, instrumentation, and manual testing were used to assess the glenohumeral translation. The glenohumeral translation in unstable shoulders ranged from 0.0 ± 0.8 mm to 11.6 ± 3.7 mm, as measured during various motion tasks, arm positions, and application of external force. The glenohumeral translation was larger or more anteriorly directed in unstable shoulders than in stable when contralateral healthy shoulders or a healthy control group were included in the studies. Several studies found that the humeral head was more anteriorly located on the glenoid in the unstable shoulders.

Conclusion: This systematic review provides an overview of the current literature on glenohumeral translation in traumatic anterior shoulder instability. It was not able to identify a threshold for abnormal translation in unstable shoulders, due to the heterogeneity of data. The review supports that not only the range of translation but also the direction hereof as well as the location of the humeral head on the glenoid seem to be part of the pathophysiology. Technical development and increased attention to research methodology in recent years may provide more knowledge and clarity on this topic in the future.

The anatomy of the glenohumeral joint allows for great mobility, while making it more susceptible to instability. The traumatic glenohumeral dislocation is a common shoulder injury, with incidence rates of 1.7% in a general population aged 18 to 70 years and 11.2 to 56.3 per 100,000 person years.[17,33,47,54] The partial dislocation, referred to as a subluxation, is even more common.[41] In approximately 95% of all events, the humeral head is dislocated in the anterior direction.[30] An anterior glenohumeral dislocation or subluxation can cause damages to the stabilizing structures of the joint, such as the bones, glenoid labrum, or surrounding joint capsule and ligaments, which leads to further decreased stability.[50,53] The recurrence rates are thus high, in some reports exceeding 70%.[14,39] The risk of recurrence increases with male sex, primary dislocation at age <40 years, in people with hyperlaxity,

Institutional review board approval was not required for this review.

*Corresponding author: Catarina Malmberg, MD, Department of Orthopedic Surgery, Hvidovre Hospital Sports Orthopedic Research Center Copenhagen, Copenhagen University Hospital Amager & Hvidovre, Hvidovre Hospital Sports Orthopedic Research Center Copenhagen, Kettegård Allé 30, Hvidovre, Capital Region 2650, Denmark.

E-mail address: catarina.anna.evelina.malmberg.02@regionh.dk (C. Malmberg).

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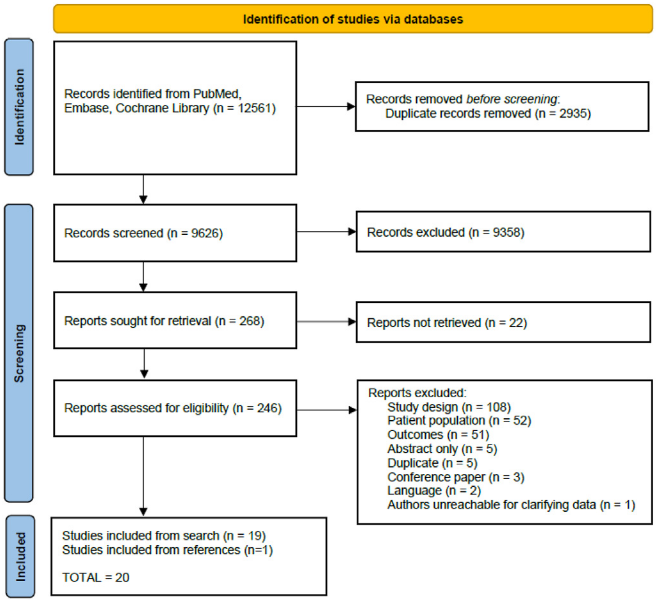

Figure 1 Prisma flow diagram.
From: Page MJ, et al.[42]

and participation in contact or overhead sports (especially high--level).[3,39] Recurrent as well as first-time events can give rise to chronic shoulder instability and diminished shoulder and upper limb function.[2,7-9,23,27,31,43] Ultimately, shoulder instability can reduce quality of life.[18,36]

Structural instability might influence the glenohumeral joint kinematics, which is the motion between the humerus and the scapula.[1] Glenohumeral joint kinematics are commonly defined as the anterior-posterior and superior-inferior translations of the humeral head in relation to the glenoid cavity.[13] Ultrasound, radiography, magnetic resonance imaging (MRI), computed tomography (CT), and 3-dimensional motion tracking systems have been used to assess glenohumeral translations, and abnormal measurements have been reported in patients with chronic symptomatic instability.[4,7,9,19,24,29,31,32,34,35] However, the reports are inconsistent and disagreeing, and a lack of consensus remains on how and to what extent the kinematics are affected in shoulder instability.

The primary aim of this systematic review was to investigate the anterior-posterior glenohumeral translation in shoulders with traumatic anterior instability. Our hypothesis was that traumatic instability leads to increased anterior-posterior glenohumeral translation and further that the extent varies depending on which measurement technique is used.

Materials and methods

Study design

This is a systematic review of studies reporting anterior-posterior glenohumeral translation in patients with traumatic anterior shoulder instability. The study protocol was registered in the International prospective register of systematic reviews (PROSPERO), record ID: CRD42020170765. The Preferred Reporting Items for Systematic reviews and Meta-analysis (PRISMA) guidelines were followed throughout the review process.[37,42]

Data sources and search strategy

A systematic search of the electronic databases PubMed, Embase, and Cochrane library was performed on July 17, 2022. The search strategy was developed in collaboration with a medical librarian and included medical subject headings (Medical Subject Headings terms) and keywords related to our eligibility criteria. The complete search strategies can be found in Supplementary Table S1.

Study selection and data collection

The search was imported to Covidence Systematic Review Software (Veritas Health Innovation, Melbourne, Australia). Following removal of duplicates, titles and abstracts were screened by 2 independent reviewers (C.M. and K.R.A.). The full-text articles that appeared to meet eligibility criteria were obtained and reviewed independently by the same reviewers. Discrepancies were resolved through discussion and a senior author (K.W.B.) was consulted where remaining uncertainty or discrepancy occurred. Reasons for exclusion are presented in a PRISMA flow diagram (Fig. 1).[42] For all studies that met the eligibility criteria, the reference lists were reviewed to identify further potential eligible studies. Finally, data extraction was performed independently by C.M. and K.R.A. None of the reviewers were blinded to the journal and study titles, authors, or institutions. The studies were thoroughly investigated and compared to identify duplicates not previously found, or studies where the same dataset was presented, in which case the authors discussed which study was the most appropriate to include. Where uncertainties remained, the study authors were contacted via e-mail.

Randomized control trials, prospective or retrospective cohort studies, case-control studies, cross-sectional studies, and case reports in English, Danish, Swedish, and Norwegian were included. Unpublished studies (eg, abstract only, conference papers, protocols) and cadaveric studies were excluded.

The eligibility criteria were predefined and based on the Population, Intervention, Comparison, and Outcome framework:[46]

- **Population**: Patients (aged ≥15 years) with anterior shoulder instability due to verified traumatic anterior glenohumeral joint dislocation(s) or subluxation(s). Studies with populations suffering from other shoulder conditions (eg, posterior, multidirectional, or atraumatic instability; rotator cuff or biceps tendinopathy, superior labral from anterior to posterior tear; fracture of the humerus, clavicula, or scapula [other than Hill-Sachs or osseous Bankart lesions]; dislocation of sternoclavicular or acromioclavicular joints; or atraumatic shoulder pathologies such as impingement, frozen shoulder, osteoarthritis, or acute calcific tendonitis) were excluded unless the results for the instability group were reported separately.
- **Intervention/measurement**: Anterior-posterior glenohumeral translation or humeral head displacement during upper limb movements or in specified positions.
- **Comparison**: Studies did not have to include a comparator or control group but could include stable shoulders or shoulders with other impairing conditions.
- **Outcome**: The primary outcome was the anterior-posterior glenohumeral translation. Any quantification of the translation was accepted, hereunder metric, grades, or otherwise defined classifications. The studies had to include the primary outcome to be included. Secondary outcomes were humeral head position, superior-inferior glenohumeral translation, the measurement method (technique, motion task, or shoulder position), and reported quality of the method (validity and/or reliability).

Table I
Quality of the included studies.

Study	Study type	Results from the adapted NOS form				Reported validity and reliability
		Selection (max. 4 stars)	Comparability (max. 2 stars)	Exposure/ Outcome (max. 2-3 stars)	Total assessment	
Radiography						
Hawkins (1996)[15]	case-control	☆☆☆		☆☆	5/9 stars	N/A
Howell (1988)[19]	case-control	☆☆☆		☆☆	5/9 stars	N/A
Howell (1991)[20]	cross-sectional	☆		☆	2/8 stars	Interobserver variability, paired differences: −0.0 mm ± 1.2.
Jalovaara (1992)[24]	case-control	☆☆☆		☆☆	5/9 stars	N/A
Paletta (1997)[43]	cohort	☆		☆☆	3/9 stars	Interobserver reliability, kappa: 0.9478 and 0.9678, $P < .0001$. Intraobserver reliability, kappa: 0.914, $P < .0001$.
Ultrasound						
Inoue (2022)[21]	cross-sectional	☆☆☆☆	☆☆	☆☆	8/8 stars	ICC 1.1: 0.810 (95% CI, 0.628-0.908). ICC 2.1: 0.724 (95% CI, 0.481-0.864). Assessed as moderate to good reliability.
Krarup (1999)[29]	case-control	☆		☆	2/9 stars	Average interobserver coefficient of variation: 32.7% (0.5%-95.3%). Average intraobserver coefficient of variation: 50% (13.9%-98.0%) and 49.9% (10.6%-114.0%), respectively.
Motion tracking						
Lädermann (2016)[31]	cohort	☆☆☆☆	☆☆†	☆☆☆	9/9 stars	Reportedly translational error <3 mm, rotational error <4°.
Lippitt (1994)[34]	case-control	☆☆☆		☆☆	5/9 stars	Reportedly accurate within 1 mm in cadavers.
MRI						
Kiss (1997)[28]	case-control	☆☆		☆☆	4/9 stars	Reproducibility from 2 measurements (2 SD): 0.76 mm for internal rotation, 0.28 mm for external rotation, 1.52 mm for overhead position.
von Eisenhart-Rothe (2002)[9]	case-control	☆☆☆	☆☆†	☆☆☆	8/9 stars	N/A
CT						
Kim (2017)[27]	case-control	☆☆☆	☆☆†	☆☆	7/9 stars	Estimated root-mean-square errors (RMSE): 0.43 mm for the in-plane direction, 1.53 mm for the out-of-plane direction.
Matsumura (2019)[35]	case-control	☆☆☆	☆☆†	☆☆☆	8/9 stars	Reportedly not validated.
Peltz (2015)[44]	cohort	☆☆☆		☆☆☆	6/9 stars	Reportedly accurate within ± 0.4 mm and ± 0.5°.
Instrumented						
Jørgensen (1995) [26]	case-control	☆☆		☆	3/9 stars	Intratester reproducibility, ICC: 0.996.
Manual testing						
Faber (1999)[10]	case-control	☆☆☆	☆☆†	☆☆☆	8/9 stars	N/A
Jia (2009)[25]	cross-sectional	☆☆☆	☆☆†	☆☆	7/8 stars	N/A
Oliashirazi (1999)[40]	case-control	☆☆☆☆	☆☆†	☆☆☆	9/9 stars	Sensitivity: 83%, positive predictive value: 100%. Specificity: 100%.
Tanaka (2012)[49]	cross-sectional	☆☆☆		☆☆	5/8 stars	N/A
Warner* (2006)[51]	case report	☆☆		☆☆☆	5/9 stars	N/A

N/A, Not applicable, meaning that data were not reported; *ICC*, interclass correlation coefficient; *MRI*, magnetic resonance imaging; *CT*, computed tomography.
Results from the NewCastle Ottawa Scale (NOS) forms for case-control, cohort, and cross-sectional studies, respectively, and the reported validity and reliability.
The studies were given maximum 2-3 points for exposure/outcome depending on which NOS scale was used; hence, the maximum total was 8-9 points.
*Case report with 11 patients, assessed using the NOS scale for cohort studies.
†Matched as they are the same patients (injured vs. uninjured shoulder).

Data synthesis

Data were collected independently by 2 reviewers and stored in the Covidence Systematic Review Software. The complete data collection was reviewed by the 2 reviewers together to ensure agreement. The first author (C.M.) hereafter sorted data into the tables. The presentation of data is narrative due to their heterogeneity and no meta-analysis or subgroup analysis was made.

Quality assessment

Cohort and case-control studies were assessed with corresponding versions of the NewCastle-Ottawa Scale (NOS), while cross-sectional studies were evaluated using an adapted version of the cohort scale (Supplementary Appendix S2).[16,45,52] Two reviewers performed independent quality assessments of the included studies. Any discrepancies were resolved through discussion and, if necessary, a senior author was consulted.

Results

Selection of studies

Following removal of duplicates, 9626 titles and abstracts were screened, of which 268 fulfilled the criteria for full-text review. Twenty two were excluded as the full text could not be retrieved either electronically or in paper form. Further 227 studies were excluded after full-text review, as demonstrated in the PRISMA flow diagram (Fig. 1).[42] The reference lists of the included studies were cross-checked and did not result in additional eligible studies. One additional study was identified as a reference from a study including a subpopulation from one of the included studies.[21,22] In

Table II
Demographics.

Study	Subjects and number hereof	Age	Gender (n f/m)	Dominant side affected (n [%])
Radiography				
Hawkins (1996)[15]	Recurrent anterior instability: 10	Overall: 30 (15-40) Patient group: 25	4/6	NA
	Comparator: MDI: 10	*21*	*7/3*	*NA*
	Healthy control: 18	*NA*	*7/11*	
Howell (1988)[19]	Recurrent anterior dislocation: 8			
	Recurrent anterior subluxation: 4	Overall: 23 (17-28)	2/8	NA
	Healthy control: 20	*24 (20-31)*	*4/16*	
Howell (1991)[20]	Recurrent traumatic anterior instability: 13 (all with normal kinematics during 90° abduction and maximum external rotation)	22 (16-34)	1/12	12 (92.3)
Jalovaara (1992)[24]	Recurrent anterior dislocations: 16	31 (15-46)	6/10	NA
	Recurrent anterior subluxations: 11 (3 with general joint hyperlaxity)	28 (17-45)	1/10	NA
	Comparator:		*1/8*	*NA*
	MDI: 9 (6 patients, 2 with bilateral MDI and 4 with general joint hyperlaxity)	*28 (15-34)*		
	Healthy control: 19	*37 (24-49)*	*11/8*	
Paletta (1997)[43]	Recurrent anterior shoulder instability: preoperative: 18 postoperative: 12 (all with abnormal anterior translation preoperative)	22 (14-32)	2/28	10 (55.6)
	Comparator: *Full-thickness rotator cuff tears:* *preoperative: 15* *postoperative: 14 (all with abnormal superior translation preoperative)*	*56 (45-65)*	*5/24*	*11 (73.3)*
	Healthy control: 6	*27 (23-30)*	*2/4*	
Ultrasound				
Inoue (2022)[21]	Traumatic anterior instability: 39	24.1 ± 10.2 (15-51)	4/35	NA
Krarup (1999)[29]	Traumatic anterior dislocation(s): 20 (2 with previous surgery 12 years earlier)	Median 28 (18-57)	7/13	NA
	Healthy control: 20	*Median 34 (22-53)*	*10/10*	
Motion tracking				
Lädermann (2016)[31]	Unilateral, traumatic anterior instability: 11	26.6 (17-44)	1/10	8 (72.7)
	Comparator: *Postoperative: 11 (open Latarjet: 9, arthroscopic Latarjet: 1, arthroscopic Bankart repair: 1)*			
	Healthy control: 11 (contralateral)	*26.6 (17-44)*	*1/10*	
Lippitt (1994)[34]	Traumatic anterior instability (TUBS): 8	28 (18-39)	1/7	NA
	Comparator:			*NA*
	Atraumatic MDI (AMBRII): 8	*23 (15-37)*	*4/6*	
	Healthy control: 8	*(25-45)*	*0/10*	
MRI				
Kiss (1997)[28]	Recurrent anterior instability: 9	27.3 (17.2-54.2)	NA	NA
	Comparator:		*NA*	
	After Putti-Platt operation: 5	*33 (17.2-54.2)*		NA
	MDI: 1	*23.6*		NA
	Healthy control: 7	*30.9 (26-35)*	*NA*	
von Eisenhart-Rothe (2002)[9]	Traumatic, unilateral anterior instability: 12	30.3 (24-39)	4/8	NA
	Comparator:			
	Atraumatic instability (anterior-inferior/MDI): 10	*24 (8-53)*	*6/4*	*NA*
	Hyperlaxity (contralateral atraumatic): 10	*24 (8-53)*	*6/4*	*NA*
	Healthy control: 12 (contralateral)	*30.3 (24-39)*	*4/8*	
CT				
Kim (2017)[27]	Primary anterior dislocation: 10	23.4 ± 8.8 (17-35)	0/10	NA
	Healthy control: 10 (contralateral)	*23.4 ± 8.8 (17-35)*	*0/10*	
Matsumura (2019)[35]	Recurrent, unilateral instability: 10	22.5 ± 3.5	0/10	NA
Peltz (2015)[44]	Unilateral anterior instability: 11	20.5 ± 4.9 (16-29)	NA	NA
	Comparator: *After arthroscopic stabilization: 11*	*20.5 ± 4.9 (16-29)*	*NA*	*NA*
	Healthy control: 11	*27.0 ± 4.2 (19-34)*	*NA*	*NA*
Instrumented				
Jørgensen (1995)[26]	Unilateral traumatic anterior dislocation: 10	30 (18-49)	3/7	NA
	Comparator:			
	Overhand athletes: 10	*23 (16-45)*	*5/5*	*NA*
	Atraumatic MDI: 10	*24 (18-45)*	*9/1*	*NA*
	Healthy control: 10	*25 (15-40)*	*5/5*	
Manual testing				
Faber (1999)[10]	Traumatic unidirectional anterior instability: 50	28	3/47	29 (58)
	Healthy control: 50 (contralateral)	*28*	*3/47*	
Jia (2009)[25]	Anterior instability: 231	Whole cohort: 45 (12-86)	NA	136 (58.9)

Table II (*continued*)

Study	Subjects and number hereof	Age	Gender (n f/m)	Dominant side affected (n [%])
	Comparators:		*NA*	
	Posterior instability: 31			54.8%
	MDI: 26			57.7%
	Other GH instability: 34			88.2%
	GH arthritis: 21			66.7%
	AC joint arthritis: 102			50.0%
	Tendinitis: 121			57.9%
	Partial cuff tear: 140			65.0%
	Full-thickness cuff tear: 369			63.0%
	Massive cuff tear: 67			57.6%
	SLAP: 39			74.4%
	Other: 25			48.0%
Oliashirazi (1999)[40]	Traumatic anterior instability: 30 (7 with general joint hyperlaxity)	23 (17-37)	5/25	13 (43.3)
	Healthy control: 30 (contralateral)	*23 (17-37)*	*5/25*	
Tanaka (2012)[49]	Recurrent anterior shoulder instability (eligible for Bankart repair): 40 (38 patients)	28.0 (13-73)	6/32	NA
Warner (2006)[51]	Recurrent traumatic anterior instability: 11	30 (19-41)	1/10	8 (72.7)

MRI, magnetic resonance imaging; *CT*, computed tomography; *NA*, Not applicable, meaning data were not reported; *MDI*, multidirectional instability; *TUBS*, traumatic, unidirectional, surgically requiring Bankart lesion; *AMBRII*, atraumatic multidirectional bilateral (responds to) rehabilitation inferior capsular shift interval closure; *GH*, glenohumeral; *SLAP*, superior labrum to posterior lesion.
Age reported in mean years (range). The italics values represent comparator groups.

total, 20 studies published in the period 1988-2022 were included. Twelve were case-control studies, 4 cross-sectional, 3 cohort studies, and 1 case report (Table I). Further study information is provided in the following sections.

Quality assessment of the included studies

The case-control studies scored 2-9 of 9 stars, the cross-sectional studies 2-8 of 8 stars, and the cohort studies 3-9 of 9 stars on the adapted NOSs (Table I). Reasons for introducing risk of bias were most often lack of representativeness and comparability, as selection of patients and comparators were undefined. Eight of the included studies did not report method validity or reliability.[9,10,15,19,24,25,49,51] Ten studies reported either the method validity or reliability, and 1 study reported both.[40] One study reported that their method had not been validated.[35] The reliability was most often reported, with intraclass correlation coefficient (ICC) as the most commonly used statistical method.[21,26]

Population

The studies included between 8 and 231 patients with anterior shoulder instability. Fifteen of the studies had 1 or more comparators (Table II). Several studies used the contralateral shoulder as healthy control.[9,10,27,31,40] The mean age of the patients with anterior instability varied from 20.5 to 31 years.[24,44] Whereas most studies included patients with recurrent instability, one study included patients with first-time dislocation only.[27] Three studies did not report the number of dislocations but defined their shoulder instability group as having anterior instability, unilateral traumatic anterior dislocation, and traumatic anterior instability, respectively.[25,26,34]

Examination of glenohumeral translation

A variety of examination methods were used to assess the translation. Radiography was the most commonly used medical imaging method.[15,19,20,24,43] Five of the studies evaluated the instability by grading the translation during dynamic manual assessment.[10,25,40,49,51] Thirteen of the studies assessed the translation in at least one measurement with external force applied to the joint, which was often a manual test performed by the examiner (Table III or Supplementary Table S1). Nine studies tested the shoulders while the patients were either in general or regional anesthesia. All used the same technique to measure the translation in the patient and comparator groups except for one study, in which the unstable shoulders were examined with the patients in general anesthesia, while the control group unanesthetized.[34]

Measurements were most often made with the joint in some extent of scapular plane elevation (scaption), sagittal (flexion) or coronal (abduction) plane elevation, and less often in neutral (arm along the body). The most tested joint position was in 90° abduction and external rotation and the anterior drawer test was the most frequent manual test.

The glenohumeral translation was reported in various ways: metric, grades, or percentage of humeral head translation against the glenoid width. Although most studies compared the patient group with a healthy control group, patients' contralateral shoulders, or other shoulder pathologies, not all reported statistical analyses on the differences between groups.[15,19,25,43] Eleven of the included studies reported the superior-inferior translation in addition to the anterior-posterior (Table IV). They all used the same examination technique as for the anterior-posterior translation, but the motion task or positions differed in some cases.

An extract of the most interesting results is presented below. The complete list of the anterior-posterior translations is found in Table III and superior-inferior translations in Table IV. Details regarding the examination methods, including the motion tasks and positions during assessment and application of external force are in Supplementary Table S1.

Radiography

Anterior-posterior translation. The measurements in shoulders with traumatic anterior dislocations in the 3 studies using radiography were well less than 10 mm.[19,20,24] The largest mean translation was 5.3 ± 4.1 mm, compared to 3.4 ± 4.0 mm in the healthy controls (not statistically significant). In the same study, patients with recurrent anterior subluxations had larger anterior-posterior translation than those with dislocation, 21.1 ± 8 mm and 5.3 ± 4.1 mm, respectively ($P < .001$).[24] Another study found abnormal anterior translation in 7 patients with unstable shoulders, while the humeral head remained centralized during the test in the remaining 5 patients.[19]

Table III
Anterior-posterior glenohumeral translation.

Study	Motion task	Comment	Translation (mm, grade, or % of glenoid width as specified) *For values in mm: pos. value = anterior, neg. value = posterior if not otherwise specified*		Conclusion	Unstable > Stable
			Anterior instability	Comparator/healthy controls		
Radiography						
Hawkins[15] (1996)	Load and shift (20° abduction, 20° forward flexion, neutral rotation) + External force	Translation as % of the diameter of the glenoid.	Anterior: 29%, 2 patients dislocated without spontaneous reduction Posterior: 21%	Healthy controls: Anterior: 17% Posterior: 26% MDI: Anterior: 28% Posterior: 52%	Anterior: patient group translated 1.9× healthy controls ($P < .05$) Posterior: patient group translated 0.8× healthy controls MDI translated 1.8× healthy controls anteriorly and 1.9× healthy controls posteriorly ($P < .5$)	Yes SS
Howell[19] (1988)	a) 90° abduction, max. extension, max. external rotation b) 90° abduction, max. extension, neutral rotation	Number in parenthesis = no. of interpretable roentgenograms. Patients divided in 2 groups whether they did had abnormal translation, or no translation.	a) With translation: 3.3 ± 0.6 mm (5) Without translation: 0.2 ± 0.7 mm (4) b) Not tested in patients	Healthy controls: a): −3.9 ± 0.8 mm (15) b): −0.3 ± 0.5 mm (16)	7/12 patients showed abnormal anterior translation, no translation in the remaining 5 patients.	No %S
	90° abduction, max. external rotation		With translation: 3.6 ± 0.7 mm (6) Without translation: 0.0 ± 0.8 mm (5)	Healthy controls: −0.1 ± 0.5 mm (18)	7/12 patients showed abnormal anterior translation, no translation in the remaining 5 patients.	Yes %S
	90° abduction, 60°-80° forward flexion, max. internal rotation		With translation: 0.2 ± 0.8 mm (4) Without translation: −0.1 ± 0.6 mm (4)	Healthy controls: −0.4 ± 0.4 mm (14)	The HH remained centered in all patients.	No %S
Howell[20] (1991)	90° abduction, max. extension, and: a) max. external rotation b) neutral rotation 90° abduction, max. external rotation 90° abduction, 60-80° forward flexion, max. internal rotation		a): −3.5-(−)4.5 mm (6 patients), −0.9 ± 1.4 (7 patients) b): 0 ± 0.8 mm 0.3 ± 1.1 mm −0.1 ± 0.7 mm		Suprascalene block had no effect on the anterior-posterior translation. Of 47 analyzed roentgenograms, 2 were with anterior translation >3.5 mm.	
Jalovaara[24] (1992)	45° to the vertical axis of the glenoid fossa + External force		Recurrent ant. dislocation: 5.3 ± 4.1 mm (range 0-14 mm). Recurrent ant. subluxation: 21.1 ± 8 mm (range 3-30 mm).	Healthy controls: 3.4 ± 4.0 mm (range 0-12 mm) MDI: 27.4 ± 4.5 mm (range 20-34 mm).	Recurrent ant. dislocation group had nonsignificantly larger translation than healthy controls. Recurrent ant. subluxation group had significantly larger translation than recurrent ant. dislocation and controls, $P < .001$, and significantly less than MDI, $P < .03$	Yes NS
Paletta[43] (1997)	90° abduction, 90° forward flexion, max. internal rotation	Ratio showing anterior translation.	6/18 (33.3%)	Healthy controls: 0/6 (0%) Rotator cuff tears: 0/15 (0%) Postoperative: 0/12 (0%)	14/18 (78%) with anterior instability showed anterior translation in ≥1 position. 18/18 (100%) had abnormal ant. translation preoperatively. 11/18 (61%) showed anterior translation in ≥2 positions. No correlation between amount of translation and size of lesion.	Yes %S
	90° abduction, neutral rotation	Ratio showing anterior translation.	11/18 (61%)	Healthy controls: 0/6 (0%) Rotator cuff tears: 0/15 (0%) Postoperative: 0/12 (0%)		Yes %S
	90° abduction, max. extension, max. external rotation	Ratio showing anterior translation unless otherwise specified.	12/18 (75%)	Healthy controls: 4/6 (67.7%) remained centered, 2/6 (33.3%) translated posteriorly. Rotator cuff tears: 0/15 (0%) Postoperative: 0/12 (0%)		Yes %S

Ultrasound						
Inoue[21] (2022)	0° abduction + External force	Reference: Beach chair position, neutral rotation, 90° elbow flexion.	5.29 ± 3.12 mm Capsular tear YES: 6.77 ± 4.92 mm Capsular tear NO: 5.07 ± 2.81 mm Glenoid track YES: 5.49 ± 3.44 mm Glenoid track NO: 4.90 ± 2.20 mm		Nonsignificant differences between capsular tear YES/NO or glenoid track YES/NO. No correlation between translation and number of dislocations, clinical data, or bone loss.	
	45° abduction + External force		8.90 ± 5.16 mm Capsular tear YES: 8.41 ± 4.42 mm Capsular tear NO: 8.98 ± 5.31 mm Glenoid track YES: 9.02 ± 5.24 mm Glenoid track NO: 8.47 ± 5.17 mm		Significantly larger translation than at 0° ($P < .01$). Nonsignificant differences between capsular tear YES/NO or glenoid track YES/NO. No correlation between translation and number of dislocations, clinical data, or bone loss.	
	90° abduction + External force		9.46 ± 4.40 mm Capsular tear YES: 6.34 ± 3.19 mm Capsular tear NO: 9.92 ± 4.40 mm Glenoid track YES: 9.52 ± 4.81 mm Glenoid track NO: 9.72 ± 3.30 mm		Significantly larger translation than at 0° ($P < .01$). Nonsignificant differences between capsular tear YES/NO or glenoid track YES/NO. No correlation between translation number of dislocations, clinical data, or bone loss.	
Krarup[29] (1999)	No elevation, internal rotation and fixed to the body with a sling. + External force		Mean 4.9 ± 0.6 mm, max. 6.2 ± 0.7 mm	Healthy controls: mean 1.8 ± 0.1 mm max. 2.8 ± 0.2 mm. Mean difference left/right 0.7 ± 0.4 mm (NS), max. difference left/right 0.9 ± 0.1 mm (NS). Uninjured: mean 2.1 ± 0.2 mm, max. 3.0 ± 0.3 mm. Mean difference uninjured/injured = 2.8 ± 0.6 mm, max. difference = 3.2 ± 0.6 mm.	Injured vs. uninjured and normal side = Significantly larger for both, $P < .01$. For healthy controls, the mean and max. difference between left and right were nonsignificant.	Yes SS
Motion tracking						
Lädermann[31] (2016)	Flexion	Subluxation was defined as the ratio between the translation of the humeral head center and the radius of width.	5.1 ± 2.0 mm GH sublux.: 42% (± 16%)	Healthy controls: 1.1 ± 2.1 mm GH sublux.: 9% (± 17%) Postoperative: 4.6 ± 2.8 mm GH sublux.: 37% (± 23%)	Significant difference between unstable and healthy shoulders data (paired, 1-tailed, *t*-test, $P < .05$). Significant difference between unstable preoperative and postoperative shoulders data.	Yes SS
	Empty can scaption		6.0 ± 1.9 mm GH sublux.: 49% (± 15%)	Healthy controls: 2.0 ± 3.0 mm GH sublux.: 15% (± 23%) Postoperative: 4.9 ± 4.0 mm GH sublux.: 40% (± 33%)	Significant difference between unstable and healthy shoulders data (paired, 1-tailed, *t*-test, $P < .05$).	Yes SS
	Internal rotation		7.3 ± 2.4 mm GH sublux.: 60% (± 21%)	Healthy controls: 6.2 ± 2.4 mm GH sublux.: 48% (± 19%) Postoperative: 7.1 ± 2.3 mm GH sublux.: 58% (± 20%)	Significant difference between unstable preoperative and postoperative shoulders translation data (paired, 2-tailed, *t*-test, $P < .05$).	Yes SS
	External rotation		7.1 ± 2.3 mm GH sublux.: 58% (± 19%)	Healthy controls: 6.4 ± 2.0 mm GH sublux.: 49% (± 15%) Postoperative: 7.0 ± 2.7 mm GH sublux.: 57% (± 23%)	Significant difference between unstable and healthy shoulders data (paired, 1-tailed, *t*-test, $P < .05$).	No NS
	90° abduction, internal rotation (90° elbow flexion)		9.0 ± 2.5 mm GH sublux.: 74% (± 22%)	Healthy controls: 8.7 ± 3.2 mm GH sublux.: 67% (± 26%) Postoperative: 9.0 ± 2.0 mm GH sublux.: 74% (± 18%)		No NS

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Table III (*continued*)

Study	Motion task	Comment	Translation (mm, grade, or % of glenoid width as specified) *For values in mm: pos. value = anterior, neg. value = posterior if not otherwise specified*		Conclusion	Unstable > Stable
			Anterior instability	Comparator/healthy controls		
	90° abduction, external rotation (90° elbow flexion)		7.9 ± 2.1 mm GH sublux.: 64% (± 18%)	Healthy controls: 7.6 ± 1.9 mm GH sublux.: 58% (± 17%) Postoperative: 7.4 ± 2.6 mm GH sublux.: 62% (± 23%)		No NS
Lippitt[34] (1994)	Anterior drawer test (abduction, neutral rotation) + External force	Reference: 0° flexion, 0° rotation, 0° abduction. Mean from maximal value from 3 repetitions.	7.9 ± 3.1 mm	Healthy controls: 8.1 ± 3.8 mm AMBRII: 8.5 ± 4.0 mm	Nonsignificant differences in the mean translation (*P* > .05). Overlap between all groups. Largest value in TUBS group (14.0 mm).	No NS
	Posterior drawer test (abduction, neutral rotation) + External force		−11.6 ± 3.7 mm	Healthy controls: −7.4 ± 5.5 mm AMBRII: −12.1 ± 2.4 mm	Nonsignificant differences in the mean translation (*P* > .05). Overlap between all groups. Trend toward greater translation in TUBS and AMBRII than controls, but largest value overall seen in control subject (19.2 mm).	Yes NS
	Push-pull test (90° abduction, 20°-30° flexion, neutral rotation) + External force		0.3 ± 3.7 mm	Healthy controls: −0.8 ± 3.2 mm AMBRII: 0.0 ± 3.5 mm	Nonsignificant differences in the mean translation (*P* > .05). Overlap between all groups.	No NS
	Fulcrum test (90° abduction, external rotation, extension) + External force		−11.1 ± 4.1 mm	Healthy controls: −8.9 ± 6.4 mm AMBRII: −13.0 ± 3.4 mm	Nonsignificant differences in the mean translation (*P* > .05). Overlap between all groups.	Yes NS
MRI						
Kiss[28] (1997)	0° elevation, max. internal rotation	Reference: 0° elevation, neutral rotation. Mean (SEM).	−0.89 (0.55) mm (NS, *P* = .067)	Healthy controls: −1.01 (0.17) mm Stabilized: −1.6 (0.64) mm MDI: 4.5 mm	Significant posterior translation among healthy controls from reference to internal rotation (*P* < .01), nonsignificant translation in other groups.	No NS
	0° elevation, max. external rotation		0.11 (0.34) mm, mean rotation 48° (± 14).	Healthy controls: 0.05 (0.20) mm, mean rotation 71° (± 7) Stabilized: −0.06 (0.59) mm, mean rotation 42° (± 14) MDI: 2.13 mm	Nonsignificant translation in all groups.	No NS
	Full elevation, internal rotation (overhead)		0.11 (0.51) mm, mean rotation 64° (± 20).	Healthy controls: −0.01 (0.39) mm, mean rotation 90° (± 0) Stabilized: −0.50 (1.18) mm, mean rotation 72° (± 18) MDI: 4.13 mm	Nonsignificant translation in all groups.	No NS
von Eisenhart-Rothe[9] (2002)	90° abduction, neutral rotation.	Reference: 30° abduction, neutral rotation HH position = Mean 3D position of HH relative to the glenoid	2.6 ± 1.1 mm HH position: 2.3 ± 1.6 mm	Healthy (contralateral traumatic): 0.7 ± 0.6 mm HH position: 0.8 ± 1.1 mm Atraumatic unstable: −0.5 ± 2.7 mm HH position: −1.0 ± 1.9 mm Hyperlax (contralateral atraumatic): 1.1 ± 0.7 mm HH position: −0.7 ± 0.8 mm	Patient group: Significantly different location of the HH between reference and first position, *P* < .05. Comment HH position: All patients demonstrated inferior and anterior displacement of the HH at 30° of abduction. The location of the HH in the contralateral healthy was not uniform (6 patients anteriorly, 6 posteriorly). However, all shoulders were seen to have a nearly centered humeral head position with displacement < 1 mm and there was no significant difference in HH location between unstable and contralateral healthy. Atraumatic unstable: Generally nonuniform translations between subjects. Comment HH position: The HH was located significantly more superior (*P* < .05) and posterior (*P* < .05) in the atraumatic group vs. the traumatic.	Yes %S

	90° abduction, max. external rotation, and: a) No weight b) Weight inducing external rotation (no weight as reference) + External force	a) 3.0 ± 1.1 mm HH position: 2.8 ± 1.1 mm b) −1.1 ± 0.5 mm HH position: 1.6 ± 0.7 mm	Healthy (contralateral traumatic): a) 0.2 ± 1.1 mm HH position: 0.3 ± 0.7 mm b) −0.3 ± 0.6 mm HH position: −0.1 ± 0.5 mm Atraumatic unstable: a) −1.9 ± 3.1 mm HH position: −1.6 ± 3.0 mm b) 3.6 ± 1.9 mm. HH position: 2.6 ± 2.9 mm Hyperlax (contralateral atraumatic): a) 0.3 ± 1.1 mm HH position: −1.6 ± 2.2 mm b) 1.9 ± 1.4 mm HH position: 0.6 ± 1.3 mm	Patient group: a) significantly larger translation than in contralateral. b) Translation centralizing the HH, $P < .05$. Healthy (contralateral traumatic): b) translation centralizing the HH, $P < .05$. Atraumatic unstable: b) Significantly larger than traumatic unstable. Hyperlax (contralateral atraumatic): b) no centralizing effect. The amount and direction of translation was significantly different vs. healthy/contralateral traumatic, $P < .05$.	a) Yes SS b) No NS
CT					
Kim[27] (2017)	Max. scaption	1-2 mm	Healthy controls: 1-2 mm	No significant effect of abduction angle on AP translation for either shoulder ($P > .05$). HH location: Significant difference in unstable vs. healthy AP translation at starting position, 2.29 mm ($P = .0089$) but diminished during elevation.	No NS
	90° abduction, internal-to-external rotation	1.7 mm	2.1 mm	No significant difference between groups. HH location: Unstable humeral head located 0.4 mm more anterior than healthy at starting position.	No NS
	Modified apprehension (90° abduction, internal-to-external rotation) + External force	−0.246 ± 0.206 mm	−0.270 ± 0.429 mm	Nonsignificant difference between groups.	No NS
Matsumura[35] (2019)	90° abduction, 0° to max. external rotation	Differences patient group vs. healthy controls: 20° ER: 1.4 mm 40° ER: 2.0 mm 60° ER: 2.1 mm max. ER: 2.6 mm HH location in starting position: on average 0.4 ± 1.8 mm anterior, 0.6 ± 1.7 mm inferior, 24.7 ± 1.7 mm lateral to the glenoid origin.	Healthy controls: 40° ER: −2.1 mm, $P = .008$ 60° ER: −2.8 mm, $P < .001$ max. ER: −3.4 mm, $P < .001$ HH location in starting position: on average 0.6 ± 1.7 mm posterior, 0.1 ± 1.2 mm superior, 24.0 ± 1.5 mm lateral to the glenoid origin.	Patient group: Nonsignificant posterior translation during external rotation within group. Patient group vs. healthy controls: The unstable shoulder showed significantly less posterior translation at all measurements. 20° ER: $P = .028$ 40° ER: $P = .009$ 60° ER: $P = .017$ max. ER: $P = .013$ HH location at starting position: Nonsignificant changes patient-group vs. healthy controls.	No NS
Peltz[44] (2015)	Apprehension test (90° abduction, neutral to 50° external rotation)	4.7 ± 1.8 mm HH location: −0.2 ± 2.5 mm	Healthy controls: 5.7 ± 2.3 mm HH location: −2.3 ± 1.5 mm Postoperative: 3.6 ± 1.0 mm HH location: −1.3 ± 2.7 mm	Nonsignificant difference between unstable and healthy ($P = .39$). Postoperative vs. unstable and postoperative vs. healthy controls: Significant ($P = .01$) HH location: Statistically significant difference unstable vs. healthy controls and unstable vs. postop ($P = .03$).	No NS
Instrumented					
Jørgensen[26] (1995)	0° elevation, neutral rotation (90° elbow flexion). + External force	6.4 ± 3.6 mm	Healthy controls: Left: 2.1 ± 1.7 mm Right: 2.1 ± 1.7 mm Uninjured side: 2.8 ± 2.9 mm Overhand atheletes: Symptomatic: 5.8 ± 2.6 mm Unsymptomatic: 3.2 ± 2.0 mm MDI:	Traumatic unstable vs. healthy: Highly significant difference ($P < .002$). Traumatic unstable vs. MDI: Highly significant ($P < .002$). Within groups: Patient group: delta AP = 3.6 ± 2.0 mm, $P = .008$ Overhand athletes: delta AP = 2.6 ± 1.8 mm, $P = .02$ MDI: delta AP = 2.3 ± 2.1 mm, $P = .4$ (NS) Healthy controls: delta AP = .6 ± 0.5 mm, $P = 1.0$ (NS)	Yes SS

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Table III (*continued*)

Study	Motion task	Comment	Translation (mm, grade, or % of glenoid width as specified) *For values in mm: pos. value = anterior, neg. value = posterior if not otherwise specified*		Conclusion	Unstable > Stable
			Anterior instability	Comparator/healthy controls		
				Left: 11.9 ± 6.3 mm Right: 11.0 ± 6.4 mm		
Manual testing						
Faber[10] (1999)	Awake: Load and shift (20° abduction, 20° forward flexion, neutral rotation) + External force	Mean translation grade. Grade 0: no translation Grade 1: Up glenoid force (1 cm) Grade 2: To glenoid rim (2 cm) Grade 3: Dislocated over rim (3 cm).	anterior: 1.6 ± 0.6 (grade 0: 0, grade 1: 23, grade 2: 24, grade 3: 3) posterior: 1.2 ± 0.5 (grade 0: 0, grade 1: 13, grade 2: 34, grade 3: 3)	Healthy controls: anterior: 1.2 ± 0.4 (grade 0: 0, grade 1: 40, grade 2: 10, grade 3: 0) posterior: 1.1 ± 0.4 (grade 0: 2, grade 1: 17, grade 2: 31, grade 3: 0)	Significant difference between awake and EUA within patient group and within control group for both anterior and posterior translation ($P < .05$). 92% of patients translated > 1 grade higher in anterior direction during EUA. Awake: Significant difference in anterior translation only between groups.	Anterior) Yes SS Posterior) No NS
	EUA: Load and shift (20° abduction, 20° forward flexion, neutral rotation) + External force		anterior: 2.8 ± 0.4 (grade 0: 0, grade 1: 1, grade 2: 7, grade 3: 42) posterior: 1.8 ± 0.5 (grade 0: 0, grade 1: 13, grade 2: 34, grade 3: 3)	Healthy controls: anterior: 1.8 ± 0.6 (grade 0: 2, grade 1: 12, grade 2: 31, grade 3: 5) posterior: 1.7 ± 0.6 (grade 0: 2, grade 1: 15, grade 2: 31, grade 3: 2)	EUA: Significant difference in anterior translation between groups ($P < .05$). 84% of patients translated > 1 grade higher than healthy control.	Anterior) Yes SS Posterior) No NS
Jia[25] (2009)	EUA: Anterior/posterior drawer test (60°-80° abduction, 10°-15° forward flexion) + External force	Grade 1: < 1 cm Grade 2: 1-2 cm Grade 3: > 2 cm NB Only comparators with instability included in this report.	Anterior: Grade 1: 6 (2.6%), grade 2: 191, (82.7%), grade 3: 34 (14.7%) Posterior: Grade 1: 41 (17.7%), grade 2: 187 (81.0%), grade 3: 3 (1.3%)	Posterior instability: Anterior: Grade 1: 0 (0%), grade 2: 31(100%), grade 3: 0 (0%) Posterior: Grade 1: 2 (6.5%), grade 2: 16 (51.6%), grade 3: 13 (41.9%) MDI: Anterior: Grade 1: 1 (3.8%), grade 2: 23 (88.5%), grade 3: 2 (7.7%) Posterior: Grade 1: 4 (15.4%), grade 2: 18 (69.2%), grade 3: 4 (15.4%) Other GH instability: Anterior: Grade 1: 2 (5.9%), grade 2: 32 (94.1%), grade 3: 0 (0%) Posterior: Grade 1: 10 (29.4%), grade 2: 24 (70.6%), grade 3: 0 (0%)	Grade 2 and grade 3-laxity, compared to grade 1, in anterior direction, increased the odds of a diagnosis with anterior instability (odds ratio 9.8 and 170, respectively). Grade 2 and grade 3-laxity, compared to grade 1, in posterior direction, increased the odds of a diagnosis with anterior instability (odds ratio 4.6 and 32, respectively).	
Oliashirazi[40] (1999)	EUA: Load and shift, 20°-30° abduction, 0°-10° extension (anterior) or flexion (posterior), and: a) neutral rotation b) 40° internal (posterior)/ external (anterior) rotation c) 80° internal (posterior)/ external (anterior) rotation + External force	Grade 1: no translation Grade 2: mild translation (between none and upward onto the glenoid rim) Grade 3: moderate translation (upward onto the glenoid rim) Grade 4: severe translation (over the glenoid rim = dislocated) While awake, clinical examination with passive translation in neutral rotation revealed grade 3 or 4 in 12 patients in anterior direction and in 9 patients and in posterior direction.	Mean anterior: a) 3.9 b) 2.0 c) 1.1 Mean posterior: a) 3.3 b) 2.1 c) 1.1	Healthy controls: Mean anterior: a) 3.8 b) 1.7 c) 1.0 Mean posterior: a) 3.3 b) 2.0 c) 1.1	Significant difference in translation within group depending on rotation ($P < .0001$).	No NS
	EUA: 70°-80° abduction, 0°-10° extension (anteroinferior) or flexion (posteroinferior), and: a) neutral rotation b) 40° internal (posterior)/		Mean anteroinferior: a) 4.0 b) 4.0 c) 3.9 Mean posteroinferior: a) 3.8	Healthy controls: Mean anteroinferior: a) 4.0 b) 2.3 c) 1.5 Mean posteroinferior:	Only significant difference between unstable and control were in anteroinferior direction with external rotation: b) $P < .0001$ c) $P < .0001$	Anteroinferior b, c) Yes SS Posteroinferior a, b, c) No NS

	external (anterior) rotation c) 80° internal (posterior)/ external (anterior) rotation + External force		b) 1.9 c) 1.0	a) 3.8 b) 1.8 c) 1.0	
Tanaka[49] (2012)	EUA: 90° scaption, external-to-internal rotation. + External force	Grade 1: The humeral head rises up the glenoid slope but not over the glenoid rim. Grade 2: The humeral head rides up and over the glenoid rim but spontaneously reduces when stress is removed. Grade 3: The humeral head rides up and over the glenoid rimand remains dislocated on removal of stress.	Anterior: Grade 1: 5, grade 2: 27, grade 3: 8		The average rotational angle for patients that showed grade 2 translation was between 1.9° internal rotation and 52.2° external rotation (center 25.2°). For patients with grade 3 translation, the rotational angles ranged from 8.8° internal rotation to 65° external rotation. Meaning, shoulders with grade 3 translation showed anterior translation in a wider range of rotation, especially in external rotation. The differences were nonsignificant. Only 1 patient showed translation at end-range external rotation, remaining shoulders translated in the middle range of rotation.
Warner[51] (2006)	EUA: Abduction, external rotation. + External force		Grade 3+: 11. All dislocated and remained locked out		

EUA, examination under anaesthesia; *MRI*, magnetic resonance imaging; *CT*, computed tomography; *MDI*, multidirectional instability; *Scaption*, scapular plane elevation; *HH*, humeral head; *SS*, statistical significance; *NS*, nonstatistical difference; *%S*, no reported statistics; max., maximum; *ER*, external rotation; *AP*, anterior-posterior; *AMBRII*, atraumatic multidirectional bilateral (responds to) rehabilitation inferior capsule shift interval closure; *GH*, glenohumeral.

Supplementary Table S1 provides full details on motion task and positions and external force. The last column shows whether the results indicate that the translation was larger in the unstable than the stable shoulders (>1 mm, >1 grade or statistically significant difference, or >30% difference between stable and unstable was considered as a positive indication).

Three years later, the same group published an experiment in a similar setup but in patients with a suprascapular nerve block. Under these circumstances, patients were also split up into groups showing either no (defined as normal) or abnormal translation.[20] Abnormal kinematics were only seen in the posterior direction in this study (3.5-4.5 mm). The results from 2 other studies clearly indicated that the anterior-posterior translation was larger in unstable shoulders than in stable, of which one showed statistical significance while the other did not publish a statistical analysis.[15,43]

Superior-inferior translation. One study reported superior-inferior translation in millimeters.[24] During autotraction of the arm with 45° angle to the vertical axis of the glenoid, a mean inferior translation of 9.8 ± 6.6 mm was found in patients with recurrent anterior dislocations. Compared to the healthy control group, with a mean of 6.7 ± 6.3 mm, the difference was without statistical significance. The dislocation group translated significantly less than patients with recurrent subluxations ($P < .001$). The results from the remaining studies also indicated that inferior translation was larger in the unstable shoulders than in healthy controls.[15,43]

Ultrasound

Anterior-posterior translation. The mean anterior-posterior translation in the unstable shoulders was less than 10 mm. An external anterior force and stepwise abduction from 0° to 45° and 90° led to a statistically significant increase in translation from 5.29 ± 3.12 mm to 8.90 ± 5.16 mm and 9.46 ± 4.40 mm, respectively ($P < .01$).[21] Associated capsular tear and being glenoid on-track/off-track did not statistically influence the translation in this study. The other study found a mean anterior-posterior translation of 4.9 ± 0.6 mm in the injured shoulders, 2.1 ± 0.2 mm in the uninjured, and 1.8 ± 0.1 mm in the healthy controls.[29] The difference between the unstable and both other groups was statistically significant ($P < .01$).

Motion capture

Anterior-posterior translation. Skin-based motion capture technique showed larger translation in unstable shoulders than in healthy with the arm along the side, elevated, and rotated.[31] All tests in this study showed anterior translation, ranging from a mean of 5.1 ± 2.0 mm during flexion to 9.0 ± 2.5 mm during 90° abduction and internal rotation in unstable shoulders, compared to 1.1 ± 2.1 mm and 8.7 ± 3.2 mm in the contralateral stable shoulders. The differences between unstable and stable shoulders were statistically significant during flexion and empty can scaption, while the other tests were not.

Electromagnetic motion capture showed less consistent results.[34] Anterior translation was seen during anterior drawer test, posterior translation during posterior drawer test, and fulcrum test, while the humeral head remained centralized during push-pull test. The study compared patients with traumatic instability to patients with atraumatic instability and healthy controls and found overlap between all groups in each test and statistically nonsignificant differences. However, the group with traumatic instability tended to have larger posterior translation than the healthy control group.

Superior-inferior translation. A manual sulcus test showed a mean inferior translation of 11.2 ± 3.1 mm in patients with traumatic anterior instability and 11.2 ± 3.6 mm in healthy subjects, while it was 9.1 ± 3.3.4 mm in patients with atraumatic multidirectional instability.[34] None of the group differences were statistically significant.

Magnetic resonance imaging

Anterior-posterior translation. The MRI studies found diverging results. One measured <1 mm translation with the arm along the side and overhead (elevation and internal rotation) and found no difference between stable and unstable shoulders.[28] The other study found an anterior translation of 2.6 ± 1.1 mm as the arm was elevated from 30° to 90° and in neutral rotation and 3.0 ± 1.1 mm from 30° to 90° elevation and external rotation. A 10 N weight inducing external rotation applied to the abducted shoulder led to a posterior translation of 1.1 ± 0.5 mm in unstable shoulders, thus recentering the humeral head.[9] In this study, all tests showed larger mean translation in the patients' injured than in the uninjured sides, leading to a statistically significant further anterior position of the humeral head.

Superior-inferior translation. Elevation of a neutrally rotated arm from 30° to 90° abduction led to a mean inferior translation in both shoulders in patients with unilateral traumatic instability, while the same movement caused a mean superior translation in patients with unilateral atraumatic instability.[9] When the abducted shoulder was further externally rotated, the traumatically unstable shoulder translated more inferior than the stable contralateral (1.7 ± 1.5 mm and 1.2 ± 0.7 mm, respectively, $P < .05$). The same pattern was seen in patients with atraumatic instability. Applying a 10 N weight inducing external rotation led to superior translation recentering the humeral head in the shoulders with both traumatic and atraumatic instability as well as the contralateral of the traumatically unstable, but not in the contralateral of those with atraumatic instability.

Computed tomography

Anterior-posterior translation. A dynamic 4-dimensional CT scan registered posterior translation in both unstable and contralateral uninjured shoulders during 90° abduction and external rotation. In all measurements, the unstable shoulders translated statistically significantly less than the uninjured contralateral shoulder. Furthermore, the posterior translation in the unstable shoulders during rotation from 20° to 40° and 60° and maximal external rotation was without statistical significance.[35] Besides less posterior translation, the humeral head starting position tended to be more anterior on the injured side. The 2 other CT studies similarly found a more anterior location of the humeral head in the unstable shoulders than in stable.[27,44] One found a translation of 1-2 mm in both unstable and stable shoulders during active elevations and there was neither any difference between the groups when applying an anterior force.[27] The other study measured the translation during an apprehension test and found 4.7 ± 1.8 mm in the unstable and 5.7 ± 2.3 mm in the healthy control group.[44] The difference between unstable and healthy shoulders was not statistically significant ($P = .39$).

Superior-inferior translation. All 3 CT studies found a net inferior translation during the motion tasks, although one study measured an initial superior translation.[27] Matsumura et al found 1.7-2.1 mm inferior translation in unstable shoulders, while it was significantly less in stable ($P < .05$).[35] Another study found a mean inferior translation of 5.2 ± 1.9 mm in unstable shoulders during the apprehension test, which was less than the mean 6.7 ± 2.9 mm in healthy controls but without statistical significance.[44]

Instrumented

Anterior-posterior translation. Using a knee laxity tester to apply external force as well as to measure the translation with the arm along the side and in neutral rotation, an anterior force led to a mean anterior translation of 6.4 ± 3.6 mm in unstable shoulders.[26] The difference between the injured and the uninjured side was 3.6 ± 2.0 mm ($P = .008$). The translation in the unstable shoulders was also different from a healthy control group ($P < .002$).

Manual testing

Anterior-posterior translation. Five studies reported the translation in grades during manual laxity testing.[10,25,40,49,51] Patients were in general anesthesia during the examination in all studies except for one, which examined their patients both anesthetized and awake. In this study, the mean grade of anterior translation increased from 1.6 ± 0.6 to 2.8 ± 0.4 and the posterior translation from 1.2 ± 0.5 to 1.8 ± 0.5 after anesthesia was induced. The change was statistically significant for both directions ($P < .05$).[10] The measurements were also compared to healthy controls, showing statistically significantly larger anterior translation both with and without anesthesia in the unstable shoulders.

Superior-inferior translation. General anesthesia led to a mean inferior translation that was statistically significantly larger than when the patients were awake ($P < .05$). Under anesthesia, the difference between unstable and stable shoulders was also statistically significant, while nonsignificant difference was found between the groups when they were awake.[10]

Validity and reliability

Eleven studies reported measurement validity and/or reliability (Table I). Similar to the differing methods used for measuring the translation, the studies assessed their examination techniques differently. Two studies using radiography reported reliability, one with interobserver variance of −0.0 ± 1.2 mm and the other with kappa values of 0.914-0.9678 for intraobserver and interobserver reliability.[20,43] The 2 studies using ultrasound also reported the reliability. One found moderate to good reliability, assessed from the ICC.[21] The other described their method as "considerable", although one examiner consistently recorded higher values than the other.[29] The 2 studies using motion capture reported the measurement accuracy: one within 3 mm translation and 4° rotation and the other within 1 mm in cadavers.[31,34] One study performing manual laxity tests under anesthesia assessed the validity based on a predetermined standard of abnormality, defining instability as having grade 3 or 4 and 2 or more grades higher than in the contralateral and argued that the sensitivity was 83%, while both specificity and positive predictive value were 100%.[40] The highest measurement accuracy was from one of the CT studies, reportedly within ± 0.4 mm and ± 0.5°.[44] The study using a knee laxity tester reported the highest ICC of 0.996.[26]

Discussion

Most important findings

The anterior-posterior glenohumeral translation in shoulders with traumatic anterior instability ranged from none to almost 12 mm during different motion tasks or positions or exposed to external force. Our aim to create an overview of the unstable glenohumeral joint kinematics showed more difficult than expected due to the lack of standardization and unity in measurement methods and test setup. The comparison of unstable and stable shoulders was more consistent and clearer, confirming the hypothesis that the anterior-posterior translation is larger in the unstable joint. Furthermore, some studies reported a more anterior position of the humeral head on the glenoid of unstable shoulders, which might affect the pathophysiology.

Table IV
Superior-inferior glenohumeral translation.

Study	Motion task	Comment	Translation (mm, grade, or % of glenoid width as specified) *For values in mm: pos. value = inferior, neg. value = superior if not otherwise specified*		Conclusion	Unstable > Stable
			Anterior instability	Comparator/healthy controls		
Radiography						
Hawkins[15] (1996)	Inferior traction to end point in supine patient	Translation as % of the diameter of the glenoid.	Inferior: 49%	Healthy controls: Inferior: 29% MDI: Inferior: 46%	Patient group translated 1.7× healthy controls ($P < .05$). MDI translated 1.6× healthy controls ($P < .5$).	Yes SS
Jalovaara[24] (1992)	45° to the vertical axis of the glenoid fossa + External force		Recurrent ant. dislocation: 9.8 ± 6.6 mm (range 2-23 mm) Recurrent ant. subluxation: 19.3 ± 6.6 mm (range 9-31 mm)	Healthy controls: 6.7 ± 6.3 mm (range 0-21 mm, 2 controls 20-21 mm) MDI: 25.7 ± 5.4 mm (range 21-39 mm)	Recurrent ant. dislocation nonsignificantly larger translation than healthy controls. Recurrent ant. subluxation significantly larger translation than recurrent ant. dislocation and controls, $P < .001$, significantly less than MDI $P < .02$.	Yes NS
Paletta[43] (1997)	Scaption 0°, 45°, 90°, 120°, maximal. + External force		Superior: 7/18 (39%)	Healthy controls: 0/6 (0%) Rotator cuff tears: Superior: 0°: 7/15 (47%) 45°: 10/15 (67%) 90°: 12/15 (80%) 120°: 11/14 (79%) max.: 5/9 (56%) Postoperative: 0/12 (0%)	No correlation between amount of translation and size of lesion	Yes %S
Motion tracking						
Lippitt[34] (1994)	Sulcus test (0° flexion, neutral rotation, abduction) + External force	Reference: 0° flexion, 0° rotation, 0° abduction. Mean from maximal value from 3 repetitions.	11.2 ± 3.1 mm	Healthy controls: 11.2 ± 3.6 mm AMBRII: 9.1 ± 3.4 mm	Nonsignificant difference between groups ($P > .05$)	No NS
MRI						
von Eisenhart-Rothe[8] (2002)	90° abduction, neutral rotation.	Reference: 30° abduction, neutral rotation HH position = Mean 3D position of HH relative to the glenoid	0.6 ± 0.6 mm	Healthy (contralateral traumatic): 0.7 ± 0.4 mm Atraumatic unstable: −0.2 ± 1.5 mm Hyperlax (contralateral atraumatic): −1.3 ± 1.1 mm	Patient group: Significantly different location of the HH between reference and first position, $P < .05$. Comment HH position: All patients demonstrated inferior displacement of the HH at 30° of abduction. In the contralateral healthy the location of the HH was not uniform (7 patients superiorly, 5 inferiorly). However, all shoulders were seen to have a nearly centered HH position with displacement < 1 mm, and there were no significant differences in HH location between unstable and contralateral healthy. Atraumatic unstable: Generally nonuniform translations between subjects. Significantly different from traumatic unstable. Comment HH position: The HH was located significantly more superior ($P < .05$) in the atraumatic group vs. the traumatic.	No NS
	90° abduction, max. external rotation, and: c) No weight d) Weight inducing external rotation (no weight as reference) + External force		c) 1.7 ± 1.5 mm d) −1.2 ± 1.1. mm	Healthy (contralateral traumatic): c) 1.2 ± 0.7 mm d) −1.1 ± 0.7 mm Atraumatic unstable: c) 1.8 ± 2.3 mm d) −0.8 ± 2.8 mm.	Patient group: a) Significantly larger translation than in contralateral. b) Superior translation centralizing the HH, $P < .05$. Healthy (contralateral traumatic): b) Superior translation centralizing the HH, $P < .05$. Atraumatic unstable: b) Significantly larger	a and b) No NS

(*continued on next page*)

Table IV (*continued*)

Study	Motion task	Comment	Translation (mm, grade, or % of glenoid width as specified) *For values in mm: pos. value = inferior, neg. value = superior if not otherwise specified*		Conclusion	Unstable > Stable
			Anterior instability	Comparator/healthy controls		
				Hyperlax (contralateral atraumatic): c) 0.4 ± 0.8 mm d) −0.4 ± 0.8 mm	than traumatic unstable. Hyperlax (contralateral atraumatic): b) no centralizing effect. The amount and direction of translation was significantly different ($P < .05$) vs. healthy.	
CT						
Kim[27] (2017)	Max. scaption		1-2 mm	Healthy controls: 1-2 mm	No significant effect of abduction angle for either shoulder ($P > .05$). Nonsignificant difference unstable vs. healthy ($P = .0585$).	No NS
Matsumura[35] (2019)	90° abduction, 0°-to-max. external rotation		The HH translated inferiorly during external rotation 20° ER: N/A 40° ER: N/A 60° ER: 1.7 mm max. ER: 2.1 mm HH location in starting position: on average 0.6 ± 1.7 mm inferior to the glenoid origin.	Healthy controls: 40° ER: N/A 60° ER: 1.2 mm, $P < .001$ max. ER: 1.7 mm, $P < .001$ HH location in starting position: on average 0.1 ± 1.2 mm superior to the glenoid origin.	Patient group: Significant inferior translation at 60° and maximal external rotation within group. Patient group vs. healthy controls: The unstable shoulder showed significantly larger translation. Differences: 20° ER: 0.8 mm, $P = .037$ 40° ER: 0.6 mm, $P = .047$ 60° ER: NA max. ER: 0.4 mm, $P = .047$ HH location at starting position: Nonsignificant changes patient group vs. healthy controls.	Yes SS
Peltz[44] (2015)	Apprehension test (90° abduction, neutral to 50° external rotation)		5.2 ± 1.9 mm	Healthy controls: 6.7 ± 2.9 mm Post-operative: 6.0 ± 2.1 mm	Nonsignificant differences between all groups.	No NS
Manual testing						
Faber[9] (1999)	Awake: Sulcus test + External force	Mean translation grade. Grade 0: no translation Grade 1: Up glenoid force (1 cm) Grade 2: To glenoid rim (2 cm) Grade 3: Dislocated over rim (3 cm).	Inferior: 1.1 ± 0.3 (grade 0: 1, grade 1: 45, grade 2: 4, grade 3: 0)	Healthy controls: inferior: 1.1 ± 0.3 (grade 0: 2, grade 1: 45, grade 2: 3, grade 3: 0)	Significant difference between awake and EUA within patient group and within control group ($P < .05$). Awake: Nonsignificant difference between groups	No NS
	EUA: Sulcus test + External force		Inferior: 1.6 ± 0.7 (grade 0: 2, grade 1: 20, grade 2: 25, grade 3: 3)	Healthy controls: inferior: 1.4 ± 0.6 (grade 0: 2, grade 1: 28, grade 2: 20, grade 3: 0)	EUA: Significant difference between groups ($P < .05$).	Yes SS
Jia[25] (2009)	Sulcus sign in EUA. Patient supine.	Grade 1: < 1 cm Grade 2: 1-2 cm Grade 3: > 2 cm NB Only comparators with instability included in this report.	Inferior: Grade 1: 128 (55.4%), grade 2: 94, (40.7%), grade 3: 9 (3.9%)	Posterior instability: Inferior: Grade 1: 15 (48.4), grade 2: 15 (48.1%), grade 3: 1 (3.2%) MDI: Inferior: Grade 1: 7 (26.9%), grade 2: 15 (57.7%), grade 3: 4 (15.4%) Other GH instability: Inferior: Grade 1: 13 (38.2%), grade 2: 19 (55.9%), grade 3: 2 (5.9%)	Grade 2 and grade 3-laxity, compared to grade 1, in inferior direction, increased the odds of a diagnosis with inferior instability (odds ratio 4.4 and 10.3, respectively).	
Oliashirazi[40] (1999)	Inferior translation: 20° abduction, 0° flexion, and neutral rotation Approximately 1-3 kg	Estimated in cm	Mean inferior: 2.8 cm	Healthy controls: Mean inferior: 2.4 cm	Nonsignificant difference between groups.	Yes NS

MRI, magnetic resonance imaging; *CT*, computed tomography; *MDI*, multidirectional instability; *SS*, statistical significance; *Scaption*, scapular plane elevation; *EUA*, examination under anaesthesia; *NS*, nonstatistical difference; *HH*, humeral head; *ER*, external rotation; *N/A*, not applicable; *GH*, glenohumeral; *%S*, no reported statistics.
See Supplementary Table S1 for full details on motion task and positions and external force.
The last column shows whether the results indicate that the translation was larger in the unstable than the stable shoulders (>1 mm, >1 grade or statistically significant difference, or >30% difference between stable and unstable was considered as a positive indication). Studies not listed in the table did not report superior-inferior translation.

Based on the heterogeneity of the collected data, it is not possible to define normal and abnormal translation. The smallest anterior-posterior translation found was 0.0 ± 0.8 mm in 5 of 12 patients with recurrent instability during 90° abduction and maximal external rotation.[19] However, in the same study, 7 patients with similar characteristics translated 3.6 ± 0.7 mm during the same test. The largest registered translation overall was 11.6 ± 3.7 mm in posterior direction during a posterior drawer test found in patients with traumatic anterior instability.[34]

Differences between shoulder conditions

Considering the differing test protocols, comparing data between studies is complicated, but data from the same test protocol provide a better comparison of the biomechanical states in the unstable and stable glenohumeral joint. The anterior-posterior translation was generally larger in the unstable than in stable shoulders. None of the reports with larger translation in healthy shoulders were statistically significant. In some measurements, the direction of the translation was different between the groups: anterior in the unstable group and posterior in the stable. This indicates that the translation in the unstable shoulders not necessarily is larger but primarily anteriorly directed toward the structural pathology. Furthermore, several of the included studies support the excessive translation does not necessarily equal clinically relevant instability and vice versa.[15,24,25,34]

Examination methods

Our second hypothesis was that the measurement technique would influence the measured translation. It is essential to know the validity and reliability of a technique to fully evaluate its measurements, but 9 of the 20 studies did not provide such data. The reported translations varied a lot. But not only the measurement technique differed between studies, so did the test setup and protocols. Some performed examinations under anesthesia while others did not, and different motion tasks and shoulder positions were tested, with or without external force applied to the shoulders. Some even had different protocols for patients and controls within the same study.[19,34] Nevertheless, the largest translation seems to be measured with motion capture technique followed by ultrasound. The pin-based electromagnetic tracking reported a high level of accuracy, but its invasiveness hinders clinical application, and it was the only study that used it.[12]

Humeral head location

In 2015, Peltz et al used bi-plane radiography combined with 3-dimensional CT scans, with a reported accuracy of ± 0.4 mm, to measure the glenohumeral translation while performing the apprehension test.[44] Similar to few other studies, they found larger translation in the healthy controls than in unstable shoulders, but without statistical significance.[34,35] More interestingly, the average joint contact center was found significantly more anterior on the glenoid in patients than in controls. The average joint contact center was moved posteriorly following arthroscopic stabilizing surgery ($P = .03$), and the patient-reported outcome measures were significantly improved ($P = .0002$). These results indicate that an excessive anterior position of the humerus in unstable shoulders—not increased micromotion—cause apprehension, and a less anterior position postoperatively would explain the improved clinical scores. There was only one study with a study population with primary dislocation.[27] They found a significant difference in translation during scapular plane elevation between groups, but none during a modified apprehension test. Although patients had only suffered a single dislocation, the humeral head was more anteriorly located in the patients than in controls, which further supports the theory that the position more than the translation triggers apprehension. The same pattern was seen in the study by von Eisenhart-Rothe et al in patients with recurrent instability.[9] Apprehension is central in the anterior shoulder instability disorder. The discomfort and unstable sensation that patients experience arise from a complex pathology probably including both mechanical and neurological impairments.[32]

Limitations of the study

A limitation of this systematic review was the heterogeneity of data, which made it impossible to perform a meta-analysis. Furthermore, our search yield identified an enormous number of articles. The search terms were broad, but there is a risk that some studies were missed. Furthermore, although 2 reviewers independently performed screening prior to final inclusion, there is a risk that studies were wrongly excluded. The same authors performed quality assessment of the included studies. The NOS was used for all studies, and a specific scale was chosen depending on study type. The NOS was chosen based on its simplicity and previous reports on validity for systematic reviews of nonrandomized studies.[6] The scale has been criticized, but primarily for use in meta-analyses, which this review does not include.[48]

Strengths of the study

The authors strictly followed the PRISMA guidelines throughout the process.[42] Two reviewers were dedicated in fulfilling the review steps and full agreement on data collection was ultimately ensured. The search strategy was optimized by consulting a medical librarian. The authors are thus confident that the data collection was exhaustive, and the research question answered as good as possible, considering the available data.

Perspectives

In today's management of traumatic shoulder instability, the surgeon gathers information from the medical history, the clinical examination, and imaging. The authors of this review support a multifactorial approach to treatment decision-making. However, it remains to be determined if an objective parameter would improve decision-making in the management of shoulder instability. Our results indicate that both glenohumeral translation and humeral head position play a role in the pathology of traumatic shoulder instability. Dynamic real-time MRI is nonirradiating, safe, and provides information on the glenohumeral translation as well as the humeral head position.[38] It is a promising method for objective measurements of glenohumeral kinematics.[5,11] Future research should determine the validity and reliability of real-time MRI in unstable shoulders and evaluate its clinical application.

Conclusion

The anterior-posterior glenohumeral translation is increased or more anteriorly directed in shoulders with traumatic anterior instability, and their humeral head is located more anteriorly on the glenoid cavity. However, data heterogeneity and questionable methodology of the current literature complicate interpretation of the results and no specific threshold for anterior shoulder instability was identified.

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Supplementary Data

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