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REVIEW

A structured review addressing the use of radiographic measures of alignment and the definition of acceptability in patients with distal radius fractures

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Abstract
Background Standard radiographs are routinely used in clinical care to characterize the severity of a distal radius fracture and to monitor patients following a distal radius fracture. The objective of this review was to describe the range and variability of radiographic measures described in the literature in patients following a distal radius fracture.
Methods A structured literature review was conducted using the Embase and PubMed databases. Inclusion criteria included full-text publications which employed radiographic measures to examine 100 or more participants following a distal radius fracture. A standardized data extraction form was used to identify study design, fracture classification systems, the types of and definitions of radiographic measurements, and acceptability criteria following distal radius fractures.
Results From an initial 263 studies, 31 studies were included in the final data extraction process. A narrative synthesis of the articles included in this review indicated that there was a set of commonly used radiographic measurements examined in patients with a distal radius fracture which included radial inclination, volar/dorsal tilt, intra-articular step/gap, and a measure of ulnar variance/radial shortening. While 52 % of studies referenced or published a standardized measurement technique, there was substantial variability in the actual description of each radiographic measurement performed.
Conclusions Substantial variability in how radiographic measurements are defined in large clinical studies as seen in this review suggest a need for consensus on the assessment and interpretations of radiographic measures used in patients following a distal radius fracture. Guidelines for radiographic measures should be established to ensure consistency between research and treatment centers.

Keywords Structured review · X-ray · Radiographic · Alignment · Distal radius · Fractures

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Introduction

Many factors influence the clinical result following a distal radius fracture such as gender, age, injury compensation, education, other medical comorbidities, and the characteristic of injury. As such, much of the literature examining distal radius fractures (DRF) focuses on predicting which factors are associated with successful patient outcomes.

Traditionally, fracture severity and anatomic reduction have been measured using planar radiographs. Gartland and Werley et al. published a landmark paper in 1951 which investigated radiographic measures following distal radius fractures [15]. They used a set of radiographic measures that are typically altered in a distal radius fracture injury. Many subsequent studies have examined the association of pre-reduction and post-reduction radiographic measures with functional or patient-reported outcomes. A previous study examining the relative risk of a poor outcome following mal-alignment of the distal radius concluded that patients at all ages had a higher risk of a poor outcome with mal-alignment when compared with those with acceptable alignment [18]. However, controversy exists in the literature surrounding the impact of radiographic measures on predictors of patient outcomes, particularly in the older population. Grewal et al. reported that the relative risk of poor outcomes with mal-alignment decreased with increasing age but was not statistically significant in patients older than 65 years [18]. Similarly, Anzarut et al. in a cohort of patients older than 50 years reported that acceptable radiographic reduction was not associated with better generic physical or mental health status, lower disability, or greater satisfaction [4]. Other studies suggest that substantial deformity in the alignment of the distal radius is needed before significant alteration in wrist function is evident [15].

The discrepancy between "form and function" has been attributed to a lack of highly powered studies employing standardized outcome measures while controlling for confounding variables such as fracture type and age [18, 19] or lack of standardized radiographic measures [27, 32]. Previous studies have attempted to establish normative guidelines for radiographic measurements following distal radius fractures [27, 32, 57]. However, it is unclear if standardized approaches for taking radiographic measures are consistently being used or even if there is consistent interpretation of these radiographic measures.

The objective of this structured literature review was to determine how radiographic measures are used in evaluating patients with distal radius fractures. Additionally, we sought to assess the variability in the radiographic measurement properties. Specifically, the objective was to examine the extent and range of radiographic parameters measured in research studies investigating distal radius fractures as well as their acceptability criteria and measurement properties using a systematic literature search and structured data extraction process.

Material and Methods

Literature Search and Study Identification

A literature search was conducted using the Evidence-based Medicine Reviews (Embase) and PubMed with publication dates up to and including December 2013. The search was limited to full-text-only publications, written in English. The following keywords were used to search all databases for eligible studies: Distal Radius Fracture OR Wrist Fracture AND Radiographic Outcome OR x-ray OR Imaging OR Measure OR Mal-Alignment Or Alignment. The first stage of study identification was reviewing the titles listed from Embase and PubMed using the specified keywords. In total 988 titles were reviewed (Fig. 1). Studies were excluded if they involved nonhumans, if they included less than 100 participants, if they were review articles, and if there were published in conference proceedings or as a thesis or dissertation. Additionally, studies were excluded if they did not include radiographic measurements of the distal radius, investigated medical imaging technologies other than X-ray or were surgical technique papers.

Study Selection

In total, 263 studies were included after removing two duplicate studies listed in both Embase and PubMed. All 263 abstracts were collected and screened. After abstract screening, 209 studies were excluded and 54 full-text articles were then considered eligible for data extraction. Twenty-three studies were then further excluded if after reading the full article (resulting in a final of 31 studies included), it was evident that they did not meet the inclusion criteria (16 had a sample size less than 100, 5 articles did not have actual radiographic measures, 1 was not in English, and 1 was a description of a surgical technique) (see Fig. 1).

Data Collection Process

The data extraction and review process was conducted using a standardized data extraction form that was developed for this review (Table S1). All articles were reviewed by the first author. Where there was uncertainty in the extraction, the senior author was consulted.

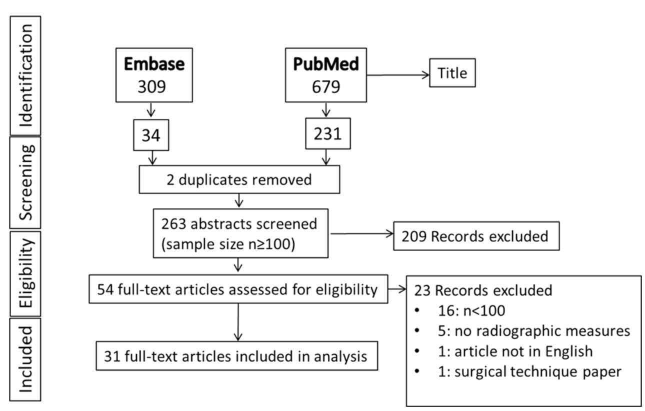


Fig. 1 Structured review flowchart

Results

Study Demographics

In total, 31 studies were included in the data extraction process. The mode of the sample size of the studies included in this review was 124 participants. Of the studies not included (231), the mode of the sample size was 20 participants and the overall average was 38 participants. Additionally, 80 % of articles not included in the study had 50 or less participants included. Table 1 lists the authors, titles, and journal reference in alphabetical order. The majority of the articles reviewed investigated adult patients (19–64 years) with distal radius fractures (84 %) (3/31 studies examined older patients ≥65, 2/31 studies investigated pediatric patients (≤18 years), and were conducted in Europe (15 studies), North America (11 studies), and Asia (5 studies)). The majority of participants/patients in these studies were woman (70 % woman). Detailed information describing the study location, sample size, age, and gender is shown in Table 2. The frequency of studies investigating radiographic measures of distal radius fracture alignment increased from 2007 to 2009 (Fig. 2) and then decreased from 2009 to 2013.

How Are Radiographic Measures Used in Studies Evaluating Patients with DRFs?

Table 2 lists the designation of each study design as a (radiographic) technique paper, prognostic or explanatory paper (for definitions of these see Table S1). Fifty-eight percent (58 %) of the studies had prognostic analysis present in their study design and reported results. The majority of these

Table 1 Summary of Studies Investigating Radiographic Measures and Distal Radiographic Fractures

Article #	Authors	Date	Start Page	End Page	Journal	Issue	Volume
1	Al-Ansari et al. 2007 [2]	2007 Jan	9	15	CJEM	9	1
2	Altissimi et al. 1986 [3]	1986 May	202	210	Clin Orthop Relat Res	33	
3	Arora et al. 2007 [5]	2007 May	316	322	J Orthop Trauma	21	5
4	Brogren et al. 2011 [6]	2011	9		BMC Musculoskelet Disord	12	
5	Brogren et al. 2013 [7]	2013 May	1691	1697	Clin Orthop Relat Res	471	5
6	Chen et al. 2013 [8]	2013	186		BMC Musculoskelet Disord	14	
7	Clayton et al. 2009 [9]	2009 Mar 1	613	619	J Bone Joint Surg Am	91	3
8	Einsiedel et al. 2009 [12]	2009 Jun	795	800	Int Orthop	33	3
9	Finsen V et al. 2013 [13]	2013 Feb	116	126	J Bone Joint Surg Am	95	15
10	Forward et al. 2008 [14]	2008 May	629	637	J Bone Joint Surg Br	90	5
11	Geller et al. 2009 [16]	2009 Oct	E161	E166	Can J Surg	52	5
12	Grewal et al. 2007 [19]	2007 Sep	962	970	J Hand Surg Am	32	7
13	Hayes et al. 2008 [20]	2008 Aug	540	547	Acta Orthopaedica	79	4
14	Jupiter et al. 2009 [21]	2009 Jan	55	65	J Bone Joint Surg Am	91	1
15	Karanta A et al. 2013 [33]	2013 Oct 2	1737	1744	J Bone Joint Surg Am	95	19
16	Kateros et al. 2010 [24]	2010 Jan	166	172	J Trauma	68	1
17	Khan et al. 2010 [25]	2010 Nov	1169	1174	Acad Emerg Med	17	11
18	Kwon et al. 2012 [28]	2012 Nov	3171	3179	Clin Orthop Relat Res	470	11
19	Leung et al. 2000 [29]	2000 Dec	145	153	Hand Surg	5	2
20	Leung et al. 2008 [30]	2008 Jan	16	22	J Bone Joint Surg Am	90	1
21	MacDermid et al. 2007 [33]	2007 Mar	47	62	J Occup Rehabil	17	1
22	MacKenney et al. 2006 [34]	2006 Sep	1944	1951	J Bone Joint Surg Br	69	4
23	Makhni et al. 2008 [35]	2008 Oct	1301	1308	J Hand Surg Am	33	8
24	Makhni et al. 2010 [36]	2010 Oct	652	658	J Hand Surg Eur Vol	35	8
25	Matschke et al. 2011 [38]	2011 May	312	317	J Orthop Trauma	25	5
26	McQueen et al. 1996 [39]	1996 May	404	409	J Bone Joint Surg Br	78	3
27	Mignemi et al. 2013 [42]	2013 Jan	40	48	J Hand Surg Am	38	1
28	Richard et al. 2011 [45]	2011 Oct	1614	1620	J Hand Surg Am	36	10
29	Sammer et al. 2008 [47]	2008 Nov	1441	1450	Plast Reconstr Surg	122	5
30	Souer et al. 2009 [50]	2009 Apr	830	838	J Bone Joint Surg Am	91	4
31	Stein et al. 1990 [51]	1990 Oct	453	456	Acta Orthop Scand	61	5

Table 2 Study Demographics

Authors	Study Location	Sample Size	Age	Male:Female	Study Design: Technique, Prognostic, Explanatory
Al-Ansari et al. 2007 [2]	Canada	124	8.7(3.3)	65:60	A, B2, B3
Altissimi et al. 1986 [3]	Italy	289	55	approx.93:196	B1,B2, C1,C2
Arora et al. 2007 [5]	Italy	114	57 (17–79)	21:93	B1, B2, C2
Brogren et al. 2011 [6]	Sweden	143	65	33:110	A, B2, B3, C1, C2, C3
Brogren et al. 2013 [7]	Sweden	123	63(19–88)	29:94	B1, B2, C1, C2
Chen et al. 2013 [8]	China	106	no fx: 50.7 (10.3), tip fx: 51.0 (11.9), Base fx: 51.7 (13.5)	53:53	B1, B2, C1
Clayton et al. 2009 [9]	UK	137	71(45–87) years old	10:127	A, B1, B2, B3, C3
Einsiedel et al. 2009 [12]	Germany	311	68(15–100)	168:143	B1, C1
Finsen V et al. 2013 [13]	Norway	260	62 (30–84) years	32:228	B2, C1, C2
Forward et al. 2008 [14]	England	106	25 (16–40) years at injury	74:32	C1, C2
Geller et al. 2009 [16]	Canada	211	NSEF:59.4,ORIF:51.2, CRPP:55.7	NSEF(6:24), ORIF(50:57), CRPP (28:46)	B1, B3,C3
Grewal et al. 2007 [19]	Canada	216	55.2(18–89)	48:168	B2
Hayes et al. 2008 [20]	UK	588	61(16–96)	118:470	B1, B3, C3
Jupiter et al. 2009 [21]	USA	150	51 years	62:88	B1
Karanta A et al. 2013 [23]	UK	130	volar locking plate: 48(15), control: 21(16)	volar locking plate: 47:19, control: 50:14	B1, B3, C1, C3
Kateros et al. 2010 [24]	Greece	113	57(24–68)	45:67	B1, B2, B3, C2
Khan et al. 2010 [25]	USA	103	Pediatric EP: 9.7(3.8), Orthopedic Group: 9.1 (3.7)	Pediatric EP:36:16 , Orthopedic Group: 39:12	B1, C3
Kwon et al. 2012 [28]	Korea/South Korea	221	Unstable DRUJ: 52, Stable DRUJ: 55	86:135	B2, C3
Leung et al. 2000 [29]	China	111	Intra-articular:40 yrs(16–60)	Not Specified	B1, B2, B3, C1, C2, C3
Leung et al. 2008 [30]	Taiwan	137	42	85:52	A, B1, B2, B3
MacDermid et al. 2007 [33]	Canada	227	43.8(12)	85:132	B1, B2, C2
MacKenney et al. 2006 [34]	Scotland	4024	59	851:3173	B1, C1
Makhni et al. 2008 [35]	USA	124	56	32:92	B1, B3, C1
Makhni et al. 2010 [36]	USA	124	56.5	32:92	B1, B3
Matschke et al. 2011 [38]	Germany	161	57.1	36:82	B1, C1
McQueen et al. 1996 [39]	Scotland	120	63(16–86)	13:107	B1, B3, C1
Mignemi et al. 2013 [42]	USA	185	49	96:89	A, B1, C1
Richard et al. 2011 [45]	USA	115	External Fixation: 50(16), ORIF (volar): 50(17)	External Fixation: 28:31, ORIF (volar): 28:28	B1, B3, C3
Sammer et al. 2008 [47]	USA	100	fragment specific(46(23–79)): fixed angle (49(18–63))	fragment specific(9:5), fixed angle (30:55)	B1, B2, B3, C1, C3
Souer et al. 2009 [50]	Scotland	374	none:53, styloid tip: 51, Styloid base: 54, Ulnar neck: 64	non:50:100, styloid tip: 13:19, styloid base: 68:101, ulnar neck: 3:20	B1, B2, C1, C2
Stein et al. 1990 [51]	Israel	126	Extra-articular: 56 (20–89)yrs / Intra-articular (cast): 54 (22–79)yrs / Intra-articular (ex-fix): 48 (19–72) yrs	Not Specified	B1, B2, B3, C1, C2

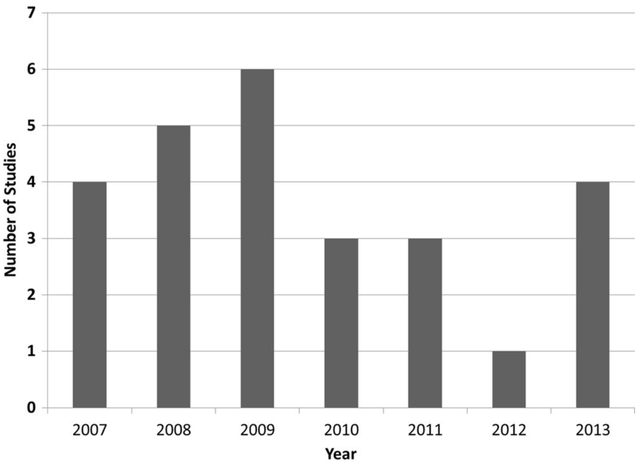


Fig. 2 Number of studies by year

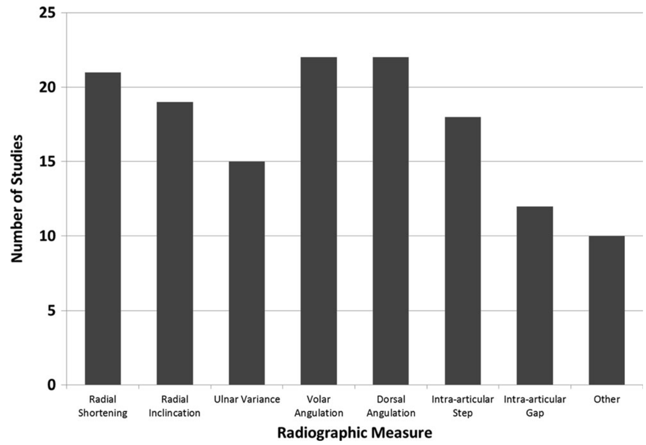


Fig. 3 Frequency of radiographic measures examined

prognostic studies compared radiographic measures (typically at baseline, and this would also include radiographic fracture classification at baseline) to radiographic measures at a follow-up visit (44 % of all prognostic studies). Radiographic measures (also measured at baseline, or fracture classification measured at baseline) were also compared to patient outcome measures at follow-up (33 % of all prognostic studies). Fracture classification or baseline radiographic measures (usually of alignment, reduction or mal-alignment, or loss of reduction) were used to predict treatment requirements or characteristics (23 %). Thirty-seven percent of all the studies had explanatory (cross-sectional design). Similar to the prognostic studies, the majority of these studies compared radiographic measures to other radiographic measures (46 %). This explanatory analysis typically compared fracture classification to radiographic measures of mal-alignment. Radiographic measures were also compared cross-sectionally to patient outcomes and to treatment requirements or characteristics in 30 and 24 % of the explanatory studies, respectively.

What Is the Variability in the Extent, Range, and Acceptability Criteria of Radiographic Measures Examined in Studies Evaluating Patients with DRFs?

Radiographic Parameters

The distribution of radiographic measures examined in these studies is shown in Fig. 3. Overall, there is an even distribution in the type of radiographic measures with the most common being dorsal/volar angulation (22 studies) and radial inclination (19 studies). Table 3 lists the radiographic measures used in each study. When considering the country of origin of each study, there was no consensus with regard to the radiographic measures employed. Only one study examined a composite radiographic measure that combined two or more of these radiographic measures and called this the "absolute degree of deviation" which combined radial inclination and volar tilt [47]. Radial inclination was also termed radial deviation and radial angle but was always measured in the posterior-anterior radiograph. Volar and dorsal angulation was always measured simultaneously as it described the angulation of the radial articular surface in the sagittal plane and was examined in the lateral radiographs. Volar tilt was also called palmar tilt or these terms were combined and were called dorso-volar plane angulation. Intra-articular step and gap were alternatively called articular congruency and were only applicable in intra-articular distal radius fractures. Over half of the studies (18/31) measured additional radiographic parameters as shown in Table 3 and consisted primarily of identification of comminution present in the metaphysis (four studies), measures of carpal mal-alignment (four studies), and inter-carpal angles (three studies).

Definitions for the established radiographic acceptability were extracted for each study and are also shown in Table 3. Acceptability values for each radiographic measure, when indicated, were used to define mal-alignment, displacement, or mal-union or used to establish successful and unsuccessful radiographic outcomes. Radial height had two acceptable radiographic criteria but had overlap in their range 14 mm vs. 9 (8–14 mm). Radial shortening had acceptability criteria and unacceptability criteria in the range of 2 mm (age of participants in study, 16–60 years) [29, 42] to 5 mm (age of participants in study, 20–89 years) [35, 36, 51] with increased shortening considered unacceptable. Radial inclination had the most unique definitions of acceptability and unacceptability criteria, but these definitions were similar in magnitude. Ulnar variance had two definitions for acceptability and indicated that less ulnar variance was best (aligned with the distal radius with neutral or slightly negative ulnar variance was best). Volar and dorsal angulation were measured simultaneously with a general consensus that any deviation from the native volar tilt into dorsal tilt was considered unacceptable with increasing dorsal angulation representing the largest deviation

Table 3 Radiographic measure

Authors	RS	RI	UV	VA	DA	IS	IG	Other
Al-Ansari et al 2007(2)				✓				Minimally Displaced/Angulated: sagittal view: <0.5mm, <15°
Altissimi et al 1986(3)		X[c]		X[D]				Radio Ulnar Index (Ulnar Variance)
Arora et al 2007(5)	✓[*]		✓	✓	✓[*]	✓[*]		
Brogen et al 2011(6)		**X**	**X***	X	✓[Δ]	✓		
Brogen et al. 2013(7)			✓[*]		✓[Δ]	✓		
Chen et al 2013(8)	✓[*Δ]	**X**		**X**	**X**[Δ□]			Dorsal or Volar Comminution of the Metaphysis
Clayton et al 2009(9)			✓[AΔ]		X[AΔ]	✓[Δ]		Carpal Mal-Alignment
Einsiedel et al 2009(12)	**U**	X			**x**			
Finsen V et al.2013(13)		X	X		X-	✓	✓	
Forward et al 2008(14)	✓[A*]	✓[E*]		✓	✓[~]	✓	✓	Tear-drop Angle/AP Distance
Geller et al 2009(16)	✓[Δ]	**X**	**X**	**X**[C]	**X**[□]	✓	✓	Dorsal Cortex Comminution, Dorsal Shift, Radial Shift
Grewal et al 2007(19)		✓[Δ]	✓[Δ]		✓[Δ]			Ulnar Styloid Fracture, Ulnar Head Fracture, DRUJ Involvement

Hayes et al 2008(21)	U			X-				Carpal Mal-alignment
Jupiter et al 2009(22)	**X**	**X**	**X**	**X**		✓	✓	
Karanta et al. 2013(24)	✓	✓		✓		✓	✓	
Kateros et al 2010(25)	✓	✓			✓			
Khan et al 2010(26)				✓	✓			
Kwon et al. 2012(29)	X	X	X	X	X[□˜]			
Leung et al 2000(30)	✓[A]	✓[B]		✓[A]	✓[A]	✓[A]	✓[A]	Carpal height ratio, radiolunate, capitolunate and scapholuante angles
Leung et al 2008(31)	✓	✓[B]		✓[A]	✓[A]	✓[A]	✓[A]	
MacDermid et al 2007(34)	U	X			X	✓		(Scapholunate gap (mm), Scapholunate angle (°), DRUJ gap (mm)
MacKenney et al 2006(35)			X[AΔ]		X[B]			Carpal mal-alignment
Makhni et al 2008(37)	✓[B]			✓[B]	✓[A]	✓[A]	✓[A]	Dorsal Comminution, Metaphyseal Comminution
Makhni et al 2010(37)	✓[B]			✓	✓	✓[A]	✓[A]	Metaphyseal Comminution
Matschke et al	X	X	X	**X**[B]	**X**[A]	✓	✓	

2011(39)								
McQueen et al 1996(40)	✓[♥]		✓	✓[*]	✓[Δ]			Carpal Mal-alignment
Mignemi et al 2013(43)	X[A]	X[AB]	X[B]	X[C]		✓[A]		
Richard et al 2011(46)	✓			✓		✓	✓	Scapholunate angle
Sammer et al 2008(48)		✓[A]	✓	✓[C]				Absolute degree of deviation (of radial inclination and volar tilt(normal values were 22, 11 respectively)), combined measure.
Souer et al 2009(51)			X	X		✓	✓	Ulnar Inclination
Stein et al 1990(52)	✓[B]	✓[D]		✓[C]	✓			Radial Shift (displacement)

An '✓' indicates that this measure was used in this study and an 'X' indicates that the study referenced a standard technique that is shown below. A 'U' indicates that although the study stated that they measured radial height/shortening, the actual definition of the measure was more consistent the description of ulnar variance.

Radial Height			
Acceptable-Variable	Values		
A	<2mm		
B	9 (8-14)mm		

Radial Shortening			
Acceptable - Variable	Values	Unacceptable-Variable	Values
A	<2mm	*	>2mm
B	<5mm	♥	>3mm
		Δ	>5mm

Radial Inclination			
Acceptable-Variable	Values	Unacceptable-Variable	Values
A	>22°	*	<20°
B	>10°	Δ	<15°
C	16-28°		
D	23(10-30)°		
E	≥20°		

Intra-Articular Step			
Acceptable-Variable	Values	Unacceptable	Values
A	<2mm	*	>1mm
		Δ	>2mm

Ulna Variance			
Acceptable-Variable	Values	Unacceptable-Variable	Values
A	≤3mm	*	>1mm
B	1-2mm (≤5mm)	Δ	>3mm

Volar Angulation			
Acceptable-Variable	Values	Unacceptable-Variable	Values
A	<20°	*	>15°
B	<25°		
C	11°		
D	0-18°		

Dorsal Angulation			
Acceptable-Variable	Values	Unacceptable-Variable	Values
A	<10°	*	>15°
B	neutral (0)	Δ	>10°
C	≤20°	o	>20°
		~	>0°

Intra-Articular Gap			
Acceptable-Variable	Values	Unacceptable-Variable	Values
A	<2mm		

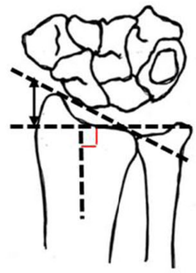
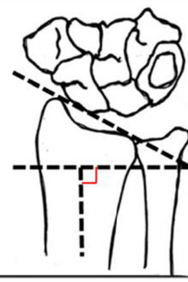
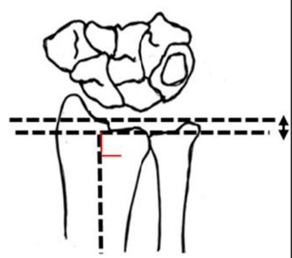
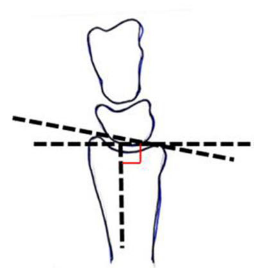
Radiographic Measures	Posterior-Anterior View	Lateral View
Radial Shortening (X)		
Radial Inclination(X)		
Ulnar Variance(X)		
Volar/Dorsal Angulation(X)		

Table 4 Ulna Variance, Radial Shortening and Radial Length Referenced Techniques

Reference	Article	Discrepancy/Notes
Altissimi et al.. 1986 [3] (Radioulnar Index) "Radioulnar Index: the distance between the most proximal point of the articular surface of the radius and the ulnar head (positive values when the ulna is more distal than the radius and negative values when it is more proximal)"	Altimissi et al. 1986	Definition of Ulnar Variance
Steyers and Blair 1989 [53] (Ulnar Variance)	Brogren et al. 2011 [6] "Ulnar variance was measured on the posteroanterior view with a horizontal line drawn from the ulnar side of the mid-articular surface of the distal radius toward the ulna. Variance was determined as the distance between this line and the carpal surface of the ulna" Mignemi et al. 2013[42] "we measured ulnar variance on a PA radiograph using the method of perpendiculars. We identified the long axis of the radius and drew a line perpendicular to this, extending through the ulnar-most corner of the lunate fossa. We recorded the distance between this line and the distal most point of the ulnar done as the ulnar variance, where a positive number denoted ulnar positive and a negative number denoted ulnar negative"	
Kreder et al. 1996 [27] (Ulnar Variance) "A line perpendicular to the central axis of the radius is drawn at the level of the ulnar margin of the distal radial articular surface. A second line is drawn perpendicular to the central long axis of the radius of the radius is drawn at the level of the distal ulnar articular surface" Variance is measured in between	Chen et al. 2013 [8], Geller et al. 2009 [16], Jupiter et al. 2009 [21], Kwon et al. 2012 [28], Matschke et al. 2011 [38], Souer et al. 2009 [50]	
Gartland and Werley [15] (shortening of the radius) "Shortening of the radius results from a combination of impaction, loss of normal inward radial tilt and absorption of the bone at the fracture site."	Altimissi et al. 1986 [3], Kateros et al. 2010 [24], Leung et al. 2008 [30], Matschke et al. 2011 [38], Souer et al. 2009 [50], Stein et al. 1990 [51]	
Melone et al. 1984 [40] (Ulnar Variance) "measurement is the distance between the distal ends of the medial corner of the radius and the ulnar head"	Clayton et al. 2009 [9]	
Melone et al. 1984 [40] (Radial Shortening) "Radial length is usually measured as the vertical distance between the distal ends of the radial styloid and the ulnar head"	Hayes et al. 2008 [20], McQueen et al. 1996 [39]	
Einsiedel et al. 2009 [12] (Radial Shortening) "The radial shortening was measured as the difference in axial direction of the radius between the radial epiphysis on the ulnar side versus the ulnar plateau on the dorsovolar radiograph (a shortening was noted as a positive value)"		Definition of Ulnar Variance
Finsen et al. 2013 [13] (Ulnar Variance) "Ulnar variance was measured as the axial difference between the articular surfaces of the ulna and radius at the distal radio-ulnar joint and given a positive value when the ulna was longer than the radius"		
Kreder et al. 1996 [27] (Radial Length) "A line perpendicular to the central long axis of the radius is drawn at the level of the most distal aspect of the radial articular surface. A second line is drawn perpendicular to the central long axis of the radius is drawn at the level of the distal ulnar articular surface"	Geller et al. 2009 [16], Jupiter et al. 2009 [21], Kwon et al. 2012 [28], Matschke et al. 2011 [38]	

Table 4 (continued)

Reference	Article	Discrepancy/Notes
Jupiter and Fernandez 2002 [22] (Radial Shortening) "the amount of shortening is measured between the head of the ulna and the ulnar corner of the radius on the antero-posterior radiograph. The lines for the measurement are perpendicular to the long axis of the radius"	Forward et al. 2008 [14]	Definition of Ulnar Variance
Lidstrom et al. 1959 [31] (loss of radial length) "radial shortening is measured by comparison with the ulna'	Kateros et al. 2010 [24], Stein et al. 1990 [51]	
Warwick et al. 1993 [57] (Radial Shortening) "distal radial surface to the distal ulnar surface" (Steward et al. 1985)	MacDermid et al. 2007 [33]	Definition of Ulnar Variance
MacKenney et al. 2006 [34] (Ulnar Variance) " relative measurement taken as the distance between the ulnar variance of the fractured wrist compared to the non –fractured wrist"		
Van Der Linden et al. 1981 [56] (Radial shortening) "is the decrease in the distance that the styloid process projects distal to a perpendicular to the long axis drawn through the contour of the ulnar part of the wrist joint"	Makhni et al. 2010 [36], Stein et al. 1990 [51]	
Mann et al. 1993 [37] (Radial Height) "Measurement of radial height (also known as radial length) can be used to assess radial shortening due to impaction or displacement." "Method of measuring radial height. The length of the radius beyond the distal most articular surface of the ulna is radial height. This is measured as the distance between lines perpendicular to the long axis of the radius (see text), which pass through the tip of the radial styloid and the apex of the ulnar dome, respectively. The normal range is 10 to 18 mm; however, normal is within 1 mm of the unaffected wrist."	Mignemi et al. 2013 [42] "We determined radial height by finding the long axis of the radius and then extending a line perpendicular to it at the tip of the radial styloid on a PA radiograph. We recorded the distance between this line and the distal most point of the ulnar dome"	
Sarmiento et al. 1975 [48] (Radial Length)	Stein et al. 1990 [51]	

from the native volar tilt. The presence of intra-articular step and intra-articular gap less than 2 mm was considered acceptable in all studies and deformities larger than this were considered to be unacceptable radiographically.

The terms "radial height/shortening/length and ulnar variance" were not consistently employed or described. Table 4 lists the referenced techniques and the description of the referenced techniques related to radial shortening/height or ulnar variance cited in the studies included in this review. Ulnar variance as described in this review (shown in Table 3) study is measured on a posterior-anterior radiograph and measures the distance between horizontal lines (that are perpendicular to the long axis of the radius/ulna) drawn from the distal ulnar and radial articular surfaces (at the level of the distal radioulnar joint). After a detailed examination of the referenced techniques cited in this review, it appeared as though four studies measured ulnar variance according to this definition but instead called it radioulnar index [3] or radial shortening [12, 14, 33].

Radiographic Measurement Characteristics

Table 5 lists the characteristics of the radiographs (when measured, type of projection and the use of bilateral comparison) as well as the reliability and measurement properties of the radiographic measures. Lateral and posterior-anterior radiographs were used in 17 of the articles (55 %) whereas lateral, posterior-anterior, and oblique radiographs were used in four studies (13 %). Ten articles (32 %) did not indicate the type of projection used. Twenty-three percent of the time bilateral radiographs were acquired of the noninjured wrist, and this comparison was typically made at baseline to compare radiographic measures of radial height for example or during the last follow-up visit. Twenty-one (68 %) of all the articles specified who was taking the radiographic measures (the other ten articles did not specify). Five of these articles had radiologists take the radiographic measures. The majority of the studies had either co-authors (nine), research nurses (one), had an independent assessor (one), research assistant (two), or the

Table 5 Radiographic Measures Characteristics

Authors	When Radiographs Measured	X-rays	Bilateral	Who Measured	Reliability
Al-Ansari et al. 2007 [2]	initial, 6 week follow-up		no	Research assistants	Intra-observer: 0.92
Altissimi et al. 1986 [3]	post-reduction, long term follow-up visit	AP/Lateral	no	Not specified	
Arora et al. 2007 [5]	immediately post-op, 4 weeks, 8 weeks, 12 weeks and final follow-up >12 mo.	AP/Lateral	no	Co-author	
Brogren et al. 2011 [6]	1 year	AP/Lateral	yes	Experienced radiologist	Had a second rater randomly examined 54 patients and had ICC(volar tilt): 0.98 (injured),0.99(uninjured and ICC(ulnar variance) L=:0.94(injured),0.88 (uninjured
Brogen et al. 2013 [7]	pre-treatment,1 year	AP/Lateral	yes	Experienced radiologist	Referenced reliability measure estimated to be high (ICC 0.88 to 0.94 between two examiners)
Chen et al. 2013 [8]	At ex fix removal (6–8 weeks), 3 mo. final follow-up (12–24 mos.)		no	Not specified	
Clayton et al. 2009 [9]	(1,2 weeks), 6 weeks	AP/Lateral	no	RACE AND MMCQ	In a pilot study and also rechecked 10 % randomly, variation was never greater than 3 degrees or >1 mm.
Einsiedel et al. 2009 [12]	time of injury, after reduction and after bony consolidation (end)	AP/Lateral	no	Not specified	
Finsen V et al. 2013 [13]	baseline, long term follow-up visit	AP/Lateral	yes	Not specified	
Forward et al. 2008 [14]	latest follow-up	AP/Lateral	yes	Not specified	
Geller et al. 2009 [16]	pretreatment, post-operative (intra-operative-fluoro, 1–2 days after) 6 weeks	AP/Lateral/Oblique	no	Three orthopedists	
Grewal et al. 2007 [19]	initial visit(1 week), 3 mo., 6 mo., 12 mo.	AP/Lateral	no	Two orthopedists	
Hayes et al. 2008 [20]	initial, pre-operative, post-operative, final		no	Trained research nurse	
Jupiter et al. 2009 [21]	intra-operatively, immediately post-operatively, 6 weeks, 6 months, 1 year, 2 years	AP/Lateral	no	Independent radiologists	
Karanta et al. 2013 [23]	6 weeks,12 weeks 1 year	AP/Lateral/Oblique	yes	Independent research assistant, orthopedist	Verified by a second assessor (NDD)
Kateros et al. 2010 [24]	1 mo., 3 mo., 6 mo., 12 mo.		no	KK (senior author)	
Khan et al. 2010 [25]	after surgery and 5–7 days after			Attending surgeon	
Kwon et al. 2012 [28]	pre-treatment	AP/Lateral	no	One author (BKS)	Referenced other studies who measured ICC=0.70 and gave a very detailed explanation and drawings
Leung et al. 2000 [29]	1,2 weeks	AP/Lateral	yes	Not specified	
Leung et al. 2008 [30]	6 mo., 12 mo., 24 mo.		no	Two co-authors	Inter-observer:0.82, Intra-observer:0.88
MacDermid et al. 2007 [33]	Pre-treatment, post-treatment, follow-up (12 mo.)		no	Not specified	
MacKenney et al. 2006 [34]	at reduction, 1 week, 6 weeks,		yes	Senior author MMcQueen	

Table 5 (continued)

Authors	When Radiographs Measured	X-rays	Bilateral	Who Measured	Reliability
Makhni et al. 2008 [35]	at presentation, immediately after splinting and 8 weeks		no	Two co-authors but arbitrated by PI	
Makhni et al. 2010 [36]	pretreatment, after reduction, 1st clinic visit (7–14 days) and after healed >8 weeks	AP/Lateral		Two authors measured everything and if different >5 degrees they had PI arbitrate	
Matschke et al. 2011 [38]	pre-operative, post-operative, 2 years	AP/Lateral	no	One independent radiologist	
McQueen et al. 1996 [39]	6 weeks, three months, 6 months 1 year	AP/Lateral	no	MMCQ, CCB (authors)	
Mignemi et al. 2013 [42]	time of injury or after closed reduction, initial post-operative and minimum of 6 week follow-up	AP/Lateral	no	2 fellowship trained musculoskeletal radiologists and a senior orthopedic resident	Detailed description and referenced Mann et al./did a pilot study of 10 fractures with 4 radiographs/fracture did spearman rank correlation to get >0.75 for all measurements accept step off (therefore did consensus measures for this variable)
Richard et al. 2011 [45]	2 weeks, 12 weeks, 6 months, 1 year (on average)	AP/Lateral/Oblique	no	One independent observer	
Sammer et al. 2008 [47]	immediately post op, 6 mo., 12 mo.	AP/Lateral/Oblique	no	Not specified	
Souer et al. 2009 [50]	6 mo., 1 year, 2 years	AP/Lateral	no	Not specified	
Stein et al. 1990 [51]	1,2,4,6 weeks		no	not specified	

attending surgeon/resident/fellow (five) take the radiographic measures.

Measures of reliability were assessed in four studies and three additional studies referenced the reliability reported in previous studies. This reliability component typically involved reviewing a subset of the radiographic measures and comparing retest measures between observers or within the same observer (approximately half of the articles either referenced or published a standardized technique to specific radiographic measures (13 studies, 52 %) (ICC 0.70–0.99). Table 6 lists the articles that either had detailed description (drawings or text) (11 studies, 35 %) or that referenced standardized techniques for each of the radiographic measures (13 studies, 42 %). Six studies used Kreder et al. 1993 for radial height, ulnar variance, and dorsal and volar tilt [27]. Table 6 also lists the other specific reference standards for acceptability in radiographic measures and if this decision was based on a literature review or clinical experience.

Table 7 lists the type of fracture classification system and degenerative scale used in each study. Twenty-three of the articles (74 %) classified the fractures with the majority of the studies using the AO classification system (19 articles). All studies that used a degenerative scale used the one developed by Knirk and Jupiter (26) (6 studies).

Discussion

The results of this structured review indicate that there appears to be a commonly used set of radiographic parameters that are routinely measured. The primary measures described in all studies are those translations or angulations that are most consistently found following a dorsally angulated distal radius fracture (Colles' fracture) and are also those parameters that were described in the initial Gartland and Werley study. However, despite having a commonly used set of radiographic measures, approximately 65 years later, no consensus has been established as to the relative impact radiographic measurements have on wrist function, or standardization of measurement technique or acceptability criteria. Even after focusing on large clinical studies, we found substantial variation in how radiographic images are being measured and interpreted.

When examining the study demographics of the articles included in this review, the majority of these patients/participants examined were adult woman which is consistent with the cumulative incidence of 15 % in women and 2.5 % for men [1, 10, 46, 49, 55]. Also, the number of studies per year taking radiographic measurements in cohorts of 100 or more people was expected to increase with time due to the advances in accessibility of digital radiographs. However, the results of this review did not indicate this increased trend.

Table 6 Referenced radiographic measurement techniques and acceptability criteria

Authors	Radiographic Parameters(Acceptability or Definition of Malunion/Displacement)	Referenced Standardized Technique
Al-Ansari et al. 2007 [2]		
Altissimi et al. 1986 [3]		Detailed description
Arora et al. 2007 [5]		
Brogren et al. 2011 [6]	based on literature and clinical experience	Ulnar Variance (Steyers and Blair 1989 [53]), Radial Inclination, Dorsal Tilt (Goldfarb et al. 2001 [17])
Brogren et al. 2013 [7]		
Chen et al. 2013 [8]		Kreder et al. 1996 [27]
Clayton et al. 2009 [9]		Dorsal Angulation(van der Linden and Ericson 1981 [56]), Ulnar Variance (Melone et al. 1984 [40]), Carpal mal-alignment (McQueen et al. 1996 [39])
Einsiedel et al. 2009 [12]		Detailed description
Finsen V et al. 2013 [13]		Detailed description
Forward et al. 2008 [14]	Jupiter and Fernandez (mal-union definition)	
Geller et al. 2009 [16]		Kreder et al. 1996 [27]
Grewal et al. 2007 [19]	American Society for Surgery of the Hand	
Hayes et al. 2008 [20]		Radial shortening (Melone et al. 1984 [40]), Dorsal angulation (van der Linden and Ericson 1981), Carpal mal-alignment (McQueen et al. 1996 [39])
Jupiter et al. 2009 [21]		Kreder et al. 1996 [27]
Karanta A et al. 2013 [23]		
Kateros et al. 2010 [24]	Lindstrom Radiographic Scoring System	
Khan et al. 2010 [25]	Stardardized predefinted critera for distal forewarm fracture manipulation by pediatric orthopedists (children younger than 9)	
Kwon et al. 2012 [28]		Kreder et al 1996 [27]
Leung et al. 2000 [29]		
Leung et al. 2008 [30]		
MacDermid et al. 2007 [33]	ASST	Warwick et al 1993 [57]:radial shortenting, "standardized technqiue"
MacKenney et al. 2006 [34]		
Makhni et al. 2008 [35]	based on literature and clinical experience	
Makhni et al. 2010 [36]	literature review	Radial Shortening (Earnshawe et al. 2002 [11], Melone et al. 1993 [41], Missakian et al. 1992 [43]), Volar Tilt (Earnshawe et al. 2002, Pouge et al. 1990 [44]), Intra-articular Gap (Knirk and Jupiter 1986, Melone et al. 1993 {}, Missakian et al. 1992 [26,43])
Matschke et al. 2011 [38]		Kreder et al. 1996 [27]
McQueen et al. 1996 [39]	van der Linden (redisplacement defined by dorsal angulation), Melone (1984) redisplacment defined radial shortening	Dorsal Angulation (van der Linden and Ericson 1981 [56]), Radial Shortening (Melone 1984 [40]), Carpal mal-alignment (Taleisnik and Watson 1984 [54])
Mignemi et al. 2013 [42]		Radiographic Measures: Mann et al. 1993 [37], Ulnar Variance: Steyers and Blair 1989 [53])
Richard et al. 2011 [45]		
Sammer et al. 2008 [47]		
Souer et al. 2009 [50]		Ulnar inclination, palmar tilt, ulnar variance and articular congruity: Kreder et al. 1996 [27] (all in reference to length of capitate)
Stein et al. 1990 [51]	Lindstrom (1959) as modified by Sarmiento (1975 [48]) and criteria of van der Linden and Ericson 1981 [56]	

Table 7 Fracture Classification and Degenerative Scales Employed

Authors	Fracture Classification	Degenerative Scale
Al-Ansari et al 2007		
Altissimi et al 1986	Frykman	
Arora et al 2007	AO/ASIF Classification	
Brogren et al 2011	AO	
Brogen et al. 2013		
Chen et al 2009		
Clayton et al 2009	AO	
Einsiedel et al 2009	AO	
Finsen V et al. 2013	AO	
Forward et al 2008		(Knirk and Jupiter-JSN)
Geller et al 2009	AO and Melone	
Grewal et al 20070		
Hayes et al 2008	AO, Gustilo and Anderson (1976 classification for open fractures()	
Jupiter et al 2009	Muller AO Classification	(Knirk and Jupiter-JSN)
Karanta et al. 2013	AO	
Kateros et al 2010	AO	Knirk and Jupiter-JSN
Khan et al 2010	did classify dorso-volar angulation/displacement/ radioulnar angulation/displacement	
Kwon et al. 2012	AO	
Leung et al 2000		
Leung et al 2008	AO	Knirk and Jupiter-JSN
MacDermid et al 2007	AO, McMurtry	
MacKenney et al 2006	AO/OTA	
Makhni et al 2008		
Makhni et al 2010		
Matschke et al 2011	AO/OTA	Knirk and Jupiter-JSN
McQueen et al 1996	AO	
Mignemi et al 2013	AO/Frykman	
Richard et al 2011	AO	
Sammer et al 2008	AO Classification	
Souer et al 2009	Fernandez	Knirk and Jupiter-JSN
Stein et al 1990	Older (1965)	

After examining the terminology used in the radiographic measures employed in the studies included in this review, it appears that there is some discrepancy in the measurement of ulnar variance and radial shortening. Ulnar variance is described as the measurement between the two horizontal lines visible on the posterior-anterior radiograph (and perpendicular to the long axis of the radius/ulna) between mid-articular surface of the distal radius and the distal articular surface of the ulna. The exact same definition of this radiographic measure was also given to definition of radial shortening [12, 14, 33] or radioulnar index [3]. Radial shortening was also described in the studies included in this review as the distance between two horizontal planes (posterior-anterior radiograph) from the radial styloid to the distal ulnar articular surface. Warwick et al. compared three techniques used to measure radial shortening as described by Stewart et al. [2, 52] (distal ulnar styloid to distal radial styloid), by Gartland and Werley [15] (radial styloid to distal ulnar surface), and by Altissimi [3] (although termed "radioulnar index") (at the level of the distal radioulnar joint) and determined that the definition of radial shortening which is measured at the level of the distal radioulnar joint [3] should be adopted as this was the measurement technique that was most correlated with measured clinical outcomes. However, based on the results of this structured review, it appears that confusion surrounding the exact description of ulnar variance and radial shortening persists. We therefore suggest standardized, measurement techniques as shown in Table 3 for radial shortening, ulnar variance, radial inclination, and volar/dorsal tilt.

Kreder et al. and MacDermid et al. recognized the importance of standardization of radiographic measurements for use in studies relating functional outcome to radiographic alignment and also noted that despite the pervasiveness of this imaging technique and measures in patients with distal radius fractures, little work has been published that comments specifically on the reliability and standardization of the these radiographic measures [27, 32]. Furthermore, the use of acceptability criteria or the development of benchmark values which dictate the efficacy of treatment options seems unwarranted when the reliability of these measurements is not reported is unknown or the measurement technique is not standardized. Based on the results of this review, three studies investigated the reliability of the radiographic measures and three additional studies referenced previous studies which investigated the reliability of the measurements examined.

A limitation of our review was that we decided to limit the inclusion of studies to those studies which examined 100 or more participants. The purpose of this review was to examine the extent and range of radiographic parameter used in studies investigating patients with distal radius fractures. Based on the results of our initial literature search, it appeared that the majority of studies included sample sizes less than 50 participants. We decided to limit the inclusion criteria for this structured review to those studies that had 100 more participants included as we assumed that larger high-quality studies would be employing radiographic measures that were representative of the types and uses of radiographic measures employed in studies with smaller sample sizes

Anatomic alignment and radiographic measures of restoration of joint alignment has been the focus of much of the research surrounding fractures of the distal radius. Restoration of the alignment of the joint continues to be a primary goal in treating patients with distal radius fractures. However, definitions of acceptability and benchmark indicators for good patient outcomes vary greatly as well as definitions of mal-union, re-displacement, and loss of reduction. Since many studies evaluated radiographic measures over time to measure or monitor treatment response, and since multiple raters are often involved, the lack of standardization of methods is a substantial barrier to defining prognosis and outcomes in patients with distal radius fractures.

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