Volar Plating: Imaging Modalities for the Detection of Screw Penetration

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Abstract

Background Volar plating for distal radius fractures exposes the risk of extensor tendon rupture, mechanical problems, and osteoarthritis due to protruding screws.

Purposes The purpose of this review was to identify the best intraoperative diagnostic imaging modality to identify dorsal and intra-articular protruding screws in volar plating for distal radius fractures.

Methods The Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines were followed for this review. In vitro and in vivo studies that analyzed the reliability, efficacy, and/or accuracy of intraoperatively available imaging modalities for the detection of dorsal or intra-articular screw protrusion after volar plating for distal radius fractures were included.

Results Described additional imaging modalities are additional fluoroscopic views (pronated views, dorsal tangential view [DTV], radial groove view [RGV], and carpal shoot through [CST] view), three-dimensional (3D) and rotational fluoroscopies, and ultrasound (US). For detection of dorsal screw penetration, additional fluoroscopic views show better results than conventional views. Based on small (pilot) studies, US seems to be promising. For intra-articular screw placement, 3D or 360 degrees fluoroscopy shows better result than conventional views.

Conclusion Based on this systematic review, the authors recommend the use of at least one of the following additional imaging modalities to prevent dorsal protruding screws: CST view, DTV, or RGV. Tilt views are recommended for intra-articular assessment. Of all additional fluoroscopic views, the DTV is most studied and proves to be practical and time efficient, with higher efficacy, accuracy, and reliability compared with conventional views.

Level of Evidence The level of evidence is Level III.

Keywords
- distal radius fracture
- volar plate
- screw penetration
- dorsal
- intra-articular

Volar plating for distal radius fractures have demonstrated to reduce the incidence of postoperative iatrogenic extensor tendon injuries compared with dorsal plating.[1] However, with this technique, the average reported incidence of postoperative complications is still as high as 16.5%.[2] The overall reported complication rate of extensor tendon rupture is as

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high as 6%.[3] Based on findings during surgical re-exploration for tendon transfer, prominent screws are thought to be a cause of extensor tendon ruptures.[4] One study found that screws protruding as much as 6.5 mm may be hidden by Lister's tubercle on standard lateral views.[5] Also, distal screws in comminuted fracture patterns can cut through the subchondral bone and penetrate the radiocarpal joint.[3] The articular surface of the distal radius is biconcave and tilted in two planes,[6] which makes it difficult to show screws to be intra- or extra-articular on radiographic views. Depth gauge measurement in distal radius fractures is difficult, especially with dorsal multifragmentation.[7,8] The use of depth gauge for initial measurement of screw length results in the screws penetrating the cortex in ~9.1 to 9.4% of locking screws placed in volar plates.[8,9]

Intraoperative detection of dorsal protruding or intra-articular placed screws gives the surgeon the opportunity to change the screw and thereby prevent the risk of postoperative iatrogenic complications and prevent the risk of reinterventions. The objective of this study is therefore to perform a systematic review of studies on intraoperative diagnostic imaging strategies with respect to the detection of both dorsal and intra-articular screw penetrations in volar plating for distal radius fractures. The specific goal of this review was to determine what fluoroscopic view or imaging modality has the highest observer reliability, diagnostic efficacy, and/or accuracy based on both in vitro and in vivo studies for detection of dorsal protruding screws and intra-articular protruding screws.

Methods

Our systematic review was conducted and reported in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines.[10]

Search Strategy

Keywords included: "radius fractures," "volar plating," and "screw penetration." The full search including all keywords can be found in ►**Supplementary Appendix 1**. There were no limitations for year of publication. With the help of a medical librarian, we performed a comprehensive search of five electronic medical databases: MEDLINE, PubMed, SCOPUS, Web of Science, and Cochrane in June 2018 to identify relevant studies. To ensure comprehensive searches, search strategies were individualized to each electronic database. The electronic search was supplemented with manual searches. The references list of each selected article was checked to identify additional studies missed at the electronic search. We did not include gray literature. EndNote X8 software was used to manage the search and remove duplicates. We included all retrospective and prospective in vitro and in vivo studies analyzing imaging strategies to detect protruding screws in distal radius fractures treated with volar plating in models, cadavers, and/or adult patients that reported diagnostic performance characteristics (i.e., intra- and inter-observer reliabilities, efficacy and/or sensitivity, specificity, and/or accuracy) of respective fluoroscopic views, additional imaging modalities, or a combination of these. We included in vitro studies with and without fractured distal radii and in vivo studies of extra- and intra-articular fractures. All studies published in English with full text available were included.

Study Selection

Titles and abstracts were screened on relevance by two independent reviewers. Discrepancies were resolved by consensus after discussion between the two reviewers and a third researcher. Both reviewing authors examined the full-text articles for eligibility, and cases of doubt were sorted out by discussion with the coauthors.

Quality Assessment

We assessed the quality of each included study in duplicate by having two reviewing authors using the "user's guide to the surgical literature, how to use an article about a diagnostic test" by Bhandari et al.[11] This evaluation assesses six aspects of methodological quality. Primary guides include (1) whether the clinicians faced diagnostic uncertainty and (2) whether there was an independent, blind comparison with a reference study. The secondary guidelines focus on (1) whether the results of the test being evaluated influence the decision to perform the reference standard and (2) whether the methods for performing the tests were described in sufficient detail to permit replication. Regarding the results, it evaluates if the likelihood ratios are being calculated, or the data necessary for this calculation are provided. It also evaluates if the results aid in caring for patients in the clinical setting.

Results of the quality assessment can be found in ►**Table 1**.

Data Collection

We collected information pertaining to study characteristics, including general study descriptive, description of the imaging modality, information regarding the reference standard and reported outcomes. These data are represented in a predefined database. The database is enclosed in ►**Supplementary Appendix 2** (for dorsal screw penetration) and ►**Supplementary Appendix 3** (for intra-articular screw penetration). Especially for studies reporting on dorsal screw penetration, different outcomes to report on accuracy were presented. As it is relatively easy to change a screw perioperatively, even if it is falsely showing to protrude, we opted to present the sensitivity of additional modalities to compare their accuracy in these cases.

Statistical Analysis and Data Synthesis

To find the best intraoperative modality to detect protruding screws in volar plating for distal radius fractures, we aimed to analyze the intra- and interobserver reliabilities, efficacy and/or sensitivity, specificity, and accuracy of available modalities. Where applicable, data were pooled and a meta-analysis for sensitivity and efficacy was performed. Since there was substantial heterogeneity in the outcomes of the studies, we refrained from performing a formal meta-

Table 1 Methodological quality of included studies according to Bhandari et al (2003)

Study	Primary guidelines		Secondary guidelines		Results	Implications for patient care
	Did clinicians face diagnostic uncertainty?	Independent blind comparison with a reference standard	Did the results of the test influence the decision to perform the reference standard?	Were the methods described in sufficient detail to permit replication?	Are likelihood ratios of the test being evaluated or data necessary for their calculations provided?	Will the reproducibility of the test result and its interpretation be satisfactory in clinical setting?
Bianchi et al (2008)	No	Indeterminate	Yes	Yes	No	No
Borggrefe et al (2015)	No	Yes	No	Yes	Yes	No
Brunner et al (2015)	No	No	N/A	Yes	No	Yes
Cha and Shin (2017)	No	Yes	No	Yes	Yes	No
Dolce et al (2014)	No	Yes	No	Yes	Yes	Yes
Ganesh et al (2016)	No	Yes	Indeterminate	No	Yes	Yes
Giugale et al (2017)	No	Yes	No	No	Yes	Yes
Gurbuz et al (2017)	No	Yes	No	No	No	Yes
Haug et al (2013)	No	Yes	No	Yes	No	Yes
Hill et al (2015)	No	Yes	No	Yes	No	Yes
Joseph and Harvey (2011)	No	No	N/A	Yes	Yes	No
Kiyak (2018)	No	No	Indeterminate	Yes	Yes	Yes
Kumar et al (2001)	Yes	Yes	No	Yes	Yes	Yes
Lee et al (2013)	No	Yes	No	Yes	Yes	Yes
Marsland et al (2014)	No	No	N/A	Yes	No	No
Oc et al (2018)	Yes	Yes	No	Yes	No	Yes
Ozer and Toker (2011)	No	No	N/A	Yes	Yes	No
Ozer et al (2012)	No	Yes	No	Yes	No	Yes
Pace and Cresswell (2010)	Yes	Yes	No	No	Yes	Yes
Patel et al (2013)	No	Yes	No	No	No	No
Poole et al (2016)	No	Yes	No	Yes	No	Yes
Rausch et al (2015)	No	No	N/A	Yes	Yes	No
Riddick et al (2012)	No	Yes	No	No	No	Yes
Soong et al (2008)	No	Yes	No	No	Yes	Yes
Stoops et al (2017)	No	Yes	No	Yes	No	Yes
Sügün et al (2011)	Yes	No	N/A	Yes	Yes	Yes
Takemoto et al (2012)	No	Yes	No	Yes	No	Yes
Taylor et al (2017)	Yes	No	N/A	Yes	Yes	No
Thomas and Greenberg (2009)	No	Indeterminate	No	No	No	No
Tweet et al (2010)	No	Yes	No	No	Yes	Yes
Vaiss et al (2014)	No	No	No	Yes	Yes	No
Vernet et al (2017)	Indeterminate	Yes	No	No	No	No
Watchmaker et al (2016)	No	Yes	No	No	Yes	Yes
Williams et al (2016)	No	Yes	No	No	Yes	No

Note: Indeterminate: unable to determine based on data provided in article; N/A: not applicable, that is, no reference standard used.

analysis that directly tests for differences in outcomes among the various treatment options. We elected to merely summarize the outcomes per imaging modality. Summary outcomes per imaging modality are reported in ►**Tables 2–5**.

The search yielded 163 citations, of which we included 47 studies after title and abstract screening (►**Supplementary Appendix 4**). Thirteen studies were excluded based on full text review. Thirty-four articles met criteria after full-text review and were included in our systematic review (►**Supplementary Appendix 5**). The characteristics of individual studies can be found in **Supplementary Appendices 2** and **3**.

Quality Assessment

The studies included in this review were diverse. The methodological quality of the included studies is presented in ►**Table 1**.

Results

Imaging Modalities

All studies comparing anteroposterior (AP) and lateral views with additional views (oblique, dorsal tangential view [DTV], carpal shoot through [CST] view, and radial groove view [RGV]) or additional imaging modalities (360 degrees or three dimensional [3D] fluoroscopy and ultrasound [US]) found additional views and imaging modalities obtain better results compared with only conventional fluoroscopic views. Additional imaging modalities included additional fluoroscopic views in 27 studies, 360 degrees fluoroscopy in 1 study, rotational fluoroscopy in 1 study, and US in 7 studies. We interpreted the "Hoya view," the "skyline view," and the "dorsal horizon view" to be the same as the DTV, which was studied in a total of 19 studies.

Dorsal Screw Penetration

A total of 27 studies analyzed imaging modalities detecting dorsal screw penetration. One of these studies analyzed dorsal and intra-articular screw penetrations simultaneously. Thirteen were in vitro (cadaveric) studies, and 13 were in vivo (clinical) studies. Additionally, one study had an in vitro and in vivo components. Study characteristics of all studies reporting on the detection of dorsal screw penetration can be found in ►**Supplementary Appendix 2.**

In vitro—Cadaveric

Fourteen studies reported on imaging modalities for detection of dorsal screw penetration in a cadaveric setting.[7–9,12–22]

Reliability

Four studies analyzed the reliability of additional views or imaging modalities.[7,13,14,17] The lowest interobserver reliability was found for oblique pronated views[7] and AP views.[7,13] One study analyzing the interobserver reliability of US found an agreement between observers that could be attributed to chance for US (intraclass coefficient [ICC] = −0.0129) when comparing the results of three observers

Table 2 Studies reporting on the reliability for detection of dorsal screw penetration

	Study	N					Level observers	Outcome	AP		Lateral		Pronation		Supination		DTV[a]		CST		US	CT	
		Images	Cadavers	Patients	Screws	Observers			Inter	Intra	Inter	Intra	Inter	Intra	Inter	Intra	Inter	Intra	Inter	Intra	Inter	Inter	Intra
Cadaveric	Vernet et al (2017)	Indeterminate	10		40	3	Orthopaedic surgical residents	Concordance correlation coefficient (K)									0.91				−0.0129		
	Poole et al. (2016)	42	1		10	10	Orthopaedic surgeons	Inter-/intra-observer reliability (K)	0.2	0.37	0.36	0.96	0.05	0.52	0.69	0.86	0.72	0.76	0.66	0.86			
	Hill et al (2015)	84	21		84	63	All levels	Cumulative interrater agreement (K)	0.31				0.19		0.72		0.44						
	Ozer et al. (2012)	40	10		40	2	Consultants/specialized registrars	Interobserver agreement (%)			100%		90%				100%						
Clinical	Brunner et al (2015)			22	88–110	3	Not described	Inter- and intraobserver reliabilities (ICC)									0.72	0.77				0.87	0.85

Abbreviations: AP, anteroposterior; CST, carpal shoot through; CT, computed tomography; DTV, dorsal tangential view; ICC, intraclass coefficient; Lat, lateral; US, ultrasound.
[a]We interpreted the Hoya view, skyline view, and dorsal horizon view to be the same as the dorsal tangential view.

Table 3 Studies reporting on the efficacy for detection of dorsal screw penetration

		Design	*N*		Outcome		AP + Lat	DTV[a]	CST	RGV	3D	US
			Patients	Screws	% Cases with penetrating screws detected	% Penetrating screws detected						
Clinical	Taylor et al (2017)	Retrospective	25	Indeterminate	x			8%				
	Brunner et al (2015)	Prospective	22	93		X		11.8%				
	Rausch et al (2015)	Prospective	48	232		X		5.2% additional after AP + lat			4.3% additionally after DTV(1 intra articular)	
	Marsland et al (2014)	Prospective	42	Indeterminate	x	X			Cases: 14% Screws:17% (1 intra articular)			
	Vaiss et al (2014)	Retrospective	75	300	x	X	0%	Cases: 14.7% Screws: 5%				
	Lee et al (2013)	Prospective	91	Indeterminate	x		0%			14%		
	Sügün et al (2011)	Indeterminate	46	230		X						25.7%
	Joseph and Harvey (2011)	Retrospective	15	Indeterminate	x			26.7%				
	Ozer and Toker (2011)	Indeterminate	27	125		X	6.4%	8.8%				

Abbreviations: 3D, three-dimensional fluoroscopy; AP, anteroposterior; CST, carpal shoot through; DTV, dorsal tangential view; lat, lateral; *N*, number; RGV, radial groove view; US, ultrasound.
[a]We interpreted the Hoya view, skyline view, and dorsal horizon view to be the same as the dorsal tangential view.

Table 4 Studies reporting on the sensitivity for detection of dorsal screw penetration

	Study	*N*		Design	Reference[a]	Lateral	AP	Pronation	Supination	DTV[a]	CST	RGV	360/3D	US
		Cadavers/ patients	Screws											
Cadaveric	Cha and Shin (2017)[b]	4	32	Cadaveric	Direct visualization			Depending on angle and position		88%		63%		
	Vernet et al (2017)	10	40	Cadaveric survey	Not described					97.0%				43.3%
	Stoops et al (2017)[b]	7	126–231	Cadaveric survey	Direct visualization					75%	86%			
	Giugale et al (2017)	2	32	Cadaveric survey	Direct visualization	96.4%				97.2%				
	Poole et al (2016)	1	10	Cadaveric survey	Direct visualization	16%	12%	12%	40%	51%	78%			
	Williams et al (2016)	4	16	Cadaveric	Direct visualization									100%
	Gurbuz et al (2017)[b,c]	10	40	Cadaveric survey	Direct visualization					100%				100%
	Watchmaker et al (2016)	5	33	Cadaveric + prospective series	Direct visualization	18.2% (incl. oblique)								63.3%
	Hill et al (2015)	21	252	Cadaveric survey	Direct visualization	58.7%		54.4%	88.2%	66.5%				
	Dolce et al (2014)	8	128	Cadaveric	Direct visualization	24.5%				100%				
	Haug et al (2013)	6	25	Cadaveric survey	Direct visualization/CT					96%				
	Ozer et al(2012)[b,c]	10	40	Cadaveric survey	Not described	80% (inc. oblique)		65% (4th comp 93%)	0% (2nd comp 92%)	95%				
	Riddick et al (2012)	1	14	Cadaveric survey	Direct visualization	66%		64%		83%				
	Thomas and Green-berg (2009)[c]	Indetermi-nate	4/cad	Cadaveric survey	Direct visualization								77%	
Clinical	Oc et al (2018)	47	Indetermi-nate	Retrospective cohort	US	41.2%		16.2%	50.0%	58.3%				
	Kiyak (2018)	10		Case series	Surgery					70%				
	Ganesh et al (2016)	25	175	Retrospective cohort	CT					66.7%				
	Bianchi et al (2008)	9 sympto-matic patients	Indetermi-nate	Case series	Surgery								100%	100%
	Lee et al (2013)	93	Indetermi-nate	Indeterminate	CT							95%		

Abbreviations: 360/3D, 360 degrees or three-dimensional fluoroscopy; AP, anteroposterior; CST, carpal shoot through view; DTV, dorsal tangential view; *N*, number; RGV, radial groove view; US, ultrasound.

[a]We interpreted the Hoya view, skyline view, and dorsal horizon view to be the same as the dorsal tangential view.

[b]In case sensitivity in studies was given per amount of DSP and could not be recalculated, 2 mm DSP was chosen (because less is irrelevant due to manufactured length interval of 2 mm). These studies are not included in the meta-analysis unless they gave exact numbers with which overall sensitivity could be calculated.

[c]In case, sensitivity in studies was given per compartment/region and overall sensitivity could not be calculated, the central region or third compartment were chosen (because EPL rupture is most relevant complication described in the literature). These studies are not included in the meta-analysis unless they gave exact numbers with which overall sensitivity could be calculated.

Table 5 Studies reporting on the sensitivity, specificity and accuracy for detection of intra-articular screw penetration

	Study	*N*			Design	Reference Standard	Outcome	Lateral	AP	Oblique	Tilt	3D	360	DVT	CT
		Cadavers	Patients	Screws											
Cadaveric	Borggrefe et al (2015)	12		36–48	Cadaver survey	3D CT reconstruction	Sensitivity	58%			68%		88%		
	Takemoto et al (2012)	8		40	Cadaver survey	Direct visualization	Sensitivity	84.5%							95.2%
	Tweet et al (2010)	30		30	Cadaver survey	Direct visualization	Sensitivity	61%	93%		11 deg AP: 91% 22 deg Lat: 63%		93%		
	Soong et al (2008)	1		20	Cadaveric	Direct visualization	Specificity	10%	30%		11 deg AP: 100% 15 , 23, and 30 deg lat: all 60%				
Clinical	Pace and Cresswell (2010)		128	Indeterminate	Retrospective cohort	No revision surgery	Specificity	28%		63%					
	Patel et al (2013)		34	Indeterminate	Survey	rotational fluoroscopy	Accuracy	58.8%			AP + lat + 30 deg lat: 77.5%				
	Kumar et al (2001)		10	Indeterminate	Indeterminate	Indeterminate	Specificity	0%			100%				

Abbreviations: 360, 360 degrees fluoroscopy; 3D, three-dimensional fluoroscopy; AP, anteroposterior; DVT, digital volume tomography; lat, lateral; *N*, number; Tilt, anatomical tilt.

using DTV and US to detect dorsal screw penetration (DSP) in 10 cadaveric wrists.[17] The interobserver reliability of DTV ranged from K = 0.44 to K = 0.91.[7,13,17] One study found an interobserver reliability for CST view of 0.66 when analyzing the results of 10 observers interpreting the views made of one model.[7] All studies analyzing intra- and interobserver reliabilities of conventional and additional views used premade views, made by the researchers, rather than including the positioning of the wrist by the observers in their analysis.

Reliability per imaging modality can be found in ►**Table 2**.

Efficacy

No cadaveric studies have analyzed the efficacy of imaging modalities for detection of dorsal screw penetration.

Accuracy

Fourteen studies have reported on the accuracy of imaging modalities in a cadaveric setting.[7–9,12–22] Two of these studies did not describe their used reference standard,[14,17] all other studies used direct observation of screw penetration as reference standard. The lowest ranges of sensitivity were described for AP[7] (12%, one study involving 10 screws) and oblique pronation[7,13,14] (range: 12–65%, three studies involving a total of 302 screws). A wide range of sensitivity was found for both lateral[7,9,13,15,18] (range: 16–96%, five studies involving a total of 436 screws) and oblique pronation[7,13,14] (range: 0–88%, three studies involving a total of 302 screws). The reported sensitivity of RGV was 63%[20] (one study involving 32 screws) and of CST view was 78 to 86%[7,8] (two studies involving a total of 136 screws). A sensitivity of up to 100% was found for both DTV[7–9,13–15,17–21] (range: 51–100%, a total of 11 studies involving a total of 739 screws) and US[12,16,17,19] (range: 43.3–100%, four studies involving a total of 129 screws).

Sensitivity per imaging modality can be found in ►**Table 4**.

Meta-analysis

Data of nine studies could be included in a meta-analysis analyzing the sensitivity of additional fluoroscopic views. In this meta-analysis, the DTV showed a sensitivity of 91% for the detection of dorsal screw penetration.[6,9,15,17,18,21,23–25] Sensitivity for the detection of dorsal screw penetration of lateral fluoroscopic views was 81%.[9,15,18] Combined results of available data of only a total of 56 screws of two studies showed a sensitivity of 54%, specificity of 100%, and accuracy of 63% for US.[12,17]

In vivo—Clinical

Thirteen studies analyzed imaging modalities detecting dorsal screw penetration in a clinical setting.[6,16,23–33]

Reliability

Brunner et al performed the only clinical study in this review that reported on reliability.[25] They analyzed the inter- and intraobserver reliabilities of three blinded observers on the screw tip cortex distance measurements of fluoroscopic DTV images and computed tomography (CT) reconstructions of 22 patients. This study showed an interobserver reliability of ICC = 0.72 and intraobserver reliability of ICC = 0.77 for measurements on DTV.

Reliability per imaging modality can be found in ►Table 2.

Efficacy

Eleven clinical studies reported numbers that indicate efficacy of imaging modalities detecting dorsal screw penetration in a clinical setting.[6,16,23,25,27–33] DTV is reported to lead to a change in intraoperative management in up to 27% of patients.[23,25,27,29,32] Pooled data for the efficacy defined as cases with changed management due to DTV is 20.7%, in a total of 163 patients.[6,27,29,33] One study analyzing the efficacy of US found 25.7% of all screws to be protruding in 46 patients.[30]

The CST showed an efficacy of 17% in a prospective study of 42 patients.[28] The RGV detected DSP in 14% of the patients in one study involving 91 patients.[31]

Efficacy per imaging modality can be found in ►Table 3.

Accuracy

Five clinical studies analyzed the accuracy of additional imaging techniques for dorsal screw penetration in a clinical setting.[23,24,26,31,34] The lowest reported sensitivity is 16.2% for pronated oblique views and 42% for lateral views in a study comparing lateral views, pronated views, supinated views, and DTV in 47 patients using US as reference standard.[34] The highest reported sensitivities were found for the RGV and US. A reported sensitivity of RGV of 95% was found in one study analyzing 93 patients with CT scan as reference standard.[31] Again, a reported sensitivity of 100% was found for US; however, this was only in one study that analyzed nine patients with symptoms of tendon pathology, with surgery as reference standard.[26] Sensitivity of DTV ranged from 58.3 to 70%.[23,24,34] Ganesh et al performed a retrospective study of 22 nonconsecutive patients with intraoperative DTV and postoperative CT as reference standard. They found a sensitivity of 67% for the DTV.[23]

Sensitivity per imaging modality can be found in ►Table 4.

Intra-articular Screw Penetration

Nine studies analyzed imaging modalities detecting intra-articular screw penetration.[7,12,35–41] Six studies were in vitro (cadaveric) studies, and three were in vivo (clinical) studies. Study characteristics of all studies reporting on the detection of intra-articular screw penetration can be found in ►**Supplementary Appendix 5.**

In vitro—Cadaveric

Six studies analyzed imaging modalities for detection of intra-articular screw penetration in a cadaveric setting.[7,12,35,36,38,40]

Reliability

The only cadaveric study including intra-articular screw detection in its analysis is the study of Poole et al,[7] which pooled numbers for dorsal and intra-articular screw detections. For results, see the Cadaveric—Reliability section for dorsal screw penetration.

Efficacy

No cadaveric studies have analyzed the efficacy of imaging modalities for detection of intra-articular screw penetration.

Accuracy

Six studies analyzed the accuracy of imaging modalities for intra-articular screw penetration in a cadaveric setting.[7,12,35,36,38,40] Tweet et al reported on the sensitivity of lateral and AP views when using direct visualization as reference standard, which were respectively, 61 and 93%.[35] For both views, a low specificity was found in another study when using the same reference standard, respectively, 10 and 30%.[38] Both studies found good results of additional 11 degrees AP views: a sensitivity of 91%[35] and a specificity of 100%.[38] Tweet et al also found a sensitivity of 93% for 360 degrees fluoroscopy.[35] Surprisingly, they found a sensitivity for elevated lateral views of only 63%; however, they did not label the views they showed the observers as elevated which might have influenced the outcomes. 3D fluoroscopy was analyzed in one study using CT scan as reference standard.[40] In this study, a sensitivity of 68% for 3D fluoroscopy was found. By adding digital volume tomography, the sensitivity increased to 88%.

Sensitivity, specificity, and/or accuracy per imaging modality can be found in ►Table 5.

In vivo—Clinical

Three studies analyzed imaging modalities for detection of intra-articular screw penetration in a clinical setting.[37,39,41]

Reliability/Efficacy

No clinical studies have analyzed the reliability or efficacy of imaging modalities for detection of intra-articular screw penetration.

Accuracy

The accuracy for the detection of intra-articular screw penetration is reported in three clinical studies.[37,39,41] Kumar et al reported only tilted lateral and AP views correctly showed no screws to penetrate the joint in 10 patients, which would result in a specificity of 100%.[37] No reference standard was described in this study. Pace and Cresswell retrospectively analyzed 186 patients and found that in half of these patients screws appeared to be intra-articular in standard AP and lateral views, while tilted views of only 8 patients showed screws to appear intra-articular.[39] They assumed only these eight to have true intra-articular screw penetration, however, do not describe reference standard.

Patel et al performed a survey of conventional and tilt views of 34 patients among 65 physicians.[41] They found that adding a 30-degree tilt lateral view to lateral and AP views increases the accuracy by 19%.[41]

Sensitivity, specificity, and/or accuracy per imaging modality can be found in ►Table 5.

Discussion

The purpose of this review was to identify the best evidence-based intraoperative diagnostic imaging strategy, based on reliability, efficacy, and accuracy to identify dorsally protruding screws and intra-articular placed screws in volar plating for distal radius fractures based on in vitro cadaveric and in vivo clinical studies.

The results of this study should be interpreted in the light of its limitations. As there was a large heterogeneity between all the included studies, a direct comparison is hard to make. This review also reports on separate additional modalities, while clinical practice might require a combination of additional modalities. Most studies included only a small number of patients or cadavers,[7–9,12,15,16,18,20,21,26] and a majority of the clinical studies had a retrospective design,[23,27,29] lacked a reference standard[6,27–30,32,33,37,39] or seemed to be biased.[17,23,26,34] If a reference standard was used, this was often CT scan, which in itself could be argued to be a questionable golden standard especially for intra-articular placed screws given the cartilage layer situated in the joint.

Conventional fluoroscopic AP and lateral views are still commonly used as final check of hardware placement. However, several authors have stated the limitations of these conventional views.[14,21,27,32] The results of this systematic review show AP and lateral views to be inferior in all studies where they were compared with another modality. For intra-articular screw placement, these views are insufficient as well, often projecting screws to be intra-articular while they are not.[37,38]

Oblique views in 45 degrees supination or pronation align the X-ray beam with the natural tilt of the dorsal cortex, which could allow for better detection of DSP. The 45-degree supination view has been described to best detect DSP in the first and second dorsal compartments.[5,7,14,25] The 45-degree pronation view has been described to be accurate in the fourth compartment, but only slightly better than the DTV.[32] However, these views are sensitive only for isolated screw positions, and do not image the third extensor compartment.[14]

In the past years, several additional views have been described to detect dorsal screw penetration. We found the dorsal horizon view, tangential view, skyline view, and Hoya view to be the same as the DTV. Several authors have described this view to be the most reliable view to detect dorsal screw penetration in the third and in some studies also the fourth compartment.[14,23,32] In contrast, Giugale et al described an increased accuracy of the DTV in evaluation to more radial screws.[18] Another study found supinated oblique views to be reliable for the radial region of the distal radius, RGV for the central region, and DTV for the ulnar region, while DSP in the ulnar region was difficult to identify with oblique view.[20] A third study found DTV to be most sensitive in the central region, compared with the ulnar and radial regions.[15]

However, the disagreement between accuracy of the DTV in the ulnar and radial regions could be independent of the benefit of the DTV. It has been suggested that the central screws are more likely to include the extensor pollicis longus (EPL) in their trajectory.[42] Protrusion as small as 1.5 mm has been described to be associated with tendon pathology, particularly in those screws that threaten the third or fourth dorsal compartment.[30] Based on this evidence, the improved sensitivity of the DTV in a cadaveric setting in the identification of a small amount of dorsal cortex perforation through the central holes highlights its true benefit.[18] However, small, nonconsecutive or retrospective clinical series reported a lower sensitivity of DTV.[23,24] This could indicate the DTV is a better "rule out" indicator than a "rule in" indicator.[18]

Limitations of the DTV include the fact that it cannot (always) be a perfect DTV due to the volume of the forearm soft tissues.[43]

Also, the variability of the angle in which the screws are positioned limits the visualization of the same transversal plane. Additionally, the accuracy of the DTV decreases as inclination of the forearm deviates from 15 degrees relative to the axis of the X-ray beam.[18,21] There is also a potential for overexposure of the image, as the image intensifier has difficulty regulating radiation dose based on perceived density.[8,28] This would result in the need to obtain more images and therefore more exposure to radiation. Stoops et al found less images needed to obtain an accurate CST view.[8]

The CST view is also reported to be efficacious and reliable in detecting dorsal screw penetration in the first, third, and fourth compartments.[7] A recent cadaveric study comparing the CST view to the DTV found the CST view to be more sensitive.[8] However, the accuracy nor the reliability of this view has been evaluated in a clinical setting. The RGV has also proven to have a high sensitivity in one cadaveric study[31] and might be most useful in the proximal halve of the EPL groove.[20]

Overall, even though additional views improve the detection of dorsal screw penetration compared with lateral views alone, none of these views has proved to be perfect. Furthermore, according to Vaiss et al additional views add to radiation exposure and surgical time.[29] It has been suggested US might be a better modality to analyze dorsal screw penetration, as it is safe and easily available in operating rooms. Gurbuz et al found US to be equally accurate to the DTV for protrusion in the second and third compartments, and superior to the DTV in the fourth compartment.[19] One recent study did report a poor interobserver agreement for US, which implies the use of US is highly user dependent. Even though US does not expose to additional radiation, the authors of this review feel the setup of US is more time consuming than additional fluoroscopy.

With regard to intra-articular screw penetration, conventional views are mostly described to falsely show screws to be protruding intra-articular on conventional views.[37–39] Described additional imaging modalities to detect intra-articular screws are tilt views, wrist series, tangential AP and lateral views, 360 degrees fluoroscopy, 3D fluoroscopy, and digital volume tomography.[35–40] Results of these studies show conventional AP and lateral views to be inferior to the other modalities, but only 360 degrees fluoroscopy to have a comparable accuracy to CT,[35,36] but no combination of views seems to detect all intra-articular screws.

Due to the limitations of additional imaging modalities and US, several other methods to prevent screw penetration have been proposed. Several authors describe routinely downsizing the screw length to avoid screw prominence,[44] even though this may reduce the biomechanical construct compared with bicortical screw fixation.[45]

Benson et al suggested to intraoperatively make a dorsal incision ulnar to Lister's tubercle to check on the third compartment.[44] Ljungquist et al recommended the use of the lunate depth measure on X-ray to estimate the length of the longest screw.[46] Magaraggia et al are currently working on an unified planning and guidance framework for guided drilling using a camera and reference points and preoperatively defined screw lengths.[47] In this review, we have found only one case in which arthroscopy has been used to check upon intra-articular screw placement.[37] As wrist arthroscopy is upcoming in the evaluation and reduction of fractures, this technique might also be used in the future to intraoperatively detect intra-articular placed screws. Early removal has also been suggested to prevent tendon ruptures for patients that develop problems.[48]

Conclusion

Even though the heterogeneity of the studies is large and the overall quality of the included studies is moderate, we can conclude that conventionally used fluoroscopic views are not sufficient to detect screw penetration in volar plating for distal radius fractures. Therefore, additional intraoperative imaging modalities are required. Several additional fluoroscopic views have been described, of which the DTV is most studied and shows good results for the detection of dorsal screw penetration. The CST view has been subject to a few studies and shows good results as well. US seems to be promising in preclinical and small cohort studies. No additional imaging technique has proven to be perfect. As it appears to be most practical in daily operative practice, we recommend the use of the DTV for the detection of DSP, especially for the third compartment where the EPL is situated. Additional views adapted to the concave surface of the joint make interpreting fluoroscopic views on intra-articular screw penetration easier; however, no accurate method has been described yet.

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Conflict of Interest
None.

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