

**Appendix 1** Search strategy (e.g., PubMed)

#	Searches
1	(Palmar Plate/or Fracture Fixation, Internal/or Bone plate/) and (Wrist/or Wrist Joint/or Radius/or Radius Fractures/)
2	((radius or radial) adj3 fracture*).tw,kw.
3	((volar or palmar) adj3 (plat* or fixati*)).tw,kw.
4	2 and 3
5	1 or 4
6	((Leyton Hewitt or horizon or tangential or oblique or carpal shoot through or skyline or Hoya or radial groove) adj3 view*).tw,kw.
7	((screw* or hardware) adj8 (penetrat* or promin* or placement* or protrud* or protrusion*)).tw,kw.
8	6 or 7
9	5 and 8
10	Limit 9 to English language

Note: Databases used were: Ovid MEDLINE, PubMed, Scopus, Web of Science, and Cochrane.

**Appendix 2** Characteristics of studies on the detection of dorsal screw penetration

Author	Year	Design	N	Modality	Control	Variables	Results	Conclusion
Vernet et al	2017	Cadaveric	10 cadavers	Skyline vs. US	Not described	To demonstrate the detection rate of DSP of US and fluoroscopic skyline	Detection rate US 43.33% Detection rate skyline view 96.97% Agreement US: Poor K = -0.0129 Agreement skyline: Excellent K = -0.91	US cannot replace skyline view in clinical practice
Giugale et al	2017	Cadaveric	2 cadavers	DTV vs. lat views	Visual inspection through incision	To compare the relative efficacies of the lat and DTV in identification of DSP across training backgrounds	DTV: Accuracy 78.6%, sensitivity 97.2%, specificity 22.8% lat view: Accuracy 62.5%, sensitivity 96.4% specificity 14.7%	The DTV is superior to the lat view in the identification of any degree of DSP in the radial most screw. Further, the DTV may also be superior to the lat view in detection of 2 mm screw prominences in central plate holes
Gurbuz et al	2017	Cadaveric	10 cadavers	DTV vs. US	Dorsal approach	To compare the efficiency/ detect the reliability of dorsal tangential fluoroscopy and ultrasonography in detecting DSP	No significant difference was observed on correct detection of 0, 1, and 2 mm DSP at second and third compartments. In the fourth compartment, there was no difference with 0 and 2 mm DSP but correct detection. Accuracy of 1 mm DSP was 87% in US and 71% in DHV. Positive correlation between the observers was $p < 0.01$ in the DHV group and $p < 0.05$ in the US group	The accuracy of US on 1 mm DSP at the fourth compartment is better than DTV. Accuracy of DSV and US is similar for other compartments and penetration levels. US is a reliable and effective procedure
Stoops et al	2017	Cadaveric	7 cadavers	Skyline vs. CST	Dorsal dissection	(1) To determine the accuracy of using depth gauge (2) To determine the specificity and sensitivity of using the skyline and CST to detect DSP	When relying on depth gauge, 9.1% of screws were too long Sensitivity skyline 75%, CST 86% for 2 mm DSP Sensitivity skyline 76%, CST 89% for 4 mm DSP Specificity skyline 85%, CST 84%	The CST has the utility and can be implemented to augment standard intraoperative views and may decrease the incidences of DSP resulting in soft tissue injuries
Cha and Shin	2017	Cadaveric	4 cadavers	Oblique, DTV, RGV	Direct observation	To evaluate the detection for DSP in serial oblique, DTV, RGV in volar plating fixation	Radial region fully visible with supinated oblique views Penetration of screw distal to EPL on several views, radial groove view showed excellent sensitivity	Appropriate combinations of these well-known radiological views are essential for the overall detection of penetrated screws. The RGV appears to be more useful than the DTV for the detection of DSP in the proximal half of the EPL groove
Poole et al	2017	Cadaveric	1 model	CST vs. AP, lat, oblique and DTV	Direct vision	To assess sensitivity of CST vs. conventional for DSP and joint screw penetration (DRUJ), including	Sensitivity CST 78%, skyline 51%, conventional 12-16% All views high specificity (89-100%) Sensitivity CST in first radial screw 100%, second radial screw 80%, second ulnar screw 90%, first ulnar screw 90% Sensitivity skyline in first radial screw 80%, second radial screw 100%, second ulnar screw 10%, and first ulnar screw 90% Interobserver agreement CST 0.66, intraobserver agreement 0.86 Interobserver agreement skyline 0.72, intraobserver agreement 0.76	(1) CST view has been shown to be the optimal view tested for detection of SP. (2) The dorsal skyline view had a lower detection rate, but proved to be more sensitive than inclined lat and supinated and pronated oblique views
Williams et al	2016	Cadaveric	4 cadavers	US	Direct vision	To ascertain sensitivity and specificity of US for identification of DSP	Sensitivity: 100% for DSP Specificity: 100% for DSP 0/2 Intra-articular screws detected	(1) US can be used for early diagnosis of SP and thereby reducing need for CT (2) US could not be used to clarify intra-articular screws
Hill et al	2015	Cadaveric	21 cadavers	lat, 45 deg pro/ sup DTV	After dissection	To determine most vulnerable screw position and most useful fluoroscopic views for DSP	At least one DSP: 18 mm screws in 3.6% of specimens, 20 mm 25%, 22 mm 57% second from radial position most likely to long view sensitivity lat 58.7%	(1) DTV and 45 deg supination views should be considered (2) Clinician may opt to subtract a few mm from measured screw length to avoid DSP

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Appendix 2 (Continued)

Author	Year	Design	N	Modality	Control	Variables	Results	Conclusion
							45 supination 88.2% 45 pronation 53.4% DTV 66.5% Inter-rater agreement slight to substantial for all views	(3) Radial-sided screws most commonly breached the dorsal cortex
Dolce et al	2014	Cadaveric	8 cadavers	Hoya vs. lat view	After dissection	To evaluate the accuracy for assessment of DSP	Screws gauge length: -6/64 screws showed DSP, average protrusion was 1.08 mm and most frequently located at the two most radial screw positions (83.3%) - lat: 0% (0/6) of DSP detected - Hoya: 100% (6/6) of DSP detected Screws 2 mm longer: - 49/64 screws showed DSP - lat: 24.5% (12/49) detected - Hoya: 100% (49/49) detected	(1) Hoya is a quick and accurate assessment of DSP. (2) Additional views should be considered, but opt to subtract few millimeters from measured length to avoid penetration.
Haug et al	2013	Cadaveric	6 cadavers	DHV	Direct vision and CT	To determine ideal angle of inclination To assess capability of axial fluoroscopy to detect dorsal screw penetration	Optimal angle 15 deg inclination of the forearm relative to the X-ray beam DSP seems to be measured slightly too long in CT scans	(1) Dorsal horizon view can facilitate insertion of screws with minimal dorsal penetration (2) The ideal angle if inclination of the bone relative to the X-ray beam is 15 deg 3. Correct screw length cannot be measured exactly with a CT scan
Ozer et al	2012	Cadaveric	10 cadavers	DTV vs. conventional (lat, pro/sup oblique)	Direct vision	To determine improvement of accuracy in detecting dorsal SP by using DTV	Highest sensitivity per compartment 2 mm SP 3 mm SP Second 45 sup 92% 45 sup 98% Third DTV 95% DTV 98% Fourth 45 pro+ DTV 90% 45 pro + DTV 95% Interobserver agreement 100% on lat view, 90% oblique vies and 97-100% in DTV	(1) Standard lat view fails to detect all DSP (2) DTV increases accuracy of dorsal screw penetration in 3th compartment (3) Oblique views are needed for evaluation of second and fourth compartments
Riddick et al	2011	Cadaveric	1 model	DTV vs. lat vs. oblique	Direct vision	To determine ability of skyline view to demonstrate DSP	Detection of DSP, sensitivity, specificity, accuracy Skyline 83%, 83%, 83% lat 66%, 89%, 77% Oblique 64%, 37%, 51% Sensitivity, skyline view radial screws (1 and 2) 85%, central screws (3-5) 77%, ulnar screws (6 and 7) 90%	Skyline view could be an accurate addition to routine fluoroscopy, especially in the ulnar region
Thomas and Greenberg	2009	Cadaveric	?	Rotational fluoroscopy	Not described	To determine the ability of standard fluoroscopic imaging to asses DSP	Sensitivity Level observer radial central ulnar combined 82%, 77%, 57% Experienced 100%, 90%, 75% Inexperienced 70%, 61%, 56%	Standard fluoroscopic imaging has limited sensitivity for SP, particularly less in inexperienced observers and the most ulnar screw position
Oc et al	2018	Cohort	47 pts	Lat, pronation, supination, DTV	US	To compare four-plate radiography and US in the evaluation of DSP	Sensitivity kappa Agreement level to US lat 41.67%, 51.5% 45 deg supinated 50.00%, 59.8% 45 deg pronated 16.67%, 23.0% DTV 58.33%, 67.6%	US is recommended for evaluation of DSP In addition to lat views, oblique views and DTV are necessary
Kiyak et al	2017	Case series	12 pts with extensor synovitis and/or rupture	DTV	Direct visualization	To evaluate the reliability of the DTV of the wrist using direct visualization of the extensor compartments in vivo	DSP confirmed in 10/12 pts. DTV detected 7 of these DSP. No false positives	The DTV is sufficiently reliable to be used routinely to reduce postoperative extensor tendon complications
Taylor et al	2017	Case series	25 pts	DTV	None	To describe a technique to prevent DSP	DSP detected in 2 cases (8%)	The skyline view has proven to be a useful adjunct to more traditional intraoperative fluoroscopic techniques

Appendix 2 (Continued)

Author	Year	Design	N	Modality	Control	Variables	Results	Conclusion
Watchmaker et al	2016	Cadaveric + prospective clinical study	5 cadavers 10 pts	US in longitudinal and transverse planes vs. conventional (lat/AP + oblique) views	Dissection in cadaveric group, none in clinical group	To evaluate the accuracy of US and fluoroscopy in the detection of DSP	Cadaveric: -DSP on fluoroscopy 3/11, on US 7/11 Sensitivity DSP < 1 mm DSP > 1 mm US 50% 100% Fluoroscopy 0% 50% ICC US to dissection 0.78 (high) ICC fluoroscopy to dissection 0.19 Clinical: - 3/68 PS detected by US and not by fluoroscopy (0.71, 1.1, 1.1, 2.17 mm)	(1) US is able to detect DSP not visible in fluoroscopy (2) In cadaveric study higher correlation between US imaging and true DSP than between fluoroscopy and DSP
Ganesh et al	2016	Retrospective cohort	26 pt	DTV vs. conventional (AP, lat, 20 deg tilt lat)	CT scan	To assess the utility of DVT in detecting intraoperative DSP	Standard fluoroscopy detected 1.71% prominent screws DTV detected 5.71% additional prominent screws CT detected 2.86% additional prominent screw of which 80% in the second compartment Sensitivity DVT: 66.7% sensitive in any compartment, 100% in the third compartment, 60% in the second compartment, and 50% in the fourth compartment	(1) DTV is not sufficient to avoid dorsal screw penetration in all compartments. (2) DTV provides unique information about DSP (3) DTV is most sensitive in DSP in the 3rd compartment and least accurate in the fourth dorsal compartment (4) It is risky and unnecessary to place bicortical screws (5) distal screws should be 2-4 mm shorter than measured
Brunner et al	2015	Prospective cohort?	22 pts	DTV	CT scan	To evaluate if DTV allows for reliable and valid measurement of distance between screw tips and dorsal radial cortex (STCD)	11 screws were changed intraoperative after DTV, no screw perforations were seen on CT postoperative Mean correlation coefficient between STCD on DTV and CT 0.764 (p < .001) Mean interobserver reliability of STCD on DTV was 0.72 Mean intraobserver reliability of STCD on CT was 0.87 Mean intraobserver reliability of STCD on DTV was 0.77	(1) Both DTV and CT enable reliable measurements for STCD (2) DTV may allow detection of DSP (2) STCD values measured with DTV showed good and excellent correlations with those measured based on CT reconstructions
Rausch et al	2015	Prospective cohort	48 pts	Conventional (AP, lat), tangential view, and 3D fluoroscopy scan	None	To assess the usefulness of DTV and 3D fluoroscopy in detection of dorsal screw misplacement/persistent fracture dislocation and identify the most dangerous plate hole	Screws exchanged after AP/lat unknown, additional 12 screws exchanged after 3D fluoroscopy additional 10 Most lat screw position had highest risk for screw misplacements (45.5% of all exchanged screws)	Additional Tangential View is recommended for detection of screw misplacements.
Marsland et al	2014	Prospective cohort	42 pts	CST vs. conventional (AP + lat)	None	To report impact of new technique upon intraoperative identification of DSP	Capal shoot through revealed 14% (6) additional cases of SP compared with AP/lat	(1) CST has high sensitivity compared with a lat view in detecting dorsal compartment penetration (2) This view also provides excellent visualization of the DRUJ
Vaiss et al	2014	Retrospective cohort	75 pts	DTV vs. conventional (AP + lat)	None	To compare the sensitivity of skyline view to lat view for DSP	DSP seen in lat view 0% (0/300) DSP seen in skyline view 5% (15/300) (average 0.8 mm range 0.5-2) intraoperative change of strategy in 14.7% (11/75) of pts	Skyline view is more sensitive than lat view in detecting of SP
Lee et al	2013	Prospective cohort	91 pts	RGV	CT scan	To assess the efficacy of radial groove view for detection of protrusion of screws in the groove To determine optimum position forearm to obtain view	Postoperative CT showed only 1 screw that had been missed by RGV Sensitivity RGV in detection of SP: 95% Sensitivity RGV in detection of SP in the EPL groove 92.8% Reduction screw prominence by RGV from 14-1% Angle representing most accurate determination of protrusion 5 deg sagittal and 20 deg horizontal	(1) The RGV improves the assessment of protrusion to the EPL groove. (2) The ideal position involved a horizontal angle of 20 deg and a sagittal angle of 5 deg

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**Appendix 2 (Continued)**

Author	Year	Design	N	Modality	Control	Variables	Results	Conclusion
Sugun et al	2011	Cohort	46 fr	US 18.4 (mean) mo postoperative	None	To correlate location and length of DSP as measured with US and clinical evidence of extensor pathology	US showed DSP in 59/230 screws 18/59 penetrating screws showed tendosynovitis 4/18 pts with tendosynovitis was asymptomatic 21/59 DPS in second compartment, 22/59 in fourth compartment	US is accurate for measuring size and qualities of structures in the wrist
Joseph and Harvey	2011	Retrospective case series	15 pts	DHV vs. conventional (AP/lat/oblique)	None	To describe the change in intraoperative management/dorsal screw protrusion in DHV	Changed intraoperative management due to DHV in 26.6% of patients	DHV offers improved determination of DSP
Ozer and Toker	2011	Prospective cohort	27 pts	DTV vs. lat + oblique pro/ sup	None	To compare the standard radiographic views with dorsal tangential for detection of DSP	8 penetrating screws were detected in lat/oblique views 11 screws were detected in DTV. 3 penetrating screws in zone 1 were detected in supination view and in DTV 1 out of 4 penetrating screws in zone 2 was detected by pronation views, 4/4 by DTV 3/3 penetrating screws in zone 3 were detected in pronation views and in DTV	Screw penetration to 3rd dorsal compartment is missed in standard views, but visualized in DTV
Bianchi et al	2008	Case Series	9 pts with signs of tendon pathology	US	Surgery	To analyze the sonography examinations	12 protruding screws were found, with a mean length of 2.7 mm upon US All pts had signs of impingement and surgery confirmed the sonography diagnosis	US is an effective, dynamic and non-invasive technique to diagnose screw impingement and evaluate damage to the extensor tendons

Abbreviations: AP, anteroposterior; CST, carpal shoot through view; DHV, dorsal horizon view; DSP, dorsal screw penetration; DTV, dorsal tangential view; EPL, extensor pollicis longus; lat, lateral; N, number; pro, pronation; pts, patients; RCV, radial groove view; sup, supination; US, ultrasound.

**Appendix 3** Characteristics of studies on the detection of intra-articular screw penetration

Study	Year	Design	N	Modality	Control	Variables	Results	Conclusion
Cadaveric Poole et al	2017	Cadaveric	1 model	CST vs. AP, lat, oblique and dorsal skyline	Direct vision	To assess sensitivity of CST vs. conventional for DSP and joint screw penetration (DRUJ)	Sensitivity CTS 78%, skyline 51%, conventional 12–16% All views high specificity (89–100%) Sensitivity CST in: first radial screw 100%, second radial screw 80%, second ulnar screw 90%, first ulnar screw 90% Sensitivity skyline in: first radial screw 80%, second radial screw 100%, second ulnar screw 10% First ulnar screw 90% CST: inter observer agreement 0.66 Intra observer agreement 0.86 Skyline: interobserver agreement 0.72, intraobserver agreement 0.76	(1) Elevated lat view cannot be relied upon alone (2) CST is a valid technique to detect DSP
Borggrefe et al	2015	Cadaveric	12 cadavers	AP + lat, 3D fluoroscopy, digital volume tomography (DVT)	High-resolution CT scan	To investigate if intraoperative 3D flat panel imaging improves the detection of radiocarpal intra-articular screw misplacement compared with standard X-ray	Sensitivity Specificity X-ray (AP + lat) 58% 88% DVT 88% 53% 3D fluoroscopy 68% 95%	(1) 3D fluoroscopy and DVT appear to be at least as sensitive and specific to detect intra-articular screws than regular X-ray (AP/lat). (2) Especially discrete screw misplacement can still be missed with either method
Takemoto et al	2012	Cadaveric	8 cadavers	Standard (PA, AP, oblique lat) and anatomic tilt (11° angled PA, 45° pronated and 23° angled lat) vs. CT	Direct Vision	To compare CT and radiographs in their ability to detect intra-articular screw penetration	Detection of intra-articular SP Sensitivity Specificity Accuracy Radiographs 84.5% 91.7% 85.4% CT 95.2% 100% 95.8% Detection of location of SP Sensitivity Specificity Accuracy Radiographs 65.4%	CT is the preferential radiographic modality in evaluating radiocarpal joint penetration

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Appendix 3 (Continued)

Study	Year	Design	N	Modality	Control	Variables	Results	Conclusion
Tweet et al	2010	Cadaveric	30 cadavers	AP, lat, 11 deg tilt PA, 22 deg tilt lat vs. rotational 360 deg fl	Dorsal arthroscopy	To evaluate surgeons' ability To detect intra-articular screws on static and rotational screws	Reliability to detect intra-articular hardware Sensitivity Specificity 360° 93% 96% PA 93% 86% Lat 61% 53% 11° AP 63% 95% 22° lat 63% 95%	(1) rotational fluoroscopy was significant more reliable than most images and trended toward more reliability for all remaining images (2) no combination of views detected all intra-articular screws
Soong et al	2008	Cadaveric	1 cadaver	Tilt-AP (11 deg) + tilt lat (15, 23, 30 deg) vs. AP + lat	Dorsal incision	To evaluate tilt views for assessment of intra-articular screw placement	Screws appeared to be penetrating (0 were PA first + second ulnar Lat first + second radial, second ulnar Tilt AP 0 Tilt lat 15 deg first radial Tilt lat 23 deg first radial Tilt lat 30 deg first ulnar	(1) Tilt PA view is the only view that correctly showed all 4 screws to be extra articular (2) The lowest angle tilt lat view and anatomic tilt lat view are specific for more ulnar screws (3) The highest angle lat view is specific for the more radial screws
Pace and Cresswell	2010	Retrospective cohort	128 patients	Articular wrist series (11 deg sup/pronated AP and tangential and lat 23 deg to the horizon) vs. standard (AP + lat)	None	To evaluate effectiveness of the articular wrist series	Standard views: in 92 radiographs screws appeared intra-articular (false positives) Articular views: in 8 radiographs screws appeared intra articular (true positive)	Articular wrist series make interpreting radiographs much easier
Kumar et al	2001	Unclear	10 patients	Tangential AP + tangential lat vs. routine PA + lat	Arthroscopy in 1 patient	To describe two new radiographic views	Screw appeared penetrating into the joint in 10/10 on lat, 8/10 on AP, 0/10 on tangential AP, and 0/10 on tangential lat	(1) Tangential views show position of the screw better (2) With these views it is possible to place plates more distal

**Appendix 3** (Continued)

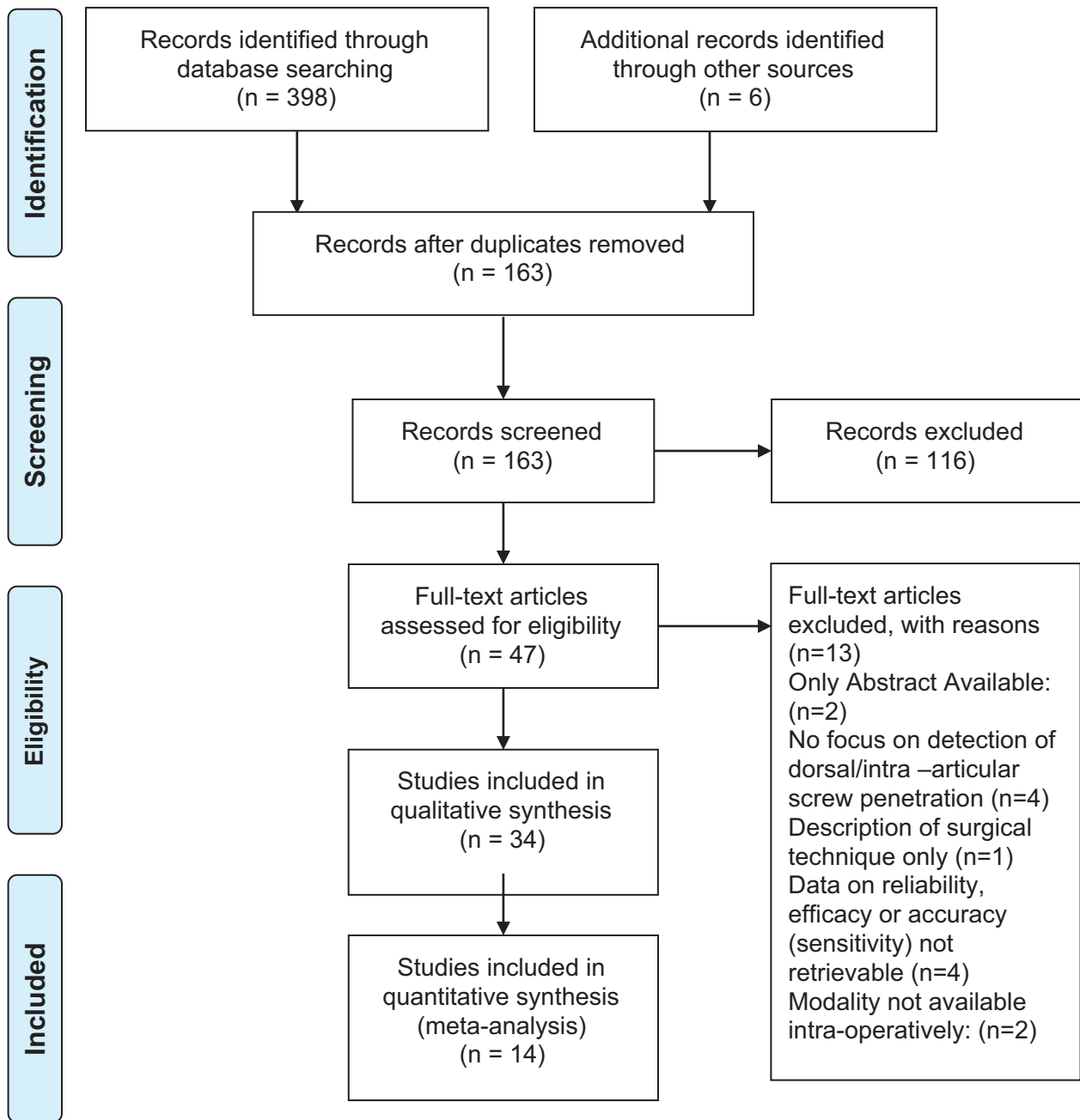
Study	Year	Design	N	Modality	Control	Variables	Results	Conclusion
Patel et al	2013	Survey of clinical cases	34 fractures	AP + lat vs. AP + lat + 30 deg tilt	Rotational fluoroscopy	To assess the extent to which a 30 deg tilt lat view increases accuracy and confidence ratings	Accuracy AP + lat: 58.8% Accuracy AP + lat + 30 deg tilt lat: 77.5% Confidence ratings increased with 18.7% by adding 30 deg tilt lat views to AP and lat views	A supplemental view of the distal radius combined with AP and lat views improves the accuracy and confidence of clinical evaluators tasked with ensuring the proper position of radial volar plate screws (i.e., intra-/extra-articular)

Abbreviations: AP, anteroposterior; CST, carpal shoot through view; DHV, dorsal horizon view; DSP, dorsal screw penetration; DTV, dorsal tangential view; fl, fluoroscopy; lat, lateral; pro, pronation; pts, patients; RGV, radial groove view; sup, supination; US, ultrasound.





## Appendix 4 PRISMA 2009 Flow Diagram



**Appendix 5** Characteristics of excluded study (ordered by first author)

Study	Reason for exclusion
Aldemir and Duygun (2017)	Focused on the use of an improved design of the volar plate
Balfour (2016)	Description of technique and illustrative cases only
Boyer et al (2003)	Focused on the use of a dorsal plate
Diong et al (2018)	No data reporting on reliability, efficacy or accuracy
Granville et al (2012)	No full text available
Herisson et al (2017)	No data reporting on reliability, efficacy, or accuracy
Klammer et al (2012)	Not focusing on screw penetration, but on imaging the distal radioulnar joint itself
Klein et al, year indeterminate	No full text available
Ljunquist (2015)	Measuring the lunate depth as predictor for screw length is not useful as intraoperative imaging modality
Maschke et al (2007)	No data reporting on reliability, efficacy, or accuracy
Magaraggia et al (2017)	Pilot study of a new device. No reported numbers on statistical reliability, efficacy or accuracy
Matullo and Dennison (2010)	Use of the contralateral hand to obtain lateral tilt wrist radiographs not useful as intraoperative imaging modality
Smith et al (2004)	Focused on evaluation of placement of the plate, not screws