Interventions to reduce imaging in children with upper or lower extremity injuries: a systematic review and meta-analysis

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ABSTRACT

Background Radiation exposure, transition delays and costs associated with unnecessary imaging in children have stimulated research into clinical decision rules and other interventions to reduce imaging in the emergency department (ED). The objective of this systematic review is to examine the effectiveness of implementing interventions to reduce imaging in children with upper/lower extremity injuries in the ED.

Methods Seven databases and the grey literature were searched up to May 2024. Comparative studies assessing interventions to reduce imaging in children with upper/lower extremity injuries implemented in the ED were eligible. Two independent reviewers screened for study eligibility, quality assessment and data extraction, with disagreements settled via third-party adjudication. Changes in imaging are reported as ORs with 95% CIs, using a random effects model.

Results From 9387 citations, eight unique studies enrolling 7793 children were included with the majority using a before–after design. Potential concerns for bias were documented due to a lack of reporting of key quality domains. Decision rules for ankle injuries successfully reduced radiography (OR=0.11; 95% CI 0.07 to 0.16, I^2=38%). A decision rule for wrist injuries reduced imaging (OR=0.06; 95% CI 0.03 to 0.11); however, eight injuries were missed. Two studies implementing clinical guidelines reported decreases in radiographs per patient (p<0.001). One trial reported increased imaging in children assessed by triage nurses using an established clinical decision rule (OR=5.44; 95% CI 2.96 to 10.02), with 16 missed injuries identified.

Conclusions Guidelines incorporating clinical decision rules, particularly decision rules for ankle injuries, can reduce radiography for children with extremity injuries in the ED. Further investigations are warranted to identify other extremity injuries, the components of the intervention and the most efficient clinicians to target.

PROSPERO registration number CRD42016042875.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ To reduce unnecessary exposure to radiation, guidelines and clinical decision rules (CDRs) have been developed to help physicians identify patients with extremity injuries who can be cleared clinically without imaging.

⇒ Implementing these interventions in the emergency department (ED) can be challenging, and it is not clear whether they can effectively change image ordering practices in the ED without missing injuries.

WHAT THIS STUDY ADDS

⇒ Decision rules for ankle injuries are safe and effective in reducing X-ray ordering in the ED (OR=0.11; 95% CI 0.07 to 0.16; I^2=38%). There was no increase in missed injuries after implementing the interventions.

⇒ For children presenting with wrist or other extremity injuries, there is insufficient evidence available to recommend any CDR to safely reduce X-ray imaging without missing injuries.

⇒ The majority of the evidence is based on non-randomised study designs, with inconsistent reporting of key methods to reduce potential sources of bias such as blinding.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Ankle CDRs can safely be implemented in the ED to reduce unnecessary X-rays ordering in children.

⇒ For children with other extremity injuries, additional high-quality evidence is required to identify interventions that can consistently reduce imaging across multiple studies without missing significant injuries.

INTRODUCTION

Presentations to the emergency department (ED) among children with extremity injuries are common and are often the result of falls or sports/leisure activities.[1–4] While radiographs are routinely ordered, the majority of children do not present with clinically important extremity fractures,[5 6] resulting in unnecessary exposure to harmful radiation,[7–9] delayed transitions and increased healthcare costs.[10 11] Several interventions, including clinical decision rules (CDRs), have been developed to help emergency clinicians to identify children who can be cleared clinically without radiography.[12] For children with extremity injuries, several CDRs including the Ottawa Ankle Rule (OAR),[13] the low risk ankle rule (LRAR)[14] and

Amsterdam Pediatric Wrist Rules (APWR)[15] have been developed for use in the ED.

While the CDR evidence is encouraging, implementing interventions to reduce imaging has been challenging, and even when successful, the impact is often far smaller than predicted in the validation literature. There are many reasons for these challenges, including fear of missing a fracture, litigation, patient/caregiver/parent demands, local and consulting practices and clinician autonomy.[16] Despite these concerns, joint calls from societies collaborating with Choosing Wisely initiatives globally have recommended reducing simple and advanced imaging for common paediatric conditions.[17–19]

In other paediatric conditions, the effectiveness of implementing CDRs or guidelines is accumulating. For example, a systematic review found that CDRs such as the Pediatric Emergency Care Applied Research Network (PECARN) rule effectively reduced head CT imaging ordering when implemented in the ED.[20] The review also reported that EDs with higher baseline imaging and additional intervention components were associated with larger decreases in imaging.[20] There are lessons to be learned from all of these granular examinations of implementation practices. The objective of this systematic review was to explore the effectiveness of interventions implemented in the ED to reduce imaging in children with extremity injuries.

MATERIALS AND METHODS

Protocol

A study protocol was registered on PROSPERO (registration # CRD42016042875) regarding interventions to reduce imaging in children with any injuries. Post hoc modifications were completed to focus the scope of this review on children presenting with extremity injuries. Another systematic review from this protocol examined children with minor head injuries.[20] Reporting of this review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations.[21]

Study selection and screening

Inclusion/exclusion

Randomised or non-randomised comparative studies assessing interventions to reduce imaging in children presenting to the ED with extremity injuries were eligible for inclusion. Included patients were required to be children (<18 years old) with traumatic upper or lower extremity injuries such as ankle, elbow, forearm, knee or wrist injuries. Studies that enrolled both children and adults were eligible for inclusion if at least 80% of the patient population were children, or if the study reported outcomes separately for children. The interventions had to be implemented in the ED and studies had to report changes in image ordering in the ED to be eligible for inclusion. Interventions where the aim was to replace one imaging modality with another instead of reducing imaging were not eligible for inclusion.

Outcome

The primary outcome was the change in simple or advanced image ordering, including X-rays, as well as other imaging modalities. Secondary outcomes of interest included a descriptive summary of the intervention components and implementation strategies were categorised as education, decision support, audit/performance feedback, change in electronic order entry, CDR, policy implementation and clinical guidance (ie, guidelines/pathways). Interventions were considered multifaceted if the study reported two or more intervention components. Additional secondary outcomes of interest included missed injuries, return to ED, patient disposition, ED length of stay (LOS), healthcare costs and radiation exposure. Clinician adherence to the intervention and compliance with the intervention recommendation for imaging were documented.

Search methods for identification of studies

An expert health librarian (SC) completed a literature search of databases including PROSPERO, OVID MEDLINE, OVID EMBASE, Wiley Cochrane Library (CDSR and Central), EBSCO CINAHL, ProQuest Dissertations and Theses Global and SCOPUS using controlled vocabulary (eg, Medical Subject Headings, Emtree) and key words. Searches incorporated modified ED and paediatric filters to promote identifying ED-based studies involving paediatric patients. Databases were searched from the database's inception until 6 May 2024. The search results were exported to Covidence (Veritas Health Innovation; Melbourne, Australia, www.covidence.org) review management software, where duplicates were removed. There were no limitations based on year of publication, language or publication status. Detailed search strategies are available in online supplemental supplement 1. A search of the grey literature included Google Scholar, clinical trial registries (ClinicalTrials.gov and controlled-trials.com), snowballing and searching recently published conference abstracts in the *Canadian Journal of Emergency Medicine*, *Annals of Emergency Medicine* and *Academic Emergency Medicine* (2021–2024).

Data collection and analysis

Selection of studies

The title and abstracts of studies were screened for relevance by at least two independent reviewers (EY, NL, SWK, EH or JU), who then screened the full text of potentially relevant articles using predefined inclusion/exclusion criteria. Disagreements on study inclusion were settled via third-party adjudication (LDK or SWK).

Data extraction

Patient characteristics and primary/secondary outcomes of interest were extracted onto standardised forms in Research Electronic Data Capture (REDCap) platform hosted at the University of Alberta (Alberta, Canada)[22] by at least two independent reviewers (NL, SWK, EH or JU). Reviewer disagreements were settled via third-party adjudication (LDK or SWK). Tabulation of the outcomes and summary of findings tables was completed. The authors were contacted to clarify any missing or unclear methodology or imaging outcomes.

Quality assessment

Before–after studies were assessed using the National Heart, Lung and Blood Institute quality assessment tool (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). Studies using an interrupted time-series design were assessed via criteria developed by the Cochrane Effective Practice and Organisation of Care group,[23] while randomised controlled trials (RCTs) were assessed using the Cochrane Risk of Bias tool.[24] Two independent reviewers (NL, SWK, EH or JU) completed the quality assessment, with disagreements settled via third-party mediator (CV-R or SWK).

Data synthesis

Individual and pooled analysis for changes in imaging was completed via Review Manager (RevMan, V.5.4.1). Imaging

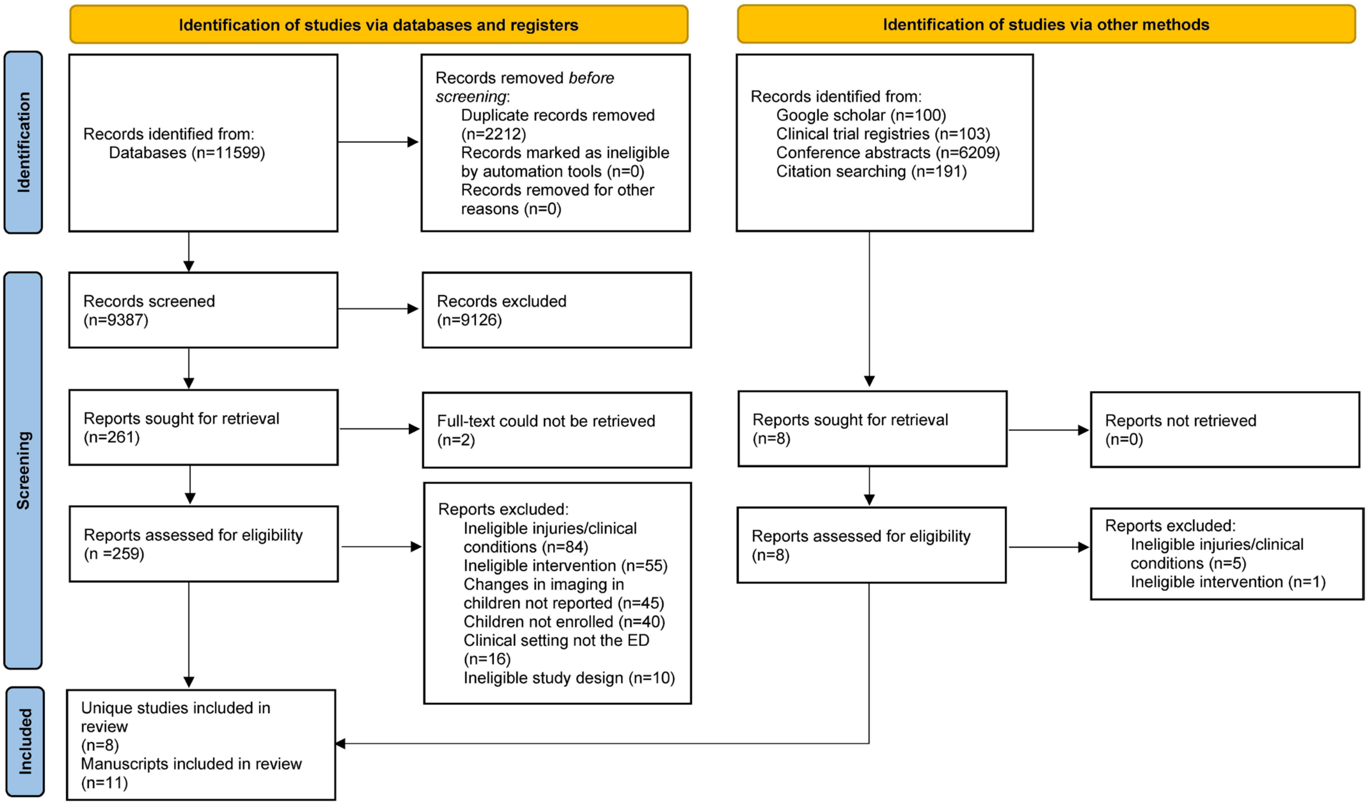

Figure 1 PRISMA flow diagram. ED, emergency department; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

modalities were analysed in subgroups based on injury location and study design. Dichotomous variables were calculated as odds ratios (ORs) with 95% confidence intervals (CIs) using a random-effects model and the weights given to each study were based on the Mantel-Haenszel method. Heterogeneity was assessed using the I^2 statistic with 25, 50 and 75% values representing low, moderate and high degrees of heterogeneity, respectively.[24] A sensitivity analysis of the primary outcome based on study quality was planned. If outcomes could not be pooled, a descriptive summary was reported. Median baseline X-ray imaging rates with interquartile ranges (IQR) were reported. A funnel plot for publication bias could not be completed due to insufficient available studies.[25]

Patient and public involvement

There was no involvement of patients or the public in the development or conduct of this review.

RESULTS

Search results

The results of the database and grey literature search are reported in figure 1. A total of 9387 titles and abstracts were screened from the database search; from these, the full text of 259 studies was retrieved and reviewed by two independent reviewers. 8 unique studies were included,[26–33] as well as 3 secondary publications,[34–36] resulting in a total of 11 publications included in this review (table 1).

Study characteristics

Characteristics of the included studies are reported in table 1. The studies were conducted in the USA,[32 33] Canada,[26 28 31] Ireland,[27] Portugal[29] and the Netherlands.[30] The majority of studies used a before–after design; one RCT[31] and one interrupted time series design were included.[26] A total of 7793 children were enrolled across the studies. Studies enrolled patients with ankle[26–28 31] or wrist[30] injuries, while other studies enrolled patients with various upper/lower extremity injuries (eg, wrist, knee, hand/foot, ankle, elbow, forearm or tibia injuries).[31–33] The majority of studies were based in either paediatric or mixed EDs and most of the studies did not specify the academic affiliation of the study hospitals. Clinicians involved in patient care included emergency physicians, paediatricians, orthopaedic or surgical specialists.

Interventions

Additional details on the intervention components are provided in table 2. All of the studies implemented a multifaceted intervention, with the median number of intervention components being 3 (IQR 2–3). Two studies implemented locally developed guidelines,[32 33] while the remaining studies implemented validated CDRs. Interventions were applied by the attending physicians for all of the studies except one, which strictly used triage nurses to apply the CD.[31] One study reported employing a plan-do-study-act cycle when implementing the LRAR.[28]

Studies assessing CDRs for ankle injuries implemented the LRAR[26–28] or the OAR.[29] All of the studies educated clinicians and nurses on the interventions via educational sessions or posters, while one study used local champions to promote the use of the LRAR.[26] Two of the studies modified the electronic order entry system to include prompts[27] or requisition forms[28] which were mandatory. For patients with suspected wrist fractures, the APWR was made available to clinicians via a mobile app or a website which was not integrated into the local electronic ordering system.[30] Canadian researchers trained triage nurses to screen children presenting with upper/lower extremity injuries using the Brand protocol at triage.[31] Finally, researchers in two studies were trained in the application of two locally developed

Table 1 Study characteristics of studies assessing the effectiveness of interventions in reducing imaging in children presenting to the ED with extremity injuries

Study author and publication date	Study design, data collection year(s)	Sample size Patient age (median, IQR or mean, SD), sex (%)	Interventions	ED setting/clinicians providing patient care	Study inclusion criteria	Exclusion criteria
Ankle injuries						
Boutis *et al* & Boutis *et al* Canada[26 36]	Interrupted time series 2009–2011	N=2151 I: range: 3–16.9 years, 48 male C: range: 3–16.9 years, 49 male	LRAR	Six EDs including academic PEDs, general EDs and non-academic community EDs EM physicians, paediatricians, radiologists and orthopaedic surgeons	Isolated acute, non-penetrating ankle injury, <72 hours since injury. Children aged 3–16 years	Presented to the ED more than 72 hours after the injury or with prior imaging. Developmentally delayed. Risk for pathological fractures. Recent history of injury to same ankle.
Jeong *et al* & Jacobson & Al-Sani *et al* Canada[28 34 35]	B-A 2015–2018	N=610 NR	LRAR	One PED Unspecified staff	Isolated acute ankle injuries. Children aged 3–18 years.	Presenting with outside imaging. Greater than 72 hours. Previous visits for the same injury.
Tormey *et al* Ireland[27]	B-A 2016–2017	N=1061 NR	LRAR	One mixed ED Unspecified physicians	Ankle injury, <72 hours since injury. Children >3 years.	Less than 3 years old. Ankle injury occurring >72 hours prior to presentation. Risk of pathological fracture. Recent surgery or injury to the ankle.
Almeida *et al* Portugal[29]	B-A 2018–2019	N=184 I: 11.3 years (SD: 3.5), 44 male C: 11.9 years (SD: 3.3), 44 male	OAR	One PED Paediatricians, paediatric residents, general physicians	Isolated ankle and/or midfoot injury. Children aged 2–17 years	Previously evaluated for same injury. Open fracture. Obvious deformity or polytraumatised patients. Neuromuscular disease, coagulopathy, neurodevelopmental disorder, previous history of surgery or a recent trauma in the injured joint.
Wrist injuries						
Mulders *et al* The Netherlands[30]	B-A 2011–2016	N=1207 I: 12 years (IQR 9–14), 52 male C: 11 years (IQR 10–14), 60 male	APWR	Four mixed EDs including academic and teaching hospitals EM physicians and surgical residents	Acute wrist trauma defined as any high or low energetic accident involving the wrist, <72 hours since injury. Children aged 3–18 years.	Wrist injury for more than 72 hours before presentation to the ED. Multiple injuries with an ISS >15. Prior imaging before presentation to the ED. Previous fracture in the past 3 months.
Combined upper/lower extremity injuries						
Klassen *et al* Canada[31]	RCT 1990–1991	N=985 patients (N=1002 injury sites) I: 11.1 years (SD: 4), 52 male C: 10.9 years (SD: 4.3), 54 male	Brand protocol	One PED Triage nurses, PEM physicians	Upper or lower extremity trauma within 7 days. Children <18 years.	Patients with neurovascular compromise of the involved extremity. Major trauma. Underlying disease that could predispose to fracture. Underlying disease with sensory abnormalities.
Lander *et al* USA[33]	B-A 2016–2019	N=767 NR	MSK injury imaging protocol and algorithm	One PED Unspecified physicians	Musculoskeletal injury Children aged 0–18 years	NR
Schlacter *et al* USA[32]	B-A 2019–2020	N=828 I: 9 years (SD: 4.5), NR C: 10 years (SD: 4.7), NR	Radiographic protocol	One mixed ED and one urgent care centre Orthopaedic residents, physician assistant or EM physician	Patients with suspected extremity fractures seen by an orthopaedic consultant Children <18 years	Presenting with known fracture. Suspicion of non-accidental trauma.

APWR, Amsterdam Pediatric Wrist Rules; B-A, before–after; C, control group; ED, emergency department; EM, emergency medicine; I, intervention group; ISS, Injury Severity Score; LRAR, low risk ankle rule; MSK, musculoskeletal; NR, not reported; OAR, Ottawa Ankle Rules; PED, paediatric emergency department; PEM, paediatric emergency medicine; RCT, randomised controlled trial.

Table 2 Components of interventions to reduce imaging in children presenting to the ED with extremity injuries

Study author and publication date	Education	Decision support	Audit/performance feedback	Change to electronic order entry	Clinical decision rule	Clinician guidance
Ankle injuries						
Boutis *et al* & Boutis *et al*[26,36]	✔ A single training session was provided to clinicians. Posters displaying the LRAR displayed in the ED. Local physician champions were identified at each study site.	✔ Computerised decision support system automatically provided recommendations for imaging. Pocket cards outlining the LRAR provided to clinicians.	—	—	✔ LRAR	—
Jeong *et al* & Jacobson & Al-Sani *et al*[28,34,35]	✔ Staff education of the LRAR. Posters of the LRAR placed in ED.	—	—	✔ Mandatory electronic diagnostic requisition of ankle injuries encouraging use of LRAR.	✔ LRAR	—
Tormey *et al*[27]	✔ Education sessions. Disseminated study information in ED (ie, posters).	—	—	✔ Mandatory prompts for the LRAR placed in electronic X-ray ordering system.	✔ LRAR	—
Almeida *et al*[29]	✔ All clinicians in PED instructed on how to apply the OAR. Small remembrance board left in every doctor's office.	—	—	—	✔ OAR	—
Wrist injuries						
Mulders *et al**[30]	✔ Physicians trained on use of the APWR. Posters placed in the ED.	✔ Rules available to clinicians via mobile application or website. Pocket cards provided.	—	—	✔ APWR	—
Combined upper/lower extremity injuries						
Klassen *et al*[31]	✔ A single training session provided to ED triage nurses on the use of the Brand protocol.	—	—	—	✔ Brand Protocol	—
Lander *et al*[33]	✔ Department chair sent clinicians emails on the use and implementation of the algorithm. The algorithm was printed and posted within the ED, radiation technologist workspace and orthopaedic resident work room.	—	—	✔ Non-mandatory electronic standardised extremity order set.	—	✔ Locally developed MSK algorithm distinguishing between cooperative and non-cooperative children.
Schlacter *et al*[32]	✔ Protocol introduced via academic conferences, emails and displayed in the ED and urgent care centres. Periodic reminders provided to clinicians.	—	—	—	—	✔ Multi-imaging clinical guidance
Overall total:	Total: 8/8 (100%)	Total: 2/8 (25%)	Total: 0/8 (0%)	Total: 3/8 (38%)	Total: 6/8 (75%)	Total: 2/8 (25%)

*Information on the education and clinical decision support implementation strategies provided by the authors.
APWR, Amsterdam Pediatric Wrist Rules; ED, emergency department; LRAR, low-risk ankle rule; MSK, musculoskeletal; OAR, Ottawa Ankle Rules; PED, paediatric emergency department.

guidelines,[32] with one study implementing non-mandatory electronic extremity order set.[33]

Risk of bias assessment

The majority of the before–after studies[27–30 32 33] reported clear study objectives, eligibility criteria for patients, details on the interventions and conducted appropriate statistical analysis (see online supplemental 2A). No studies reported blinding outcome assessors and only one study conducted sample size calculations.[30]

The remaining studies included one interrupted time series design which was assessed to have a low risk of bias for the majority of categories except for unclear risks for intervention effects and blinding of outcomes (see online supplemental 2B).[26] The RCT was assessed as having a low risk of bias for most domains including randomisation and blinding; however, there was an unclear risk of bias due to insufficient reporting of allocation concealment and selective reporting (see online supplemental 2C).[31]

Primary outcome

Change in imaging

All studies strictly assessed changes in simple radiography ordering, and no other imaging modalities were evaluated. The median baseline X-ray ordering across six studies was 93% (IQR 91%–97%; table 3), which decreased to 75% (IQR 59%–80%) after implementing the interventions.

The median relative decrease of X-ray imaging in studies implementing ankle CDRs was 31% (IQR 22%–44%). A meta-analysis identified decreased likelihood of X-ray imaging after implementing ankle CDRs (OR=0.11; 95% CI 0.07 to 0.16; I^2=38%) with no significant subgroup differences noted between studies implementing the LRAR (OR=0.10; 95% CI 0.07 to 0.14; I^2=34%) or the OAR (OR=0.20; 95% CI 0.07 to 0.57) (figure 2).[26–29]

Children with wrist injuries were less likely to undergo X-ray ordering after implementing the APWR (OR=0.06; 95% CI 0.03 to 0.11).[30] Children screened via the Brand protocol were more likely to undergo X-ray imaging compared with control patients (OR=5.44; 95% CI 2.96 to 10.02).[31] A planned

Table 3 Change in imaging outcomes in studies assessing the effectiveness of interventions to reduce imaging in children presenting to the ED with extremity injuries

Study author and publication date	Baseline X-ray imaging n/N (%)	Post intervention X-ray imaging n/N (%)	Absolute change in X-ray imaging (%)
Ankle injuries			
Boutis *et al*[26]	412/427 (97)	243/341 (71)	**Between group differences: −24 (−30 to −18)** % change: 26 ↓ Relative % change: 27 ↓
Jeong *et al**[28]	183/201 (91)	242/409 (59)	**p<0.0001** % change: 32 ↓ Relative % change: 35 ↓
Tormey *et al*[27]	879/969 (91)	40/92 (44)	p=NR % change: 47 ↓ Relative % change: 52 ↓
Almeida *et al*[29]	85/90 (94)	73/94 (78)	**p=0.001** % change: 16 ↓ Relative % change: 17 ↓
Wrist injuries			
Mulders *et al*[30]	788/799 (99)	326/408 (80)	**p<0.001** % change: 19 ↓ Relative % change: 19 ↓
Combined upper/lower extremity injuries			
Klassen *et al*[31]	434/498 (87)	480/493 (97)	**p<0.001** % change: 10 ↑ Relative % change: 12 ↑
Lander *et al*[33]	2.75 unnecessary† radiographs per patient	0.72 unnecessary† radiographs per patient	**p<0.001** ↓
Schlacter *et al*[32]	Average of 5.1 X-ray views per patient Patients with injuries receiving imaging of three or more anatomic areas **Elbow injuries** 44 **Forearm/wrist injuries** 41 **Tibia injuries** 29 **Ankle injuries** 12	Average of 3.4 X-ray views per patient Patients with injuries receiving imaging of three or more anatomic areas **Elbow injuries** 7 **Forearm/wrist injuries** 9 **Tibia injuries** 20 **Ankle injuries** 10	**p<0.001** ↓ **Elbow injuries** **p<0.001** ↓ **Forearm/wrist injuries** p=NR ↓ **Tibia injuries** p=NR ↓ **Ankle injuries** p=NR ↓

Bolded indicates significant change reported in the text; ↓ indicates a decrease in imaging; ↑ indicates a increase in imaging.
*Patient population data provided by study authors.
†Unnecessary radiographs defined as the difference in the radiographs that were obtained versus indicated based on the recommendation of the intervention.
C, control; ED, emergency department; I, intervention; NR, not reported.

Study or Subgroup	Post-intervention Events	Post-intervention Total	Pre-intervention Events	Pre-intervention Total	Weight	Odds Ratio M-H, Random, 95% CI	Year
1.1.1 Low Risk Ankle Rule							
Boutis 2013	243	341	412	427	26.6%	0.09 [0.05, 0.16]	2013
Tormey 2020	40	92	879	969	33.0%	0.08 [0.05, 0.13]	2020
Jeong 2021	242	409	183	201	29.2%	0.14 [0.08, 0.24]	2021
Subtotal (95% CI)		**842**		**1597**	**88.8%**	**0.10 [0.07, 0.14]**	
Total events	525		1474				
Heterogeneity: Tau² = 0.04; Chi² = 3.04, df = 2 (P = 0.22); I² = 34%							
Test for overall effect: Z = 12.31 (P < 0.00001)							
1.1.2 Ottawa Ankle Rule							
Almeida 2022	73	94	85	90	11.2%	0.20 [0.07, 0.57]	2022
Subtotal (95% CI)		**94**		**90**	**11.2%**	**0.20 [0.07, 0.57]**	
Total events	73		85				
Heterogeneity: Not applicable							
Test for overall effect: Z = 3.04 (P = 0.002)							
Total (95% CI)		**936**		**1687**	**100.0%**	**0.11 [0.07, 0.16]**	
Total events	598		1559				
Heterogeneity: Tau² = 0.06; Chi² = 4.84, df = 3 (P = 0.18); I² = 38%							
Test for overall effect: Z = 11.58 (P < 0.00001)							
Test for subgroup differences: Chi² = 1.68, df = 1 (P = 0.19), I² = 40.5%							

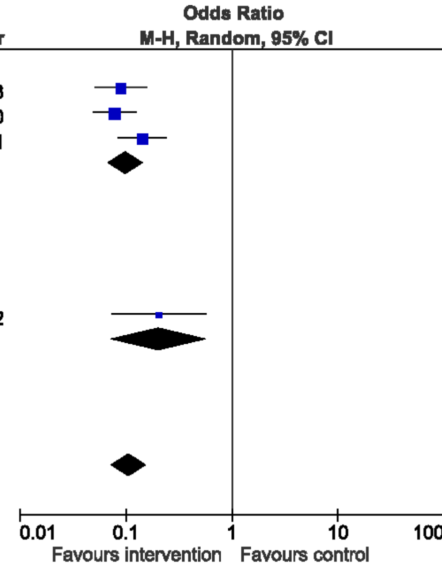

Figure 2 Meta-analysis of studies assessing the effectiveness of interventions to decrease imaging in children presenting to the ED with ankle injuries. ED, emergency department.

sensitivity analysis of study quality could not be completed due to a lack of available studies. Schlacter 2023 reported a decrease of 5.1–3.4 X-ray anatomic views per patient (p<0.001), and that patients with elbow injuries were significantly less likely to receive imaging in three or more anatomic areas after implementing the guidelines (44% vs 7%, p<0.001) (table 3).[32] A reduction of 2.75–0.72 unnecessary radiographs per patient (p<0.001) was reported after implementing the musculoskeletal injury imaging algorithm (table 3).[33]

Secondary outcomes

A summary of the secondary outcomes of interest is reported in online supplemental 3 and 4. Proposed secondary outcomes, including patient disposition and radiation exposure, were not reported in the included studies.

Missed injuries

Five studies reported either no missed injuries[27 29 32 33] or no significant difference in missed injuries[26] after implementing the interventions (see online supplemental 3). Among patients screened by the Brand protocol, 16 patients with missed extremity injuries were identified, including 2 patients with clinically important fractures.[31] Eight patients with missed wrist fractures were identified after implementing the APWR, four of whom had clinically significant fractures.[30]

Return to ED

No significant changes in return ED visits were reported in three studies (see online supplemental 3).[27 29 32] A significant decrease in return visits was reported after implementing the LRAR (1% vs 5%, p<0.01).[28]

Emergency department length of stay

The majority of studies reported no significant changes in ED LOS,[26–30 32] except one study reporting decreased LOS after implementing the Brand protocol (3.6 vs 3.3 hours; p<0.001) (see online supplemental 3).[31]

Healthcare costs

The authors for one study estimated the costs to implement the LRAR across six Canadian EDs at $C3941.83 per site, or $C6.28 per patient.[36] After implementing the LRAR, a significant decrease in the mean healthcare costs per patient of $C36.93 was reported (see online supplemental 3).[36]

Adherence

Three studies reported that clinicians applied the LRAR to 69%,[26] 86%[27] and 100%[29] of the patients, respectively. Two studies reported improved uptake of the intervention across the study period (see online supplemental 4).[28 33]

Compliance

Three studies reported clinician compliance with the imaging recommendations of the interventions (see online supplemental 4).[26 27 30] Clinicians complied with the recommendation of the APWR to not request imaging in 31% of patients, with reasons for non-compliance including physicians suspecting associated injury (40%), parents insisting on imaging (21%) and physicians disagreeing with the recommendation (14%).[30] Clinicians complied with the recommendations of the LRAR for all but one patient who underwent imaging as a result of pressure from the child's parents.[27] Physicians complied with the LRAR recommendations in 81% of patients in another study, with reasons for non-compliance including fear of missing a significant fracture (31%), preference for the OAR (14%) and family requesting imaging (10%).[26]

DISCUSSION

Concerns about imaging risks have prompted the development of interventions to safely identify children with traumatic injuries who can be cleared clinically without imaging.[12] For example, implementing the PECARN rule in the ED can effectively reduce CT head image ordering in children with minor head injuries.[20] Using an extensive search of the literature, and high-quality methodology to minimise the risks of publication and selection bias, this review assessed the effectiveness of interventions implemented in the ED to reduce imaging in children with extremity injuries. Eight studies were identified, with the majority of evidence based on non-randomised controlled designs. Independent quality assessment by two reviewers identified some potential concerns across the studies due to a lack of reporting of blinding and other key domains to allow for an assessment of low or high risk of bias. The results of our review indicate that implementing ankle CDRs can reduce simple radiography ordering for children with ankle injuries in the ED; however, further investigations of CDRs for children with other upper/lower extremity injuries are needed.

While the availability of implementation studies of ankle CDRs in the ED is limited, healthcare providers should consider implementing the LRAR or OAR as a strategy to safely reduce the long-term health risks associated with simple radiography in children.[37] Previous research has indicated that the LRAR and OAR can accurately identify children at low risk of clinically significant injury,[38 39] and the current evidence revealed no increases in missed injuries, return ED visits or delays in ED LOS, indicating that the LRAR or OAR do not negatively impact patient safety or impede patient flow. Additional research is recommended to provide further insights into the impact of implementing the LRAR or OAR in the ED. Boutis *et al* 2015 reported decreases in healthcare provider costs after implementing the LRAR across six Canadian EDs[26]; additional research is required to assess whether this finding is consistent across other ED settings. Clinician adherence and compliance with the ankle CDRs was generally high; however, several factors were identified that prevented full acceptance of the intervention among the clinicians. Gaining a better understanding of the factors impacting clinician compliance[16] could identify strategies to promote changes in physician image ordering behaviour across complex ED and healthcare settings.

For children presenting with other upper or lower extremity injuries, there was insufficient evidence to recommend specific CDRs or intervention as a strategy to reduce simple radiography. The APWR was successful in reducing X-ray imaging in children with wrist injuries; however, concerns for missing clinically significant injuries and poor compliance with the APWR[30] suggest further research is needed to assess whether the performance and physician adaptation of the APWR can be improved. Implementing the Brand protocol resulted in an increase in X-ray ordering and missed injuries[31]; however, this increase was the result of additional imaging being requested by the attending emergency clinicians who were not involved in the implementation of the intervention.[31] Ensuring that all members of the clinical team involved in assessing and providing patient care are all trained and active participants in the implementation of interventions to reduce unnecessary imaging may play a role in promoting long-term changes in image ordering. Two locally developed guidelines reduced imaging in children with various upper/lower extremity injuries; however, additional research is needed to assess whether implementing these guidelines in other ED settings can produce similar results.[32 33] In addition to CDRs, there is mounting evidence that point-of-care ultrasound exhibits high sensitivity and specificity for identifying distal forearm fracture in children, and could prove to be an effective strategy for reducing X-ray imaging in children with distal forearm injuries.[40] Additional evidence clarity is needed to assess the impact of implementing point-of-care ultrasound in the ED on X-ray imaging in children with distal forearm injuries, and whether CDRs in amalgamation with point-of-care ultrasounds can further reduce X-ray imaging.

Limitations

There are several study limitations to consider. First, the majority of the evidence is based on studies using non-randomised study designs, so there are some concerns about potential bias.[41] While RCTs are the gold standard in evidence-based research,[42] this finding is not surprising since implementing health strategies to change physician practices in ED settings using an RCT design is expensive and has significant risks for cross-contamination. Second, as previously discussed, the results of this review are based on a limited number of available studies that implemented these interventions in the ED and additional research is recommended to provide evidence clarity on the impact of these interventions on imaging, patient safety, and other outcomes including LOS, healthcare costs and clinician adherence and compliance with the interventions. In addition, none of the studies assessed whether clinicians pivoted to other imaging modalities or substituted (eg, point-of-care ultrasound). These outcomes are necessary to fully understand the implications of implementing these interventions on patient safety and throughput in the ED, and a standardised approach to reporting these outcomes is recommended for future studies. Third, assessment of the implementation strategies employed by the studies was limited to the information reported within the manuscripts. It is possible that some studies, particularly those that were not yet published, may not have included all of the details of their implementation strategy within the text; however, it is unlikely that studies would not provide some details on their specific strategies to train and promote utilisation of the interventions. Only one study reported using quality improvement methodology (ie, plan-do-study-act cycle)[28] and it is possible that the effectiveness of the interventions to promote behaviour change could have been impacted if more studies used quality improvement methodologies.[43] Additional research is needed to identify whether there is an optimal implementation strategy to promote the effectiveness of these interventions, and it is imperative that implementation strategies are fully documented in future studies. Comparative effectiveness of different CDRs or guidelines would also help understanding the effectiveness of these interventions. Finally, there is a risk of publication and selection bias, which could have affected the availability of publications in the review. Efforts were taken to minimise the risk of selection and publication bias, including an extensive search of the published and unpublished literature developed by a trained, experienced health librarian and reviewed independently by at least two reviewers; regardless, it is possible that some studies could have been missed.

Conclusion

This review found that several interventions can effectively reduce X-ray ordering when implemented in the ED for children presenting with various extremity injuries. The LRAR and OAR reduced X-ray ordering in children with ankle injuries, with no reported increases in missed injuries or return ED visits. Decision rules or guidelines for children with wrist or other upper/lower extremity injuries can reduce imaging; however, further investigations are required to ensure these interventions can reduce imaging while minimising the risk of missed injuries across multiple ED settings before they can be widely implemented into any imaging reduction campaigns.

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