www.jpeds.com • THE JOURNAL OF PEDIATRICS

Proximal Interphalangeal Hyperextension Injuries in Children: The Development of a Clinical Decision Guide

Christina N. Steiger, MD, PhD, Romain Dayer, MD, Anne Tabard-Fougère, PhD, and Dimitri Ceroni, MD

Objective To develop a clinical decision guide for the diagnosis and treatment of hyperextension injuries of long fingers.

Study design Consecutive patients age <16 years (n = 300) with an acute proximal interphalangeal (PIP) joint hyperextension injury were included. High-risk and low-risk measures for severe injury were established with a standardized clinical examination and anteroposterior and lateral radiographs of the injured finger. Four clinical variables were assessed: location of pain; swelling and bruising, stability, and mobility. Pathological radiographic findings were compiled, and the risk of late complications was analyzed. The predictive value of the clinical examination in the identification of low-risk injuries was assessed.

Results The majority (67%) of children consulting for a hyperextension finger trauma did not have a fracture. No child with a low-risk clinical examination had a subsequent high-risk diagnosis (eg, relevant intra-articular fracture, dislocation). Among 64 clinical high-risk diagnoses only 12 significant fractures were found.

Conclusion Treatment decisions after PIP hyperextension injuries can be based on a clinical examination using a standardized evaluation protocol. Application of the clinical decision guide presented here has a sensitivity of 100% to rule out a significant injury. Present results showed that the majority of radiographs currently performed are avoidable. Once the decision rule is validated, its clinical application will improve patient care, reduce waiting times in emergency departments, avoid unnecessary radiation exposure, and possibly reduce costs. *(J Pediatr 2021;230:140-5)*.

Hand injuries are among the most frequent trauma treated in children.[1-6] Although no data exist on the number of finger sprains and minor finger trauma seen in pediatric emergency departments, they likely account for a substantial amount of all pediatric hand injuries. Finger injuries acquired during sports activities occur with a peak incidence at age 10-17 years.[4-7] The majority of these injuries are sprains, bony avulsions of the volar plate of the proximal interphalangeal (PIP) joint, and stable childhood fractures that require only symptomatic treatment and heal without sequelae. The incidence of significant injuries in these cases is low.[8,9] However, in the absence of validated guidelines, as exist for ankle and cervical spine injuries, most physicians routinely refer patients for finger radiographs. Consequently, many patients are subjected to avoidable radiation exposure and prolonged waiting times in emergency departments. Another aspect to be considered is cost. Although a single radiograph is considered a low-cost procedure, the accumulated costs from frequent application are substantial. Thus, from an economic standpoint, efforts should be taken to avoid all unnecessary investigations.

Specific guidelines concerning the clinical examination do not exist, and there are no recommendations for the use of radiographs. The purpose of the present study was to develop a clinical decision guide for the use of radiography in children with finger hyperextension injuries.

When developing a clinical decision guide, several issues must be addressed. Neither parents nor treating physicians can accept guidelines that miss fractures requiring treatment. Therefore, the developed protocol has to have near-100% sensitivity to detect significant injuries and should be valid for all age groups. The clinical examination must be easy to learn and reproducible by different examiners. Because patients with minor injuries are often first assessed by junior doctors, the physical examination must not require specialist knowledge. Moreover, the clinical decision guide must be applicable in every emergency department and family medicine practice setting.

Methods

After obtaining approval from the local Ethics Committee, we performed a single-center prospective study from January 2006 to December 2012 including 300 consecutive cases of long-finger PIP hyperextension injuries. All patients presented to the pediatric emergency department of the county's university hospital where the initial treatment was performed. Follow-up consultations were conducted by the pediatric orthopedic surgery

PIP	Proximal interphalangeal

From the Service of Pediatric Orthopedics, Department of Child and Adolescent, University Hospitals of Geneva, Geneva, Switzerland

The authors declare no conflicts of interest.

https://doi.org/10.1016/j.jpeds.2020.10.038

department until full consolidation of a fracture, or in cases of sprains until full resolution of symptoms.

Patients

Children included in the study were aged 6-16 years with a mean age of 11.7 years. Children aged <6 years were excluded because the clinical examination required patient cooperation, which is difficult to obtain in preschool children. All traumas were hyperextension injuries of the fingers acquired during a ball sports activity. Patients either presented spontaneously after the accident or were referred to our center by a pediatrician. The initial examination was conducted within 48 hours of the accident. Children were excluded if surgery on the injured finger had been performed within the previous 6 months, if the mechanism of trauma was not clear, and if injury occurred during activities other than ball sports activities. No child in the cohort suffered from genetic musculocutaneous disease or developmental retardation.

Development of the Clinical Examination Protocol

Simple finger sprains and small avulsion fractures of the volar plate have a very similar clinical presentation, which is well documented in literature. Pain, hematoma, and swelling are centered at the location of injury, mobility is slightly reduced, and there is no joint instability or angulation. In contrast, unstable or displaced fractures and serious ligament injuries often present with axial or angular deformity of the finger, inability to move the digit, or joint instability. Based on this, we chose 4 clinical examination features that were considered to require only basic medical training: (1) location of pain/swelling/hematoma, centered at the volar aspect of the PIP joint or at any other location; (2) presence or absence of angular or rotational deformity in extension and in maximal flexion (evaluation compared with the uninjured side); (3) evaluation of active mobility of the finger; and (4) evaluation of joint and bone stability.

Application of the Developed Protocol in the Emergency Department Setting

On admittance, patients were examined by an emergency department senior consultant and an orthopedic or emergency department resident according to a predefined protocol (Figure 1). Based on the clinical examination findings, doctors assigned the patients to the "high-risk" or the "low-risk" group. At least 1 of the 4 clinical features had to be positive for assignment to the high-risk group. All patients were referred to the radiology department for anteroposterior and lateral radiography of the injured finger. Clinical data and radiographs were evaluated by the 2 treating physicians and reviewed by a senior orthopedic surgeon.

Radiographic Evaluation

Injuries were classified as either significant or nonsignificant. A significant injury was defined as one that required either operative or conservative treatment to avoid complications. Absence of treatment in these injuries could potentially cause functional impairment. We considered all intra-articular fractures (with the exception of volar plate avulsion fracture, as described below), fractures with angular or rotational deformity, fracture dislocations, and joint dislocations and subluxations significant injuries.

A nonsignificant injury was defined as an injury that would heal without sequela in the absence of any but symptomatic treatment. These injuries included palmar plate avulsion fractures in which the bone fragment represented less than one-third of the articular surface, nondisplaced Salter–Harris I and II fractures, and metaphyseal torus fractures.

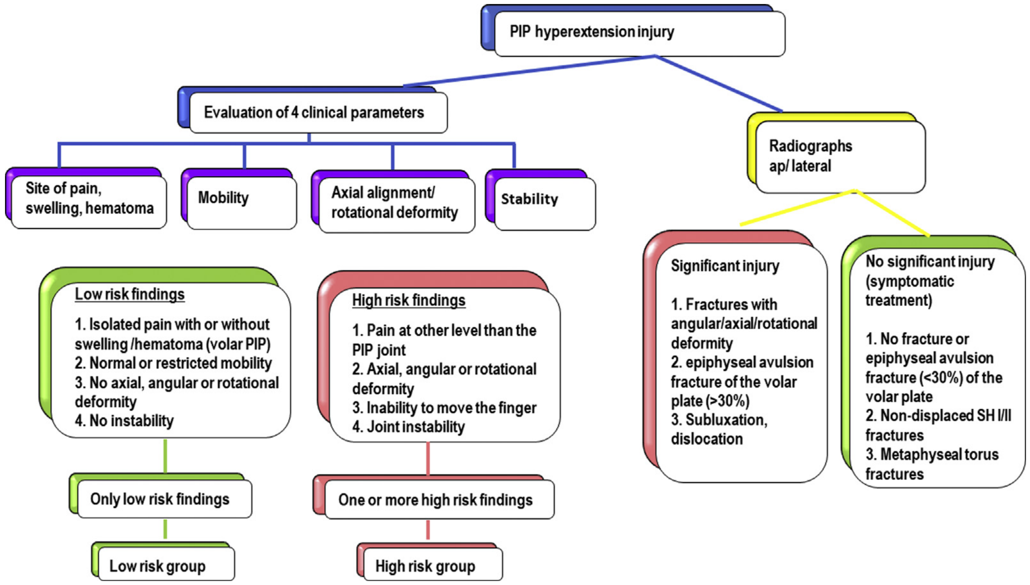

Figure 1. Emergency department evaluation protocol.

Statistical Analyses

Statistical analyses were performed using R version 3.3.2 and the 2016 R Studio interface (R Studio Team). Sensitivity, specificity and positive and negative predictive values with 95% CIs were computed using the R package "epiR". Comparisons were made between high-risk fractures and combined low-risk and no-risk fractures based on radiography findings.

Finally, multivariate logistic regression analysis was performed with the clinical signs to identify predictors of high-risk fracture as detected on radiography with aOR and 95% CI.

Results

Evaluation of the Clinical and Radiological Grouping

Three hundred consecutive patients with a mean age of 11.6 years, with a total of 318 injured fingers, were included in the study. Examinations were low-risk in 219 patients (233 fingers) and high-risk in 81 patients (85 fingers) (Table I). Analysis of the radiographs determined 306 nonsignificant injuries and 12 significant injuries. A total of 98 fractures and 3 joint dislocations were found. Of these fractures, only 9 were considered significant and required specific treatment. Six fractures were treated with closed reduction and cast immobilization; in 2 cases, percutaneous k-wires were used to stabilize the fracture after closed reduction, and 1 fracture required open reduction and stabilization with k-wires. The 3 dislocations were treated with closed joint reduction and immobilization. The remaining low-risk fractures consisted of 28 nondisplaced Salter–Harris type 1 and 2 fractures, 27 metaphyseal torus fractures, and 34 palmar plate avulsion fractures.

All 12 significant injuries were found in the clinical high-risk group (Table II); all 12 had the clinical risk factor deformity, and 11 had impaired mobility. Twenty-two nonsignificant fractures and 30 palmar plate avulsion fractures were found in the clinical low-risk group. Statistical analyses thus confirmed that the sensitivity to detect a significant injury using all 4 variables was 100% (95% CI, 64%-100%) and specificity was 76% (71%-81%) (Table III). The positive predictive value was 15% (95% CI, 8%-24%), and negative predictive value was 100% (95% CI, 97%-100%).

Table I. Patient demographics

Variables	Number of patients	Number of fingers
Cases		
Total number	300	318
Fractures	98	98
Dislocations	3	3
No fractures	199	217
Injuries		
Significant injuries	12	12
Total nonsignificant injuries	288	306
Nonsignificant fractures	89	89
No fractures	199	217
Clinical evaluation		
Low-risk clinic	219	233
High-risk clinic	81	85
Radiological evaluation		
Low-risk radiographic	288	306
High-risk radiographic	12	12

To determine whether the specificity of the decision rules could be increased without decreasing sensitivity to detect significant injuries, combinations of risk factors were evaluated (Table II). We determined that all significant injuries had more than 1 positive risk factor. In fact, 8 patients had 3 risk factors and the other 4 patients had 2 risk factors. In all but 1 patient, mobility was impossible or significantly reduced. Instability and/or deformity were always present. The highest sensitivity (100%; 95% CI, 64%-100%) and specificity (100%; 95% CI, 98%-100%) were reported when the clinical risk factor deformity was present (Table III).

Analyses of the 89 nonsignificant and palmar plate avulsion fractures found a combination of 2 positive risk factors (mobility and pain, mobility and deformity) in 8 fingers. In another 28 patients, 1 risk factor (pain or mobility) was present. Insufficient stability was not reported in this fracture group. We also noted the presence of positive risk factors in patients presenting without a fracture (217 fingers). In 2 patients, 2 risk factors (mobility and stability) were positive, and in 31 patients, 1 risk factor (mobility or pain) was positive. The multivariate logistic regression analysis confirmed that high-risk fractures were more strongly associated with the clinical risk factors deformity (OR, 2.19; 95% CI, 2.10-2.30) and stability (OR, 1.22; 95% CI, 1.15-1.29) than with reduced mobility (OR, 1.02; 95% CI, 1.01-1.04) and pain (OR, 0.98; 95% CI, 0.96-0.99) (Figure 2). Furthermore, the presence of a combination of any 3 risk factors was highly predictive of a significant fracture (Table III).

Development of the Decision Guide

The results of our analyses showed that some variables (pain and reduced mobility) were less sensitive in distinguishing between a significant injury and a nonsignificant injury. Analyses of risk factor combinations did not enhance specificity without reducing sensitivity. The only feature with a 100% percent sensitivity and specificity was deformity. However, some significant fractures can initially present without a visible deformity. Thus, we believe that the specificity for this variable might change in further studies that include more patients. In developing the decision guide, we considered each variable as equally important in excluding a significant fracture. The resulting decision guide for radiographs following hyperextension PIP joint trauma is illustrated in Figure 3.

Discussion

Clinical decision guidelines concerning the use of radiography after trauma have previously been developed and

Table II. Association of risk factors and injury type

Combination of risk factors	Risk factors	Total	Significant injury	Nonsignificant fracture	No fracture
Total	Mobility	51	11	19	21
	Pain	39	1	24	14
	Stability	8	8	0	0
	Deformity	13	12	1	0
Combination of 3 risk factors	Mobility/stability/deformity	7	7	0	0
	Pain/stability/deformity	1	1	0	0
Combination of 2 risk factors	Pain/deformity	1	0	1	0
	Mobility/deformity	4	4	0	0
	Mobility/pain	9	0	7	2
One risk factor	Pain	28	0	16	12
	Mobility	31	0	12	19

Significant injuries and fractures were identified using radiography. Palmar plate avulsion fractures (<30% of the joint surface) were considered nonsignificant fractures.

validated for several joints in the adult and pediatric population.[10-17] Finger injuries have not been investigated until now. In children, hand injuries are frequent and occur mainly during sports practice and play.[4,5,8] PIP joint hyperextension injuries are the predominant mechanism of injury in ball sports activities.

The data from this study were used to establish a decision rule with 100% sensitivity to include significant injuries and specificity of 76%; however, this remains to be confirmed in a validation study. Furthermore, this study has helped determine the significance of different clinical findings in the detection of PIP injuries requiring

Table III. Performance analyses for identifying high-risk injuries using different combinations of the 4 clinical parameters

Variables	High risk	low risk	Sensitivity/specificity/PPV/NVP (95% CI)
>1 clinical sign			
High risk	12	69	1.00 (0.64-.00)/0.76 (0.71-0.81)/0.15 (0.08-0.24)/1.00 (0.97-1.00)
Low/no risk	0	219	
Pain			
High risk	1	10	0.08 (0.00-0.38)/0.97 (0.94-0.98)/0.09 (0.00-0.41)/0.96 (0.93-0.98)
Low/no risk	11	278	
Mobility			
High risk	11	40	0.92 (0.62-1.00)/0.86 (0.82-0.90)/0.22 (0.11-0.35)/1.00 (0.98-1.00)
Low/no risk	1	248	
Stability			
High risk	8	0	0.67 (0.35-0.90)/1.00 (0.98-1.00)/1.00 (0.52-1.00)/0.99 (0.97-1.00)
Low/no risk	4	288	
Deformity			
High risk	12	1	1.00 (0.64-1.00)/1.00 (0.98-1.00)/0.92 (0.64-1.00)/1.00 (0.98-1.00)
Low/no risk	0	287	
Deformity/mobility/stability			
High risk	7	0	0.58 (0.28-0.85)/1.00 (0.99-1.00)/1.00 (0.59-1.00)/0.98 (0.96-0.99)
Low/no risk	5	288	
Deformity/pain/stability			
High risk	1	0	0.08 (0.02-0.07)/1.00 (0.98-1.00)/1.00 (0.47-1.00)/0.98 (0.96-0.99)
Low/no risk	11	288	
Pain/deformity			
High risk	0	1	0.00 (0.00-0.38)/1.00 (0.98-1.00)/0.00 (0.01-0.19)/0.96 (0.93-0.98)
Low/no risk	12	287	
Mobility/deformity			
High risk	4	0	0.33 (0.62-1.00)/1.00 (0.98-1.00)/1.00 (0.40-1.00)/0.97 (0.95-0.99)
Low/no risk	8	288	
Mobility/pain			
High risk	0	9	0.00 (0.00-0.36)/0.97 (0.94-0.99)/0.00 (0.00-0.45)/0.96 (0.93-0.98)
Low/no risk	12	279	
Only pain			
High risk	0	28	0.00 (0.00-0.36)/0.90 (0.86-0.93)/0.00 (0.00-0.18)/0.96 (0.92-0.98)
Low/no risk	12	260	
Only mobility			
High risk	0	31	0.00 (0.00-0.36)/0.89 (0.85-0.93)/0.00 (0.00-0.16)/0.96 (0.92-0.98)
Low/no risk	12	257	

NPV, negative predictive value; *PPV*, positive predictive value.
Pain is defined as the presence of pain at another level than the PIP joint; mobility is defined as inability to move the finger; stability is defined as the presence of joint instability; and deformity is defined as the presence of axial, angular, or rotational deformity.

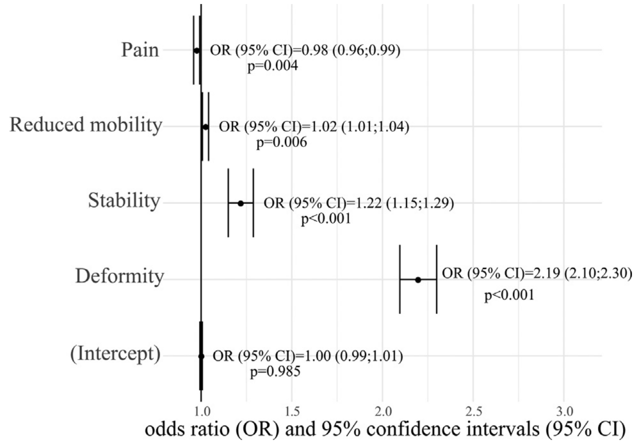

Figure 2. Multivariate logistic regression analysis with the 4 clinical signs to identify predictors of high-risk fracture as reported on radiography.

treatment. Our results show that deformity and stability have high specificity and sensitivity, whereas pain and mobility do not.

The strength of our decision rule is its easy and rapid application in clinical practice. Once the trauma mechanism—hyperextension of the PIP joint—has been verified, the clinical examination requires only basic medical training. Pain evaluation is done by palpation of the finger, with hematoma formation and finger deformity observed during the examination. Stability testing of a joint/bone requires initial instruction, but medical and paramedical personnel feel confident in doing so after having examined only a few patients. The examination requires neither a special setting nor any equipment, and the evaluation of an injured finger takes <10 minutes on average. We are convinced that the evaluation is suitable for doctors (pediatricians, general practitioners, and emergency department doctors) and nurses working in emergency department settings, primary health care clinics, and private practice settings. A retrospective evaluation of our data shows that the application of the decision guide in our hospital would have reduced the need for radiography by 63% without the risk of missing a significant injury. As a result, two-thirds of the patients would have avoided long waiting times in the emergency department. Furthermore, a >60% reduction in radiographs will significantly decrease treatment costs.

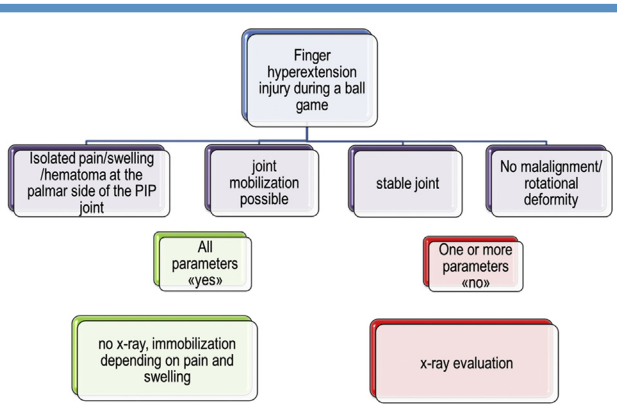

Figure 3. PIP joint hyperextension decision rule.

This study has some limitations. Because the decision guide concerns children, patient age is an important factor to consider when determining which variables to evaluate during a clinical examination. The majority of benign PIP hyperextension injuries are volar plate avulsions or sprains that do not affect stability of the joint. The clinical presentation of these injuries is rather typical, with localized pain and hematoma formation on the volar aspect of the PIP joint, reduced joint mobility but immobility, and absence of instability. Based on our clinical experience, we identified 4 clinical measures used to evaluate an injured finger. Of these 4 variables, joint stability and angular/axial/rotational deformity were the most reliable in determining a significant injury, because they depend only on the physician's examination and require little cooperation from the child. The other 2 measures require certain compliance and thus were less specific for significant injuries. Although the location of pain, swelling, and hematoma formation was easily assessed in teenagers, pain evaluation took more time in younger, anxious children. In addition, in smaller fingers, swelling was sometimes diffuse and hematoma formation was not always visible. Older patients required little motivation before trying to move the injured finger, whereas young patients were often hesitant to do so. Despite these minor difficulties in young children, doctors participating in the study found the study protocol easy to follow and reported no difficulties with the technical aspect of the clinical examination.

Another limitation of our study was our strict inclusion criteria concerning the accident mechanism. To be able to evaluate a homogenous patient cohort, we limited the trauma mechanism to hyperextension injuries occurring during ball sports activities. The finger had to be injured as a result of the impact of a ball. Although the majority of injuries occur in this setting, other hyperextension injuries of the PIP joint were neglected. To improve the study protocol and to broaden its applicability, a future validation study should include all hyperextension injuries.

Finally, the study was limited by the lack of a validation study, without which the clinical decision guide cannot reliably be used in a clinical setting. We are currently in the process of conducting this validation study. In addition to including all hyperextension injuries, this study will also determine the interobserver reliability of the variables and their variability, comparing children age <10 years and >10 years.

To avoid a monocentric bias, the validity of our decision rules should be tested in different hospitals. We encourage other institutions to conduct validation studies in their hospital settings. ■

Submitted for publication May 12, 2020; last revision received Oct 16, 2020; accepted Oct 19, 2020.

Reprint requests: Christina N. Steiger, MD, PhD, Service of Pediatric Orthopedics, Department of Child and Adolescent, University Hospitals of Geneva, 6 Rue Willy Donzé, 1211 Geneva 14, Switzerland. E-mail: christina.steiger@hcuge.ch

References

1. Collins CL, Comstock RD. Epidemiological features of high school baseball injuries in the United States, 2005-2007. Pediatrics 2008;121:1181-7.
2. Naranje SM, Erali RA, Warner WC Jr, Sawyer JR, Kelly DM. Epidemiology of pediatric fractures presenting to emergency departments in the United States. J Pediatr Orthop 2016;36:e45-8.
3. Pappas E, Zazulak BT, Yard EE, Hewett TE. The epidemiology of pediatric basketball injuries presenting to US emergency departments: 2000-2006. Sports Health 2011;3:331-5.
4. Knobloch K, Rossner D, Jagodzinski M, Zeichen J, Gössling T, Martin-Schmitt S, et al. Prevention of school sport injuries–an analysis of ballsports with 2234 injuries. Sportverletz Sportschaden 2005;19:82-8 (in German).
5. Yde J, Nielsen AB. Sports injuries in adolescents' ball games: soccer, handball and basketball. Br J Sports Med 1990;24:51-4.
6. Chew EM, Chong AKS. Hand fractures in children: epidemiology and misdiagnosis in a tertiary referral hospital. J Hand Surg Am 2012;37:1684-8.
7. Bhende MS, Dandrea LA, Davis HW. Hand injuries in children presenting to a pediatric emergency department. Ann Emerg Med 1993;22:1519-23.
8. Voth M, Lustenberger T, Frank J, Marzi I. Pediatric finger and hand injuries: an epidemiolgy. Chirurg 2017;88:871-8 (in German).
9. Rimmer CS, Burke D. Proximal interphalangeal joint hyperextension injuries in children. Emerg Med J 2009;26:854-6.
10. Coffey F, Hewitt S, Stiell I, Howarth N, Miller P, Clement C, et al. Validation of the Canadian c-spine rule in the UK emergency department setting. Emerg Med J 2011;28:873-6.
11. Stiell IG, Wells GA, Vandemheen KL, Clement CM, Lesiuk H, De Maio VJ, et al. The Canadian C-spine rule for radiography in alert and stable trauma patients. JAMA 2001;286:1841-8.
12. Karaca Y, Turkmen S, Cansu A, Baki ME, Eroglu O, Tatli O, et al. A study to develop clinical decision rules for the use of radiography in wrist trauma: Karadeniz wrist rules. Am J Emerg Med 2016;34:2074-8.
13. Plint AC, Bulloch B, Osmond MH, Stiell I, Dunlap H, Reed M, et al. Validation of the Ottawa Ankle Rules in children with ankle injuries. Acad Emerg Med 1999;6:1005-9.
14. Seaberg DC, Jackson R. Clinical decision rule for knee radiographs. Am J Emerg Med 1994;12:541-3.
15. Slaar A, Walenkamp MMJ, Bentohami A, Maas M, van Rijn RR, Steyerberg EW, et al. A clinical decision rule for the use of plain radiography in children after acute wrist injury: development and external validation of the Amsterdam pediatric wrist rules. Pediatr Radiol 2016;46:50-60.
16. Stiell IG, Greenberg GH, McKnight RD, Nair RC, McDowell I, Worthington JR. A study to develop clinical decision rules for the use of radiography in acute ankle injuries. Ann Emerg Med 1992;21:384-90.
17. Stiell IG, McKnight RD, Greenberg GH, Nair RC, McDowell I, Wallace GJ. Interobserver agreement in the examination of acute ankle injury patients. Am J Emerg Med 1992;10:14-7.