ORIGINAL CONTRIBUTION
radiograph
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A Randomized, Controlled Trial of Radiograph Ordering for Extremity Trauma in a Pediatric Emergency Department

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Study objectives: The objectives of this study were to determine whether triage nurses using the Brand protocol would order fewer radiographs than would physicians carrying out standard practice procedures, without missing an increased number of joint or bone injuries; the test characteristics and the interobserver reliability of the Brand protocol; and whether having triage nurses order radiographs could reduce total patient waiting time in the emergency department.

Design: Randomized, controlled trial.

Setting: The ED of a free-standing children's hospital with approximately 55,000 visits annually.

Type of participants: Children less than 18 years of age who had a history of extremity trauma in the preceding seven days.

Interventions: Triage nurses applied the Brand protocol to determine the need for a radiograph.

Measurements and results: Of the Brand protocol group, 81.9% had radiographs ordered compared with 87.1% of the control group ($P = .03$). The percent of positive radiographs was 40.8% in the Brand protocol group compared with 42.6% in the control group ($P = .21$). There were 3.2% (16) missed radiographic findings in the Brand protocol group compared with none in the control group ($P < .001$). Patients randomized to the Brand protocol group spent 3.3 hours in the ED compared with 3.6 hours for the control group ($P < .001$).

Conclusion: Having triage nurses use the Brand protocol reduced the number of radiographs ordered but at the same time increased the number of missed radiographic findings. However, having triage nurses order radiographs also significantly shortened waiting time in the ED.

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INTRODUCTION

Extremity trauma is a common reason for which children present to the emergency department.[1] The indications for radiograph ordering in such cases may vary[2] because of competing concerns of physicians ordering radiographs, including medicolegal concerns, parental expectations, and the lack of validated criteria for such ordering.[3] Increased selectivity in radiograph ordering is required to minimize radiation exposure of children as well as to reduce health care costs.[4-7]

Recognizing the need for selective patient criteria, Brand and colleagues developed and validated a protocol for ordering radiographs of injured extremities in patients older than 15 years. This protocol later was applied retrospectively to children and found to be valid.[8] However, research that has not been validated by a randomized, controlled trial can have biases.[9] Therefore, we decided to conduct a trial in which patients would be randomized for assessment by either a triage nurse who would use the Brand protocol[6] or a physician who would follow his or her own criteria, as was standard practice.

The three objectives in this trial were to determine whether triage nurses using the Brand protocol would order fewer radiographs than would physicians carrying out standard practice procedures, without missing an increased number of joint or bone injuries; the test characteristics (sensitivity, specificity, and predictive values) and the interobserver reliability of the Brand protocol; and whether having triage nurses order radiographs could reduce total patient waiting time in the ED.

Figure.
Brand protocol

A radiograph was ordered if one or more of the following signs were assessed to be present:

Upper Extremity
Gross signs
- Bone deformity
- Bone instability
- Crepitation

Point tenderness
Severe swelling
Ecchymosis

Lower Extremity
Gross signs
- Bone deformity
- Bone instability
- Crepitation

Hip/thigh
- Moderate-to-severe pain with weight-bearing

Knee
- Decreased range of motion
- Severe swelling
- Point tenderness
- Ecchymosis
- Moderate-to-severe pain with weight-bearing

Distal to knee
- Point tenderness

MATERIALS AND METHODS

The Children's Hospital of Eastern Ontario is a free-standing children's hospital in the Ottawa-Carlton region. The ED has approximately 55,000 visits annually and is staffed 24 hours a day by full-time pediatric emergency physicians.

Between March 1990 and February 1991, patients presenting to the ED at the Children's Hospital of Eastern Ontario when the research assistant was on duty were approached for entry into the study if they were less than 18 years old and had a history of extremity trauma in the preceding seven days. Patients were excluded if they had evidence of neurovascular compromise of the involved extremity, major trauma, underlying disease that would predispose to fracture (eg, osteogenesis imperfecta), or underlying disease with sensory abnormalities (eg, meningomyelocele). This study was approved by the Research Ethics Committee at the Children's Hospital of Eastern Ontario. Informed, written consent was obtained from all parents before entry into the study.

Twenty-one triage nurses working in the ED underwent a training session dealing with the application of the Brand protocol[6] (Figure) and assessment of extremity neurovascular status. In addition, during a pilot phase, all participating triage nurses were observed in their application of the Brand protocol. Only after demonstrating acceptable application of the protocol as assessed by the research assistant was a nurse approved to participate in the study. The interobserver reliability of the protocol was assessed by having both the research assistant and a triage nurse independently assess the same patient.

Parents of all patients deemed eligible by the inclusion/exclusion criteria and giving consent were block-randomized (blocks of ten by a random-numbers table) to either the Brand protocol group or the control group. Block-randomization was performed to ensure even distribution of patients during the different time periods.

Those randomized to the Brand protocol group were sent directly for radiographic studies if the criteria in the Brand protocol were satisfied. On return to the ED, the child was examined by the medical staff, and the radiograph was interpreted. Those patients who did not satisfy the Brand protocol were directed to the ED for standard care.

Those randomized to the control group waited to be seen by the physician (intern, resident, fellow, or staff physician), who then would assess the need for a radio-

graph according to usual practice. Physicians were blind as to the whether the patient had entered through the Brand protocol group but was deemed ineligible for a radiograph, or had been randomized to the control group.

Patients not radiographed by either physician or nurse had telephone follow-up by the research assistant after five days. Those who were asymptomatic were considered to be negative for fracture or joint injury. Those still symptomatic were instructed to see their physician, and the results of this visit were obtained if possible.

A positive finding on radiography was defined as a fracture, joint effusion, or dislocation as identified by the radiologist. Although the emergency physicians interpreted their radiographs for immediate clinical management, all films were reviewed by a radiologist within 24 to 48 hours. Joint effusion was considered positive because when found in children, especially in the elbow joint, it is considered a very important sign, even in the absence of obvious bony injury.[10] Six full-time pediatric radiologists who read the radiographs were unaware of the group assignment. To assess the interobserver reliability, one radiologist re-read all the radiographs that had been interpreted by the other five radiologists. To establish intraobserver reliability, the same radiologist also re-read the radiographs he had initially interpreted, unaware as to whether the radiographs were ones he or another radiologist had initially interpreted. These re-readings were done without the clinical information and at some point between the initial reading and the end of the study.

Table 1.
Patient characteristics at time of randomization

Variable	No. of Patients (%) Brand Protocol	Control Group	*P*
No. of patients	491	494	
No. of injury sites	498	504	
Distribution of injury sites			
Upper	303 (60.8)	263 (52.2)	
Lower	195 (39.2)	[illegible] (47.8)	.007
Gender			
Male	259 (52.0)	(54.4)	
Female	239 (48.0)	230 (45.6)	.45
Age (yr, mean ± SD)	11.1 ± 4.0	10.9 ± 4.3	.37
Time since injury (hr)*			
< 6	287 (63.4)	306 (64.2)	
6-24	58 (12.8)	42 (8.8)	
> 24	108 (23.8)	129 (27.0)	.11

*Total number is less than 1,002 because of missing information.
Numbers in parentheses represent percentages.

Any bone or joint injury that was not radiographed during the initial assessment by the health professional to whom that patient had been assigned was reviewed by an experienced pediatric orthopedic surgeon after the completion of the study; this person determined whether the injury had any long-term clinical importance. This was defined as an abnormality that could potentially result in long-term morbidity to the patient if not diagnosed immediately. The orthopedic surgeon involved was blind as to which group the patient had been randomized.

Patients were given a time card for self-reporting of their time spent in the ED and radiology department. The total time spent in the ED was defined as time between arrival at the ED and either referral to the orthopedic surgery service or discharge.

Data were analyzed by a statistical consultant using the SPSS-PC[11] and BMDP-PC90[12] software. Most analyses were conducted on injury sites rather than individual patients. Differences between proportions were tested for statistical significance by χ^2 test, and differences between means were tested for statistical significance by *t*-tests with significance set *a priori* at the conventional level of $P < .05$. Confidence intervals for test characteristics were calculated by the method described by Gardner and Altman.[13] Reliability was calculated using the κ statistic, which corrects for agreement due to chance alone. For interpreting the strength of agreement for each value of κ, the guidelines suggested by Landis and Koch were used: .20 or less, slight; .21 to .40, fair; .41 to .60, moderate; .61 to .80, substantial; and .81 to 1.0, almost perfect.[14] Potential confounding of the primary outcome measure by unequal baseline characteristics was examined by using the Mantel-Haenszel χ^2 test.

Table 2.
Primary outcome variables

Variable	No. of Patients (%) Brand Protocol (493)	Control Group (498)	*P*
No. of radiographs ordered	404 (81.9)	434 (87.1)	.03
No. of positive radiographic findings (% of ordered radiographs)	165 (40.8)	185 (42.6)	.21
Fracture*	141	160	
Effusion*	39	35	
Dislocation*	2	1	
No. of missed positive radiographic findings (% of entire group)	16 (3.2)	0 (0)	< .001

*Patient may have had more than one type of positive finding.
Numbers in parentheses represent percentages.

RESULTS

During our study, 1,016 patients were approached for entry. Twenty-six of these patients were not entered into the trial due to refusal of or difficulty with obtaining consent (23), neurovascular compromise (one), fractured femur (one), and radiograph already performed (one). Five patients were not included because their data forms were incomplete. Therefore, 985 patients were randomized to the two groups. Seventeen of these patients had two injury sites, so 1,002 injury sites were entered into the study—498 in the Brand protocol group and 504 in the control group.

Table 1 outlines the characteristics of the patients at time of randomization. All recorded baseline characteristics were comparable, except for the distributions of upper and lower extremity injuries, which were significantly different ($P = .007$).

Of these 985 randomized patients, 11 left the hospital before being radiographed (six from the Brand protocol group and five from the control group) and therefore were excluded from further analysis. There remained 974 patients with 991 injury sites for analysis.

A statistically significant lower percentage (81.9%) of the Brand protocol group were radiographed compared with the control group (87.1%) ($P = .03$; Table 2). Because of the significantly disproportionate distribution of upper and lower extremity injuries, a Mantel-Haenszel χ^2 test was used to control for injury location; the difference in the number of radiographs ordered remained unchanged. Although significantly fewer radiographs were ordered in the Brand protocol group, 16 bone or joint injuries (3.2%) were missed in this group compared with none in the control group.

Of the 18.1% in the Brand protocol group who were not radiographed based on the criteria of the protocol, a physician subsequently ordered a radiograph for 85.4%. Thus, overall, 97.4% of the patients in the Brand protocol group eventually were radiographed. This figure was significantly higher than the 87.1% of the control group ($P < .001$). All 16 missed fractures were detected by this second assessment.

Table 3 outlines the characteristics of the missed fractures. All patients but one were more than 2 years old. Two of the fractures were considered clinically significant by an experienced orthopedic surgeon (a spiral fracture of the tibia and an impacted fracture of the humerus).

Seventy-seven patients were not radiographed according to either the triage nurse or the physician. Six of these patients were lost to follow-up, and 68 were asymptomatic at the time of their five-day follow-up. Three were assessed by an orthopedic surgeon on follow-up: one was normal clinically, and the other two had negative radiographs.

Overall, the Brand protocol had a sensitivity of .90 and a specificity of .23 (Table 4). While the sensitivity and specificity varied between anatomic regions, these differences were not large, and the confidence intervals overlapped one another. The positive-predictive value of the Brand protocol varied from a low of .31 for the knee to a high of .44 for the upper extremity.

The self-record of time spent in the ED was completed by 94% of all patients entered into the trial. Patients randomized to the Brand protocol group (466) spent

Table 3.
Bone and joint injuries missed by Brand protocol

Age (yr)	Radiographic Finding	Difficult to Assess
Clinically important*		
6	Spiral fracture tibia	Yes
8	Humerus fracture	No
Not clinically important		
14	Proximal phalanx fracture	No
7	Clavicle fracture	No
5	Clavicle fracture	No
11	Fibula fracture	No
7	Metatarsal fracture	No
1	Buckle fracture tibia	Yes
10	Clavicle fracture	No
2	Clavicle fracture	No
7	Buckle fracture radius	No
9	Buckle fracture radius	No
6	Metatarsal fracture	No
10	Buckle fracture radius	No
14	Buckle fracture radius	No
15	Fibula fracture	No

*Clinically important means potential for long-term morbidity.

Table 4.
Test characteristics of the Brand protocol

Anatomic Region	No. of Patients	Sensitivity (95% CI)	Specificity (95% CI)	Positive-Predictive (95% CI)	Negative-Predictive (95% CI)
Overall	493	.90 (.85 – .94)	.23 (.18 – .28)	.41 (.33 – .48)	.80 (.72 – .88)
Upper extremity	298	.92 (.87 – .96)	.20 (.14 – .26)	.44 (.38 – .50)	.78 (.64 – .92)
Lower extremity	195	.86 (.77 – .95)	.28 (.20 – .36)	.34 (.26 – .42)	.83 (.77 – .86)
Knee*	48	.93 (.66 – 1.0)	.17 (.06 – .34)	.31 (.18 – .47)	.86 (.42 – 1.0)
Distal to knee*	149	.82 (.70 – .96)	.33 (.24 – .42)	.35 (.26 – .44)	.81 (.69 – .93)

There were insufficient numbers for hip region.
*Assessments were done on more than one anatomic region for each injury.

approximately one-half hour less in the ED (3.3 ± 1.7 hours [mean ± SD] compared with 3.6 ± 1.5 hours for the control group [469]; $P < .001$). In the subset of patients for whom no radiograph was ordered by the professional initially assessing the patient, time spent in the ED was significantly longer for the Brand protocol group (81) (3.8 ± 1.7 hours) compared with the control group (62) (2.7 ± 1.6 hours; $P < .001$). In cases in which a radiograph was ordered on initial assessment by the professional involved, the time spent in the ED was significantly less for the Brand protocol group (385) (3.2 ± 1.7 hours) than for the control group (407) (3.8 ± 1.4 hours; $P < .001$).

Results showed that when two nurses applied the Brand protocol to assess the same patient on 112 occasions, the overall κ was .25. When the upper extremity assessments were considered alone (67), the κ was .46 compared with .08 for the lower extremity assessments (45).

Interobserver reliability of the radiologists' interpretation of radiographs resulted in a κ of .71 (149). The κ for intraobserver reliability was .88 (56).

DISCUSSION

The strength of this study was its design, ie, a randomized, controlled trial, to determine the effectiveness of having triage nurses order radiographs using the Brand protocol. While the Brand protocol significantly reduced the number of radiographs ordered, it resulted in an increased number of missed fractures. However, because patients in the Brand protocol group also were assessed by a physician, none of those with initially missed fractures were sent home. Thus, a high proportion of patients in the Brand protocol group eventually were radiographed (97.4%, which is significantly higher than the 87.1% for the control group).

The rate of missed findings in the Brand protocol group (3.2%) may seem high. However, any selective protocol that reduces the number of ordered radiographs is likely to be accompanied by such an increase. This rate is lower than that of another protocol that was developed for the pediatric population, which had a rate of 5.3% for missed fractures in the protocol group.[5] When Brand and colleagues studied adults, only one fracture was missed for every 287 injuries. However, adults and children respond differently to musculoskeletal injury,[15] which could account for the difference in our findings. Children may experience minor buckle fractures that may be more difficult to diagnose due to the paucity of clinical findings. Also, any selective protocol may be more difficult to apply to children because their response to pain can vary greatly,[16] as can their ability to verbalize these responses.

Charney and colleagues showed that when the baseline fracture yield is high (ie, the proportion of positive radiographs among patients radiographed), the institution of a selective protocol does not improve the fracture yield.[17] In their study, the fracture yield was 36%. Brand and colleagues had a lower baseline fracture yield of 21%,[6] which might explain why their selective protocol significantly reduced the proportion of patients referred for radiography. In our study, the fracture yield in the standard practice group was 42.6%, and it would be difficult to improve on this with any selective protocol without resulting in an inordinate number of missed bone or joint injuries. The control group fracture yield may already be high in our ED because it is staffed 24 hours per day by full-time pediatric emergency physicians who are experienced in assessing children with extremity trauma and their need for radiographs.

The best method for developing a selective protocol in children may be to develop decision rules for specific anatomic regions. Stiell and colleagues have shown that in adults with ankle injuries, such decision rules significantly reduce the number of radiographs ordered. These rules also achieve an extremely high sensitivity of 100% for detecting clinically important fractures.[18]

Having triage nurses order radiographs significantly shortened total patient waiting time in the ED, although the total waiting time was still longer than may be optimal for patient satisfaction. This decrease in time for the Brand protocol group was not only statistically significant but also clinically so. This is consistent with other studies that have looked at the impact of having triage nurses order radiographs for patients with extremity trauma.[19,20] We chose to examine one variable that affects waiting time in our ED—patients waiting to be referred for radiography. However, adopting a fast-track system for processing patients with minor problems such as extremity injuries would only accentuate this time savings.[21]

CONCLUSION

Having triage nurses order radiographs based on the Brand protocol, with a second assessment by a physician on all patients prior to their discharge from the ED, improves the efficiency of patient flow in the ED but at the same time increases the total number of radiographs ordered. EDs still may opt for the use of this selective protocol because of the need for greater efficiency, with the knowledge that the number of radiographs will increase. Future studies should attempt to develop decision rules for radiograph ordering in children with extremity trauma based on specific anatomic regions.

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