



Prophylactic fixation or surveillance: predicting subsequent displacement of lateral condyle of humeral fractures based on soft tissue swelling



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Background: Nondisplaced or minimally displaced fractures (≤ 2 mm) of the lateral condyle of the humerus (LCH) could undergo subsequent displacement (> 2 mm), which would be a potential surgical indication. We describe a new method to quantify soft tissue swelling in LCH fractures and to identify a threshold value to predict subsequent displacement of LCH fractures. We hypothesized that the larger the soft tissue swelling, the more likely a subsequent displacement would occur.

Methods: Elbow x-ray images (anteroposterior view) at initial presentation in 87 patients with subsequent displacement and in 87 patients with no subsequent displacement were compared. All fractures were initially nondisplaced or minimally displaced. The lateral elbow swelling-to-humeral shaft diameter (LES-H) ratio was measured. A threshold value for diagnosing a subsequent displacement was identified from the receiver operating characteristic curve analysis.

Results: Both groups had similar age (subsequent displacement: 5.1 ± 2.3 years vs. no subsequent displacement: 5.7 ± 3.2 years; $P = .459$). The LES-H ratio was significantly larger in the subsequent displacement group (1.8 ± 0.4 vs. 1.4 ± 0.4 , $P < .001$). The area under the receiver operating characteristic curve was 0.728, which was moderately accurate in predicting subsequent displacement. A threshold LES-H ratio of 1.90 had a sensitivity of 41.4% and specificity of 90.8% in diagnosing subsequent displacement. The odds ratio of having subsequent displacement with LES-H ratio of ≥ 1.90 was 6.1 (95% confidence interval, 2.7–13.8; $P < .001$).

Conclusion: The LES-H ratio could be used to objectively quantify soft tissue swelling in LCH fractures. An LES-H ratio of ≥ 1.90 was used as threshold value to predict subsequent displacement.

Level of evidence: Level III; Case-Control Design; Prognosis Study

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Almost one-fifth of all distal humerus fractures in pediatric patients occur at the lateral condyle of the humerus (LCH).³ At presentation, up to 69% of LCH fractures were minimally displaced (≤ 2 mm) or nondisplaced, of which about 12% would go on to subsequent displacement (> 2 mm).¹⁴ A subsequent displacement of > 2 mm would be a potential indication for an open surgery and fixation. The minimally displaced or nondisplaced fractures would have been managed conservatively with immobilization.

Prophylactic percutaneous pinning could be an option to avoid the open surgery required in the 12% of the minimally displaced or nondisplaced LCH fractures in which subsequent displacement (> 2 mm displacement) occurs despite immobilization.¹⁴ The use of prophylactic percutaneous pinning could reduce the tissue injury, surgical duration, and allow faster recovery compared with an open operation that would be required in the event of a subsequent displacement.¹⁵

Previously, Finnbogason et al⁷ and Thonell et al¹⁷ attempted to predict subsequent displacement of LCH fractures based on whether the fractures were incomplete or complete. Pirker et al¹⁴ described various locations of LCH fractures, also in an attempt to predict subsequent displacement of LCH fractures. However, the differentiation between incomplete and complete fractures, as well as localizing the fractures, could be ambiguous on plain radiographs.

Hence, there was a need to better predict subsequent displacement of LCH fractures. With better prediction of subsequent displacement of LCH fractures, there might be a role in offering the less invasive intervention of prophylactic percutaneous surgical fixation to those who would have subsequent displacement. These patients would otherwise require open surgery with its inherent higher rate of surgical complications.

A LCH fracture might be prone to subsequent displacement if there was a significant soft tissue swelling present.² This relationship had only been suggested but was neither objectively quantified nor investigated before.

We therefore aimed to describe a new radiographic measurement to quantify the soft tissue swelling in LCH fractures. After that, we aimed to identify a threshold value from the measurement to predict subsequent displacement of LCH fractures. We hypothesized that the larger the soft tissue swelling was at the fracture site, the more likely a subsequent displacement would occur.

Materials and methods

This was a retrospective case-control study at the largest tertiary pediatric public hospital in Singapore. The requirement for patients' informed consent was waived.

Patient selection

Patients were selected from the department's fracture registry between February 2005 and December 2015. Patients with minimally displaced (≤ 2 mm) or nondisplaced LCH fractures were identified. Backslab immobilization was applied, and they were subsequently reviewed at the orthopedic surgery outpatient clinic.

If subsequent displacement (> 2 mm) occurred during the period of weekly surveillance, patients underwent open reduction with percutaneous or internal fixation. This group of patients formed the subsequent displacement group.

From the remaining pool of patients who were treated successfully with immobilization and avoided the need for surgery, an equal number of patients in the no subsequent displacement group were randomly selected to form the control group. Randomized selection was performed using Excel 2011 software (Microsoft, Redmond, WA, USA). This group of patients formed the no subsequent displacement group.

Data collection

We collected demographic parameters, which included the patients' age, sex, ethnicity, and radiographic measurements.

For the radiographic measurement, we used the anteroposterior plain x-ray images of the injured elbow. The measurements were done using the institution's imaging software Vue Motion (Carestream Health Inc., Rochester, NY, USA). Patients were excluded if the fracture lines were ambiguous, if there was incomplete measurement, or if the view of the elbow was grossly rotated. The images were regarded as grossly rotated if the olecranon fossa was not well visualized and the medial and lateral epicondyles could not be seen. As illustrated in Fig. 1, the parameters of interest were:

1. Lateral elbow swelling (LES): This was the soft tissue distance between the fracture site and the skin taken perpendicularly to the extended lateral humeral shaft line. This measurement was used to quantify the soft tissue swelling caused by the fracture and was taken at the level of the fracture, because LCH fractures often resulted in lateral elbow swelling.²
2. Humeral shaft diameter (H): This was taken at 2 cm proximal to the distal humeral metaphyseal-diaphyseal junction.
3. Lateral arm soft tissue thickness (LAS): This was the distance between the bone and the skin, taken at the same level of the measurement of the humeral shaft diameter.

The rationale for measuring the H and the LAS at the described level was that the level was measurable within the limits of a standard elbow radiograph but clear from the fracture site and the joint capsule, which starts just proximal to the olecranon fossa.¹¹ This was to minimize the risk of overestimating the soft tissue thickness, which may arise from hemarthrosis or localized hematoma from the LCH fracture.

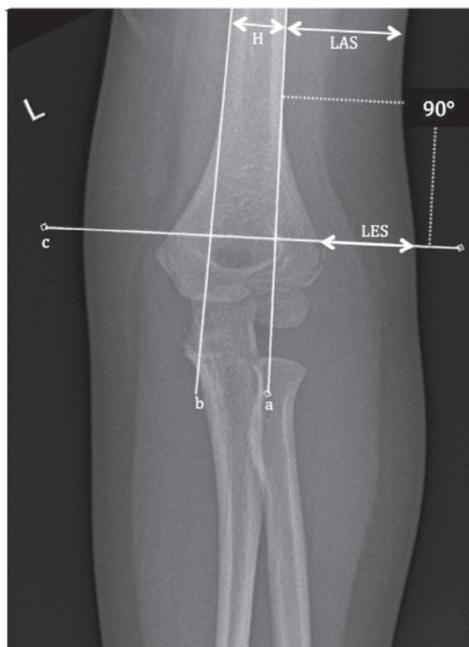


Figure 1 Various measurements obtained in the study: *a*, lateral humerus shaft line; *b*, medial humerus shaft line; *c*, line perpendicular to *line a* at the level of the fracture. *LES*, lateral elbow swelling; *LAS*, lateral arm soft tissue thickness; *H*, humerus shaft diameter.

The absolute values of the *LES*, *H*, and *LAS* could be misleading. For example, a 2-cm swelling in the large arm of a 10-year-old child would not appear as significant as a 2-cm swelling in the smaller arm of a 2-year-old child. To account for this variability, we used the following ratios for better comparisons in the pediatric population:

1. *LAS-H* ratio: This approximated how chubby a child was based on the arm girth.
2. *LES-LAS* ratio: This gave the proportion of *LES*, caused by the LCH fracture, in relation to the amount of the patient's soft tissue.
3. *LES-H* ratio: This gave the proportion of *LES*, caused by the LCH fracture, in relation to the size of the patient's bone.

Although these were new measurements, they were derived from common anatomic landmarks from a standard radiograph.⁶ We thus felt the measurements were appropriate and easily reproducible.

We did not measure the soft tissue thickness on the medial elbow, because most LCH fractures caused swelling at the lateral elbow.² Furthermore, the medial soft tissue thickness might be increased if there was an extensive soft tissue injury.⁵ Because it was rather variable, we felt that it was not a reliable measure to be used in predicting a subsequent displacement of minimally displaced or nondisplaced LCH fractures.

Statistical analysis

To test for normality, the Shapiro-Wilk test was used. Parametric variables were compared with the Student *t* test, nonparametric vari-

ables were compared with the Mann-Whitney test, and categorical variables were compared with the χ^2 test.

To assess intraobserver and interobserver reliability, 20 random samples were remeasured by the first and second authors. The intraobserver and interobserver reliability was determined using the intraclass correlation coefficient (ICC).⁹

To determine which of the 3 ratios had better predictive accuracy, we used the area under the receiver operating characteristic (ROC) curve.¹⁸ The ROC curve provided a visual analysis of the relationship between the sensitivity and the specificity for diagnosing subsequent displacement of LCH fractures at a specified threshold value.¹ The area under the ROC (AUROC) curve ranged from 0.5 to 1.0, whereby a value of 1.0 indicated that the test was able to perfectly distinguish the group with a subsequent displacement from the group with no subsequent displacement.¹ The ratio with the highest AUROC curve was then chosen as the predictive ratio for the subsequent displacement of LCH fractures.

After the ROC analysis, a threshold value with the optimal sensitivity and specificity was selected. The odds ratio of a subsequent displacement, if the patient had a measured ratio beyond the threshold value, was then determined with the logistic regression. The threshold value and prevalence of subsequent displacement of LCH fractures in our population was used to calculate the positive predictive (PPV) and negative predictive value (NPV).

We also tested the possibility of combining the top 2 ratios to produce a scoring system in an attempt to improve the accuracy of predicting a subsequent displacement. ROC analysis, identification of a threshold value, and logistic regression based on the chosen threshold value was performed on the ratio with the next highest AUROC curve. Points were then ascribed by converting the coefficients of the logistic regression model from the predictive factors of these 2 ratios into an integer.¹⁸ The accuracy of this scoring system was again tested with the ROC analysis. A *P* value of $<.05$ was considered statistically significant. SPSS Statistics 22.0 software (IBM, Armonk, NY, USA) was used for statistical analysis.

Results

The patient selection is illustrated in Fig. 2. There were 1238 LCH fractures over 10 years. Of these, there were 94 cases of subsequent displacement of nondisplaced or minimally displaced LCH fractures. After exclusions, there were 87 patients in the subsequent displacement group. As summarized in Table I, the groups with and without subsequent displacement were matched in age (5.1 ± 2.3 vs. 5.7 ± 3.2 years, $P = .459$) sex (69% vs. 62% male, $P = .425$), and ethnicity (63% vs. 55% ethnic Chinese, $P = .606$). The demographics of the randomly chosen 87 patients in the no subsequent displacement group were similar to the demographics of the remaining 619 patients from the initial 706 patients with no subsequent displacement.

As reported in Table II, the subsequent displacement group had a significantly larger *LES* (23.1 ± 6.5 vs. 18.6 ± 5.6 mm, $P < .001$) and *LAS* (23.4 ± 5.5 vs. 21.4 ± 4.8 mm, $P = .019$) than the no subsequent displacement group. However, both groups had similar *H* (13.1 ± 2.0 vs. 13.1 ± 1.9 mm, $P = .863$). This was expected because the patients in both groups were of a similar age and in the same developmental stage.¹²

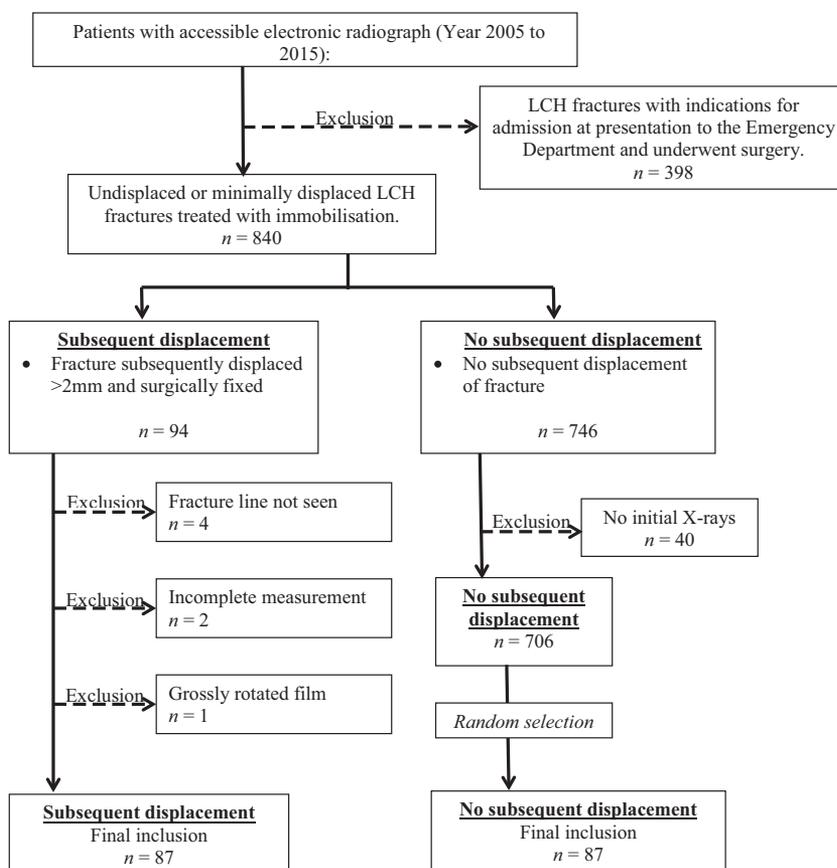


Figure 2 Patient selection. LCH, lateral condyle of humerus.

Furthermore, the humeral shaft was not affected by the fracture. All 3 ratios were significantly larger in the subsequent displacement group (LAS-H: 1.8 ± 0.4 vs. 1.7 ± 0.4 , $P = .022$; LES-LAS: 1.0 ± 0.3 vs. 0.9 ± 0.2 , $P < .001$; LES-H: 1.8 ± 0.4 vs. 1.4 ± 0.4 , $P < .001$). This was consistent with our initial hypothesis that there would be a larger soft tissue swelling at the fracture site in patients with subsequent displacement. The ICC values for intraobserver and interobserver reliability for the 3 parameters ranged from 0.88 to 0.98.

As mentioned, we concentrated on the ratios because they were more comparable in the pediatric population. To deter-

mine which ratio was the most appropriate to use in predicting a subsequent displacement, the ROC curves were used as described below.

Fig. 3 shows the AUROC curves for the various ratios. The LES-H ratio had the largest AUROC curve, with a value of 0.728 (95% confidence interval (CI), 0.653-0.804; $P < .001$).

Table I Patient demographics

Variable	Subsequent displacement (n = 87)	No subsequent displacement (n = 87)	P
Age, years	5.1 ± 2.3	5.7 ± 3.2	.459
Male	60 (69)	54 (62)	.425
Race			.606
Chinese	55 (63)	48 (55)	
Malay	18 (21)	22 (25)	
Indian	7 (8)	11 (13)	
Others	7 (8)	6 (7)	

Data are presented as the mean ± standard deviation or as number (%).

Table II Comparison of various radiologic measurements between the groups with and without displacement group

Measurement	Subsequent displacement (n = 87)	No subsequent displacement (n = 87)	P
LES, mm	23.1 ± 6.5	18.6 ± 5.6	<.001
LAS, mm	23.4 ± 5.5	21.4 ± 4.8	.019
Humeral shaft diameter, mm	13.1 ± 2.0	13.1 ± 1.9	.863
LAS-H ratio	1.8 ± 0.4	1.7 ± 0.4	.022
LES-LAS ratio	1.0 ± 0.3	0.9 ± 0.2	<.001
LES-H ratio	1.8 ± 0.4	1.4 ± 0.4	<.001

LES, lateral elbow swelling; LAS, lateral arm soft tissue thickness; LAS-H ratio, lateral arm soft tissue to humerus shaft diameter ratio; LES-LAS ratio, lateral elbow swelling to lateral arm soft tissue ratio; LES-H ratio, lateral elbow swelling to humerus shaft diameter ratio. Data are presented as the mean ± standard deviation. Bold P values are statistically significant ($P < .05$).

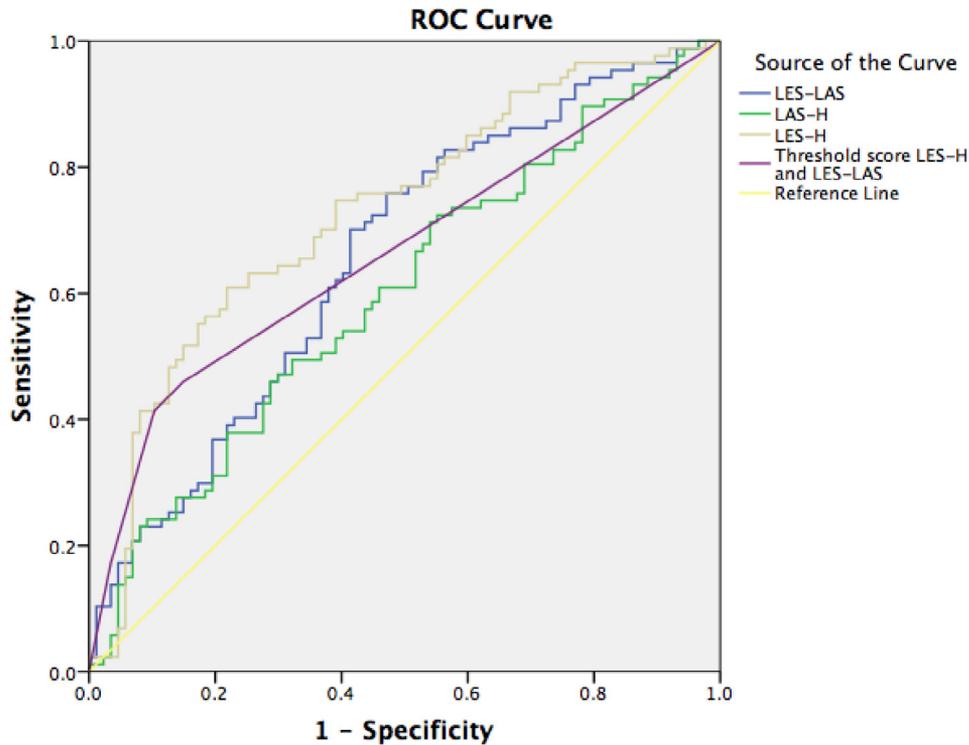


Figure 3 Receiver operating characteristic (ROC) curves for the various ratios. *LAS-H*: lateral arm soft tissue thickness-to-humerus shaft diameter ratio; *LES-LAS*: lateral elbow swelling-to-lateral arm soft tissue ratio; *LES-H*, lateral elbow swelling-to-humerus shaft diameter ratio.

The ROC curve was statistically significant in predicting a subsequent displacement ($P < .001$). The AUROC curves for LAS-H and LES-LAS ratios were 0.601 (95% CI, 0.517-0.685; $P = .022$) and 0.657 (95% CI, 0.576-0.738; $P < .001$) respectively.

With an AUROC curve being closest to 1, the LES-H ratio was selected to predict subsequent displacement. Table III reports the sensitivity and specificity of predicting subsequent displacement of LCH fractures at various values of the LES-H ratio from the ROC curve. A threshold value of 1.9

was chosen. This gave a sensitivity of 41.4% and a specificity of 90.8% in predicting a subsequent displacement of nondisplaced or minimally displaced LCH fractures. At any other threshold, the proportion of unrequired surgery was unacceptably high.

The LES-LAS ratio had the second largest AUROC curve. When the same level of desired specificity was used to avoid having a high number of unrequired operations, the threshold value of 1.2 from the LES-LAS ratio was selected. This achieved a sensitivity of 23.0% and a specificity of 92.0%.

Compared with patients with an LES-H ratio of <1.9 , the odds ratio of patients with an LES-H ratio of ≥ 1.9 having a subsequent displacement was 6.1 (95% CI, 2.7-13.8; $P < .001$). Compared with patients with a LES-LAS ratio of <1.2 , the odds ratio of patients with and LES-LAS ratio of ≥ 1.2 having a subsequent displacement was 3.2 (95% CI, 1.3-8.1; $P = .014$).

Based on logistic regression of the LES-H and LES-LAS ratios, the proposed scoring system was to award 6 points if the patient had a LES-H ratio of ≥ 1.9 , 3 points if the LES-LAS was ≥ 1.2 , and 0 points if both ratios were below the threshold values. The possible scores for any patient would be 0, 3, 6, or 9. Using this, 121 patients had 0 points, 8 patients had 3 points, 27 patients had 6 points, and 18 patients had 9 points. The AUROC curve using this scoring system was 0.664 (95% CI, 0.583-0.745; $P < .001$), as shown in Fig. 3. Because this AUROC curve was lower than that achieved by

Table III The sensitivity and specificity of predicting subsequent displacement of fractures of the lateral condyle of humerus at various values of lateral elbow swelling-to-humerus shaft diameter ratio

LES-H ratio	Sensitivity (%)	Specificity (%)
0.8	98.9	2.3
0.9	98.9	4.6
1.0	97.7	9.2
1.8	48.3	87.4
1.9	41.4	90.8
2.0	29.9	93.1
2.4	6.9	94.3
2.5	5.7	95.4
2.6	2.3	95.4

LES-H, lateral elbow swelling to humerus shaft diameter ratio.

Table IV Distribution of patients based on a threshold value of 1.90 with sensitivity of 41.4% and specificity of 90.8%*

Variable	Subsequent displacement (No.)	No subsequent displacement (No.)	Total patients (No.)	χ^2 value	<i>P</i> value
LES-H ratio					
≥1.90 (positive)	36	65	101	72.1	<.001
<1.90 (negative)	51	641	692		
Total patients, No.	87	706			

LES-H, Lateral elbow swelling-to-humeral shaft diameter ratio.

* The calculated positive predictive value is 35.6%, and the negative predictive value is 92.6%.

the LES-H ratio alone, we decided to focus on using the LES-H ratio as the sole predictor for subsequent displacement of LCH fractures.

In our population of 706 minimally displaced and nondisplaced LCH fractures, the 87 patients with subsequent displacement gave a prevalence of 11.0%. The patient distribution is presented in Table IV. The distribution of patients based on the threshold LES-H ratio value was significantly different from the expected distribution based on the prevalence ($P < .001$). From these, the calculated PPV was 35.6% and the NPV was 92.6%.

Discussion

A significant number of nondisplaced or minimally displaced LCH fractures end up with subsequent displacement (>2 mm displacement) despite immobilization.¹⁴ We have introduced a new radiographic predictor of subsequent displacement of such LCH fractures. With this, there might be a role for earlier intervention, such as prophylactic percutaneous pinning, in the nondisplaced or minimally displaced LCH fractures instead of allowing subsequent displacement, which would then necessitate an open surgery. An open surgery would carry issues such as longer surgical time, larger scar, more tissue injury, and potentially slower functional recovery.¹⁴

We confirmed the hypothesis that the larger the soft tissue swelling was at the fracture site, the more likely it was to have a subsequent displacement as evidenced by the higher LES in this group. This concurred with the suggestion of Beaty et al² that the nondisplaced or minimally displaced LCH fractures were prone to subsequent displacement if significant soft tissue swelling was present. A larger swelling signified greater soft tissue injury.² This would mean a higher energy trauma causing a disruption of the periosteum giving rise to a large hematoma.

We postulated that the initial hematoma helped to maintain the reduction of the LCH fracture fragment by a tamponade effect. However, the fragment underwent subsequent displacement as the hematoma got resorbed and the swelling reduced over time. The immobilization would then become inadequate and thus the occurrence of a subsequent fracture displacement.

Of the 3 ratios tested, the LES-H ratio had the highest predictive accuracy. Its AUROC curve was 0.731, which would be known as “moderately accurate” in predicting subsequent displacement of the nondisplaced or minimally displaced LCH fractures.¹ We believe that this would be a good ratio because it was the ratio of the parameter of interest (the LES) to a constant reliable parameter of the patient (the humeral shaft diameter). The humeral shaft diameter was a reliable constant because the size of the bone was similar in patients of the same developmental stage.¹² The LAS, however, was more variable than the humeral shaft diameter, even within the same group.

From the LES-H ratio, a threshold value was needed to distinguish the subsequent displacement group from the no subsequent displacement group. Although having a threshold value that could distinguish the 2 groups with 100% sensitivity and specificity would be ideal, there would be a tradeoff needed between sensitivity and specificity in real practice.¹⁸ We chose a threshold LES-H ratio of 1.90, meaning that an LES-H ratio of ≥1.9 would correctly identify 41.4% of patients with subsequent displacement in the subsequent displacement group, whereas an LES-H ratio of <1.90 would correctly identify 90.8% of the patients in the no subsequent displacement group. There was a small tradeoff, because 9.2% of no subsequent displacement patients were inadvertently labeled as patients who would have subsequent displacement. However, we felt that this tradeoff was acceptable because using a lower threshold value would result in too high a rate of unnecessary prophylactic surgical intervention.

Patients with an LES-H ratio of ≥1.90 were 6.1 times more likely to have subsequent displacement than those with an LES-H ratio of <1.9, with PPV of 36.6% and NPV of 92.6%. The PPV and NPV values were appropriate in our study. Given the low prevalence of subsequent displacement of the nondisplaced or minimally displaced LCH fractures, the PPV would be expected to be low whereas the NPV would be expected to be high, even if the sensitivity and specificity were high.^{10,13} A low PPV would still be useful when combined with a high NPV, similar to that of using the serum prostate-specific antigen in the screening for prostate cancer.^{4,16} In our case, the high NPV of 92.6% meant that patients with an LES-H ratio of <1.9 were very likely to not have subsequent displacement, whereas those

with an LES-H ratio of ≥ 1.9 might need some form of early intervention with a less invasive procedure, such as prophylactic percutaneous pinning, to prevent subsequent displacement.

Translating these figures to clinical practice, we would propose that patients with an LES-H ratio of ≥ 1.90 be offered prophylactic percutaneous pinning. This would be a simpler and less invasive procedure that would carry less morbidity than an open surgery required in patients who would develop late displacement. For patients declining prophylactic percutaneous pinning, a closer surveillance could be offered with consideration of earlier cast changing and radiographic evaluation.

Our study had the limitations associated with a single-institution retrospective study. Other limitations included the absence of timing between injury and x-ray imaging because this may have affected the extent of swelling captured. Unfortunately, we were unable to retrieve this information retrospectively because it was not recorded. We also recognized that not all x-ray images would be a perfect anteroposterior view with the child struggling at times. However, we did exclude those with inadequate views with gross rotation. A prospective study in the future may resolve some of these limitations and better validate these measurements.

Having said that, our sample was representative of the general pediatric population because our institution is the largest public pediatric institution in Singapore. In addition, we had reliably good ICC values for inter- and intra-reader reliability, denoting the reproducibility of this method.

Conclusions

We have described the LES-H ratio as a new measurement to objectively quantify soft tissue swelling in minimally displaced or nondisplaced LCH fractures. An LES-H ratio of ≥ 1.90 was identified as a threshold value to predict subsequent displacement of LCH fractures. A prospective study with a similar design could verify further the validity of these measurements. This would allow for the possibility of prophylactic percutaneous pinning for the LCH fractures with a high likelihood of subsequent displacement.

Disclaimer

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