

Association between Cortical Thickness and Spontaneous Non-Traumatic Fracture of the Humeral Shaft

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Abstract

Objectives: This study aimed to clarify association of spontaneous non-traumatic humeral shaft fractures with cortical thickness of the humeral shaft at the fracture site.

Methods: This study included nine humeral shaft fractures from throwing and arm wrestling. While the fracture line was traced on the anteroposterior postoperative radiograph, the fracture location was determined by the fracture line on the lateral cortex of the humerus. In addition, cortical thickness index was analysed on the same postoperative radiograph.

Results: The nine fractures were classified into two types based on the fracture line extensions from the lateral cortex of the humeral shaft. Five fractures of type A showed a spiral fracture line running from the lateral cortex downward to the distal medial cortex. Four fractures of type B demonstrated a spiral fracture line that extended from the lateral cortex upward to the proximal medial cortex as well as downward to the distal medial cortex. The fracture locations on the lateral cortex of the humeral shaft were more proximal in type A than those in type B. Cortical thickness index at the fracture site on the lateral cortex of the humerus was lower in type A than that in type B.

Conclusion: The cortical thickness of distal humerus could determine the types of spontaneous humeral shaft fractures from throwing and arm wrestling.

Keywords: Arm wrestling; Cortical thickness; Humerus; Spontaneous fracture; Throwing

Abbreviation

CTI: Cortical Thickness Index

Introduction

Based on the epidemiology of humeral shaft fractures, there is a bimodal age distribution of fractures with a peak in the third decade commonly in males as a result of high-energy direct trauma and a second peak in the eighth decade mainly in females with osteoporotic fractures [1,2]. In young individuals, spontaneous non-traumatic fractures of the humeral shaft are also reported during throwing sports and arm wrestling [3,4]. An external rotation torque generated during throwing and arm wrestling is thought to act on the humerus, resulting in a spiral fracture [3-6]. Risk factors for this type of fractures have been suggested such as underlying stress fractures [7], age, prolonged time-off from throwing, and disuse fatigue [8]. Currently, however, the precise aetiology of spontaneous non-traumatic fractures of the humeral shaft remains uncertain.

Recent biomechanical analysis using finite element model [9] has shown that application of external rotation torque to the distal end of the humerus with complete fixation of the humeral head can reproduce a typical spiral fracture. The area of maximal stress under the external rotation torque has been found on the distal portion of the humeral shaft. In addition, there is association between the torque

required to cause the fracture and the cortical thickness of the humerus at the attachment of the deltoid muscle. However, the biomechanical study has demonstrated no data on cortical thickness of the maximal stressed area in the humeral shaft.

Aim of the Study

Thus, this study aimed to characterize radiological features of spontaneous non-traumatic humeral shaft fractures and clarify correlation of this type of fractures with cortical thickness of the humeral shaft at the fracture site.

Materials and Methods

Patients

We found nine patients (eight males and one female) who sustained spontaneous non-traumatic fractures of the humeral shaft between February 2011 and November 2017. The sports at the time of injury were throwing in seven cases and arm wrestling in two cases. All the patients, an average age of 23.6 years (range 13 - 30 years), underwent surgical fixation. No patient had data or history that suggested bone pathology or abnormal bone metabolism. This study was approved by the Institutional Review Board of our hospital (acknowledgement number: zn201105).

Radiological evaluation

The fracture line was traced on the anteroposterior radiograph after reduction with surgical stabilization with reference to the pre-operative radiograph (Figure 1 and 2). Thereafter, the positions of the fracture line running into the lateral and medial cortices of the humeral shaft were identified on the radiograph. The length of the entire humerus (X) was measured on the line connecting the humeral epicondyles to the supraspinatus attachment of the great tuberosity [3,4]. The length from the humeral epicondyles to the position of the fracture line on the lateral cortex of distal humerus (Y) was also measured. Thereafter, the percentage of Y/X was calculated to indicate the fracture level on the lateral cortex in the entire length of the humerus. In addition, cortical thickness index (CTI) was evaluated on the same postoperative radiograph. CTI was defined as the ratio of the humeral diaphyseal diameter minus the intramedullary canal diameter to the humeral diaphyseal diameter.

Statistical analysis

The data are expressed as the mean \pm standard deviation. Two sample t test or Tukey's honestly significant difference test for multiple comparison was performed for continuous normally distributed data confirmed by Shapiro-Wilk test of normality. Cohen's d was calculated for the comparison between two means [10]. Statistical analyses were conducted in SPSS for Windows, Version 25 (SPSS Inc., Chicago, Illinois, USA). The level of significance was set at $P < 0.05$.

Results

Fracture classification based on the fracture line extension from the lateral cortex of the humeral shaft

The nine fractures were classified into two types based on the fracture line extension from the lateral cortex of the humeral shaft on the anteroposterior postoperative radiographs. Five fractures showed a spiral fracture running from the lateral cortex downward to the distal medial cortex, which was termed as type A (Figure 1). Four fractures displayed a spiral fracture that extended from the lateral cortex upward to the proximal medial cortex as well as downward to the distal medial cortex, which was termed as type B (Figure 2).

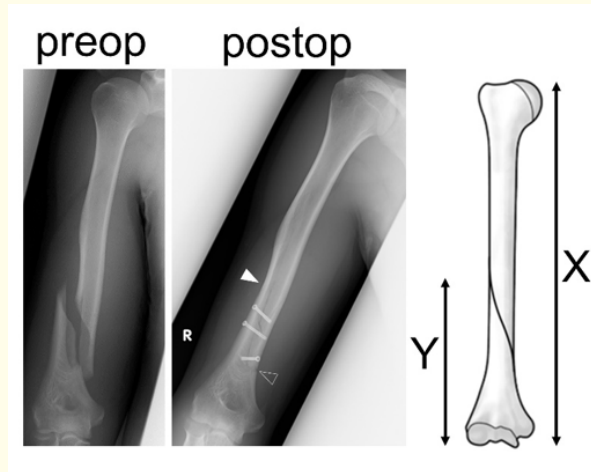


Figure 1: Type A fracture with a spiral fracture line running from the lateral cortex downward to the distal medial cortex. Preoperative (preop) and postoperative (postop) radiographs are shown. In addition to the length of the entire humerus (X), the length was measured from the humeral epicondyles to the position of the fracture line on the lateral cortex of distal humerus (Y). Closed triangle shows the position of the fracture line on the lateral humeral cortex while open triangle indicates the position of the fracture line on the medial humeral cortex.

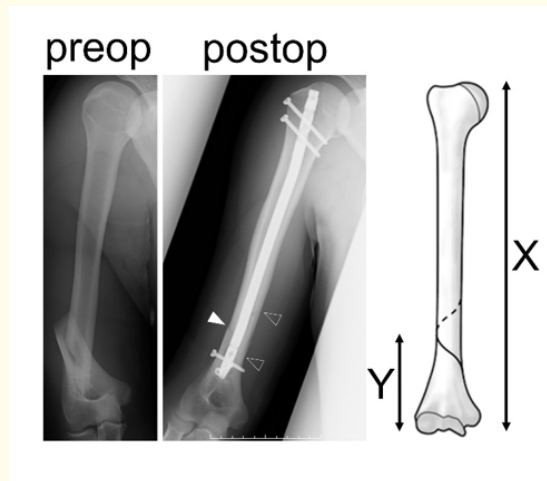


Figure 2: Type B fracture with a spiral fracture line that extends from the lateral cortex upward to the proximal medial cortex as well as downward to the distal medial cortex. Preoperative (preop) and postoperative (postop) radiographs are shown. In addition to the length of the entire humerus (X), the length was measured from the humeral epicondyles to the position of the fracture line on the lateral cortex of distal humerus (Y). Closed triangle shows the position of the fracture line on the lateral humeral cortex while open triangles indicate the position of the fracture line on the medial humeral cortex.

Comparison of radiological parameters (Table 1)

When Y/X, the indicator of the fracture level on the lateral cortex in the whole humerus, was calculated using the postoperative radiograph, Y/X was significantly higher in type A compared with that in type B (P = 0.016). In type A (Figure 3A), CTI was evaluated at the fracture level on the lateral cortex of the humerus (CTI-FL), the fracture level on the distal medial cortex (CTI-FDM), and at the level on the lateral cortex that corresponded with 34% of Y/X, the average of Y/X in type B (CTI-BL). In type B (Figure 3B), CTI was analysed at the fracture level on the lateral cortex of the humerus (CTI-FL), the fracture level on the proximal medial cortex (CTI-FPM), the fracture level on the distal medial cortex (CTI-FDM), and at the level on the lateral cortex that corresponded with 45% of Y/X, the average of Y/X in type A (CTI-AL). CTI-FL was significantly lower in type A than that in type B (P = 0.008). There was no difference in CTI-FDM between types A and B (P = 0.107). Whereas CTI-FL was significantly lower compared with CTL-BL in type A (P = 0.022), CTI-FL was significantly higher compared with CTL-AL in type B (P = 0.001). When we compared CTI-FL, CTI-BL, and CTI-FDM in the patients with type A fracture by Tukey’s test for multiple comparison, CTI-FL was significantly lower than CTI-FDM (P = 0.049, d = 1.85). There was no difference between CTI-FL and CTI-BL or between CTI-BL and CTI-FDM. When we compared CTI-FL, CTI-AL, CTI-PDM and CTI-FDM in the patients with type B fracture by Tukey’s test, no difference was found between any pair of those parameters.

	Type A (n = 5)	Type B (n = 4)	P (95% confidence interval)	Cohen’s d
Male/female	5/0	3/1		
Throwing/arm wrestling	4/1	3/1		
Right/left	4/1	4/0		
Age (years)	24.4 ± 2.6	22.5 ± 7.3	0.602 (-6.325 - 10.125)	0.37
Y/X (%)	44.9 ± 5.8	34.1 ± 4.1	0.016 (2.667 - 18.956)	2.11
CTI-FL	0.436 ± 0.041	0.534 ± 0.038	0.008 (-0.162 - -0.035)	2.46
CTI-AL	0.436 ± 0.041	0.559 ± 0.013	0.001 (-0.174 - -0.072)	3.80
CTI-BL	0.462 ± 0.035	0.534 ± 0.038	0.022 (-0.131 - -0.014)	1.97
CTI-FPM		0.568 ± 0.050		
CTI-FDM	0.511 ± 0.024	0.552 ± 0.042	0.107 (-0.094 - 0.012)	1.24

Table 1: Comparison of demographics and radiological parameters.

Values are expressed as mean ± standard deviation. Y/X was determined as shown in figures 1 and 2. Each cortical thickness index (CTI) was evaluated at the levels shown in figure 3. CTI-FL: CTI at the fracture level on the lateral cortex of the humerus; CTI-AL: CTI at the level on the lateral cortex that corresponds with 45% of Y/X, the average of Y/X in type A; CTI-BL: CTI at the level on the lateral cortex that corresponds with 34% of Y/X, the average of Y/X in type B; CTI-FPM: CTI at the fracture level on the proximal medial cortex in type B; CTI-FDM: CTI the fracture level on the distal medial cortex.

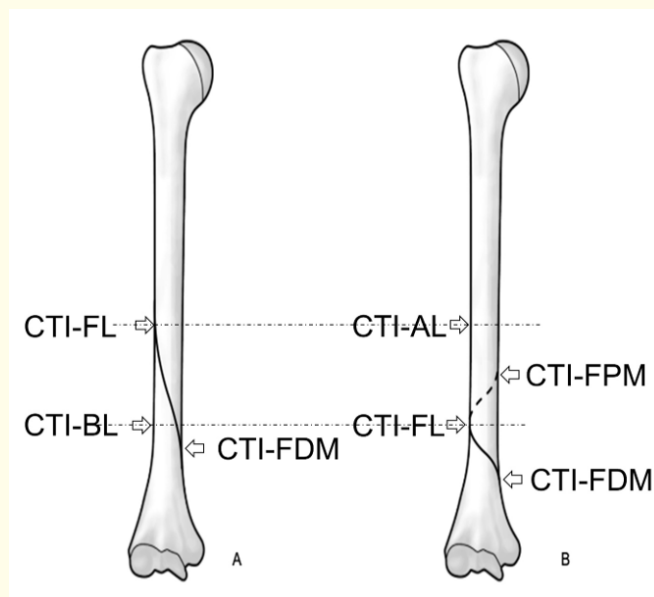


Figure 3: Cortical thickness index (CTI) of the distal humerus. In type A (A), CTI is evaluated at the fracture level on the lateral cortex of the humerus (CTI-FL), the fracture level on the distal medial cortex (CTI-FDM), and at the level on the lateral cortex that corresponds with 34% of Y/X, the average of Y/X in type B (CTI-BL). In type B (B), CTI is analysed at the fracture level on the lateral cortex of the humerus (CTI-FL), the fracture level on the proximal medial cortex (CTI-FPM), the fracture level on the distal medial cortex (CTI-FDM) and at the level on the lateral cortex that corresponds with 45% of Y/X, the average of Y/X in type A (CTI-AL).

Discussion

Ogawa, *et al.* have reported that most patients with spontaneous throwing fractures of the humeral shaft display fracture locations in the mid-distal humeral shaft with a spiral fracture line [3]. The locations and shapes of the present nine fractures are in line with their report. The previous report has also demonstrated that the length and extension of fracture line are different among patients [3]. However, the exact mechanism of such differences has not been clarified. This is the first study to indicate possible association between spontaneous non-traumatic fractures of the humeral shaft and the cortical thickness of distal humeral shaft.

Several biomechanical studies using a three-dimensional finite element model have evaluated stress distribution on the humeral shaft [9,11]. For throwing fracture simulations according to the motion analyses of pitching [3,5], an external rotation torque is applied to the humeral capitellum and to the medial epicondyle of the humerus while the humeral head is fixed in translations and rotations. The external rotation torque causes a spiral fracture that starts from the area of maximal stress in the distal humeral shaft and extends from the proximal part on the lateral side to the distal part on the medial side of the humeral shaft [9]. This fracture line resembles that of type A in the present study. For simulations of the humeral shaft fractures from arm wrestling based on the proposed fracture mechanism [11,12], an internal rotation torque is applied to the shoulder joint with immobilisation of the elbow joint. The internal rotation torque produces the maximal stress on the posteromedial side in the distal 1/3 of humerus. The resultant fracture line spreads at an angle of 45 degrees to the longitudinal axis of humerus [11]. This fracture pattern is similar to type B in the present study. Thus, loading conditions in the humerus during throwing and arm wrestling may be one of the determinants of fracture patterns.

Cortical bone is integral to the mechanical strength of bone with good relationship with bone density and compressive strength [13-15]. From the previous biomechanical analysis using finite element model of the humerus [9], the torque sufficient to cause humeral shaft fracture highly correlates with the cortical thickness at the attachment of the deltoid muscle. In addition, spiral fractures start from the maximal stressed area on the distal side of the humeral shaft [9]. The present study suggests the possibility that the cortical thickness of the distal humerus could determine the fracture types. When the cortex of the upper distal humerus is thinner than that of the lower distal humerus as observed in the patients with type A fractures, the fracture line likely spreads from the stressed area within the thinner upper lateral cortex to the lower medial cortex. In contrast, when the cortical thickness is similar from the upper to the lower parts of the distal humerus as observed in the patients with type B, the fracture line may be yielded in the lateral cortex of the distal 1/3 of humerus like the aforementioned simulation of the humeral shaft fractures from arm wrestling [11].

Limitations of this Study

This study has some limitations. First, the sample size was small. The small sample size may cause some selection bias. Second, we had no data on stress distributions and loading conditions in the humerus of each case. Areas of maximal stress could vary among different humeral shapes even under similar loading conditions [9]. Third, bone density was not analysed in this study, although cortical bone significantly correlates with bone density and compressive strength [13-15].

Conclusion

The present study has indicated for the first time that the cortical thickness of distal humerus could determine the types of spontaneous humeral shaft fractures from throwing and arm wrestling. The role of cortical thickness in association with loading conditions and stress distributions in the occurrence of spontaneous non-traumatic humeral shaft fractures should be further investigated to clarify the mechanism of those fractures.

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