Quantitative 3-dimensional CT analyses of fractures of the middle phalanx base

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Abstract

Background Quantitative 3-dimensional computed tomography (3DCT) analyses can provide a more detailed understanding of fracture morphology. For fracture-dislocation of the proximal interphalangeal joint, the extent of fragmentation of the volar lip of the middle phalanx—a factor that might influence treatment—is not always apparent from radiographs. We hypothesized that there is no correlation between number of fracture fragments and the percentage of articular surface area involved in intra-articular fractures of the base of the middle phalanx using quantitative 3DCT analyses.

Methods We used 13 computed tomography scans with a slice thickness of 1.25 mm or less to create 3-dimensional models of 15 intra-articular fractures of the base of the middle phalanx in 13 patients. We resized 3-dimensional models of a non-fractured middle phalanx of the same hand to fit the fractured middle phalanx in order to approximate the size and shape of

the fractured middle phalanx in its pre-injury state. We created a heatmap to demonstrate the location of the fractured articular surface.

Results With the number of scans available, we did not find a significant correlation between the percentage of articular surface area involved and the number of fracture fragments. The median percentage of articular surface area involved was 46 % (range, 21–90 %). The heatmap demonstrated that the radio-volar side of the articular surface seems to be more involved than the ulnar-volar side in intra-articular fractures of the base of the middle phalanx.

Conclusion Quantitative 3DCT analysis of fracture fragments provides useful information that could facilitate surgery and analysis of complex fractures of the base of the middle phalanx.

Level of Evidence: IV, Basic Science Study, Anatomic Study, Imaging.

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Introduction

Intra-articular fractures of the base of the middle phalanx are challenging injuries to treat and many operative treatments exist [1, 5, 7, 11]. Residual subluxation and articular incongruity can contribute to pain, stiffness, and arthrosis [1, 5, 11]. The choice of treatment is based on fracture pattern (the percentage of articular surface area involved and the degree of comminution) and joint stability [1, 6]. Operative treatment aims to obtain congruity of the articular surface and restore stability in order to allow early motion [1, 6]. Restoring congruity of the articular surface reduces the risk of recurrent subluxations/dislocations and secondary arthrosis [11].

Quantitative 3-dimensional computed tomography (3DCT) analyses may provide a more detailed understanding of fracture morphology, which might aid in optimal restoration of the articular surface of the base of the middle phalanx [4, 8].

Our primary aim was to measure the percentage and location of articular surface area involved in intra-articular fractures of the base of the middle phalanx using quantitative 3DCT analyses. We tested the null hypothesis that there is no correlation between the number of fragments and the percentage of articular surface area involved.

Materials and Methods

Study Design

We obtained a waiver of informed consent for this retrospective study from our institutional review board. A search of diagnostic codes for phalanx fractures combined with a procedure code for computed tomography (CT) scans identified 15 consecutive patients with 17 intra-articular fractures of the base of the middle phalanx who had a CT scan between 2005 and 2013 in Massachusetts General Hospital (Boston, USA) or Brigham and Woman's Hospital (Boston, USA). Adequate 3-dimensional modeling requires CT scans with a slice thickness between 0.62 and 1.25 mm; this was the case in 14 patients with 16 intra-articular fractures of the base of the middle phalanx. We excluded one of these patients because the quality of the CT scan did not allow accurate identification of fracture lines. The 13 remaining patients (9 men, 4 women) with 15 intra-articular fractures of the base of the middle phalanx had a median age of 28 years (interquartile range, 23–36 years; range, 14–59 years).

Modeling Technique and Evaluation

Computed tomography images were acquired with different CT scanners up to 140 kV and 500–700 mAs. The CT images were retrieved from the radiology archiving system as Digital Imaging and Communications in Medicine (DICOM) files. Three-dimensional models of the fractured middle phalanx and a non-fractured middle phalanx of a different finger of the same hand were rendered using 3D Slicer (3D Slicer, version 4.2, Boston, USA). Bony structures were identified on CT slices using a predefined threshold value in 3D slicer (300 Hounsfield units) (Fig. 1a). Next, 3-dimensional polygon mesh models were created in 3D Slicer (Fig. 1b). These 3-dimensional mesh models were imported in Rhinoceros (Version 5, McNeel North America, Seattle, WA) for further analyses [3, 8, 9]. The position of the 3-dimensional models was standardized using the x, y, and z axes in Rhinoceros; the medullary canal was used to define proximal and distal (z-axis), the articular surface of the base of the middle phalanx was used to define radial and ulnar (x-axis), and volar and dorsal (y-axis). All 3-dimensional models of left-sided phalanges were mirrored to make the orientation match that of the right-sided phalanges.

Building upon the residual intact portions of the fractured phalanx, we resized the non-fractured middle phalanx to fit the fractured middle phalanx (Fig. 1c). This resulted in a model approximating of the size and shape of the native pre-injury anatomy of the fractured middle phalanx. Subsequently, fracture lines of all fractured phalanges were drawn in a perpendicular plane to assess the location of the fractured articular surface in a heatmap and measure the size of the fractured and non-fractured part of the base of the middle phalanx in square millimeters. We calculated the percentage of fractured/

Fig. 1 **a** outline of a fractured middle phalanx (green) and a non-fractured proximal phalanx (yellow) in 3D Slicer. **b** 3-dimensional polygon mesh models of a fractured and non-fractured middle phalanx and

proximal phalanges. **c** the non-fractured middle phalanx is resized to fit the fractured middle phalanx

Fig. 2 Scatter plot demonstrating the relationship between percentage of articular surface area involved and number of fragments in intra-articular fractures of the base of the middle phalanx

involved articular surface size by dividing the size of the fractured part of the articular surface of the base of the middle phalanx by the total size of the articular surface.

Statistical Analysis

Baseline characteristic of study patients and the mechanism of injury, involved hand and finger, percentage of articular surface size, number of fracture fragments, degree of central impaction, and number of volar lip fragments were summarized with frequencies and percentages for categorical variables and as a median with interquartile range for continuous distributed variables.

Correlation of the percentage of articular surface area involved and number of fracture fragments was analyzed using the Spearman's rank correlation. A Graph was drawn to demonstrate the percentage of the articular surface area involved in the fracture in relation to the number of fracture fragments.

Results

With the number of fractures available for this study, no significant correlation was found ($r=0.50$; p value= 0.057) between the percentage of articular surface area involved in an intra-articular fracture of the base of the middle phalanx and the number of fracture fragments (Fig. 2).

The median percentage of articular surface area involved was 46 % (interquartile range, 36–49 %; range, 21–90 %).

In 8 (53 %) fractures there was a single central impaction fragment, in 6 fractures (40 %) there were multiple central impaction fragments, and in 1 (7 %) fracture there was no central impaction fragment. In 8 (53 %) fractures there were two volar lip fragments, in 5 fractures (38 %) there was one volar lip fragment, and in 2 (13 %) fractures there were no volar lip fragments (Table 1).

A heatmap created to demonstrate the location of the fractured articular surface (after rescaling all models to fit a template model of a non-fractured middle phalanx) showed that the radial and the volar side is more involved in the intra-

Table 1 Characteristics of fifteen intra-articular fractures of the base of the middle phalanx

Patient	Age	Sex	MOI ^a	Side	Finger	Number of fragments	Central impaction fragments	Volar lip fragments	Articular surface loss (in %)
1	36	Male	Sports	Right	Index finger	4	One	2	46
2	59	Female	Fall	Right	Small finger	5	Multiple	2	76
3	19	Male	Jammed in door	Right	Middle finger	6	Multiple	2	48
	19	Male	Jammed in door	Right	Index finger	3	One	2	31
4	28	Male	Sports	Left	Small finger	3	One	1	48
5	25	Male	Sports	Right	Small finger	2	One	1	35
6	41	Male	MVC ^b	Left	Ring finger	4	Multiple	1	45
	41	Male	MVC ^b	Left	Small finger	3	One	0	46
7	14	Female	Fall	Right	Middle finger	6	Multiple	2	36
8	24	Male	Assault	Left	Ring finger	3	One	2	39
9	21	Female	Sports	Right	Index finger	4	One	2	37
10	23	Female	Unknown	Right	Small finger	2	One	1	49
11	29	Male	Sports	Right	Index finger	4	Multiple	0	76
12	29	Male	Sports	Left	Index finger	7	Multiple	2	90
13	44	Male	Sports	Right	Small finger	1	None	1	21

^a Mechanism of injury

^b Motor vehicle collision

Fig. 3 Heatmap of all intra-articular bases of middle phalanx fractures drawn on a template of the base of a right hand middle phalanx. **a** perpendicular view on the base of the middle phalanx. **b** oblique view from ulnar-volar on the base of the middle phalanx

articular fracture of the base of the middle phalanx than the ulnar and the dorsal side (Fig. 3a, b).

A post hoc power analysis determined that 26 fractures were needed to provide 80 % statistical power ($\beta=0.20$, $\alpha=0.05$) to detect a correlation of 0.5 ($r=0.5$) between the percentage of articular surface area involved and the number of fracture fragments.

Discussion

Open reduction and internal fixation of intra-articular fractures of the base of the middle phalanx aims to reconstruct the congruity of the articular surface and stabilize the joint [1, 6]. This quantitative 3-dimensional study might aid in the understanding of fracture morphology, help plan the treatment of these fractures, and could be useful for clinical research.

We tested and—with the number of fractures available—failed to reject the null hypothesis that there is no correlation between number of fragments and the percentage of articular surface area involved in intra-articular fractures of the base of the middle phalanx.

The limitations of this study should be kept in mind when interpreting our results. First, the subset of patients that had a CT scan may not be representative for the average patient with an intra-articular fracture of the base of the middle phalanx. Second, only 15 intra-articular fractures of the base of the middle phalanx in 13 patients met our inclusion criteria for 3-dimensional modeling, this might have resulted in insufficient power to reject the null hypothesis. Third, the articular surface was measured 2-dimensionally in a 3-dimensional model; this might have influenced the approximation of the articular surface size of the fractured and non-fractured part of the base of the middle phalanx.

Radiography is the first-line imaging technique to assess fractures of the middle phalanx and is often used to estimate the articular surface area involvement in intra-articular fractures of the base of the middle phalanx [2, 12]. Computed tomography scans can provide 3-dimensional imaging of these fractures which can aid in a more accurate estimation

of articular surface area involvement, assessment of central impaction, and degree of comminution [2, 10]. Prior studies used CT scans to assess articular surface area involvement in intra-articular fractures of the base of the middle phalanx [2, 10]. Faccioli et al. categorized the articular surface area involvement in three groups using CT images: 12 patients with <40 %, 4 patients with 40–80 %, and 1 patient with >80 % articular surface area involvement [2]. Wolfe et al. found an average of 30 % articular surface impaction (range, 14–51 %) in 6 patients with an impaction fracture of the base of the middle phalanx using CT images [10].

We did not find a significant correlation between the number of fracture fragments and the percentage of articular surface area involvement in this series of 15 intra-articular fractures involving the base of the middle phalanx, but it does appear that there may be a significant correlation if more fractures were analyzed. The radio-volar side of the articular surface seems to be more involved than the ulnar-volar side in intra-articular fractures of the base of the middle phalanx.

Conflict of Interest Author (DR) has received consultancy fees from Wright Medical and Skeletal Dynamics. Author (DR) has received a speaker honorarium from AO North America and AO International. Author (DR) has received royalties from Wright Medical. Author (DR) owns stock in Illuminos. The other authors declare that they have no conflict of interest.

Statement of Human and Animal Rights All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Statement of Informed Consent The study was approved by our institutional review board and a waiver of informed consent was obtained.

Ethical Review Committee Statement A copy of the letter from our ethical committee approving this study is provided.

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