Curvatures of the DIP joints of the hand

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Abstract

Background The distal interphalangeal (DIP) joints of the hand are highly susceptible to osteoarthritis and trauma. Surgical treatment options mandate accurate characterization of their osseous anatomy; however, there are few studies that describe this. We describe the curvatures of the DIP joints by measuring the bone morphology using advanced imaging and modeling methods.

Methods The fingers of 16 right hand fresh frozen human cadavers were analyzed. Fingers showing signs of DIP joint arthritis were excluded. The fingers were scanned using microtomography (microCT). Measurements of the bony morphology were made using models created from the scans.

Results In each finger, there is no statistically significant difference between the radii of curvature of the ulnar and radial condyles of the middle phalanx head. Conversely, the radius of curvature of the distal phalanx ulnar groove is significantly greater than that of the radial groove. The radii of curvature of the groove of the distal phalanx and the condyles of the middle phalanx displayed nonconformity with disparity increasing from the index to small fingers. Remarkably, the radius of curvature of the distal phalanx central ridge and the mean radius of the middle phalanx condyles are essentially the same.

Conclusion The purpose of this study is to gain better insight into the DIP joints of the hand. The asymmetry between the distal phalanx grooves and the middle phalanx condyles suggests that there may be a translational component to DIP joint

motion. Our understanding of morphology may lend insight into the biomechanics and disease progression within the DIP joints.

Keywords Distal interphalangeal joint · Middle phalanx · Distal phalanx · Morphology · Curvature · Condyles · Grooves · Microcomputed tomography · MicroCT · Analysis · Biomechanics

Introduction

The distal interphalangeal (DIP) joints of the hand have received little investigative attention with only general characterization of their anatomy being reported. Proximal interphalangeal joint (PIP) and DIP joint similarities have been identified such as ligament attachment tubercles, bicondylar proximal articular surfaces as well as concavities and intercondylar ridges within the distal articular surfaces [4]. PIP joint morphology demonstrates nonconforming articular surfaces with the proximal phalangeal heads exhibiting a trapezoid appearance and asymmetric condyles [1, 9, 11]. No study has characterized the bony morphology of the DIP joint.

Microtomography (microCT) imaging has emerged as a powerful tool in the evaluation of the bony structures of the finger due to its excellent contrast and multiplanar imaging capabilities [8]. MicroCT is similar to tomography yet functions with pixel size cross sections within the micrometer range. This specialized scanner is ideally suited to the characterization of smaller objects such as the human fingers [8].

The aim of this study is to characterize the bony morphology of normal DIP joints obtained through noninvasive analysis of bone and joint morphology using advanced imaging methods.

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Material and Methods

Specimens

The index, long, ring, and little fingers were separated at the metacarpophalangeal joint level from the right hands of 16 fresh frozen cadaver specimens. Three of the hands were from male specimens, ten from female, and three were unknown. The age at death for the cadaver specimens ranged from 42 to 91 years old with three of unknown age. All procedures followed were in accordance with the ethical standards of the responsible institutional committee on human experimentation.

Data Collection

All of the DIP joints were analyzed for various types of arthritis that would affect normal morphology. Two orthopedic surgeons independently graded the radiographs of each DIP joint according to joint space, osteophyte size and location, sclerosis, and subchondral cysts. The entirety of each finger (including the proximal, middle, and distal phalanges) was scanned via microCT using the *vivaCT 40* MicroCT scanner (Scanco Medical, Southeastern, PA) at 50 kVp/35 keV (160 μ A) and a resolution of 76 μ m. The DIP joints from each finger were then dissected for gross inspection. Fingers with DIP joints with abnormal radiographic analysis and those with cartilage wear or osteophyte formation from gross analysis were excluded. This left 11 index fingers, 11 long fingers, 12 ring fingers, and 13 small fingers for analysis.

Model Creation

The images from each microCT scan were imported into Amira (Visage Imaging GmbH, Berlin, Germany) to segment the middle and distal phalanges. The segmented data were imported into Rapidform XO (JMR Systems, Derry, NH, USA) to create a corresponding model. For each model, the outer surface was isolated and smoothed to minimize stair-stepping effects created by the microCT scans. The global coordinate axes were aligned using a longitudinal axis based on a vector that minimizes the phalanx moment of inertia.

Model Validation

The software generated models were validated to ensure the accuracy of the model analysis. The middle phalanx from each finger was dissected to remove the soft tissue. Measurements of the minimum shaft height and width, maximum base height and width, and maximum head width were taken of the physical bone and the model by one investigator. Each measurement was repeated three times, and the measurements of the physical bone were made with calipers. The physical and

model measurements were compared to one another and analyzed for any discrepancy. No measurement showed a statistical difference between the physical and model measurements ($p > 0.05$).

DIP Joint Curvature Analysis

Identifying Features of the Middle Phalanx Head

Middle phalanx head features of interest are the two condyles, the central groove, and the transitional ridge when present. The transitional ridge occurs where the concavity between the condyles is lost. To find this, the head was rotated in the volar to dorsal direction from the coronal view to the axial view in one degree increments. An outline of the articular surface was created at each degree, and a circle was fitted to the middle third of each outline. The first circle that curves toward the head identifies the transitional ridge. If this does not occur, then there is no transitional ridge and the central groove persists.

The central groove is the lowest depression on the head located between the radial and ulnar condyles. The points of lowest depression between the most volar aspect of the head and the transitional ridge (or most dorsal aspect if the ridge was absent) were identified. A circle was fitted to these points to portray the central groove. The highest points on the radial and ulnar sides of the head are the condyles. For each side, the highest points between the most volar aspect of the head and the transitional ridge (or the most dorsal aspect if the ridge was absent) were identified. Circles were fitted to these points on each side to portray each condyle (Fig. 1).

Identifying Features of the Distal Phalanx Base

Features of interest of the distal phalanx base are the two grooves and the central ridge. The central ridge comprises the highest points located between the radial and ulnar grooves. These points were identified, and a circle was fitted to portray the ridge. The lowest depressions on the radial and ulnar sides of the distal phalanx base are the grooves. For each side, the lowest points were identified, and a circle was fitted to portray the grooves (Fig. 2).

Measurements

Characterization of the middle phalanx head included measurement of its maximum width and height. Condyle and groove radius of curvatures were measured. Similar characterization of the distal phalanx base included measurement of the maximum width and height. Groove and the ridge radius of curvatures were measured (Fig. 3).

Fig. 1 Middle phalanx head features. Finding the transitional ridge using *circles* fitted to the outline of the articular surface taken in one degree increments (**a**), *yellow lines* connecting the lowest points on the articular surface which is the central groove (**b**), *yellow lines* connecting the highest points on the ulnar side of the articular surface which is the ulnar condyle (**c**), *circles* fitted the points identified on the central groove and the condyles (**d**) (CT—circle falling toward head, CA—circle falling away from the head, UC—ulnar condyle, CG—central groove, RC—radial condyle)

Statistical Analysis

Statistical analysis of the measured parameters was performed to determine the statistical significance of differences between the measurements. A paired Student's *t* test compared measurements of the same finger, and ANOVA was used when comparing measurements among fingers.

Results

Middle Phalanx Head

The articular surface of the middle phalanx head consists of prominent radial and ulnar condyles separated by a central groove. The depth of the groove decreases from the volar to

Fig. 2 Distal phalanx base features. *Yellow lines* connecting the highest points on the articular surface which is the central ridge (**a**), *yellow lines* connecting the lowest points on the ulnar side of the articular surface which is the ulnar groove (**b**), *circles* fitted to the points identified on the central ridge and the grooves (**c**) (UG—ulnar groove, CR—central groove, RC—radial condyle)

Fig. 3 Measurements. Measurements taken of the middle phalanx head (a) (HW—head width, HH—head height, UC—ulnar condyle radius of curvature, CG—central groove radius of curvature, RC—radial condyle radius of curvature) and measurements taken of the distal phalanx base (b) (BW—base width, BH—based height, UG—ulnar groove radius of curvature, CR—central ridge radius of curvature, RG—radial groove radius of curvature)

dorsal surface. The condyles become confluent with the groove near the dorsal portion of some heads. The surface is convex throughout with the convexity greatest on the radial and ulnar condyles gradually decreasing toward the central groove (Fig. 4).

The condyles and central groove are best approximated by a circle. There is not a dominant condyle in any finger of significance ($p > 0.05$); however, the mean differences in the condyle radii of the index (0.012 cm), ring (0.004 cm), and small fingers (0.001 cm) show a larger radial condyle, while the difference in the long finger (0.005 cm) shows a larger ulnar condyle (Table 1). There is a significant difference between the condyle mean radius of curvature and the groove radius in each finger ($p < 0.05$).

The groove is deepest in the ring finger with the greatest ratio of groove radius of curvature to condyle mean radius that becomes shallower when progressing in both directions to the index and small fingers (Table 1). The small finger has the shallowest groove and is statistically different than all other fingers ($p = 0.03$).

Distal Phalanx Base

The articular surface of the distal phalanx base consists of radial and ulnar grooves separated by a central ridge. The

central ridge peaks within the middle third and gently slopes toward both grooves. This peak is highest at the volar and dorsal aspects of the base. The surface is concave throughout with the concavity greatest within the radial and ulnar grooves gradually decreasing toward the central ridge (Fig. 5).

The grooves and central ridge are best approximated by a circle. The ulnar groove has a significantly greater radius of curvature than the radial groove in each finger ($p < 0.05$). There is a significant difference between the groove mean radius of curvature and the ridge radius in each finger ($p < 0.05$). The articular surface becomes flatter from the index to the ring finger having increasing radii of curvatures then becomes more curved in the small finger with decreasing radii (Table 2). The index finger has the most pronounced ridge with the greatest ratio of central ridge radius of curvature to mean groove radius which progressively decreases to the small finger; however, the differences are not significant between fingers ($p = 0.32$) (Table 2).

DIP Head and Base Curvatures

The radii of curvature between the distal phalanx grooves and the middle phalanx condyles display statistically significant nonconformity in each finger ($p < 0.05$) with significantly greater disparity on the ulnar side ($p < 0.05$). The radii of curvature between the distal phalanx central ridge and the middle phalanx groove also display significant nonconformity in each finger ($p < 0.05$). These disparities increase from the index to the ring finger then decrease with the small finger. Remarkably, the radius of curvature of the distal phalanx central ridge and the mean radius of the middle phalanx condyles are essentially equal in each finger ($p > 0.05$).

Discussion

Our investigation was performed to gain a better understanding of the detailed morphological features of the DIP joints of the hand. We aimed to characterize the articular surface curvatures.

Our study analyzed fingers harvested from cadaver specimens without radiographic or visual changes consistent with osteoarthritis. Using CT scans to create models for the analysis of this joint proved beneficial in several respects. Measurements obtained by this method were easier and more reproducible than taking physical measurements, especially considering the small size of these bones. Additionally, the ability to manipulate the model in a nondestructive fashion allowed for greater data collection from each specimen. This was further enhanced by using microCT, which provided a resolution of 76 μm as opposed to 625 μm for conventional CT, thereby giving greater detail to the model and decreasing error of the measurements.

Fig. 4 Middle phalanx head. End on view (a), side view (b), volar view (c), and oblique view (d)

The kinematics of joint motion are influenced by its bony morphology. Degeorges et al. studied the axial rotations of phalanges during joint flexion and extension using a VICON system. They reported an average of 2–8° of pronation in the DIP joint of each finger through its arc of flexion [6]. Since it has a greater distance to cover, the side of the distal phalanx articulating with the larger condyle may produce rotation about the side articulating with the smaller condyle when viewing the

motion from the reference point of the smaller condyle. This produces pronation if the radial condyle is the larger of the two. Although not statistically significant, our mean results show that the radial condyle is slightly larger than the ulnar condyle in each finger except for the long finger. The small sample sizes in both studies could explain the discrepancy in the long finger.

Our results show that the DIP joints are nonconforming with significantly different radii of curvatures between the

Table 1 Measurements of the middle phalanx head

Middle phalanx head measurement	Index finger		Long finger		Ring finger		Small finger	
	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)
Linear measurement (cm)								
Max height	0.510–0.845	0.626 (0.090)	0.527–0.789	0.654 (0.078)	0.475–0.685	0.584 (0.057)	0.424–0.650	0.512 (0.059)
Max width	0.899–1.146	0.988 (0.078)	0.912–1.219	1.058 (0.099)	0.904–1.154	1.012 (0.079)	0.781–1.055	0.873 (0.083)
Radius of curvature (cm)								
Radial condyle	0.245–0.434	0.309 (0.051)	0.268–0.388	0.325 (0.038)	0.242–0.357	0.295 (0.034)	0.213–0.338	0.253 (0.034)
Ulnar condyle	0.247–0.374	0.297 (0.042)	0.276–0.401	0.330 (0.040)	0.238–0.335	0.290 (0.032)	0.198–0.320	0.252 (0.034)
Central groove	0.204–0.364	0.260 (0.043)	0.210–0.322	0.275 (0.032)	0.182–0.298	0.244 (0.032)	0.192–0.321	0.239 (0.035)
Ratio								
Radial/ulnar condyle	0.936–1.168	1.043 (0.093)	0.923–1.050	0.979 (0.042)	0.895–1.102	1.016 (0.070)	0.768–1.181	1.009 (0.101)
Groove/mean condyle	0.806–0.901	0.856 (0.031)	0.720–0.962	0.846 (0.082)	0.719–0.932	0.835 (0.062)	0.783–1.168	0.954 (0.133)

Fig. 5 Distal phalanx base. End on view (a), side view (b), volar view (c), and oblique view (d)

mating articular surfaces. This asymmetry suggests that, in addition to the rotational motion of the distal phalanx around the middle phalanx, there also may be a translational component. Motion may be dictated by the middle phalanx condyles and the distal phalanx central ridge since these two values are

essentially the same. Motion analysis of this joint may further clarify the relative contributions of rotation and translation.

The differences between radii of curvatures of the mating articular surfaces of the DIP joint may have potential implications for progression of degenerative change. As the

Table 2 Measurements of the distal phalanx base

Distal phalanx base measurement	Index finger		Long finger		Ring finger		Small finger	
	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)
Linear measurement (cm)								
Max height	0.542–0.752	0.682 (0.073)	0.598–0.878	0.734 (0.081)	0.544–0.812	0.682 (0.074)	0.456–0.711	0.603 (0.068)
Max width	0.928–1.243	1.048 (0.087)	1.008–1.299	1.126 (0.085)	0.921–1.216	1.061 (0.098)	0.771–1.106	0.901 (0.101)
Radius of curvature (cm)								
Radial groove	0.279–0.701	0.518 (0.129)	0.404–0.768	0.543 (0.121)	0.386–0.752	0.578 (0.122)	0.387–0.693	0.506 (0.093)
Ulnar groove	0.332–0.880	0.587 (0.167)	0.485–0.981	0.691 (0.152)	0.453–1.029	0.714 (0.126)	0.366–0.739	0.534 (0.116)
Central ridge	0.241–0.379	0.302 (0.054)	0.245–0.428	0.317 (0.054)	0.247–0.461	0.329 (0.073)	0.202–0.325	0.253 (0.034)
Ratio								
Radial/ulnar groove	0.732–1.083	0.893 (0.136)	0.592–0.994	0.787 (0.135)	0.654–0.994	0.814 (0.118)	0.808–1.117	0.955 (0.107)
Ridge/mean groove	0.349–0.748	0.546 (0.132)	0.329–0.731	0.519 (0.123)	0.302–0.679	0.512 (0.127)	0.376–0.643	0.483 (0.083)

difference between the radii of curvatures increases, the mating surfaces joint force contact area decreases accordingly, thus causing more concentrated joint loading as the joint moves through its range of motion.

It is debatable whether this concentrated loading may lead to faster arthritic development. The translational motion of the DIP joint during flexion-extension changes the contact point of the cartilage between the middle phalanx head and the distal phalanx base. This changes the focus area of the joint load on the middle phalanx head surface throughout the motion arc which may prevent the occurrence of the osteoarthritic change [7].

Our specimens exhibited a greater ulnar than radial radius of concavity than radial groove radius meaning they were more flat on the ulnar side of the distal phalanx base, which may contribute to an asymmetric degenerative process. An MRI study has demonstrated that articular cartilage destruction has an ulnar as well as volar predilection [14].

These anatomical considerations may explain why the DIP joint is more likely to undergo osteoarthritic change when compared to the PIP joint. However, it may also be attributed to the volar plate mechanism itself. The PIP joint has a stout volar plate that distributes joint fluid during joint flexion and extension, thus keeping the joint always lubricated during motion. Unfortunately, the DIP joint does not have such a mechanism [2, 13].

Joint motion is not a function of bony morphology alone but is also influenced by cartilage thickness and ligament structure. One limitation of this study is that it does not address cartilage thickness, which may be variable throughout the articular surfaces.

Another limitation of this study is that, although our fingers were harvested from cadaver specimens without radiographic or visual changes consistent with osteoarthritis, a wide age range was noted. Older specimens may exhibit cortical thinning which could potentially influence the outer dimensions of the middle and distal phalanges.

The projection methodology that we employed to characterize the articular surfaces of the middle and distal phalanges is highly dependent on the orientation of the bones. We aligned the global coordinates to the respective long axis of each bone. Given that our measurements are concerned primarily with the head, one potential limitation of this study relates to not aligning the global coordinates to the head of the middle phalanx.

The purpose of this study was to gain better insight into the DIP joint anatomy and to provide a platform for future investigations. Our noninvasive anatomical characterization may prove of value in arthroplasty and joint motion simulation efforts. The potential effects of joint morphology on biomechanics and disease progression can

be theorized, but formal studies need to be performed to assess actual dependence [3, 5, 8, 10, 12].

Conflicts of Interest Kraig S. Graham declares that he has no conflict of interest. Robert J. Goitz declares that he has no conflict of interest. Robert A. Kaufmann declares that he has no conflict of interest.

Statement of Human 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.

Statement of Informed Consent No personal identifying information was used in this manuscript, and the research was performed on cadaver specimens; therefore, informed consent was not needed nor obtained.

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