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ORIGINAL ARTICLE

# Bony anatomy of the third metacarpal and relationship with the capitate: a computed tomography study

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## Abstract

**Purpose** The purpose of this study was to accurately establish the anatomical variability of the third metacarpal, its medullary canal, and the relationship with the capitate in the context of high rates of component loosening still seen in total wrist arthroplasty.

**Methods** CT scans of a 100 hands (age: 41 ± 14 years (range: 16–71 years); male/female ratio: 53/47) were studied to establish the detailed anatomy of the third metacarpal and the capitate.

**Results** Although the shape of the third metacarpal and the angles formed with the capitate were highly variable, the third metacarpal length was longer in males ($p < 0.001$), the proximal cortical bone was thicker ($p < 0.001$) and the sagittal metacarpal-capitate axis offset was greater ($p = 0.01$). A relationship was found between the total length of the metacarpal and the distance to the isthmus from the base ($r = 0.63$; $p < 0.0001$) which was unaffected by gender. No age-related relationships were significant.

**Conclusion** The anatomy of the third metacarpal and capitate varies considerably more than has been alluded to in current wrist arthroplasty literature. Differences between males and females can likely be attributed to hand size. The distance of the isthmus from the base can be predicted from the total length of the metacarpal with a standard error of 1.9 mm.

**Keywords** Anatomical variation · Wrist · Intramedullary canal · Capitate · Wrist arthroplasty

## Introduction

Degeneration of the wrist joint, whether in the radiocarpal joint, the intercarpal joints or the entire wrist, is a common complication of a wide variety of conditions including post traumatic, generalised inflammatory disorders and spontaneous osteonecrosis [9]. It can be severely debilitating to lose range of motion at the wrist and this condition poses several challenges to patient, physician and therapist.

Total wrist arthroplasty is an emerging treatment modality for end stage degeneration of the carpus. However, unlike arthroplasty for knees and hips which is very well developed and reliably very effective [3, 8, 11], wrist arthroplasty has in the past been beset with problems as implants are prone to instability and loosening (75–90% cumulative survival at 5 years), especially so at the distal components [1, 15, 18]. There are various reasons for this: the wrist joint remains a complicated, partially understood articulation with biomechanics which are difficult to replicate artificially.

The understanding of wrist biomechanics is evolving rapidly, largely due to new imaging techniques. In consequence, the anatomy of the wrist and its ligaments have been well described, but a description of the variability of the third metacarpal anatomy, its medullary canal and relationship with the capitate is lacking [2, 12]. There have been descriptive computed tomography studies of the first metacarpal [21] and fourth and fifth metacarpals [16], but to our knowledge none have focused on the third metacarpal, its medullary canal, the anatomical variation between gender and/or age or the relationship with the capitate. This is surprising as fixation in line with the third metacarpal is a feature common to most current wrist arthroplasty designs. The aim of this study was to accurately establish the variability of third metacarpal anatomy, its medullary canal, the relationship

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with the capitate and the influence of gender and age on morphology. We hypothesized that a substantial variation would exist of the anatomy of the third metacarpal and that the anatomy might significantly differ between males and females.

## Methods

This was a retrospective, descriptive study of wrist and hand computed tomography (CT) scans of 100 patients treated at Tygerberg Hospital, South Africa, between January 2014 and July 2016. Ethical approval (S16/01/006) and hospital clearance for the study were granted by the Heath Research Ethics Committee of Stellenbosch University and Tygerberg Hospital, respectively. The study was conducted in accordance with the ethical standards in the 1964 Declaration of Helsinki and the regulations of the US Health Insurance Portability and Accountability Act (HIPAA).

Inclusion and exclusion criteria are depicted in Table 1. In this dataset the indications for CT scan included visualisation of complex distal radius fractures and scaphoid fractures. Exclusion criteria included injury patterns that could influence the arrangement of the third metacarpal and the capitate.

Images were created with a Siemens SOMATOM Emotion 6, with minimum slice thickness of 0.23 mm. The image files in *digital imaging and communications in medicine* format (DICOM) were anonymised by the native PACS server software and then downloaded into OsiriX 6.5.2, a medical image processing software programme.

The images were aligned in Multi-Planar Reconstruction mode (MPR) in axial, coronal and sagittal plane to produce the equivalents of *true* posterior-anterior and lateral views produced with plain film radiography.

Measurements of the third metacarpal were taken with slice thickness set to 0.23 mm and then increased to 10 mm with maximum intensity projection algorithm or the thickness that produced the best view of the capitate to measure the angles formed between the capitate and third metacarpal. All the measurements were performed by a senior orthopaedic surgeon, who also works at the department of anatomy.

Definitions of reference points marked on the sagittal view: (1) *Medullary axis* of the metacarpal: a line down the centre of the medullary canal, parallel to the long axis, representing the ideal placement for an intra-medullary device, (2) on the *medullary axis*, the shaft is divided in three, producing two reference points namely *distal* and *proximal*, (3) on the same axis the shaft is divided in half, producing the *midpoint*, (4) *Axis of the capitate*: a line joining the middle of the distal facet's widest part, articulating with the metacarpal base, and the middle of the widest part of the facet articulating with the lunate. This *axial method* of calculating carpal alignment was first described by Linscheid et al. for use with plain film radiology [4], finally (5) the shape of the capitate was classified into one of three groups: round, spherical or V-shaped, as proposed by Yazaki et al. [24].

Definitions of measured parameters were, (1) *Length of metacarpal*: distance from the most distal part of the metacarpal to the base in a plane parallel to the long axis (Fig. 1), (2) *Combined length of metacarpal and capitate*: distance from the most distal part of the metacarpal to the most proximal part of the capitate in a plane parallel to the long axis of the metacarpal, (3) *Shaft diameter, medullary canal diameter and cortical thickness*: both the total shaft diameter and the diameter of the medullary canal measured parallel to both the sagittal and coronal planes, on the axial view. Measurements taken at the two reference points, *proximal* and *distal*, as defined above and subtracted from each other to calculate the total amount of cortical bone (Fig. 2), (4) *Shaft bending angle (SBA)*: measure of the sagittal bend of the metacarpal. Defined by an angle formed between a line from the centre of the base to the midpoint of the shaft, and a line from the middle of the shaft to the midpoint of the metacarpal head. The midpoint of the metacarpal head is, in turn, defined as the midpoint of a line at the widest part of the cartilage cap of the metacarpal head (Fig. 3a), (5) *Metacarpal-capitate axis angle (MC-C angle)*: the angle formed between the axis of the two bones. Measured in both the sagittal and coronal planes (Fig. 3b, c), (6) *Metacarpal-capitate axis offset (MC-C offset)*: the distance between the points where the axes of the metacarpal and the capitate cross the joint between the two bones (Fig. 3b, c), (7) *Isthmus from base*: distance from the base of the metacarpal, along the medullary axis to the narrowest point formed by the medullary canal.

**Table 1** Inclusion and exclusion

| |
|---|
| *Inclusion criteria* |
| Patients with skeletally mature metacarpals: men and women over 16 years of age |
| Scans that include the entire third metacarpal and capitate |
| *Exclusion criteria* |
| Any fractures of the third metacarpal and/or capitate or any carpal dislocations |
| Distorted anatomy secondary to previous fracture, neoplastic conditions or congenital deformity |
| Scans with distortion secondary to technical factors |

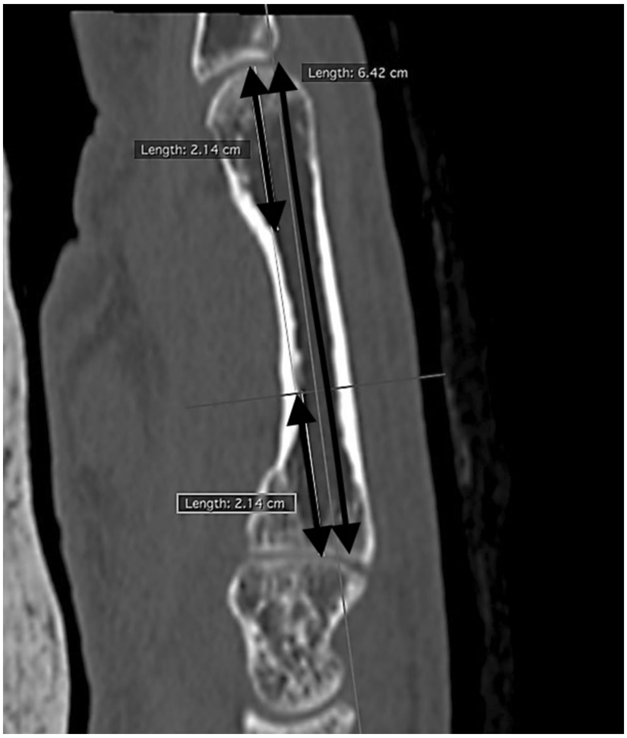


**Fig. 1** Example of the sagittal cut and measurement of metacarpal length and the *proximal* and *distal* points

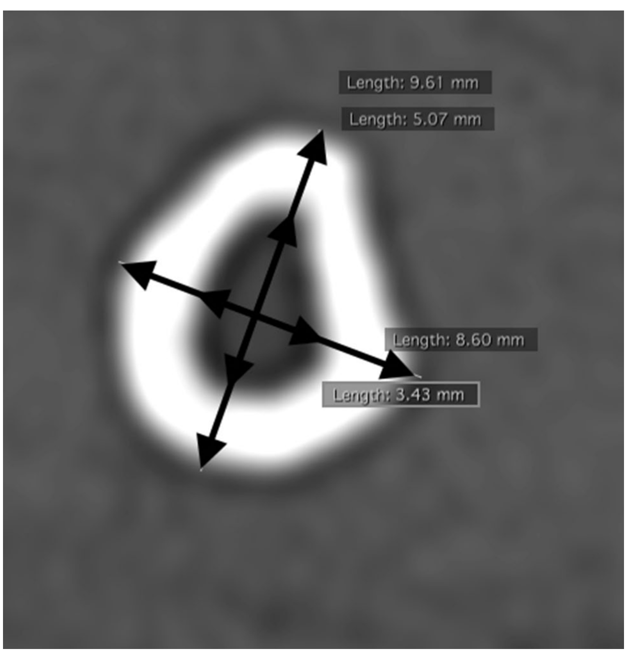


**Fig. 2** Example of the axial cut and shaft measurements

Data were analysed using STATISTICA 13.2 (Dell Inc, Austin, Texas, USA) and Prism 6.0c (GraphPad Software, San Diego, California, USA). Distribution of data was tested for normality using the Shapiro–Wilk W test. Normally distributed data are described as the mean ± standard deviation (ranges), whereas data that are not normally distributed are described as median and interquartile ranges (IQR). Differences between males and females were analysed with dependant *t* test by groups. Relationships between continuous variables were analysed using a Pearson's correlation when both variables were normally distributed and a Spearman rank correlation when one, or both, variables were not normally distributed. Significant differences were accepted at $p < 0.05$.

## Results

A total of 100 scans were included in the study, 53 of which were males and 47 females. Overall the mean age of the group was 41 ± 14 years (range: 16–71 years). The male participants had a mean age of 34 ± 11 years (range: 16–64 years), and the female participants had a mean age of 48 ± 14 years (range: 23–71 years). An overview of the anatomical measurements and comparison of these measurements between male and female participants are depicted in Table 2.

Although there was wide variability among the measured parameters, a few gender related differences were found. The lengths of third metacarpal ($p < 0.001$) and the combined lengths of third metacarpal and capitate ($p < 0.001$) were longer in the male patients, and the total cortical thickness was more in both the sagittal and coronal planes ($p < 0.001$). In addition, the metacarpal and capitate axes did not intersect at the joint between these two bones, with the third metacarpal consistently offset dorsally in both males and females (refer to Table 2). However, this sagittal metacarpal-capitate axis offset was larger in the male participants ($p < 0.05$).

The distance from the base of metacarpal to the isthmus tended to be slightly longer in the male than the female participants ($p = 0.08$), the diameter of the proximal intra medullary canal, in the coronal plane, tended to be wider in the male participants ($p = 0.09$) and the coronal metacarpal-capitate angle tended to be larger in the male participants ($p = 0.05$).

The overall distribution of morphological types of capitate was Flat 60%, Spherical 27% and V-Shaped 13%, and was neither affected by gender or any of the other anatomical measurements.

A strong relationship was found to exist between the total length of the metacarpal and the distance of the isthmus from the base ($r = 0.63$, $p < 0.001$) (refer to Fig. 4). No slope and/or y-axis intercept differences were found between male and female participants, while the standard error of the estimate of this relationship was found to be 1.9 mm.

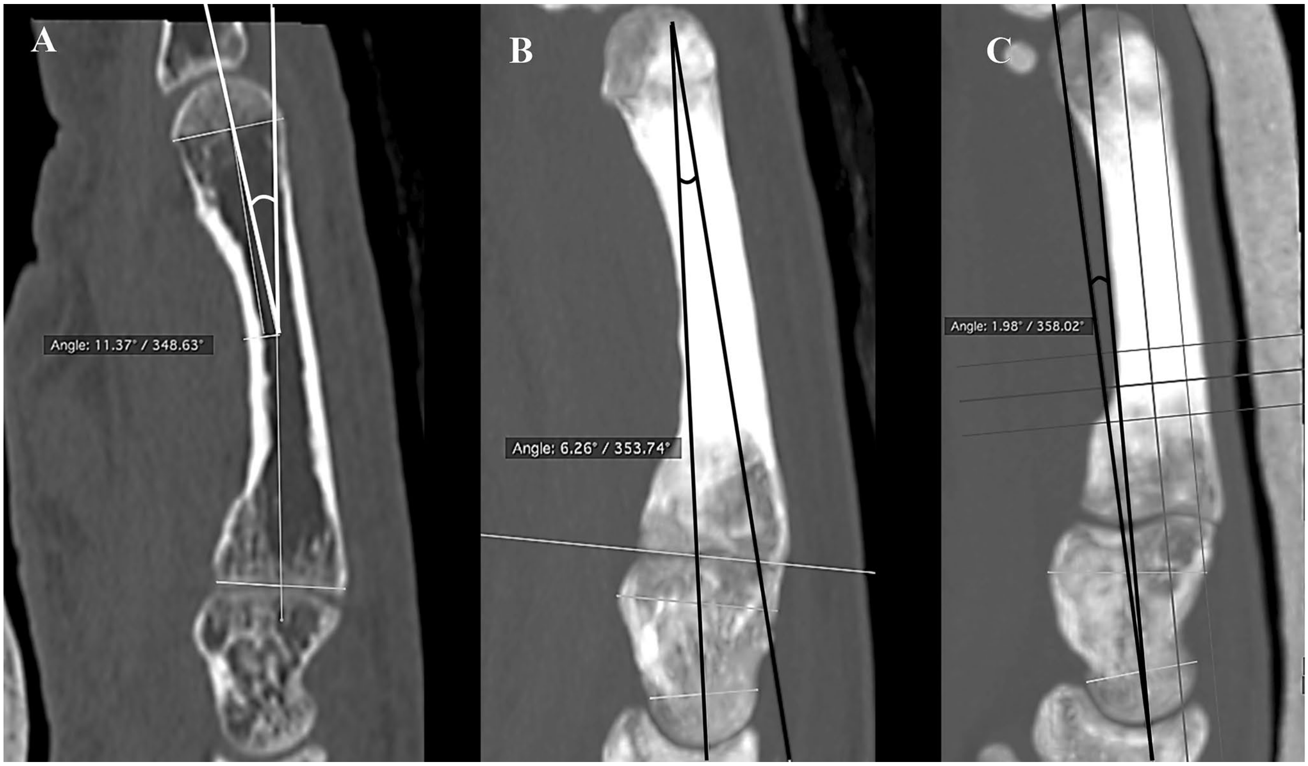


**Fig. 3** Example of the sagittal cut, calculating the shaft bending angle (**a**). Examples of a positive sagittal carpo-metacarpal axis (**b**) and a negative sagittal carpo-metacarpal axis (**c**) calculated on sagittal cuts

**Table 2** Overview of the anatomical measurements

| Variable | All | Male | Female | *P* value |
|---|---|---|---|---|
| Length of third metacarpal (mm)+ | 63.6 ± 4.4 (55.0–73.7) | 64.9 ± 4.1 (58.1–73.7) | 62.0 ± 4.1 (55.0–69.8) | < 0.001 |
| Combined length of third metacarpal and capitate (mm) | 84.5 ± 5.6 (71.5–96.5) | 86.5 ± 4.9 (75.6–96.5) | 82.0 ± 5.3 (71.5–94.4) | < 0.001 |
| Base of metacarpal to isthmus (mm)* | 26.0 (24.9–28.0) | 26.7 (25.4–28.4) | 26.1 (24.4–27.5) | 0.08 |
| Shaft bending angle (degrees)* | 14.0 (10.8–15.9) | 14.7 (11.3–16.1) | 12.7 (10.0–15.0) | 0.10 |
| Proximal cortical thickness, sagittal (mm)+ | 5.5 ± 0.9 (3.4–8.0) | 5.9 ± 0.9 (4.3–8.0) | 4.9 ± 0.7 (3.4–6.1) | < 0.001 |
| Proximal cortical thickness, coronal (mm)+ | 4.9 ± 0.9 (2.8–7.4) | 5.3 ± 0.8 (3.5–7.4) | 4.5 ± 0.8 (2.8–6.1) | < 0.001 |
| Proximal sagittal canal diameter (mm)+ | 4.4 ± 1.0 (2.2–6.7) | 4.3 ± 1.1 (2.2–6.7) | 4.4 ± 0.9 (2.8–6.5) | 0.59 |
| Proximal coronal canal diameter (mm) + | 3.5 ± 1.0 (1.4–7.3) | 3.3 ± 1.2 (1.4–7.3) | 3.7 ± 0.8 (2.3–5.6) | 0.09 |
| Sagittal metacarpal-capitate angle (deg) + | 7.3 ± 5.1 (− 6.2–20.1) | 7.5 ± 5.2 (− 6.2–18.1) | 7.0 ± 5.1 (− 5.1–20.2) | 0.65 |
| Coronal metacarpal-capitate angle, (deg)* | 6.5 (3.1–10.2) | 7.7 (3.8–10.8) | 5.5 (2.2–9.4) | 0.05 |
| Sagittal metacarpal-capitate axis offset, (mm)+ | 5.1 ± 1.4 (0.7–9.0) | 5.5 ± 1.2 (2.8–7.8) | 4.8 ± 1.5 (0.79–9.9) | 0.01 |

+Data expressed as mean ± SD (range), *data expressed as median (interquartile ranges)

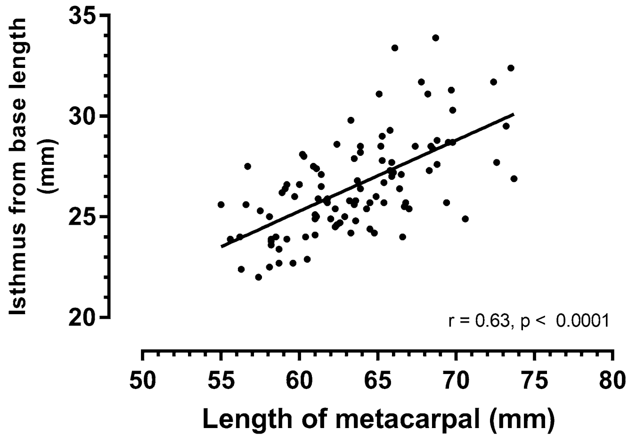


**Fig. 4** Relationship between the length of the metacarpal and distance to the isthmus from the base of the metacarpal

The relationship between the length of the metacarpal and the length from the isthmus from the base was characterised by the following formula: Distance from the base to isthmus = (length of the metacarpal * 0.532) + 4.137.

No other relationships were found between participant age and any of the anatomical wrist measurements.

## Discussion

Wrist arthroplasty is a treatment option for patients with advanced destruction of the carpus and radio-carpal joint, but the main complication is failure of fixation in the carpus. Defining the anatomy in detail and quantifying the anatomical variability is the first step to refining wrist arthroplasty designs and surgical techniques. Our study specifically focuses on the third metacarpal and the capitate as fixation points in currently available wrist arthroplasty devices [5, 10, 14, 17, 22]. The current study examined the detailed anatomy of third metacarpal and its relationship to the capitate in 100 participants.

A main finding of this study was that the length of the third metacarpal, the combined length of the third metacarpal and capitate, the metacarpal-capitate axis offset in the sagittal plane as well as the total cortical thickness in the proximal part were increased in the male participants (refer to Table 2). This is most likely explained by males generally having larger hands than females, and thus proportionally bigger metacarpals. This is in line with Schneider et al. [19] who performed a CT-based anatomical study of the first metacarpal using statistical shape modelling, and concluded that the only difference between men and women was the size of the metacarpal.

Although not significantly different, the distance of the base of metacarpal to isthmus also tended to be longer and the diameter of the proximal intra medullary canal in the coronal plane tended to be wider in the male participants. This also suggests that the male metacarpal is, in general, larger.

No gender or age-related variations were found in the sagittal metacarpal-capitate angle but it was interesting to note that the angles ranged widely from 20.1°, indicating a flexed (apex dorsal) position, to minus 6.2°, indicating an extended (apex volar) position relative to the capitate. Overall, 7% of participants had this extended (apex volar) arrangement. In the coronal plane also, although less pronounced, there was wide variability between 22.6° of ulnar deviation and minus 4.94°, indicating a radially deviated arrangement. Overall, 2% of the patients demonstrated this radially deviated metacarpal capitate axis. This has not, to our knowledge, been quantified before, and in the literature and surgical technique guides we studied, either generalisations regarding the alignment was made [10, 23], or only alluded to as a possible surgical pitfall [13].

The distribution of capitate morphology types corresponded very closely with the study conducted by Yazaki et al. [24] in which 107 cadaveric wrists were dissected to study the morphological variability of the capitate and lunate. They defined the three morphological types, and classified 69/107 (or 65%) as flat type, 23/107 (22%) as spherical type and 15/107 (14%) as *V-shaped*.

Another main finding of this study was the significant relationship between the total length of the third metacarpal and the distance to the isthmus from the base ($r = 0.625$, $p < 0.0001$). This finding indicates that the distance to the isthmus from the base can be predicted from the total length of the third metacarpal with a standard error of the estimate of 1.9 mm. This is of interest as a predictable anatomical landmark and potential fixation point for wrist arthroplasty devices.

The main limitation of this study is that the study population had anatomically normal wrists, none showed arthritic changes that needed surgical intervention. As both post traumatic and inflammatory wrist degeneration is known to alter the anatomy of the wrist [6, 7, 9, 20], a similar study protocol looking at patients with end-stage osteoarthritis might have more value.

Another limitation is that measurements were taken manually, at arbitrarily selected points, and a study using statistical shape modelling to compare the bony anatomy and its relationships would thus provide more insights into the variability of normal wrist anatomy.

In conclusion, this study shows that the anatomy of the third metacarpal varies considerably more than has been alluded to in current wrist arthroplasty literature. Our findings emphasise that consideration should be given to the carpal alignment in a specific patient and that implant design and surgical technique should be tailored. Although there are arguably several reasons for the poor success rates of wrist arthroplasty (75–90% cumulative survival at 5 years) observed globally [1], it is likely that the large variation in normal anatomy contributes significantly to this. A focus for future study may be whether different designs currently available might lead to better fixation in different morphological types of wrist. The application-orientated study of anatomical variation, made possible by modern imaging and computing techniques, will hopefully help solve the current issues in total wrist arthroplasty.

**Author contributions** RG Venter: Protocol and project development, Data collection, Data analysis, Manuscript writing and editing. MC Burger: Data analysis, Manuscript writing and editing. A Ikram: Protocol and project development, Data collection, Manuscript writing and editing. RP Lamberts: Protocol and project development, Data analysis, Manuscript writing and editing.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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