Reviewer’s report

Title: Measurement of three-dimensional morphological characteristics of the calcaneus using CT image post-processing

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Reviewer: David Gutekunst

Reviewer’s report:

1. Is the question posed by the authors new and well defined?

The authors present a novel and clinically relevant technique using computed tomography 3D to measure calcaneal geometry. This method has the potential to improve clinical outcomes by aiding surgical planning of calcaneal fractures and post-surgical assessment.

However, the specific questions answered by this research are not well-defined. Gender differences in calcaneal dimensions are a major focus of the manuscript, yet it is not clear why gender differences are clinically important. More importantly, even if gender differences are clinically important, the research design does not convince this reviewer that actual gender differences in calcaneal morphology exist, other than differences in overall bone size.

It seems to me that the most relevant issue to be addressed is the expected variability of the technique, quantified in the same units of the length, area, or angular measures. Clinical decision-making would be greatly aided by knowing the measurement precision of these measures, to provide an expected confidence interval at the level of the individual patient, rather than a group-based ICC.

2. Are the methods appropriate and well described, and are sufficient details provided to replicate the work?

As described in more detail in the main body of this review, more methodological information is needed for the following topics:

a) CT scanning parameters
b) Bone reconstruction and segmentation algorithms using the shaded-surface display (SSD) technique.
c) Area measures
d) Statistical analyses

3. Are the data sound and well controlled?

I have concerns about the quality of the bone reconstruction and segmentation process, both of which affect the accuracy of the anatomical landmarks used to define calcaneus morphological dimensions.
4. Does the manuscript adhere to the relevant standards for reporting and data deposition?

Yes.

5. Are the discussion and conclusions well balanced and adequately supported by the data?

The suggested revisions must be addressed before I can comment on how well the data support the discussion and conclusions.

6. Do the title and abstract accurately convey what has been found?

Yes.

7. Is the writing acceptable?

The writing is acceptable, though there are several minor errors in spelling and grammar.

• Major Compulsory Revisions (which the author must respond to before a decision on publication can be reached)

Overall comments:

1) Please explain why a gender comparison is necessary and important. Given the gender differences in overall body height, and likely also total foot length, it is completely unsurprising that there are gender differences in the length and area variables measured in this study. Only the gender differences in Bohler’s and Gissane’s angles seem genuinely intriguing for their possible clinical implications. Is a female foot just like a scaled-down version of a male foot? Or are there gender differences in relative morphology?

If a strong case can be made that gender differences are important for surgical decision-making or other clinical questions, then I would suggest normalizing the bone dimensions to body height, or to overall foot length. Alternatively, a statistical analysis of covariance (ANCOVA) could be run to test whether gender differences remain after accounting for body height or foot length.

2) Please add an explanation for using Mann-Whitney U tests.

Since the length and angle measurements are on the interval scale, and you present no evidence that they are non-parametric, it seems that a t-test is a simpler and more appropriate test for these data. If the data are not normally distributed, then other statistics (such as the Welch’s t-test) are applicable, and to my knowledge are preferable to the Mann-Whitney U test. Alternatively, if the authors choose to account for gender-related size differences using a statistical method, then an ANCOVA could be used instead.

3) To me, the most relevant question that can be addressed by your methods is
“What is the expected variability of the technique for an individual patient?” This requires the measurement precision to be quantified in the same units of the measure.

Thus, the ICC does not seem to be the most appropriate test for these data, at least not without the additional inclusion of a statistic such as the root mean square error (RMSE), root mean square standard deviation (RMS-SD), or the limits of agreement (LOA). The ICC is a group-based correlation, and the addition of RMSE, RMS-SD, or LOA would enhance clinical decision-making by providing an expected confidence interval around each measure at the level of the individual patient, rather than a group-based ICC.

Specific comments:
1) Abstract: please write out “computed tomography” before introducing the acronym CT. This should be done again in the main body of the manuscript (Background, page 3).
2) Background: in the purpose statement, there is no mention of the male versus female comparisons, which seems to be a major focus of the results and discussion.
3) Background: please state the hypotheses.
4) Methods, “Study Subjects” subsection: please state whether the volunteers provided their written informed consent.
5) Methods, “CT scans and image post-processing” subsection:
   a. Is the tube voltage of 120 kV the peak voltage (kVp)? If so, please note this and use the kVp designation.
   b. What was the current-time product (in units of mA*sec)? I am interested in this value because reduced current-time product increases noise.
   c. The matrix is given as 512 x 512, but it is also important to know the in-plane spatial resolution. For example, if the in-plane field of view was 400mm x 400mm, then the in-plane spatial resolution would be roughly 0.78mm x 0.78 mm.
   d. Please include more detail regarding reconstruction and bone segmentation. For example:
      i. What is the algorithm underlying the SSD reconstruction, and how does it distinguish between bone and non-bone material?
      ii. Does SSD rely on a density threshold? If so, was a bone calibration phantom included with each CT scan to ensure that the same threshold was used across patients?
      iii. How are the articular surfaces of bones defined? I am especially interested in this question, as I have serious concerns about the accuracy of the segmentation process, given what seems to be very poor segmentation of the anterior process shown in Figure 2C and 2D. It seems that the anterior process is only partially
segmented in Figure 2C, and missing most of its front half in Figure 2D. As a result, point C is definitely not in the same target location as in Figure 2A and 2B. This will have a major effect on the accuracy (and likely also the reliability) of Gislane’s angle, Bohler’s angle, and the LAP. Please comment and clarify.

6) Methods,” 3D measurements of calcaneal morphological parameters” subsection

a) I do not see how the CT measurement of Bohler’s angle or Gissane’s angle is truly a 3D measurement, or why it necessarily offers any improvement over X-ray. By defining 3 points for each angle (points A, B, and C for Gissane’s angle, and points A, C, and F for Bohler’s angle), all that you are doing is defining a new plane and measuring a 2D angle within this plane.

In X-ray, Gissane’s angle is essentially a sagittal plane angle along the lateral edge of the calcaneus. As I understand your methods, the only benefit from the CT-based 3D measurement compared to X-ray is if the calcaneus is off-axis with respect to the ideal orientation of the X-ray. Is there some other benefit?

b) Is point H the location of the perpendicular distance from point A to the calcaneal axis? Please clarify.

c) How were the areal measurements made? No description is given regarding APF and AMF. Did the operator draw the borders of these areas?

d) What effect, if any, does the spatial resolution of the SSD reconstruction have on the APF and AMF measures? In other words, if a coarser polygonal mesh is used, are the areal measures affected?

7) Results, second paragraph:

a) The authors state that morphological measurements were reliable and accurate. This does not seem correct. Certainly you have assessed reliability, but it does not seem that you have assessed accuracy. Please clarify.

b) The sentence stating “The average ICC of inter-observer reliability…” should be in the Methods.

c) The last sentence, beginning “The repeatability of measurement…” should be in the Discussion.

8) Discussion, first paragraph, page 10: in the sentence beginning “Sometimes, the standard anteroposterior, lateral…”, how do you know that CT will be better? Segmentation can be more difficult in the presence of inflammation following bone injury.

9) Discussion, second paragraph, page 10: please explain how calcaneal fractures lead to an increase in Gissane’s angle. Does the anterior process pitch down (plantarflex)? I am having a difficult time understanding this, since you later write that Bohler’s angle becomes smaller or even reversed in calcaneal fractures. If the Gissane’s angle increases as the anterior process plantarflexes, it seems that the Bohler’s angle would increase as well. Perhaps I misunderstand
the fracture pattern; regardless, a diagram or an X-ray of a typical fracture with the Gissane’s angle and Bohler’s angle identified would be very helpful.

10) Discussion, page 14, paragraph beginning “Several limitations…”: is the extra dose of radiation from a contralateral scan really a major concern? I can understand a desire to avoid additional cost, but a CT scan of the foot and ankle seems to pose extremely low risk due to radiation exposure, due both to the low radiation and the lack of absorption by susceptible organs.

11) Conclusions, page 15: the authors state that “The current data will be helpful for anatomic reduction of calcaneal fractures and calcaneal malunion.” I agree that these techniques have the potential to inform calcaneal surgeries, but I feel that the utility of your methods will be greatly enhanced if you report a measure of repeatability such as RMS-SD or LOA, and ideally use the (intact) contralateral calcaneus as a guide for surgical intervention.

• Minor Essential Revisions (such as missing labels on figures, or the wrong use of a term, which the author can be trusted to correct)

1) Background, second sentence: this sentence is unclear. Do calcaneal fractures of all types represent 60% of tarsal bone fractures, or is it specifically the intra-articular calcaneal fractures that represent 60% of tarsal bone fractures?
2) Background, page 5, in sentence beginning “Image analysis and processing…”, the word “technology” should be “technologies.”
3) Methods, page 8, in sentence beginning “Thirty-six subjects were randomly…”, the word “access” should be “assess”.

• Discretionary Revisions (which are recommendations for improvement but which the author can choose to ignore)

1) I am not convinced that all readers will consider the angular measurements to be 3D. This is in part a semantic issue, but many engineers and biomechanists consider 3D angles to be the series of rotations that describe the 3D angular relationships between two sets of 3D Cartesian coordinate axes. (Euler, Cardan, and helical axes 3D angular methods are the most common examples.) The angles presented in this manuscript are essentially 2D angles, as they connect three points and by definition any three points define a plane. It would be more accurate to say that the CT technique described in this manuscript corrects the orientation of the specific 2D plane in which the Gissane or Bohler angle is located.

2) Discussion, page 15, last paragraph. The authors state that “The width cannot be described clearly by two constant landmark points, for the calcaneus is an irregularly shaped bone.” I recognize the difficulty in locating anatomical landmarks on the calcaneus, but for future research have you considered using the distance between the sustentaculum tali and the peroneal (fibular) tubercle as a measure of calcaneal width? Alternatively, you could also locate the medial and lateral borders of the calcaneal tubercle. (These are meant only as
I would also caution you that if you try to measure the tibiocalcaneal angle, it is very important to standardize the posture of the foot and ankle in the CT scanner. Based on my own anecdotal experience, the tibiocalcaneal angle seems very much dependent on the talocrural joint angle.

**Level of interest:** An article of importance in its field

**Quality of written English:** Needs some language corrections before being published

**Statistical review:** Yes, but I do not feel adequately qualified to assess the statistics.

**Declaration of competing interests:**

I declare that I have no competing interests.