Evaluation of Automated Coverage and Distance Mapping Selections to Improve Reliability and Clinical Utility of 3D Weightbearing CT Assessments

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Introduction/Purpose: Progressive collapsing foot deformity (PCFD) is a complex three-dimensional (3D) deformity where adjacent structures may adopt subtle differences in positioning that result in increased contact or subluxation. Recent studies have highlighted the need for and utility of 3D analyses in PCFD using weightbearing CT (WBCT) and bone segmentation. Beyond the limitations of triplanar imaging, 3D distance and coverage mapping analyses have further highlighted key regional differences like sinus tarsi narrowing ahead of impingement and early middle facet uncoverage ahead of collapse. However, these analyses rely upon manual identification of subregions hindering the utility of 3D mapping clinically. The objective of this study was to compare an automated selection process with manual selections in the context of subtalar regional distance and coverage maps in PCFD.

Methods: In this IRB-approved retrospective study, WBCT data of 20 consecutive patients with flexible PCFD and 10 controls were analyzed. Subregions of the peritalar surface (middle and posterior facets of the calcaneus and talus; sinus tarsi area) were manually selected by two experts on manually generated bone surfaces of all 30 feet. An automated algorithm for selecting coverage area was applied to identify the same regions on the semi-automatically generated bones (Figure). A 3D distance mapping (DM) technique was used to create coverage maps (CMs) across the entire peritalar surface where areas with distances less than 4mm were defined as covered. DM and CM percentages were compared using intra-class correlations and t-tests between PCFD and control groups. The Sørensen–Dice index, or Dice coefficient, was used for comparisons of selections on the semi-automated surfaces to evaluate reproducibility of expert selections.

Results: The automated process produced identical selections resulting in perfect intra-method ICCs of 1.00 for all regions and Dice coefficients of 1.00. The average Dice coefficient for all manual selections was 0.903 (range: 0.865-0.935) indicating that observers were able to reliably select the same regions with 90% overlap. When assessing reliability of manual selections, intra-observer ICCs ranged from 0.41-0.92 while inter-observer ICCs ranged from 0.47-0.99 were found. Despite strong significant correlations, average coverage was significantly lower in the sinus tarsi region of the automated selections vs the manual selections (34.3+/-16.8% vs 23.1+/-12.7%, p<0.005). However, mean distances in each region were not significantly different in the middle facet or the sinus tarsi regions (p=0.323, p=0.095, respectively).

Conclusion: Understanding of the complex 3D deformities that constitute PCFD requires sensitive and reproducible measures. Fully automated 3D assessments of coverage and bone relations may have the potential to improve understanding of these deformities aiding in diagnosis, staging, and objective evaluation of treatment effects. Prior work with 3D coverage and distance maps specifically identified the middle facet and sinus tarsi regions as being of particular importance. Compared to manual selections, these regions were well identified by the automated process. This represents a step toward the goal of viable use of fully automated 3D coverage and distance mapping when evaluating PCFD patients.
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|                  | Percentage Coverage of Peritalar Regions | Average Distances in Peritalar Regions (mm) |
|------------------|-----------------------------------------|---------------------------------------------|
|                  | Automated Selection                      | Automated Selection                          |                                         |
|                  | Mean          | Standard Deviation | Mean          | Standard Deviation | P-Value | Mean          | Standard Deviation | P-Value |
| Middle Facet     | 58.7%         | 23.9%              | 68.9%         | 24.3%              | 0.106   | 1.65          | 0.74              | 0.44    |
| Posterior Facet  | 81.2%         | 5.8%               | 78.4%         | 11.1%              | 0.237   | 1.86          | 0.46              | 0.44    |
| Sinus Tarsi      | 34.3%         | 16.8%              | 23.1%         | 12.7%              | 0.005   | 3.09          | 0.70              | 0.45    |

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