Comparative assessment of midfoot osteoarthritis diagnostic sensitivity using weightbearing computed tomography vs weightbearing plain radiography

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ABSTRACT

Purpose: Accuracy in diagnosing osteoarthritis in the midfoot using weightbearing plain radiography (WBPR) remains questionable due to the overlapping osseous architecture present, occluding visualization. Weightbearing computed tomography (WBCT), providing clearer bony landmark identification and joint space visualization, can also be used for evaluation. The aim of this project is to perform a standardized retrospective intra-patient analysis identifying the discrepancy of midfoot osteoarthritis diagnosis and osteoarthritis severity grading between WBPR and WBCT.

Methods and materials: A cohort of 302 patient feet was acquired from an internal, consecutive patient database using detailed inclusion criteria. The musculoskeletal radiologist interpretation of the WBCT and WBPR of each specimen was then assessed for any direct diagnosis or mention of osteoarthritis signs in specific articulations of 3 midfoot joint groups (Chopart, “central”, and tarsometatarsal). WBPR sensitivity and specificity metrics were calculated with WBCT considered the gold standard for comparison.

Results: From the WBPR radiologist interpretation, we found diagnostic sensitivity of 72.5 \% and specificity of 87.9 \% for Chopart joints; 61.5 \% sensitivity, and 96.1 \% specificity for central joints; and 68.4 \% sensitivity, and 92.9 \% specificity for tarsometatarsal joints. The severity of degenerative changes was also consistently underestimated when interpreted from WBPR relative to WBCT.

Conclusions: In this series, midfoot osteoarthritis was often undetected on WBPR. WBCT imaging facilitates an earlier, more reliable diagnosis and grading of midfoot osteoarthritis relative to WBPR.

1. Introduction

Osteoarthritis (OA) of the midfoot has the potential to cause significant pain, disability, and decreased quality of life [1–4]. Although the most common etiology is posttraumatic degeneration, primary degeneration and inflammatory diseases can also result in osteoarthritis of these articulations [1,5]. By definition, the midfoot is considered to be the part of the foot between the tarsometatarsal (TMT) joints or

Abbreviations: WBPR, Weightbearing Plain Radiography; WBCT, Weightbearing Computed Tomography; OA, Osteoarthritis; TMT, Tarsometatarsal; CT, Computed Tomography; HIPAA, Health Insurance Portability and Accountability Act; EHR, Electronic Health Records; RI, Radiologist’s Interpretation; NWBCT, Non-Weightbearing Computed Tomography.

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“Lisfranc joint” distally and the transverse tarsal joints or “Chopart joint” proximally. Practically, osteoarthritis at the tarsometatarsal and Chopart joints is also considered to be subtypes of midfoot osteoarthritis [2].

Although many imaging modalities have been utilized, [6–8] weightbearing plain radiography (WBPR) has been widely accepted as the standard method to evaluate various conditions of foot and ankle pathology [9,10]. Weightbearing conditions are essential because changes, such as arthritic degeneration or abnormal structural alignment, may be obscured or underestimated when investigated under non-weightbearing conditions [2,11]. However, in the midfoot, observation of associated articulations and osseous borders may be affected due to the natural overlapping of adjacent bones viewed two-dimensionally with radiography [12,13]. Computed tomography (CT), with its advantages of clearer bony landmark identification and joint space visualization, may be able to solve this aforementioned shortcoming [11,12,14]. Additionally, utilizing CT under weightbearing conditions to reproduce physiologic positioning of the foot and lower extremity to perform an accurate assessment of the pathology increases its validity [11,15,16]. Weightbearing cone-beam computerized tomography (WBCT) has experienced increasing popularity for its capacity to depict the anatomical complexity of a weightbearing foot three-dimensionally [11,17,18]. Clinical utilization of this modality is also rising due to greater institutional availability than in the past, lower costs, and lower radiation exposure relative to conventional CT [19,20].

After the diagnosis of midfoot osteoarthritis has been established, nonsurgical management including intraarticular corticosteroid injections, anti-inflammatory medications, shoe modifications and/or orthotic inserts, and activity modifications are considered a mainstay of treatment, regardless of the specific symptomatic joint [1,4,21]. However, in patients with unresolving symptoms following conservative treatment, arthrodesis of the affected midfoot joint to restore functional plantigrade and pain relief should be considered. However, with the current use of WBPR, the planning and execution of this intervention can be challenging due to the complex structural anatomy, difficulty in identifying the specific joints to be fused, and the potential for unsuccessful fusions. Therefore, a reliable method of identification and grading of the potentially symptomatic joints is necessary for appropriate preoperative planning and achievement of a favorable outcome.

To the authors’ knowledge, there is currently no literature comparing the diagnostic reliability and grading of midfoot OA between WBPR and WBCT. The purpose of this study is to perform a standardized intra-patient analysis identifying the diagnostic sensitivity and specificity discrepancy of midfoot OA between the current standard, WBPR, and WBCT.

2. Methods and materials

2.1. Subjects

After an ethical and HIPAA (Health Insurance Portability and Accountability Act) compliance approval for this study was granted by our internal review board, a retrospective review of electronic health records (EHR) was performed to assess the reliability of WBCT midfoot OA diagnosis relative to WBPR imaging. EHR collected from a time period of 42 months, beginning with the advent of WBCT utilization in our department, June 2015, to the end of December 2018, were reviewed. In total, 761 consecutive WBCT images (pedCAT, CurveBeam LLC, Warrington, PA; medium view, 0.3-mm slice thickness, 0.3-mm slice interval, kVp 120, mAs 22.62) were collected and initially filtered for any duplicate cases present (e.g. same foot from the same patient; n = 30). However, right and left imaged feet from one patient were considered as individual cases. We excluded patients who did not have antero-posterior and lateral foot WBPR performed within 26 weeks (6 months) of the WBCT (n = 114). This limited timeframe between imaging was added to the inclusion criteria to avoid any injuries, surgeries, degeneration, or other events which could substantially change radiographic findings in the midfoot between both imaging studies. If these changes were present, the patients were subsequently omitted (n = 11). Our review was performed on the residual 606 cases.

2.2. Data acquisition and interpretation

A review included a standardized inspection of the radiologist’s interpretation (RI) associated with each case’s WBCT and WBPR images.

Each RI in this study was made by a board-certified radiologist or radiology resident physician that was then confirmed for accuracy and signed by a board-certified radiologist. The observer followed a predetermined list of OA qualifiers that, if mentioned in the RI, would define the case as positive for OA. This list included explicit mention of midfoot OA or any signs of the pathology including mild, moderate, or severe degeneration, joint space narrowing, osteophytic changes, spurring, cystic changes, or sclerosis. The studied articulations were also noted and placed into three groups. These joint groups were organized as follows: from proximal to distal, 1) Chopart, 2 joints: including the talonavicular joint and calcaneocuboid joint. 2) Central, 5 joints: including the medial, middle, and lateral naviculocuneiform joints, medial-middle intercuneiform joint, and middle-lateral intercuneiform joint. 3) Tarsometatarsal, 5 joints: including the tarsometatarsal joints 1st through 5th. A case was included if a single midfoot joint was interpreted as showing OA by a musculoskeletal radiologist. A foot with multiple OA joints were counted in each of the anatomic regions (e.g. a foot with talonavicular OA and 1st tarsometatarsal OA would be counted in both the Chopart and tarsometatarsal joint groups). Radiologist descriptors for stage of OA were standardized as follows: descriptions of “early”, “minimal” or “beginning” were classified as mild OA, “medium” or “average” were classified as moderate OA, and “advanced”, “end-stage”, “bone-on-bone” or “complete” were classified as severe OA. Identification of other isolated conditions such as coalitions, impingement, luxation, osteochondral lesions, and pseudoarticulations were not considered positive for OA. After completion of the review, 356 patient feet were identified as having some degree of osteoarthritis in at least one midfoot joint. Additionally, after this review, we excluded 54 cases with prior midfoot surgical interventions to have a clean cohort of 302 patient feet.

2.3. Statistical analysis

Metrics were calculated from the findings with respect to three emphases. 1) Midfoot OA or signs that were specifically mentioned and assigned to a joint in the WBCT RI but was not mentioned in the WBPR RI of the same case. 2) Midfoot OA that was specifically mentioned and assigned to a joint in the WBCT RI, but only general, non-specified midfoot OA was mentioned in the WBPR RI. 3) Midfoot OA that was reported as more severe in the WBCT RI when compared to the WBPR RI of the same case. These three metrics were assessed in all three studied joint groups (Chopart, central, and tarsometatarsal). The sensitivity and specificity of the WBPR RI, considering WBCT RI the gold standard, were subsequently calculated. The McNemar’s test and Mann-Whitney rank sum test were used for the comparison of binomial data and non-normally distributed data, respectively. All data were analyzed using IBM SPSS Statistics version 26.0 (IBM, Armonk, NY).

2.4. Results

A total of 302 feet (mean age, 56 ± 16 [range, 15–86] years; 160 males and 142 females; 140 left and 162 right) were reviewed in this study. A summary of osteoarthritis incidence and severity according to WBCT and WBPR is described in Table 1. In the Chopart, central and tarsometatarsal joint groups 244, 96, and 174 OA cases of differing severities were present, respectively, when evaluated via WBCT. Interestingly, of the same cases, only 177, 59, and 119 cases of OA in the
Table 1
Osteoarthritis prevalence and severity observed on weightbearing plain radiograph vs. weightbearing computed tomography in 302 feet.

<table>
<thead>
<tr>
<th>Joint Group</th>
<th>OA yes/no</th>
<th>OA severity none/mild/moderate/severe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WBPR</td>
<td>WBCT</td>
</tr>
<tr>
<td>Chopart</td>
<td>184/118</td>
<td>244/58</td>
</tr>
<tr>
<td>Central</td>
<td>67/235</td>
<td>96/206</td>
</tr>
<tr>
<td>Tarsometatarsal</td>
<td>129/173</td>
<td>174/128</td>
</tr>
</tbody>
</table>

OA, osteoarthritis.
WBCT, weightbearing computed tomography.
WBPR, weightbearing plain radiographs.
† using McNemar’s test.
‡ using Mann-Whitney rank sum test.

Chopart (Fig. 1), central (Fig. 2), and tarsometatarsal joint (Fig. 3) groups were identified by WBPR, with the difference consisting of false negatives and positives. The resultant sensitivity and specificity of WBPR is delineated in Table 2.

Describing these joint groups individually, the most proximal group (Chopart: talonavicular joint, calcaneocuboid joint) demonstrated a WBPR RI OA diagnostic sensitivity of 72.5 % and a specificity of 87.9 %, when considering WBCT RI as the gold standard. Of the 244 cases of Chopart OA identified in the WBCT RI, 177 were identified by the WBPR RI. Of this subgroup, 150 cases were specified to a certain articulation within the joint group in the RI, while 27 cases were general, non-specific reports of OA. Additionally, 17 cases of Chopart OA were assigned higher severities in the WBCT RI relative to the WBPR RI. (e.g. WBCT: severe, WBPR: moderate, or mild). A summary of the agreement for this joint group of these two imaging modalities is delineated in Table 3.

The central joint group (medial, middle, and lateral naviculocuneiform joints, medial-middle intercuneiform joint, and middle-lateral intercuneiform joint) was also evaluated (Table 4). Among these articulations, there were 96 total cases of OA identified in the WBCT RI. Of this sum, 59 were also identified in the WBPR RI, 44 specified and 15 non-specific cases. The central joint group reported the lowest WBPR RI diagnostic sensitivity relative to the other two joint groups at 61.5 %, however, it demonstrated the highest specificity of the joint group cohort at 96.1 %. Furthermore, 7 cases of OA in the central joint group were graded as more severe in the WBCT RI when compared to the WBPR RI (Table 4).

Data for the tarsometatarsal joint group was also calculated (Table 5). The total cases of OA identified in the WBCT RI was 174. Of these cases, 119 were also identified on the WBPR RI, 99 cases were specified to one or more of the 5 tarsometatarsal joints and 20 cases were general, non-specific reports of OA. This data culminates in a WBPR RI sensitivity of 68.4 % and a specificity of 92.9 %. Finally, there were 15 cases of tarsometatarsal OA with downgraded severity in the WBPR RI relative to the WBCT RI. Proportionally, this was the largest discrepancy among the three joint groups studied (Table 5).

2.5. Discussion

An accurate diagnosis and severity grading of osteoarthritic joints within the midfoot has been shown to be clinically relevant in treating the pathology early in its course and avoiding invasive end stage procedures such as arthrodesis. Moreover, in cases where conservative treatment has failed, and surgical intervention is indicated, a correct diagnosis is crucial for appropriate preoperative planning and favorable outcomes. Pertinently, our results demonstrate that 1) WBPR demonstrates a sensitivity and specificity range of identifying midfoot OA of 61.5 % – 72.5 % and 87.9 % – 96.1 %, respectively. This is due to the natural oblique orientations of the joints in this region of the foot, unavoidably obscuring degenerative joints and preventing visualization with WBPR. 2) WBPR allows poorer localization of degenerative midfoot joints relative to WBCT, especially within the central joint group. 3) The severity of degenerative changes evaluated by WBPR was consistently found to be underestimated when compared to WBCT grading. 4) WBPR demonstrated a considerably higher specificity, relative to sensitivity, in identifying midfoot OA. This suggests that if a WBPR is read positive, there is strong evidence that the patient does indeed have degeneration, however, the reported severity and localization may still remain questionable. 5) Many of the discrepant cases of OA identified between the two imaging modalities were mild to moderate in severity. Therefore, an early detection of this degeneration, enabled by WBCT, may allow earlier intervention.

Many factors may be responsible for this observed discrepancy in the RI between WBCT and WBPR. With regards to accurately evaluating this pathology in a highly complex, three-dimensional midfoot structure, substantial limitations can be inevitable. As described by our radiology department and others in literature, visualization of many joint spaces is unable to be obtained from a two-dimensional WBPR view due to the

Fig. 1. Right foot of a 62-year-old female with calcaneocuboid osteoarthritis (OA). A: Weightbearing computed tomography (WBCT) in the sagittal plane showing prominent dorsal spurting with concomitant subchondral cystic changes of the calcaneus and cuboid bones consistent with focal severe osteoarthritis of the dorsal articulation. B: Weightbearing plain radiograph lateral view showing an occluded view of the dorsal aspect of the calcaneocuboid joint without appreciable osteoarthritis. The degenerative changes seen on WBCT are more difficult to appreciate on radiograph due to the talus and navicular bone obscuring the region of interest.
layering of bones that comprise the midfoot (Fig. 3) [2,22]. Additionally, throughout the field of radiology, many radiographs are ordered without an indication or suspected diagnosis, therefore, the interpreting radiologist is not given any clues to what the pathology may be and does not scrutinize any specific area, rather, they give a general reading of the entire image. Conversely, in the foot, WBCT studies are only ordered for specific purposes at our institution and typically do possess a well described indication when ordered. In the case of this study, the included WBCT images were ordered to assess OA. This allows the radiologist to have a prompted three-dimensional visualization of the suspected pathology, allowing a detailed assessment of the scan. This clinical discrepancy in patient information may be reduced by improved communication between the ordering physician and radiologist before the scan is read. Lastly, a difference in skill of the interpreting radiologist may be of concern. The experience and fellowship status of the various radiologists who read the included scans were not noted or controlled for and could have contributed to the observed discrepancy [23].

Although there is not a strong correlation noted in literature comparing the localization of patient symptoms with associated abnormalities detected through diagnostic imaging, we believe that adequate and accurate information about patient’s symptoms and detail from a thorough physical examination could help detect the structure or area of concern in a patient’s foot prior to any sort of imaging. These interventions to detect a problematic area that is then communicated to the medical team, including the interpreting radiologist, before scans are acquired and read may help minimize this discrepancy of OA diagnosis among imaging modalities.

Cone-beam technology is a relatively new imaging tool, described initially in 1998 [11]. Since its advent in the dental field, the modality has found high relevance and applicability in orthopedic foot and ankle surgery [11,17,18]. The first weightbearing cone beam computed
tomographic modality was introduced in 2013 [24]. Since this inception, WBCT has been extensively investigated in literature and has gained increasing accessibility among institutions due to decreasing costs, dramatic reduction in radiation exposure relative to normal CT, and high clinical practicality in providing visualization of degradation, malalignment, and postoperative healing processes [11]. Utilization of this imaging modality in clinical practice is becoming more available with time, allowing studies, such as the current investigation, to have increasing applicability to ordering physicians who do have access to WBCT and WBPR imaging facilities in their clinic [11].

WBCT has also been found to illustrate significantly different and more accurate results than traditional non-weightbearing computed tomography (NWBCT) when assessing specific parameters within the foot [25,26]. In an investigation of non-pathologic feet, Hirschmann et al. studied the independent assessment of the same feet imaged under WBCT and NWBCT conditions by two musculoskeletal radiologists. Of the seven measurements evaluated in each foot of the study, five were found to be graded significantly different among the two observers [25]. Further, de Cesar et al. conducted a similar study of patients with a substantial flatfoot deformity and found that WBCT imaging better demonstrated the severity of deformation in the medial cuneiform-to-floor distance and forefoot arch angle when compared to NWBCT conditions [26]. While other studies do exist that measure foot and ankle alignment using WBCT vs. NWBCT or WBPR [27–32], to the authors’ knowledge, no studies exist in current literature comparing the sensitivity and specificity of NWBCT and WBCT performance in midfoot OA. Recently, Willey et al. used WBCT to demonstrate significant postoperative ankle joint-space narrowing in patients who underwent surgical treatment for a tibial pilon fracture [33].

Although we do feel that the results illuminated in this study will assist surgeons and radiologists to better understand the benefits of WBCT in the context of midfoot OA, there were some limitations associated with this project. First, as this was a retrospective study reliant upon the documented interpretation of many radiologists and radiology
resident physicians, there is inherent bias present as the training, skill level, and interpretive technique of each reader was unique from the other, resulting in a non-standardized evaluation of each foot. The next, and arguably largest, limitation of this study is that many of the degenerative joints that were not detected in the WBPR RI were mild cases of OA that may or may not have been symptomatic and needed treatment, this may have over-estimated the diagnostic discrepancy among modalities of clinically relevant cases. A possible solution to this discrepancy, which is another limitation to our study, would be the addition of functional and patient-reported scores associated with each individual case. These metrics would allow the authors to conclude with the same confidence that WBCT is diagnostically and clinically superior.

2.6. Conclusion

After assessing 244 Chopart, 96 central, and 174 tarsometatarsal cases of midfoot OA, a significant discrepancy has been observed in the diagnostic abilities of the two imaging modalities studied. In this series, WBPR, even when read by musculoskeletal radiologists, were associated with a large number of false negatives, and a notable amount of false positives. This study supports the notion that WBCT imaging should allow radiologists to make a more accurate and reliable diagnosis and grading of OA relative to WBPR.

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CRediT authorship contribution statement

Jesse Steadman: Conceptualization, Methodology, Validation, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. Yantarat Sripinanch: Conceptualization, Methodology, Validation, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. Chamnann Rungprai: Resources, Writing - original draft, Supervision. Megan K. Mills: Investigation, Resources, Writing - original draft. Charles L. Saltzman: Validation, Resources, Writing - original draft, Supervision, Project administration. Alexej Barg: Conceptualization, Data curation, Methodology, Project administration, Supervision, Writing - review & editing.

Declaration of Competing Interest

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References


