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REVIEW ARTICLE

# CT in osteoarthritis: its clinical role and recent advances

**Takeshi Fukuda**[1] · **Takenori Yonenaga**[1] · **Teruyuki Miyasaka**[2] · **Tadashi Kimura**[2] · **Masahiro Jinzaki**[3] · **Hiroya Ojiri**[1]

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**Abstract**

Computed tomography (CT) is a widely available imaging method and considered as one of the most reliable techniques in bone assessment. Although CT has limited tissue contrast and needs radiation exposure, it has several advantages like fast scanning time and high spatial resolution. In this regard, CT has unique roles in osteoarthritis (OA) and its variable utilities have been reported. Hence, this review highlights the clinical role of CT in OA of representative joints. In addition, CT showed the several technical advancements recently, for example, acquiring the CT image with standing, obtaining the dual-energy data, and novel photon-counting detector development. Therefore, the recent studies and potential utility of these new CT systems in OA are also discussed.

**Keywords** Computed tomography · Osteoarthritis · Dual-energy CT · Photon-counting CT · Weight bearing CT

## Introduction

Computed tomography (CT) is good for depicting mineralized tissue relevant to osteoarthritis (OA), such as calcified cartilage, subchondral bone plate, and trabecular bone [1]. Because radiographs were historically used to assess OA, the evaluation of bone became a key focus in the diagnosis, evaluation of progression, and measurement of outcomes of OA. CT allows three-dimensional (3D) assessment without the superimposition shortcomings inherent to radiography. Three-dimensional assessment also compensates for another problem with radiographs: variability in the positioning of joints affects the reproducibility of semi-quantitative assessments made on them and may cause false-positive or false-negative results [2, 3].

Therefore, this article reviews the clinical role of conventional CT in representative joints and recent advances in CT relevant to its use in OA clinics.

## Utility of CT in OA of the knee

CT has frequently been used to evaluate structural changes associated with bones in OA. These structural changes include osteophytes, subchondral cysts, and subchondral bone sclerosis. Changes in the joint space between bones can also be regarded as structural change. The detectability of these structural changes on CT surpasses that of other imaging tools such as radiograph and magnetic resonance imaging (MRI) [4], and CT is therefore recommended if there is a need for structural change analysis in OA [5]. However, the relationship between structural changes and pain remains unclear because up to half of patients with structural changes consistent with OA can be asymptomatic [6]. Despite this, many studies that used CT to assess OA

**Highlights**

CT is the best imaging modality for structural change evaluation in osteoarthritis. The three-dimensional analysis enables precise assessment of these changes in even anatomically complex joints.
CT has unique roles in OA research such as estimating the bone mineral density in subchondral area and semi-quantitative analysis of OA with the grading system.
Recent technical advances in CT, such as dual-energy CT, scanning with standing position, and photon-counting detector, may bring about new insight on OA in next decade.

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✉ Takeshi Fukuda
takenet616@gmail.com

[1] Department of Radiology, The Jikei University School of Medicine, 3-25-8 Nishi-Shimbashi, Minato-Ku, Tokyo, Japan

[2] Department of Orthopedic Surgery, The Jikei University School of Medicine, 3-25-8 Nishi-Shimbashi, Minato-Ku, Tokyo, Japan

[3] Department of Radiology, Keio University School of Medicine, 35 Shinanomachi, Shinjuku-Ku, Tokyo, Japan

demonstrated associations between various pathophysiology and structural changes in the knee joint, as outlined in the remainder of this section.

It is reported that bone mineral density (BMD) may change in relation to cartilage degeneration [7]. Subchondral bone sclerosis is considered to be the result of new bone deposits on existing trabeculae, compressed trabeculae, and callus formation due to microfracture [8]. One study compared the trabeculae of the subchondral medial tibial condyle between patients with OA and control age-matched cadavers [9] and found a higher bone volume fraction in the patients with OA. At the same time, the trabeculae in the patients with OA were fewer and more widely spaced but thicker than in the control specimens. These characteristic subchondral bone alterations in OA can even be observed on conventional CT (Fig. 1). Measuring the BMD of the subchondral area has been widely used to quantify changes in subchondral bone. The most commonly used method for this analysis is dual-energy X-ray absorptiometry (DXA), but the ability to precisely measure the BMD of subchondral bone on DXA is limited by insufficient spatial resolution for 3D curved structures. In addition, the presence of osteophytes may alter the correct measurement of BMD with DXA. In comparison, CT enables 3D assessment with sufficient spatial resolution and can facilitate BMD assessment in the subchondral area. When Omoumi et al. used CT to compare subchondral BMD between medial and lateral compartments of the knee, significantly higher BMD was found in the medial compartment in both OA and non-OA knees [10]. They also found that the medial-to-lateral subchondral BMD ratio was significantly higher in medial femorotibial OA than in healthy knees. Hence, CT is a promising tool for measurement of the BMD of subchondral bone, and it may help us to understand the role of subchondral bone in knee OA.

CT is also good for assessing subchondral cysts. Small subchondral cysts can be challenging to detect on radiographs because local osteopenia produced by small subchondral cysts is usually insufficient to alter local attenuation on radiographs (Fig. 2). However, CT allows detection of subchondral cysts comparable with that on MRI [11]. One CT study suggested that the number and volume of subchondral cysts were related to BMD in the medial and lateral tibia of knees with OA [12], although in late-stage OA, no association was found between the number or volume of the subchondral cysts and pain. This may suggest that other bone-related findings are more likely to be related to the source of pain.

Osteophytes, which are reported to be the most common OA-related abnormality among MRI confirmed OA patients, are also well delineated by CT [13]. Osteophytes can be classified into marginal, central, periosteal, and capsular types according to their appearance and location [14], but they can be easily overlapped by adjacent bony structures on radiographs. A study on knee OA showed that CT could detect more osteophytes than radiographs [11] and that the posterior femoral condyle was the prominent or only site for osteophytes in knee OA. Small osteophytes at this site are usually missed on radiographs, whereas CT allows easy detection of them (Fig. 3).

Lastly, the joint space width (JSW) can also be assessed on CT, but nowadays, CT with standing position like weight-bearing CT (WBCT) is believed to be more useful than conventional CT for this purpose. Hence, we discuss this topic in the later section.

## Utility of CT for depicting crystal deposition in the knee

Chondrocalcinosis is the presence of calcification in the cartilage or other soft tissue of a joint. Chondrocalcinosis is a common finding in elderly patients, being present in up to 44% of patients older than 84 years of age [15]. The two main crystal types are calcium pyrophosphate (CPP) and

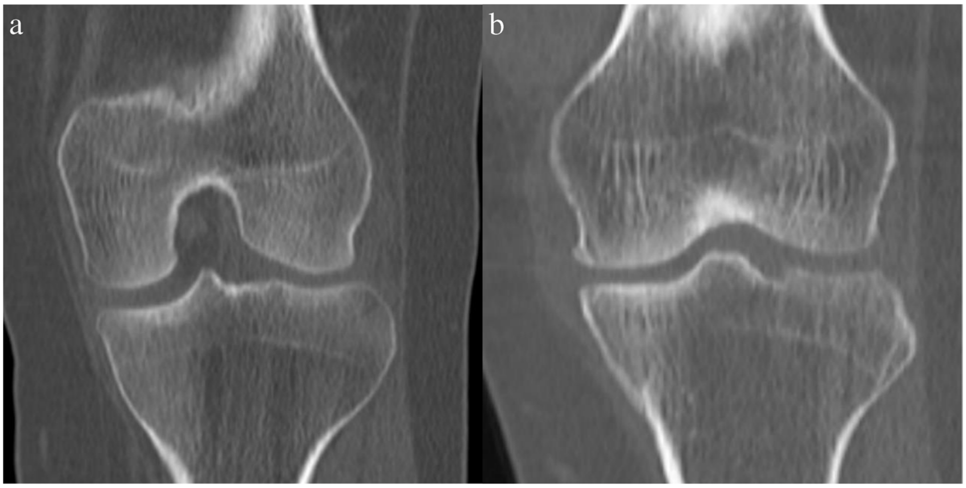

**Fig. 1** CT of the left knee **a** without OA and **b** with mild OA. Fine trabecular pattern in subchondral area is altered in OA patient. Trabecular bone is thicker and has wider space than healthy bone

**Fig. 2** 72-year-old female with mild knee OA. Compared with **a** radiograph, **b** CT can delineate tiny subchondral cysts in the medial tibial condyle (arrow), which is confirmed with **c** fat-saturated proton density-weighted MR imaging

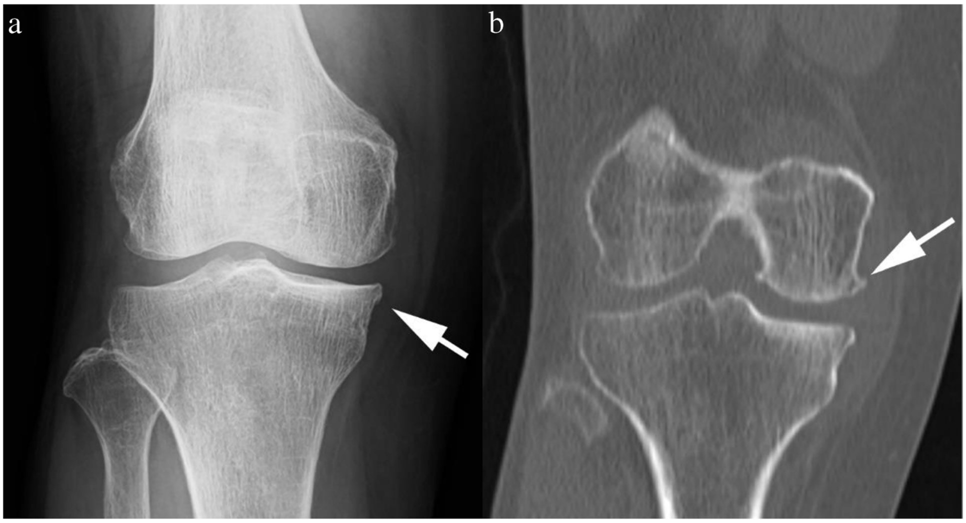

**Fig. 3** 85-year-old female with mild knee OA. **a** Radiograph showed the mild joint space narrowing in the medial tibiofemoral joint and osteophyte at the medial tibial condyle (arrow). **b** CT showed the small osteophytes at the posterior femoral condyle which are missed on radiograph (arrow)

basic calcium apatite (BCP). CT is excellent for visualizing calcification and, compared with radiographs, allows much better detection of intra-articular calcium crystal deposition in the knee joint [16] (Fig. 4). Therefore, CT is

**Fig. 4** CT of 70-year-old female with knee OA. CT showed calcification in the lateral meniscus and extruded medial meniscus which are consistent with chondrocalcinosis (arrows)

pivotal for investigating and researching the relationship between crystal deposition disease and OA.

Although it remains unclear whether crystal deposition is the cause or result of OA, one meta-analysis suggested a strong association between chondrocalcinosis and knee OA [17]. Another study reported that chondrocalcinosis in knee joints was associated with increased degeneration of cartilage and meniscus over 4 years [18]. This study also noted that a higher number of calcium depositions were associated with increased cartilage loss. Hence, there is growing evidence of the association between crystal deposition and OA in the knee, but in hand and hip joints, former mentioned meta-analysis did not find an evident association between chondrocalcinosis and OA [17].

## CT-based navigation systems for total knee arthroplasty

Currently, CT is of critical importance in the surgical planning for total knee arthroplasty (TKA). The accurate implantation of components is an essential factor for long-term prosthesis survival [19, 20]. Using CT images from the femoral head to the ankle, navigation systems can automatically provide a bone resection and implant positioning plan for neutral leg alignment (Fig. 5). After setting the reference frame, femoral and tibial cutting blocks are oriented under real-time visualization on the system display during the operation. In a meta-analysis that included 3437 TKAs, significantly more patients attained an axis of ± 3° varus or valgus alignment (which is usually said to be the optimal range to prevent worse functional outcomes and implant failure) in the computer-assisted surgery group than in the conventional surgery group [20]. However, it is also stated that correct segmentation on the navigation system may be difficult in severely varus knees with large osteophytes, and the generally documented system efficacy may not be applicable in such cases [21].

## Utility of CT in hip OA

The inferoposterior or posterolateral hip joint is frequently involved in OA, and it can be difficult to precisely evaluate these on anteroposterior radiographs. Therefore, CT has an important role in confirming the diagnosis of hip OA [22]. Because the abductor muscle of the hip is considered a primary stabilizer of the hip joint, the relationship between the abductor muscle and the pathophysiology of the hip joint is a topic of research [23–25]. CT was used to evaluate the relationship between the quality of the gluteus medium and unilateral hip OA [25]. They found that hip abductor strength is essential for normal hip function, with the results revealing a significant correlation between muscle quality and abductor strength. It is also said that atrophy of the gluteus medius of the OA side may cause an increased load on the contralateral side, which creates a risk for the development of contralateral side OA [26].

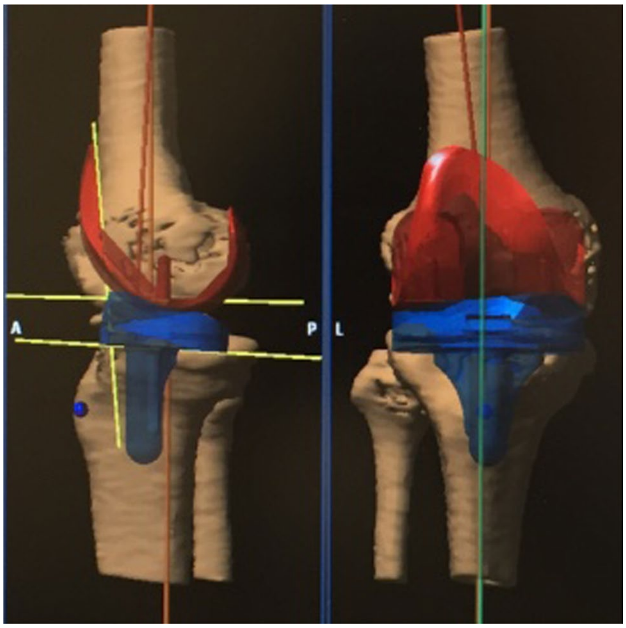

**Fig. 5** Representative image of TKA planning with navigation system. The planning for implant positioning (red for femoral and blue for tibial implant) is displayed on a volume rendering image

Turmezai et al. described a CT grading system for hip OA [27] that can be scored by referring to the severity mapping score sheets previously created [22]. The CT composite score is calculated by summating three individual scores for osteophytes, subchondral cysts, and JSW. The authors reported that the score was reliable, showing substantial intra- and inter-observer reliability (weighted kappa values of 0.74 and 0.75, respectively).

## Utility of CT in ankle OA

The ankle joint has several bony superimpositions that make it challenging to assess important landmarks on radiographs. Hence, CT has advantages for precise assessment of structural changes in the ankle OA. CT was reported to provide superior assessment of the articular surface of ankle joints than radiograph, especially subtalar joints [28]. Additionally, in comparison with radiographs, CT allows for more precise assessment of tibiofibular syndesmosis.

Cohen et al. suggested a CT grading system for ankle OA based on the Kellgren-Lawrence (KL) OA scale for the knee [29]. The intra-class correlation coefficient (ICC) for nine readers was 0.851 (95% confidence interval [CI] 0.716–0.948), representing excellent inter-observer agreement. In addition, the intra-observer agreement was very high, with ICCs between 0.962 and 1.0. The authors recommended using three true orthogonal images for reliable grading, but it is easy to reconstruct these three planes on CT without incurring image deterioration.

## Utility of CT in facet joint OA

CT can delineate structural changes in facet joint OA, such as osteophytes, hypertrophy of articular processes, and the vacuum phenomenon (Fig. 6). CT showed better inter-observer agreement than MRI in the assessment of facet joint OA. The inter-observer agreement of CT for grading the facet joint OA using a method developed by Weishaupt et al. was reported to be between 0.59 and 0.94 [30–32]. A community-based population study revealed that the prevalence of facet joint OA increases with age, with L4-L5 showing the highest prevalence level [33]. Another CT study showed that facet joint OA is significantly associated with low-density multifidus and erector spinae muscles (Fig. 6b), which may be comparable with the association between knee OA and degeneration in the adjoined quadriceps muscle [30]. However, no significant relationship was found between facet joint OA detected by CT and low back pain.

## Utility of CT in sacroiliac joint OA

The sacroiliac (SI) joint, one of the largest axial joints in the body, can be the cause of low back pain. It is said that 10–30% of low back pain is originated from the SI joint [34, 35]. In addition to the anatomical complexity of the SI joint, its obliquity makes it challenging to be reliably evaluated on the radiograph. This fact is well reported with sacroiliitis of spondylarthritis. The studies on grading sacroiliitis suggested that CT showed more reliable results than radiographs [36, 37].

**Fig. 6** 74-year-old female with facet joint OA at the level of L4/5. **a** CT with bone window showed the left-sided dominant facet joint OA with delineating osteophyte, subchondral sclerosis, and subchondral cysts. **b** Soft tissue window allows to show fatty atrophy of the erector spinae muscles, which is exaggerated on the left side. **c** T2WI of MRI at the same level with CT showed high intensity in the left facet joint, which reflect joint fluid (arrow). However, structural changes are not as clearly delineated as CT

SI joint OA is characterized by joint space narrowing, osteophytes, subchondral sclerosis, subchondral cysts, and vacuum phenomena. These changes are common in adults, and one CT study showed that SI joint degeneration could be found equally between symptomatic and asymptomatic populations [38]. Vacuum phenomena are well depicted on CT. It is said that SI joint OA and hip joint OA have significantly related, and the volume of vacuum phenomena in the SI joint was reported as one of the SI joint findings which had a significant relationship with hip OA severity [39].

## Development of semi-quantitative assessment of OA with whole-body CT

OA commonly involves multiple joints, and a recent study developed the osteoarthritis computed tomography (OACT) score, which can score a patient's structural OA burden of multiple large joints and the spine [40]. CT is an ideal method for the simultaneous assessment of structural changes in multiple joints. Evaluation of the OA severity of multiple joints may help provide accurate outcome measures in future OA research. The system scores each joint with four grades based on the previously described CT scoring system or a newly developed scoring system. The newly developed system was created by referring to the existing standard radiograph scoring system. The grading system was simplified so that readers can complete the entire evaluation within 15 min. An initial study showed high inter- and intra-observer reliability for the total OA grade, with ICCs of 0.95 and 0.97, respectively [40].

## CT arthrography (CTA)

The use of a contrast medium can be beneficial for delineating cartilage injury and meniscal injury [41]. CTA showed reliable results in the assessment of cartilage. In the knee, the diagnostic performance of CTA for cartilage injury (except for grade 1 cartilage injury showing surface blistering or fibrillation) was comparable with that of MRI [42, 43].

Omoumi et al. used CTA to investigate the correlation between subchondral BMD and cartilage thickness [44]. Their results showed a positive correlation between subchondral BMD and cartilage thickness in non-OA knees, but a negative correlation in OA knees. They suggested this fact may support the theory that subchondral bone and cartilage interact as a functional unit and that this homeostatic relationship might be disrupted in OA patients.

However, because CTA requires an invasive procedure, it has not been included in large cohort studies of OA [45].

## Disadvantages of CT

There are several disadvantages of CT, such as radiation exposure, high cost, and poor tissue contrast. The radiation dose is significantly higher than the radiograph, but recent scanners have improved in optimizing the radiation dose with maintaining the image quality. Recently, although low-dose CT (LD-CT) with half tube current was reported to show higher image noise than standard dose image, there was no statistical difference in image quality for diagnostic acceptability of peripheral extremities like the wrist [46]. In the spine, it is reported that iterative reconstruction enables to reduce radiation dose by 52%, with decreasing image noise by 31% compared with filtered back projection [47]. In patients with body mass index less than 25 kg/m$^2$, ultra-low-dose CT (ULD-CT) with 30 mAs showed no statistical difference in the diagnostic performance of lumber spine, including facet joint OA, compared with LD-CT with 150 mAs [48]. However, the radiation dose was 60–68% lower in ULD-CT than in LD-CT.

Relatively poor tissue contrast is another disadvantage of CT. The ability to delineate structures essential for assessing the development and progression of OA, such as cartilage, ligaments, and menisci, can be rather limited. As discussed in the following section, this may be partly compensated with new technologies such as dual-energy CT or photon-counting CT.

## Recent advances in CT

### Dual-energy CT (DECT)

Dual-energy CT (DECT) is now becoming a widely available technique and may have an additional role over conventional CT in the evaluation of OA.

First, it can delineate bone marrow edema (BME), which had been only visualized by MRI (Fig. 7). BME is reported to have association with pain in OA [49, 50]. Many DECT studies related to BME have focused on traumatic BME, and a meta-analysis on the appendicular skeleton revealed DECT to have sensitivity and specificity for detecting BME of 0.86 and 0.93, respectively [51], while a meta-analysis on vertebral fracture studies found sensitivity and specificity of 0.89 and 0.96, respectively [52]. However, there is a lack of DECT studies focusing on the detection of BME in OA joints.

Second, DECT can characterize the crystals, especially monosodium urate crystals, that are deposited in and around joints [53] (Fig. 8). A meta-analysis of the diagnostic accuracy for gout in joint-based evaluations showed DECT to have a sensitivity of 0.83 and specificity of 0.88 [54]. However, it should be noted that the performance was low

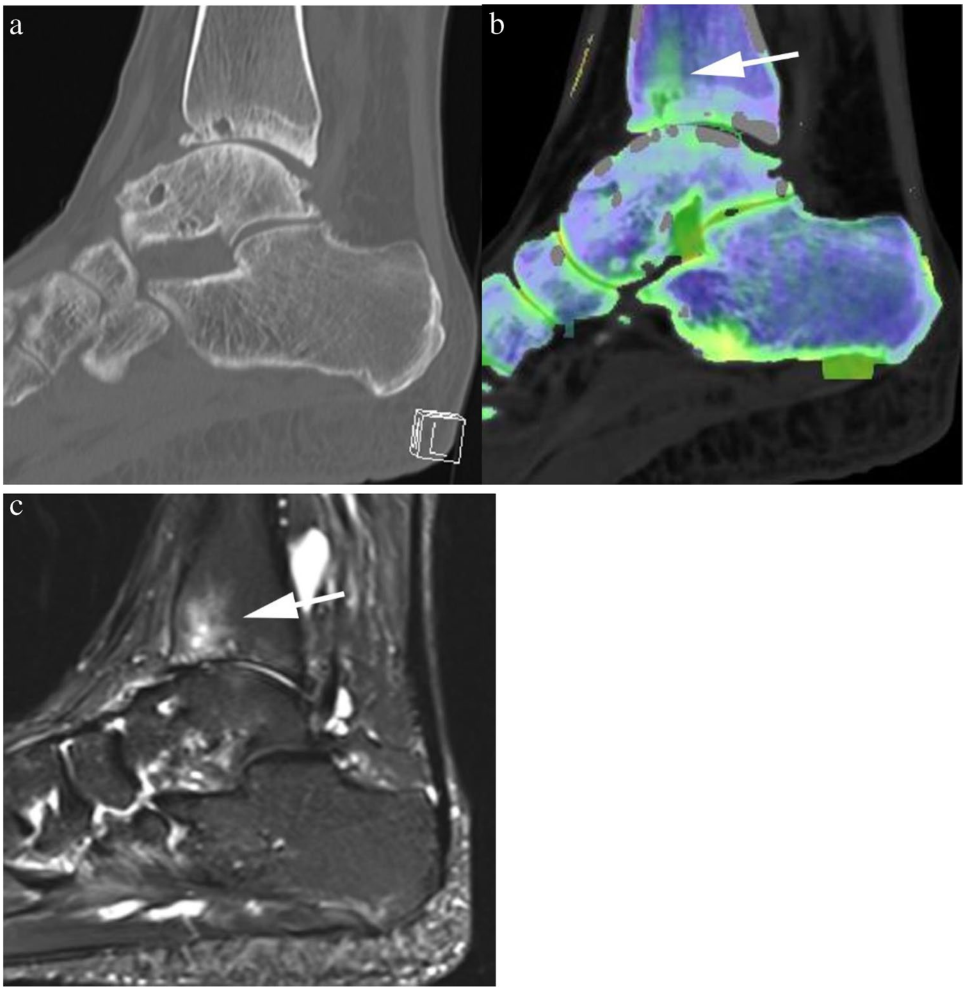

**Fig. 7** 48-year-old female with ankle OA. **a** Conventional CT showed the severe joint space narrowing in ankle joint. Subchondral cyst, osteophytes, and subchondral sclerosis were also detected. **b** DECT delineated the bone marrow edema (BME) at the tibial subarticular area (arrow). c BME at the same area is confirmed on STIR MR imaging (arrow)

(with sensitivity of 0.55 and specificity of 0.89) for early gout, defined as that equal to or less than 6 weeks from onset. An initial study showed the potential utility of DECT for discriminating meniscal CPP deposition and calcium hydroxyapatite in subchondral and trabecular bone in the knee [55]. However, a recent paper pointed out that a particular crystal concentration is required to create a DECT-relevant attenuation difference for CPP characterization [56]. Hence, DECT may be of limited value for diagnosing early CPP deposition before chondrocalcinosis occurs, which is detectable on conventional CT.

## Photon-counting CT (PCCT)

The development of the photon-counting detector (PCD) may revolutionize the value of CT in medical clinics. Whereas an energy-integrating detector needs a layer that converts X-rays into visible light to generate an electric signal, PCDs do not require a separate layer to convert photons to visible light. Instead, the PCD can directly convert individual photons into an electric signal. PCDs can sort the incoming photons into several energy bins depending on their energy and count and measure the photons according to their energy. Hence, effective noise reduction can be achieved by eliminating pulses below preset thresholds. Because the contribution of low- and high-energy X-rays to the image contrast is equally weighted in PCCT, it can provide better soft tissue contrast than conventional CT. These technological advantages enable better signal-to-noise and contrast-to-noise images than conventional CT. Due to the substantial improvement in image quality, PCCT can reduce radiation exposure by approximately 30–60%, depending on the imaging task [57].

There are only a small number of studies on the application of PCCT to musculoskeletal areas. In one study, seven cadaveric knees were scanned using a prototype system to investigate its ability to evaluate cartilage [58]. It was found that virtual monoenergetic images at 60 keV and 70 keV provided sufficient soft tissue contrast to characterize abnormal cartilage morphology. In comparison with conventional images, a 45% reduction in noise and 75% increase in the contrast-to-noise ratio were achieved with a monoenergetic PCCT image at 60 keV.

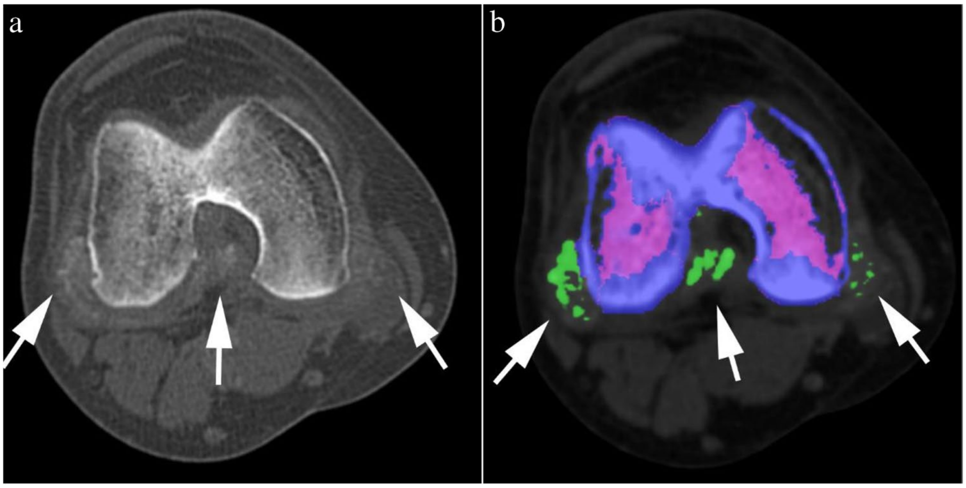

**Fig. 8** Right knee of 46-year-old male with gout. **a** Conventional CT showed the non-specific calcification around the femoral condyle (arrows). **b** DECT delineated the substance as green-colored structures which means MSU deposition (arrows)

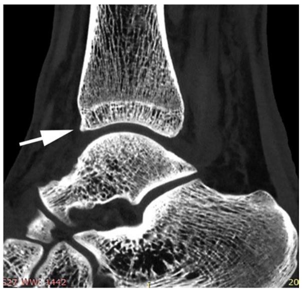

**Fig. 9** High-resolution image of right ankle taken by photon-counting CT (PCCT). PCCT can clearly visualize fine trabecular structures. There is a small osteophyte at the anterior tibial border (arrow)

Another advantage of PCCT is the ability to obtain a high spatial resolution image with a 0.2-mm slice thickness (Fig. 9). A recent study using the first commercially available PCCT compared the quality of images of tiny mouse bones with conventional CT [59]. The authors showed that both the subjective and objective image quality of PCCT visualizations of the cervical spines of mice were superior to those on conventional CT. When the latest kernel (Hr98; available only for PCCT) was used, each tiny cervical vertebra of the mice could be well separately delineated. These results were mirrored with cadaveric human wrists in another study [60], and high-resolution PCCT image can better delineate the fine trabecular structure of cadaveric wrist than standard resolution PCCT or conventional CT images.

PCCT surpasses the performance of conventional CT in multiple aspects, and future research on OA with this novel CT system may add the clinical utility of CT and contribute to understanding the pathophysiology of OA.

## CT with standing position (weight bearing CT and upright CT)

Assessment of the JSW is critical for OA evaluation in clinical trials approved by the US Food and Drug Administration [45]. However, CT was recognized as being of limited use for the assessment of JSW. This was because conventional CT acquires images of patients in a non-weight-bearing position. Previously, a knee OA study showed that severe cartilage loss was less frequently detected on CT than on radiographs, which means that CT may underestimate the JSW because of the lack of weight bearing [11]. However, recent cone-beam CT technology enables CT images to be acquired with patients in a standing position. This facilitates 3D assessment of the minimum JSW, together with evaluation of other critical structural changes such as subchondral bone cysts and osteophytes. WBCT may provide more sensitive JSW measurements than radiographs and is expected to be a promising modality for future clinical trials on OA.

When WBCT was applied to knee joints, it showed high reliability for tibiofemoral JSW measurement, with ICCs of 0.94–0.97 in a test–retest study [61]. One study that assessed the JSW of the knee using a fixed-flexion radiograph and WBCT showed a high correlation between the two modalities [62]. When computer-based 3D analysis was conducted to compare the tibiofemoral JSW between WBCT, non-WBCT, and radiographs, WBCT identified significantly more reductions in JSW and bone-on-bone apposition than other two modalities [63]. It was reported that the measured minimal JSW of the medial compartment of the knee on WBCT was 1.4–2 mm lower than on standing radiographs [62, 63]. A study making comparisons with the cartilage morphology score of the whole organ MRI scoring (WORMS) system found that an area with a JSW less than 2.5 mm by WBCT more strongly correlated with central medial tibial cartilage morphology scores than did minimum radiographic JSW [64]. In addition, osteophyte and subchondral cysts can be more precisely assessed by WBCT than by radiograph [65]. When MRI was used as a reference, the sensitivities of WBCT for detecting osteophytes and subchondral cysts were 93% and 100%, respectively, which were both significantly higher than on radiographs. It is suggested that on the basis of osteophytes, WBCT can potentially diagnose OA in a higher proportion of patients than radiographs. Meniscal extrusion is associated with rapid progression of OA, and MRI is universally used for meniscus evaluation. However, lack of weight bearing on MRI may result in the missing of a meniscal lesion that occurs while standing. Although optimization of the reconstruction parameters is still needed, WBCT has shown promising results in the evaluation of meniscal extrusion. MRI was reported to be unable to detect 36% of medial meniscal extrusions that were seen on WBCT [66].

One Japanese group developed a 320-row-detector upright CT, in which the gantry of conventional CT is arranged in a vertical position (Fig. 10). Unlike con-beam CT, this upright CT enables to obtain images of the entire body in the standing position with rapid gantry-rotation speed of 0.275 s and to visualize soft tissue as well as bony structure due to its higher contrast resolution. They used this upright CT to evaluate whole lower leg alignment in a standing position in patients with knee OA [67, 68]. They found that in patients with knee OA, a trend towards greater knee flexion and adduction with increasing KL grades was exaggerated by WBCT compared with conventional CT. Interestingly, they also found that WBCT could sensitively detect change in tibial internal rotation according to KL grade. Flexion and adduction did not differ between KL1 and KL2, especially in early OA, but greater tibial internal rotation was shown in KL2 than in KL1. Hence, the authors suggested that tibial internal rotation assessed by WBCT may be a key to grading early-stage OA correctly. The same group also analyzed the relationship between ankle alignment and knee OA, because a change in ankle joint alignment occurs to restore the neutral lower leg alignment in knee OA [69]. Usually, a lateral wedge insole is used to modify the lower limb alignment for varus knee OA, but the authors suggested that the abnormal talocrural and subtalar alignment due to knee OA may not be that simple that it can be compensated using only a lateral wedge insole. Further studies are warranted to understand the effects on whole lower leg alignment in knee OA, and they may enable us to find better rehabilitation and management methods in the future.

In the ankle, WBCT has provided novel insights into the status of the healthy joint during standing. For example, in the typical distal tibiofibular joint, the fibular is translated laterally and posteriorly and externally rotated in relation to the tibial incisura during standing [70]. The advantages of WBCT for demonstrating the alignment of the bone and ankle joint during loading are helpful not only for diagnosing OA, but also for preoperative planning and understanding the pathophysiology of OA [71]. In varus ankle OA, valgus compensation of the subtalar joint was found using WBCT [72]. Hence, the subtalar joint may compensate for deformity above the ankle joint, but this compensation is not found in valgus ankle OA. A retrospective analysis of patients with ankle OA from an institution that installed WBCT showed a 10% decrease in radiation dose and 77% decrease in scanning time in a WBCT group compared with a conventional CT group [73].

## Conclusions

CT is the reference standard for observation of structural changes in OA evaluation. Its utility has been reported not only in daily OA clinics but also in research purpose. CT shows high reproducibility in the grading of OA with scoring systems in multiple joints. Measuring the BMD of subchondral 3D structures can be difficult with other modalities.

The utility of three representative recently developed CT system was also reviewed. DECT can evaluate BME, which previously was only visualized by MRI. CT with weight-bearing position is a promising method for future clinical trials and understanding the pathophysiology of OA. Lastly, PCCT can provide higher spatial resolution images

**Fig. 10** Photograph of 320-row-detector upright CT. **a** Image shows the upright CT with gantry in the up position. **b** The subject standing in the gantry

than conventional CT with significantly reduced radiation exposure, which is the biggest drawback of CT. Hence, these novel CT systems may bring about important advances in knowledge on OA in next decade.

**Author contribution** TF mainly drafted the manuscript. TY, MJ, and HO contributed to editing the draft. TM, TK, and MJ contributed to literature survey and figure preparation. All author approved the final version of the manuscript before submission.

## Declarations

**Conflict of interest** The authors declare no competing interests.

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