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Detection of Small Periprosthetic Bone Defects after Total Knee Arthroplasty

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ABSTRACT

Large bone defect around total knee prostheses is among the most critical challenges in revision surgery. However, it is difficult to detect bone defects around a prosthesis in early stage. We compared the efficacy of the detection of small bone defects between fluoroscopically guided plain radiography, CT, MRI, and a novel tomographic technique (tomosynthesis) using the six pig knee models. No bone defects were detected with plain radiography and MRI. The sensitivity and specificity of CT were 61.5% and 64.1%, respectively. The sensitivity and specificity of tomosynthesis were 85.4% and 87.2%, respectively. The radiation dose of tomosynthesis was 6% of that of CT. The cost of tomosynthesis was 28% of that of CT. Tomosynthesis was superior in terms of diagnosis, radiation dose, and cost.

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Recent national registry data show that the number of total knee arthroplasty (TKA) procedures has increased and will continue to increase [1,4,5,7,8,14]. The number of revision TKA surgeries is also increasing [7,8]. Large bone defects around a TKA prosthesis, caused by osteolysis or loosening, are among the most critical challenges during revision TKA [2,3,9] because such large bone defects make it difficult to fix the revision prosthesis into the host bone. Thus, early detection of bone defects before they become large is important.

Although the detection of bone defects around a total knee prosthesis using plain radiographs can be enhanced with fluoroscopic guidance and use of oblique views [10–12], the sensitivity of the method has been reported to remain low [6,13]. Recently, computed tomographic (CT) scans with metal artifact suppression and magnetic resonance imaging (MRI) were shown to improve the sensitivity of detecting osteolysis-induced bone defects around total knee prostheses [6,15,16]. However, the bone defects studied in these previous reports were very large, because these studies focused not on the screening and early diagnosis of osteolysis and loosening but on the size evaluation of large bone defects for the preoperative planning of revision surgery. Moreover, CT and MRI were not recommend as routine methods for the evaluation of all patients after TKA or for all knee arthroplasty patients being considered for revision, because these methods are expensive [6,16].

It might be difficult to detect bone defects caused by osteolysis or loosening around the femoral component at an early stage even with fluoroscopically guided plain radiography, CT, and MRI because the thick metal of the femoral component hinders the visualization of small bone defects. A novel tomographic technique that is less influenced by metal artifacts was introduced to detect small bone defects around total knee prostheses. The purpose of this study was to examine, in a pig model, the sensitivity and specificity of the detection of small bone defects caused by osteolysis and loosening using fluoroscopically guided plain radiography, CT, MRI, and a novel tomographic technique.

Materials and Methods

Six cemented femoral components (PFC Sigma PS, Depuy, Warsaw, IN, USA) were implanted in pig knees (Figs. 1 and 2). This component had metal box between medial and lateral condyles. Three types of models were prepared.

Nondefect Model

In two knees, femoral components were implanted using bone cement (CMW, Depuy, Warsaw, IN) without any bone defects.

The Conflict of Interest statement associated with this article can be found at http://dx.doi.org/10.1016/j.arth.2014.05.013.

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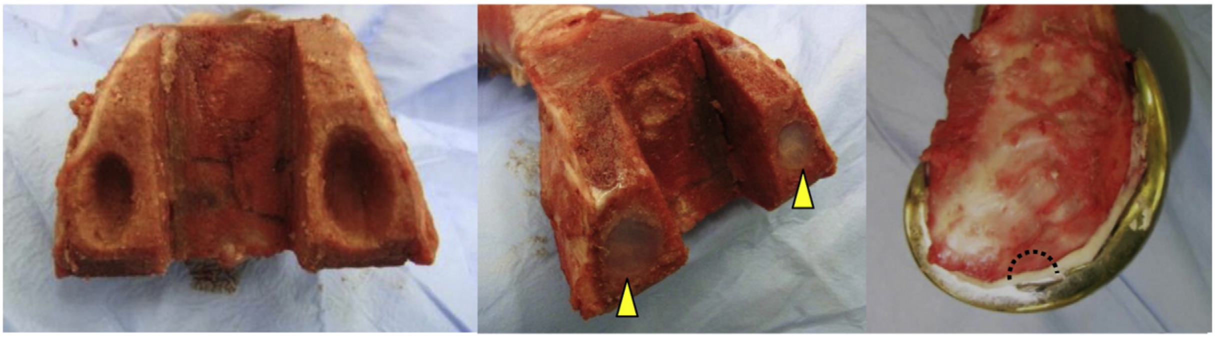

Fig. 1. Osteolysis model. The mean size of each bone defect was 0.7 cm^3. The bone defects were filled with agarose gel to simulate granuloma tissue to prevent air artifacts (arrows) [10,11]. The femoral component was fixed with bone cement. The bone defect could not be seen after cementing the femoral component (dotted line).

Osteolysis Model

To simulate osteolysis-induced small bone defects, small cystic defects (mean size, 0.7 cm^3) were created on the distal femoral condyles of two knees after the preparation of bone for implantation. The bone defects were placed on the distal surface of the femoral condyles. One defect was created in each femoral condyle. The bone defects were filled with 1% agarose to simulate granuloma tissue, in order to reduce the air artifacts around the bone lesions that can interfere with the imaging procedures [15]. Then, two components were implanted with bone cement (Fig. 1).

Radiolucent Line Model

To simulate the early stage of loosening of the femoral component, two femoral components with 2-mm-thick defects between the bone cement and the bone were implanted (Fig. 2).

The following four types of imaging examination were performed for all knees. Fluoroscopically guided plain radiographs (63 kV, 360 mA, 50 ms) were taken in four positions (anteroposterior, lateral, and ±45° oblique views) for each specimen. For the novel tomographic technique (tomosynthesis), a fully digital diagnostic table with direct-conversion-type flat panel detector was used (SONIALVISION safire17; Shimadzu Corp., Kyoto, Japan). Seventy-four frames were acquired at a rate of 30 frames/s with a fixed X-ray condition (140 kV, 320 mA, 20 ms). These linear scans were transformed into CT images with 40° rotation using an automatic reconstruction algorithm. Projection images were separated into metal and metal-free images. Then, metal and metal-free reconstruction tomographic images were created. Finally, these two images were combined. These tomographic images were automatically created. The topographies of the medial and lateral condyles for each specimen were provided. CT examinations of the knee were performed using a high-resolution CT scanner (Aquilion 16; Toshiba, Tokyo, Japan). An extended scale technique was used to suppress the resulting metal artifact. Scans were taken using the following settings: 120 kV, 400 mA s, and 500 ms spiral–0.5 mm slice, and a reconstruction interval with sagittal images of 0.5 mm. Then, the sagittal plane images were reconstructed and two slices (medial and lateral condyles) were provided for each specimen. Metal artifact reduced MRI examinations were performed using a 1.5-T magnet (Achieva 1.5 T; Philips, Amsterdam, the Netherlands) on T2-weighted images as follows: repetition time of 4500 ms, echo delay time of 100 ms, and a received bandwidth of 1166 Hz/pixel. Sagittal slices of the medial and lateral condyles for each specimen were provided.

Eight blinded assessors, all orthopedic surgeons experienced in clinical radiographic analysis, examined the fluoroscopically guided plain radiography, tomosynthesis, CT, and MRI images. Sensitivity and specificity of each method were analyzed.

The entrance surface dose was measured using a thermoluminescent dosimeter (UD-170A [Be0, 2mR-200R]) and a UD-5120PGL reader (Panasonic, Tokyo, Japan). Four dosimeters were attached to the knee phantom and then were exposed to fluoroscopically guided plain radiography, tomosynthesis, and CT. Measurements were performed three times for each exposure method.

Statistical Analysis

The chi-square test was used to compare the differences in sensitivity and specificity between the imaging methods. The computer software StatView 5.0 (Abacus Concepts, Berkeley, CA, USA) was used for statistical analysis. Statistical significance was set at a P value of <0.05.

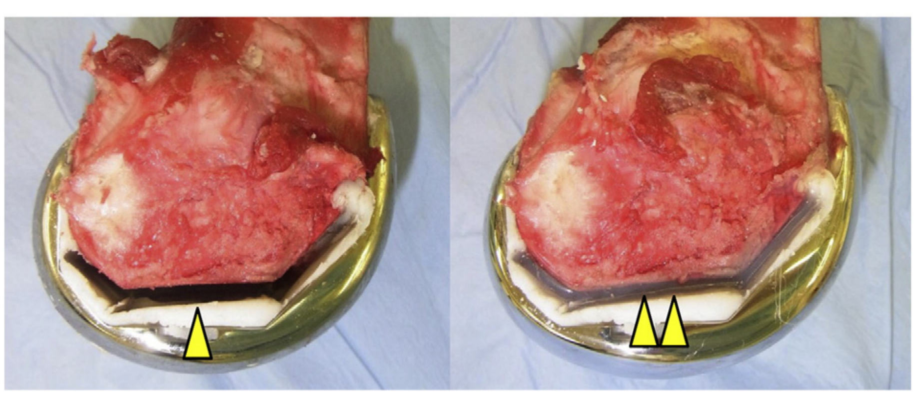

Fig. 2. Radiolucent line model. The defects between the polymethylmethacrylate bone cement and the bone were 2 mm thick (arrow). The bone defects were filled with agarose gel to simulate granuloma tissue, in order to prevent air artifacts (double arrow) [10,11].

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