



# The Usefulness of Three-dimensional Computed Tomography as an Assessment of Periacetabular Osteolysis in Revision Total Hip Arthroplasty

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**Purpose:** This study was performed to determine the usefulness of three-dimensional computed tomography (3D-CT) in measuring periacetabular osteolysis by comparing the real volume of osteolysis in revision surgery.

**Materials and Methods:** Twenty-three patients who had undergone revision surgery due to periacetabular osteolysis but not included septic osteolysis and implant loosening. The mean age of patients at the time of surgery was 55.2 years. And the mean time interval between the primary total hip arthroplasty and revision surgery was 13.3 years. We measured the polyethylene wear in plain radiographs using computer assisted vector wear analysis program, the volume of acetabular osteolytic lesions in high-resolution spiral CT scans using Rapidia 3D software version 2.8 algorithms before the revision surgery were performed. Intraoperative real osteolytic volume was calculated as the sum of the volumetric increments of the acetabular cup and impacted allo-cancellous bone volume.

**Results:** Strong correlation was found between the volume of acetabular osteolytic lesions measured on 3D-CT and intraoperative real osteolytic volume which was calculated as the sum of the volumetric increments of the acetabular cup and impacted allo-cancellous bone volume.

**Conclusion:** 3D-CT is considered a useful method for assessing and measuring the volume of periacetabular osteolysis before revision surgery.

**Key Words:** Computed tomography, Osteolysis, Arthroplasty

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## INTRODUCTION

Periacetabular osteolysis is a major complication following total hip arthroplasty and can be a cause of component loosening and periprosthetic fractures<sup>1-3</sup>. Although osteolysis through polyethylene wear particles can increase the morbidity and compromise revision surgery, patients often remain clinically asymptomatic until extensive osteolysis has occurred and if clinical symptoms develop<sup>4,5</sup>, revision surgery can be troublesome and cause component loosening and extensive bone loss<sup>6</sup>. In addition, even though there may be a

considerable amount of osteolysis, well-fixed and stable prosthesis can remain asymptomatic until a periprosthetic fracture occur. For these reasons, the ability to accurately assess and visualize the position and volume of periacetabular bone defects is paramount for clinical observation and medical treatment, as well as pre-operative planning of revision surgery, and periodic radiographic follow-ups are essential<sup>4,7,8</sup>.

Plain radiographs in the diagnosis of osteolysis are the most widely used technique due to low-cost and easy access. However, it is generally accepted that plain radiographs are not sufficiently sensitive for the reliable detection of the presence or extent of periprosthetic osteolysis because the measurement of lesion size and location is often incorrect, and thus, the amount of bone loss can be underestimated<sup>9,13</sup>.

Metal artifact-reducing software, including the current three-dimensional computed tomography (3D-CT) system has been found to provide a sensitive and accurate way to measure the location, and volume of osteolysis<sup>10,12</sup>. Some previous studies involving two-dimensional radiograph measurements of polyethylene wear and computerized tomography demonstrated that there was a correlation between the size of the osteolytic lesion and the amount of polyethylene wear<sup>14-16</sup>, while other studies involving 3D-CT studies reported that there was no correlation or poor correlation<sup>10-12</sup>.

Until now, there have been many studies about sequential analysis of periacetabular osteolysis with 3D-CT after primary total hip arthroplasty. However, there has been no research about the accuracy of CT based on measuring the *in vivo* real osteolytic volume and the polyethylene wear at the time of revision surgery. In this study, we evaluated the reliabilities of measurement of polyethylene linear and volumetric wear in plain radiographs, and the volume of acetabular osteolytic lesions on 3D-CT for comparing to the intraoperative real osteolytic volume.

## MATERIALS AND METHODS

Twenty-three patients who had undergone revision surgery due to periacetabular osteolysis from January 2006 to November 2011 at Inha University Hospital (Incheon, Korea) were enrolled. All patients were studied retrospectively. All patients received primary cementless total hip arthroplasty between May 1994 and July 2005 at the same hospital. Three patients have mild symptom including pain, limitation of motion, but other

patients had a relatively well functioning total hip arthroplasty and follow-up regularly at our hospital and met the following inclusion criteria: (1) there was evidence of periacetabular osteolysis on plain radiographs; (2) there was no evidence of acetabular cup loosening; and (3) all patients received revision surgery due to severe osteolysis on 3D-CT. In this study, all patients were selected with inclusion criteria, not randomly. We have defined severe osteolysis as the fixation of an implant which has been compromised by the lytic processes immediately before implant loosening develops. We excluded the patients who had septic osteolysis or aseptic osteolysis with implant loosening.

The mean age of patients at the time of surgery was 55.2 years (range, 45-65 years; standard deviation [SD], 13.607) with a male/female ratio of 17:6. The mean time interval between the primary total hip arthroplasty and revision surgery was 13.3 years (SD, 4.151). The reasons for primary surgery were osteoarthritis in 10 hips, osteonecrosis of the femoral head in 7 hips, post-traumatic arthritis in 3 hips, sequelae of pyogenic arthritis in 2 hips, and sequelae of tuberculosis arthritis in 1 hip. We used cementless acetabular cups (Duraloc; Depuy, Warsaw, IN, USA) and standardized polyethylene liners (Enduron, Depuy), and extensive porous coated femoral stems (AML, Depuy) (Fig. 1A).

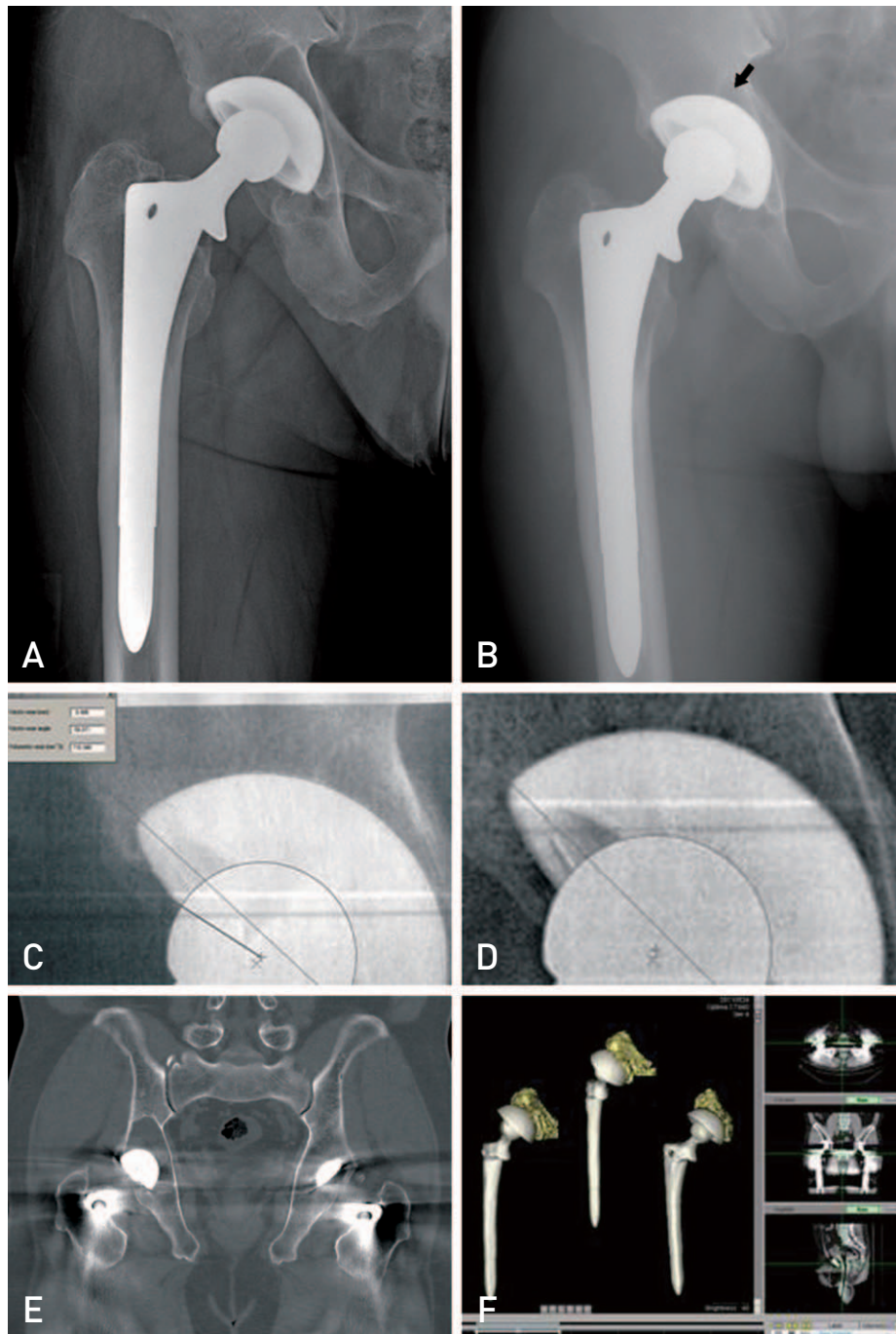
To measure the polyethylene wear accurately, the anteroposterior views of the bilateral hip joint taken immediately (Fig. 1B) and annually afterward were imaged on a computer using a Powerlook 2001XL flat bed imaging scanner (Umax Data Systems, Taipei, Taiwan). The images were analyzed applying a computer assisted vector wear analysis program (University of Chicago, Orthopedic Surgery, Hip Analysis Program version 4.0) developed by Martell and Berdia<sup>17</sup>) at the Chicago University (Fig. 1C, D). Immediately after surgery, the polyethylene wear was measured at annually. For checking accuracy of our technique, two blinded observers measured the linear wear twice.

Generally, the CT appearances of focal osteolysis were round, oval, and multilobular osteolytic lesions with discrete, smooth, or irregular margins. They were filled with soft tissue mass, which tended to displace the adjacent soft tissue rather than to infiltrate it.

High-resolution spiral CT scans (CT Scanner, MDCT, 16 Channel Somatom Sensation 16; Siemens, Berlin, Germany) were used to identify and measure the volume

of acetabular osteolytic lesions and the mean time interval between primary surgery and CT scan was 11.6

years (range, 6.4-16.3 years; SD, 3.952) (Fig. 1E). Scans of the hip were made from the top of the sacroiliac joint



**Fig. 1.** This figure shows periacetabular osteolysis after primary total hip replacement arthroplasty in avascular necrosis of the right hip and measurement of osteolysis by computer assisted vector wear analysis program and three-dimensional (3D) computed tomography in a 56 years old man. (A) This immediate postoperative anteroposterior plain radiography shows good positioning of the prosthesis (May 2001). (B) After 10 years (May 2011), the plain radiography shows periacetabular osteolytic lesion (arrow). (C, D) The images were analyzed by applying a computer assisted vector wear analysis program (University of Chicago, hip analysis program 4.0). (E) We measured the volume of acetabular osteolytic lesions via high-resolution spiral computed tomography scans. (F) We reconstructed to a 3D osteolytic volume by using via Rapidia 3D software version 2.8.

(6 cm proximal to the acetabular component) to the distal end of the femoral components for checking osteolysis of acetabular component and distal femoral component. Osteolysis was defined as a demarcated nonlinear lytic lesion measuring greater than 3 mm in diameter. In this study, we use the 16-channel multi-detect helical 3D-CT which is possible to obtain an image 356×356 mm field of view by 2 mm thickness and 0.0 mm gap. And we obtain the resolution of the image by using the 120 kvp tube voltage and 101 mAs tube current (Table 1). Osteolytic images obtained in the axial plane were reconstructed to a 3D osteolytic volume using 3D software (Rapidia 2.8; Infinite, Seoul, Korea) (Fig. 1F). A medium bone algorithm which is a bone kernel with a mid-range edge enhancement algorithm, was used to correct for image degradation caused by hip prosthesis. To check reproducibility, two blinded observers measured the volume of osteolytic lesion. Displayed section thickness was 2 mm and the mean reproducibility rate was  $\pm 4\%$ .

One senior author performed revision surgery using a posterolateral approach. After the previous acetabular cup was removed, all osteolytic lesions were curretted. The morcellized allo-cancellous bone (femoral head, proximal tibia, distal femur) were impacted into the osteolytic lesions. The last-sized reamer compressed the impacted bone, turning in reverse orientation. The acetabular cup, 2-4 mm larger than last-sized reamer, was press-fitted and more than 2 additional screw fixations were done to obtain stability. Intraoperative real osteolytic volume was calculated as the sum of the

volumetric increments of the acetabular cup and the impacted cancellous bone volume was in a proportion of 1.6 g/cm<sup>3</sup>. Although original cortical bone density was 1.8 g/cm<sup>3</sup>, cortical bone density in the course of the press is difficult. Therefore, concentration of bone graft was defined as 1.6 g/cm<sup>3</sup>.

Linear regression was performed to calculate the correlation between (1) the radiographic linear and volumetric wear rate measured by a computer assisted vector wear analysis program; (2) periacetabular osteolysis measured by CT; and (3) intraoperative real osteolytic volume was calculated as the sum of the volumetric increments of the acetabular cup and the impacted allo-cancellous bone volume.

Mann-Whitney U test and Pearson's correlation coefficient analysis was used to determine if there was a significant relationship between each measurement. All data analysis was performed with use of SPSS statistical software (version 8.0; SPSS Inc., Chicago, IL, USA). Probability values of <0.05 were considered to indicate a significant difference.

## RESULTS

The mean linear wear with polyethylene on plain radiography was 6.01 mm. The mean annual linear wear rate was 0.45 mm/year and using our technique, the mean accuracy was  $4.88\% \pm 10.9\%$ .

The mean pelvic osteolytic volume of the 23 patients on 3D-CT scans was 30.469 cm<sup>3</sup> (range, 13.432-93.098 cm<sup>3</sup>).

The mean weight of allograft bone was 52.5 g (range, 0-140 g) and the equivalent mean volume was 32.812 cm<sup>3</sup> (range, 0-113.04 cm<sup>3</sup>). The mean volumetric increment of cup size was 47.4 mm<sup>3</sup> (mean primary cup size, 55.6 mm; range, 48-64 mm; mean revised cup size, 59.1 mm; range, 50-66 mm). The mean sum of impacted bone volume and the volumetric increment of the cup was 33.286 cm<sup>3</sup>.

A weak correlation was found between the mean linear wear rate of polyethylene liners measured on plain radiographs and osteolytic volumes measured on 3D-CT with no statistically significance ( $r^2=0.18$ ,  $P=0.938$ ) (Fig. 2).

The correlation between the mean linear and volumetric wear rate of polyethylene liners was weak with no statistically significance ( $r^2=0.206$ ,  $P=0.359$ ) (Fig. 3).

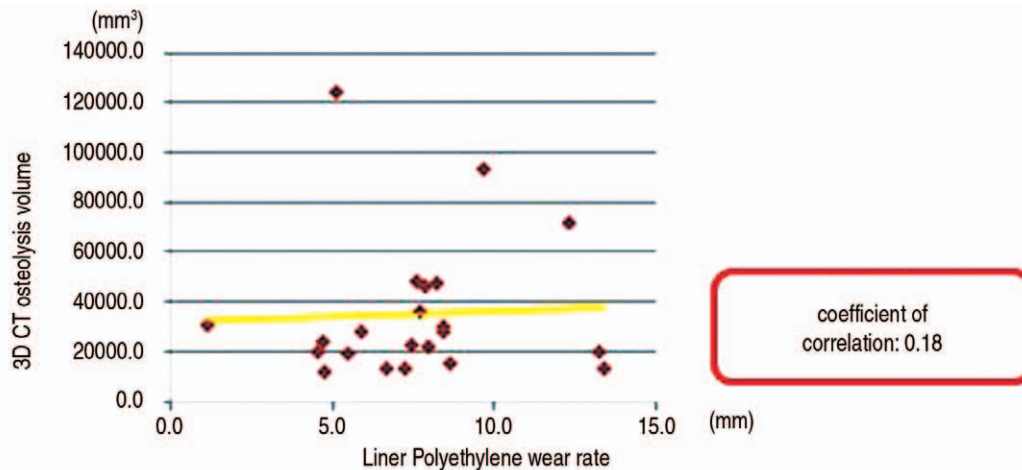
A strong and significant relationship was found between osteolytic volume measured on 3D-CT and the sum of the volumetric increments of acetabular cups and

**Table 1.** Computed Tomography Parameter Used in This Study

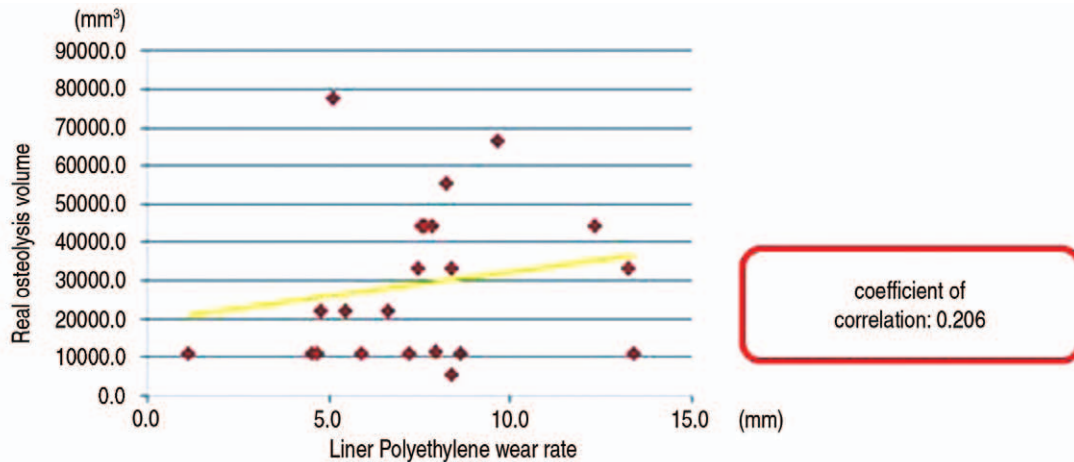
Parameter	Data
THK (mm)	2.0
GAP (mm)	0.0
FOV (mm)	356×356
TP (mm)	0.0
TI (mm)	800
Peak voltage (kV)	120.0
Electrical current (127 mA)	101
GT (°)	0
W (mm)	2,000
L (mm)	200
Z (%)	187
Compression	10:1

THK: thickness, GAP: gap, FOV: field of view, TP: table position, TI: table increment, GT: degree of gantry, W: width, L: length.

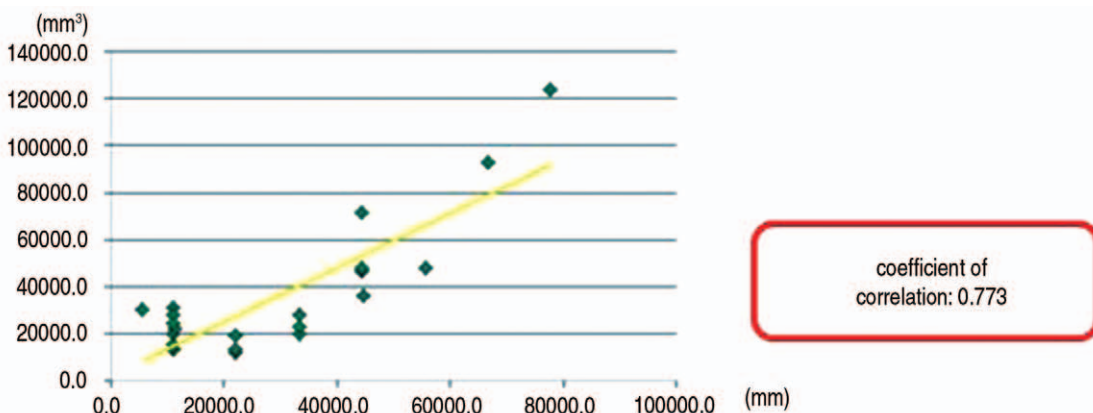




**Fig. 2.** A weak correlation was found between the mean linear wear rate of polyethylene liners measured on plain radiographs and osteolytic volumes measured on three-dimensional computed tomography (3D-CT) with no statistically significance ( $r^2=0.18$ ,  $P=0.938$ ).



**Fig. 3.** The correlation between the mean linear and volumetric wear rate of polyethylene liners was weak with no statistically significance ( $r^2=0.206$ ,  $P=0.359$ ).



**Fig. 4.** A strong and significant relationship was found between osteolytic volume measured on the three-dimensional computed tomography and the sum of the volumetric increments of acetabular cups and impacted allo-cancellous bone volume with a statistical significance ( $r^2=0.773$ ,  $P<0.001$ ).

impacted allo-cancellous bone volume with a statistical significance ( $r^2=0.773$ ,  $P<0.001$ ) (Fig. 4).

The relationship between sum of the volumetric increments of acetabular cup and impacted allo-cancellous bone volume and osteolytic volume were measured on 3D-CT.

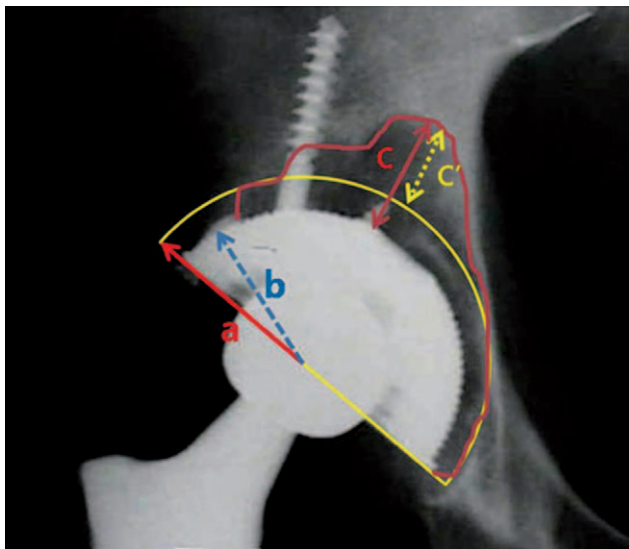
In most of the cases, revised cups were larger than previous cups and we considered that the volumetric increments of acetabular cup might influence the measurement of the osteolysis. Hence, we calculated the new calibration parameters (sum of the volumetric increments of acetabular cup and impacted allo-cancellous bone volume). This new parameter yielded a strong correlation with osteolytic volume measured on 3D-CT ( $r=0.773$ ,  $P<0.001$ ).

That positive relationship could be expressed in the equation (Fig. 5).

$c$  (osteolytic volume measured on 3D-CT)  $\div c'$  (grafted allo-cancellous bone volume)  $+ \pi/2 (a^2 - b^2)$  (volumetric increments of acetabular cup)

i.e.,  $\pi/2 (a^2 - b^2) \div c - c'$

To correspond to this equation [ $\pi/2(a^2 - b^2) \div c - c'$ ], periacetabular osteolysis should occur enough to encircle the cup and medial migration of the cup should not occur.



**Fig. 5.** The relationship between sum of the volumetric increments of acetabular cup and impacted allo-cancellous bone volume and osteolytic volume measured on three-dimensional computed tomography (3D-CT) ( $r=0.773$ ,  $P<0.001$ ). a: radius of acetabular wall, b: radius of acetabular cup, c: osteolytic volume measured on 3D-CT, c': grafted allo-cancellous bone volume.

## DISCUSSION

In this study, the goal of this study was to assess whether 3D-CT is useful for the evaluation of osteolysis, not to determine the prevalence of osteolysis in patients who have undergone total hip arthroplasty. Although we still consider plain radiography to be the most practical and important method of the postoperative evaluation of total hip arthroplasty, but radiologically we think that 3D-CT is more useful tool for evaluation of osteolysis in total hip arthroplasty. Because plain radiographs cannot detect all periacetabular osteolytic lesions and are a poor predictor of lesion size but, 3D-CT scan provided more accurate information about presence, location, and extent of osteolysis than did plain radiography.

In order to treat osteolysis, a worn polyethylene liner should be replaced with a new one, or a bone grafting should be performed through an opening of a cup when there is osteolysis around the screw. In the current study, we used a treatment protocol in which all cups were removed, because there were three symptomatic patients and all most patients with severe osteolysis of a stage immediately before loosening of implants. In addition, young patients need reoperation in the future because the cup was removed was replaced with ceramic on ceramic articulation.

In the current study, the mean osteolytic volume is 30.469 cm<sup>3</sup>. It is substantially higher than several other published studies (Looney et al.<sup>11</sup>, 3 cm<sup>3</sup>; Puri et al.<sup>12</sup>, 4.9 cm<sup>3</sup>; Egawa et al.<sup>18</sup>, 19 cm<sup>3</sup>; Howie et al.<sup>19</sup>, 10.9 cm<sup>3</sup>). Unlike previous studies which evaluated prospective patients who did not receive revision surgery, this current study included patients who received revision surgery due to severe acetabular osteolysis. The mean linear wear of polyethylene (6.01 mm) was also higher than other studies (Egawa et al.<sup>18</sup>, 1.86 mm) for the same reason. Further, this current study used cementless cups that induced more polyethylene wear and did not demonstrate biochemical defensive effects of cement on osteolysis compare to cemented cups. Devane et al.<sup>20</sup> proposed that cemented cups reduce the production of wear particle debris with its cushioning effect, so polyethylene wear could be decreased with the use of cemented cups.

There are controversies about the relationship between polyethylene wear and osteolysis. Egawa et al.<sup>18</sup> and Howie et al.<sup>19</sup> reported that polyethylene wear was closely associated with osteolysis and recommended that CT was essential when there was polyethylene wear on plain

radiographs such as eccentric positioning of the femoral head, even if there was no evidence of osteolysis. However, Puri et al.<sup>12)</sup> described that polyethylene wear on radiographs didn't imply osteolysis.

Jone Martell's technique<sup>17)</sup> didn't demonstrate 100% accuracy in measuring polyethylene wear. Martell et al.<sup>21)</sup> reported that 3D analysis detected approximately 10% more wear than two-dimensional analysis did, but, because of the poor quality of the lateral radiographs, its repeatability was four times worse. However, McCalden et al.<sup>22)</sup> reported that this technique (Martell's hip analysis suite) had been used extensively in the literature to assess *in vivo* polyethylene wear. In general, it is known that the amount of an actual osteolysis is greater than the periacetabular osteolysis measured by plain radiographs, and that there is a high correlation between the wear of a polyethylene liner and the amount of an osteolysis. In this study, however, there is a low correlation between the wear of a polyethylene liner observed in plain radiographs and the amount of an osteolysis, which demonstrates that there is a limitation in predicting the amount of an osteolysis by plain radiographs.

There were some limitations in that we assumed the real osteolytic volume as the sum of the volumetric increments of acetabular cups and impacted allo-cancellous bone volume. First, filling defect could have occurred when the allo-cancellous bone was impacted into the deficient cavity. Second, grafted allo-cancellous bone could have been depleted during acetabular reaming and spilled into the pelvic cavity through a deficient medial wall; if so, we may have overestimated the real osteolytic volume. Third, grafted bone volume could be different depending on how much was pressed into the allo-cancellous bone. To overcome this limitation, all operations were performed by one skilled senior surgeon using one kind of implant, where subjects were relative young patients (mean age, 58.2 years) with solid bone density. Lastly, this current study did not include the biologic and genetic factors, nor activity levels that may influence osteolysis. However, we included the severe osteolytic subjects need to performed revision surgery and the aims of the study were to evaluate the accuracy of 3D-CT at revision surgery, not the sequence of osteolysis. Also, concerning the loss of bone which occurs during the process of removing an acetabular cup, bone defects develop in the wall of anterior and posterior acetabular when the cup is fixed well. This kind of bone defects requires an increased amount of

bone graft during an operation, thereby exceeding the amount resulting from the actual osteolysis. In the current study, concerning the massive osteolysis which requires a revision operation, it was easier to extract the cup with no bone adhering to the cup than in the cases in which the cup is fixed well, and the extracted amount was less. When an increased amount was extracted, we measured by deducting the amount obtained by a bone curettage from the amount of osteolysis of a bone graft.

The correlation between the osteolytic volume measured on 3D-CT and impacted allo-cancellous bone volume was not significant ( $r^2=0.329$ ,  $P=0.246$ ). Of course, there can be a difference between the amount of a bone graft and that measured by 3D-CT. The reason is because the amount of a bone being condensed in the ratios which we propose can differ according to the size of bone morsels in a heterograft and the force of power which influences. However, the difference is not considered to be great if an expert surgeon compresses a purely cancellous bone with a fixed force without mixing cancellous and cortical bones.

These prerequisites verify our results; the mean osteolytic volume was substantially higher than that of several other published studies and there was no medial migration of cups in our study. It is of significance in ascertaining the accuracy of measuring the amount of a bone graft by CT, by comparing the amounts of osteolysis measured by CT and *in vivo*, similar to the study in which the amounts of osteolysis were compared by CT and in cadavers, instead of intending to use before and after operations by predicting the amounts of an actual bone graft.

## CONCLUSION

There was a strong relationship and a statistical significant relationship between the osteolytic volume measured on 3D-CT and the sum of the volumetric increments of acetabular cups and impacted allo-cancellous bone volumes. Additionally, 3D-CT is considered as a useful method for identifying and measuring periacetabular osteolysis.

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