

Original Article

Intraosseous cavity-venography to evaluate the extent and circulation of the operative bone cavity

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Abstract: The key to the success of the thorough debridement and cancellous bone grafting procedure in patients with avascular necrosis of the femoral head is to remove all necrotic bones. However, there are no reliable or objective radiological criteria for reference. A novel and simple technique is proposed, which is referred to as "intraosseous cavity-venography" (ICVG), to evaluate both the extent and circulation of the operative bone cavity. Forty-two operative bone cavities in femoral heads underwent ICVG to determine the extent and circulation of the operative bone cavity between January 2010 and September 2013. The study group consisted of 33 patients (24 men and 9 women, with a median age of 29 years). The debridement procedure was performed using the technique described by Rosenwasser and his colleagues. After plain X-ray images of the cavity were obtained, ICVG was performed in which the cavity was filled with contrast material, and the bone window was sealed. ICVG images were obtained at consecutive time points within 40 minutes. Two orthopedic surgeons independently reviewed the images. The cavity visualizing rates were calculated and compared between the groups. The empty procedure of the contrast material was identified and analyzed in the ICVG images. All 42 cases (100%) of ICVG were marked positive by both surgeons; however, 13 of 42 images (31.0%) of plain X-ray were marked positive by the junior surgeon compared with 33 of 42 hips (78.6%) by the senior surgeon. The visible rate in the plain X-ray images by the senior surgeon was significantly increased compared with the junior surgeon ($\chi^2=19.222$, $P<0.001$). The contrast material empty procedures were visualized, and a new venous drainage pattern was reported. Furthermore, four levels of intraosseous cavity circulation were reported. The current findings demonstrate that ICVG is a reliable and objective method that does not require a special instrument to evaluate the extent and circulation of the operative bone cavity.

Keywords: Intraosseous cavity-venography (ICVG), operative bone cavity, venous drainage pattern, osteonecrosis of the femoral head (ONFH)

Introduction

The debridement and cancellous bone grafting procedure perfectly follows the principles of an ideal head-preserving operation for osteonecrosis of the femoral head (ONFH), which involves removing all necrotic bones and replacing them with cancellous bone to restore vitality to the femoral head [1]. However, the effectiveness of the debridement procedure remains controversial. Studies have indicated good to excellent results [2, 3]; however, current clinical practices have indicated poor results in North America. It appears paradoxical that an ideal procedure cannot consistently result in good clinical outcomes. The explanation is likely that the evaluation of the operative bone cavity

depends on experience rather than on reliable and objective radiological criteria.

Orthopedic surgeons prefer direct observation of the operative bone cavity through a large cortical bone window; however, it is too deep in the femoral head to achieve direct vision. Thus, a curette or a Kirschner wire is placed into the cavity and moved several times under fluoroscopic observation to indicate the borders. These instruments facilitate the evaluation of the extent; however, they do not facilitate the assessment of intraosseous circulation. Nevertheless, the arterial blood supply may be judged by the observation of bleeding from the cancellous bone wall; however, the venous drainage cannot be judged by any previously

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Table 1. Cavity visualizing results of plain X-ray films and ICVG in junior and senior orthopedic surgeons

	Plain X-ray Films		ICVG	
	Positive (hips)	Negative (hips)	Positive (hips)	Negative (hips)
Junior Surgeon	13	29	42	-
Senior surgeon	33	9	42	-
χ^2 -value	19.222			
P-value*	<0.001			

*P<0.05 was considered statistically significant. Intraosseous cavity-venography (ICVG).

reported method. Several other methods may be helpful; however, they cannot be widely implemented because special devices are required, such as inter-operative CT Scans, endoscope, and laser Doppler flowmetry [4, 5]. Therefore, it is necessary to develop an effective method that does not require a special instrument to visualize the extent and circulation of the operative bone cavity.

Iodinated-based contrast media have been used in intraosseous venography; thus, it is quite possible to visualize the extent and circulation of the operative bone cavity by filling it with contrast materials. The aim of the present study was to evaluate the performance of intraosseous cavity-venography (ICVG) in the evaluation of the operative bone cavity compared with plain X-ray images.

Patients and methods

Clinical data

Between January 2010 and September 2013, 33 patients with 45 hips diagnosed as non-traumatic ONFH were treated, which included 24 men and 9 women (age range, 27-46 years; median age, 29 years). This study was approved by the institutional review board of the Third Hospital of Hebei Medical University, and informed consents were obtained. The diagnoses were made with a combination of clinical exams, radiographs, CT and MRI if necessary. Three hips were classified as Ficat Stage I, 29 hips were classified as Stage II, and 13 hips were classified as Stage III. Alcoholic ONFH was the final diagnosis in 18 patients, whereas corticosteroid-induced and idiopathic OHFN were diagnosed in 8 and 7 patients, respectively. Three hips in Ficat Stage I received core decompression, and 42 hips in Ficat Stages II and III

received the debridement and cancellous bone grafting procedure. All 33 patients exhibited negative results in the Iodine allergy test.

Operation method

The patient was subjected to combined spinal-epidural anesthesia while lying in a supine position with a cushion under the hips. The anterior neck was approached via a Smith-Petersen approach. A window was made at the head and neck junction of the femur, through which all sclerotic and necrotic bones were removed using drills, burrs and curettes. Plain X-ray and ICVG images of the operative bone cavity were subsequently obtained. The cancellous bone was harvested from the ipsilateral iliac crest and was packed tightly into the cavity. The cortical window was replaced. The hip joint was washed, and the incision was subsequently closed. Antibiotics were routinely administered for 24 hours to prevent infections. ICVG related procedure time delays and complications were assessed and recorded if they occurred within 2 weeks.

Intraosseous cavity-venography (ICVG) technique

ICVG was performed after a plain X-ray image was obtained, as described in the following steps. The hip was flexed to maintain the cortical window on the top, and the operative bone cavity was washed with saline and filled with diatrizoate (20 ml: 15.2 g, Xudonghaipu, Shanghai, China). The window was subsequently sealed with a bone wax bolt in a plastic bag, which may be modified to excellently fit the window and may be easily removed; the leakage contrast material was then washed out of the wound. The ICVG images were immediately obtained every 5 to 8 minutes within 40 minutes.

Image analysis

Two orthopedic surgeons (the senior surgeon had 15 years of experience, and the junior surgeon had 5 years of experience) who were blind to the patients' clinical data independently reviewed the plain X-ray and ICVG images of the operative bone cavities. The readers first identified the extent of the operative bone cavities (cavity visualizing). Positive marks were made if more than 2/3 of the borders were identified;

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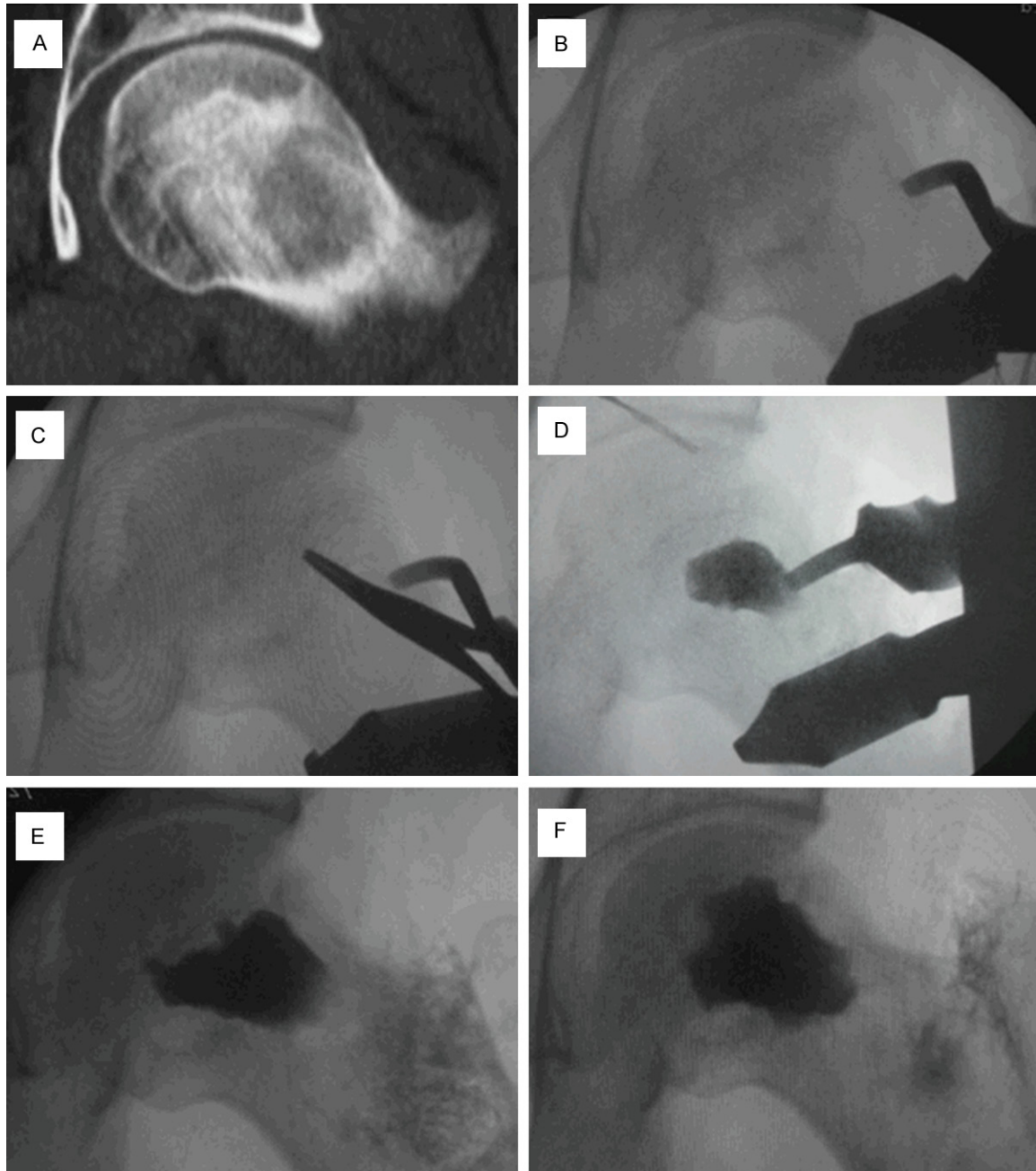


Figure 1. A 27-year-old male patient with bilateral NONFH (Left was in Ficat Stage II and right was in Ficat Stage I). The debridement and cancellous bone grafting procedure was performed in the left hip, whereas core decompression was performed in the right hip. Preoperative CT scans indicated the necrosis extent in the femoral head (A). The intraosseous cavity was observed via X-ray; however, the extent and borders were unclear (B). One point of the border was shown by putting a clamp into it (C). A full view of the cavity was observed after ICVG was performed (D). The clearance extent was enlarged, and a 2 mm hole was drilled using the Kirschner wire (E). The clearance extent was further enlarged and nearly matched the necrosis bone extent compared with the preoperative CT (F).

otherwise, negative were marked. The readers subsequently evaluated the intraosseous cavity circulation based on the empty pattern of contrast material in the cavity and its time cost (cavity fading).

Statistical analysis

Statistical analysis was performed using SPSS for Windows version 19 (SPSS, Chicago, IL, USA). The differences in the qualitative data

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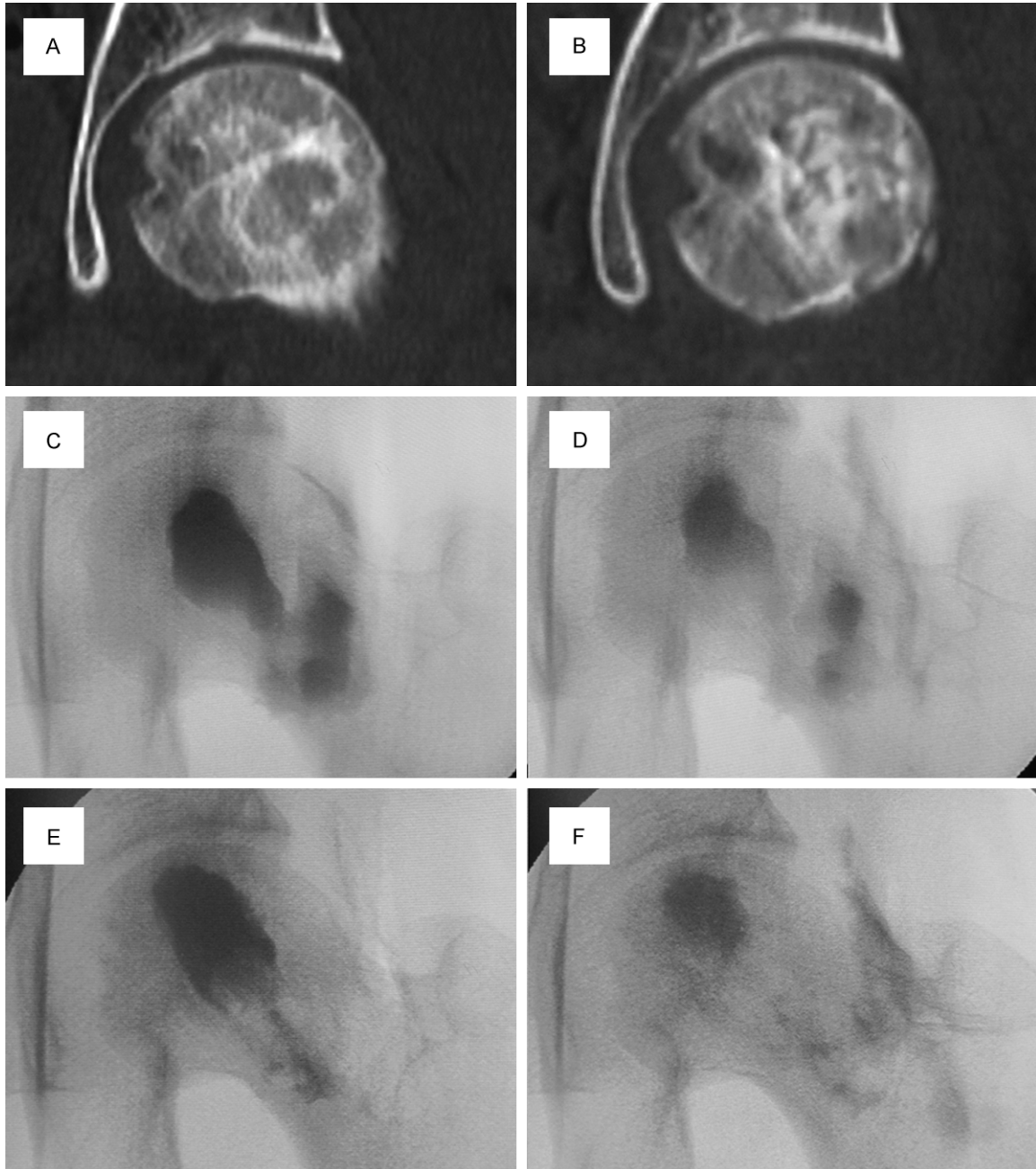


Figure 2. A 27-year-old male patient with left NONFH (Ficat Stage II) underwent the debridement and cancellous bone grafting procedure. The osteonecrotic extent in the preoperative CT (A), bone grafted extent in the postoperative CT (B) and clearance extent via ICGV (E) matched with each other well. Cavity visualizing (C) indicated a full view of the cavity with one empty point on the superior medial border. Cavity fading (D) demonstrated that half of the contrast material was left in the cavity after 23 minutes, which indicated an insufficient improvement of intraosseous circulation. After more necrotic bone was removed, a larger extent with two empty points was identified (E), and 1/3 of the contrast material remained (F) in 15 minutes, which implied a good improvement. Cavity fading was initiated at the empty beginning points, in which the enlargement of the empty point contrast material moved into the surrounding cancellous bone via the base of the femoral neck into the extraosseous venous plexus in the superior-medial of the great trochanter and ultimately disappeared (C-F).

between the junior and senior surgeons were assessed using Pearson chi-square Test. A P -value <0.05 was considered statistically significant.

Results

The cavity visualizing results of ICGV and plain X-ray by the junior and senior surgeons are

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shown in **Table 1**. All 42 cases (100%) of ICVG were marked positive by both surgeons; however, 13 of 42 images (31.0%) of plain X-ray were marked positive by the junior surgeon compared with 33 of 42 hips (78.6%) by the senior surgeon (**Table 1**). The positive rate of the senior surgeon was significantly increased compared with the junior surgeon ($\chi^2=19.222$, $P<0.001$).

Figure 1 showed a 27-year-old male patient who underwent ICVG technique during the debridement procedure in the left hip. Pre-operative CT scans indicated the necrosis extent in the femoral head (**Figure 1A**). The image of the operative bone cavity in the ICVG images exhibited a higher density and better contrast compared with the plain X-ray images (**Figure 1B-D**). It may easily be recognized as a black area with sharp borders to the surrounding bone regardless of how much necrotic bone was removed (**Figures 1D-F, 2C, 2E, 3C, 3D**). It also provided substantially greater details, i.e., a 1.5 mm hole drilled by a Kirschner wire was noted (**Figure 1E**). The contrast agent empty procedure (cavity fading) was successfully observed in the last 9 cases (**Figure 4A-D**). The arterial blood flowed into the bone cavity at one or more empty points, which were less dark black color areas on the borders (**Figures 2C, 2E, 3C**); contrast material subsequently diluted into the surrounding bone, moved via the lateral base of the femoral neck into the extraosseous venous plexus in the superior-medial of the great trochanter, and ultimately disappeared. This pattern was different from the results of previous venography of the proximal femur.

There were 4 levels of intraosseous blood circulative improvements based on the degree and time cost of cavity fading: (a) no circulative improvement indicated no obvious cavity fading (**Figure 1F**); (b) insufficient circulative improvement indicated partial cavity fading with nearly half cavity residual after 30 minutes (**Figure 2C, 2D**); (c) good circulation improvement indicated obvious cavity fading with less than 1/3 cavity residual within 30 minutes (**Figure 2E, 2F**); and (d) excellent circulation improvement indicated complete cavity fading within 30 minutes (**Figure 3C, 3D, 3F**). There was a positive correlation between the numbers of empty points and the cavity fading procedure.

The ICVG related time cost of a single hip varied from 30 to 90 minutes (50 minutes on average) and was shortened after the surgeon was familiar with the ICVG technique. The X-ray exposure of one hip ICVG was 10 to 30 times, and no case of radiologic dermatitis was reported. There was no allergy to the contrast material or other ICVG related complications within the 2 weeks following the procedure.

Discussion

Although the debridement procedure was perfectly designed to follow the ideal head-preserving operation principles, orthopedic surgeons appear to prefer core decompression [1]. The reason may be that the principles of the core decompression procedure may be verified under fluoroscopic observation, whereas the debridement procedure may only be judged by experience. That is to say experienced surgeons do better job than junior ones, which was proofed in this study. The principles of the debridement procedure were easy to develop but difficult to practice. Therefore, we designed a new method referred to as intraosseous cavity-venography (ICVG), which provides a good image of the operative bone cavity and an evaluation of the intraosseous blood circulation.

ICVG images have four advantages to plain X-ray images in the evaluation of the extent and circulation of the operative bone cavity during the debridement and cancellous bone grafting procedure. First, the images of the operative bone cavity in ICVG have better quality compared with plain X-ray images. ICVG images exhibit high contrast and more details. Second, it was substantially more recognizable in the ICVG images compared with the plain X-ray images, especially for the inexperienced surgeons. Third, it was easier to obtain inter-observer agreement on the ICVG images without the influence of experience. The ICVG positive rates were the same, i.e., 100% between the observers; however, the plain X-ray positive rates were significantly different between the observers. Fourth, the blood circulative condition of the operative bone cavity may be evaluated by ICVG but not via plain X-ray.

The empty beginning points have both an anatomical basis and clinical importance. Ana-

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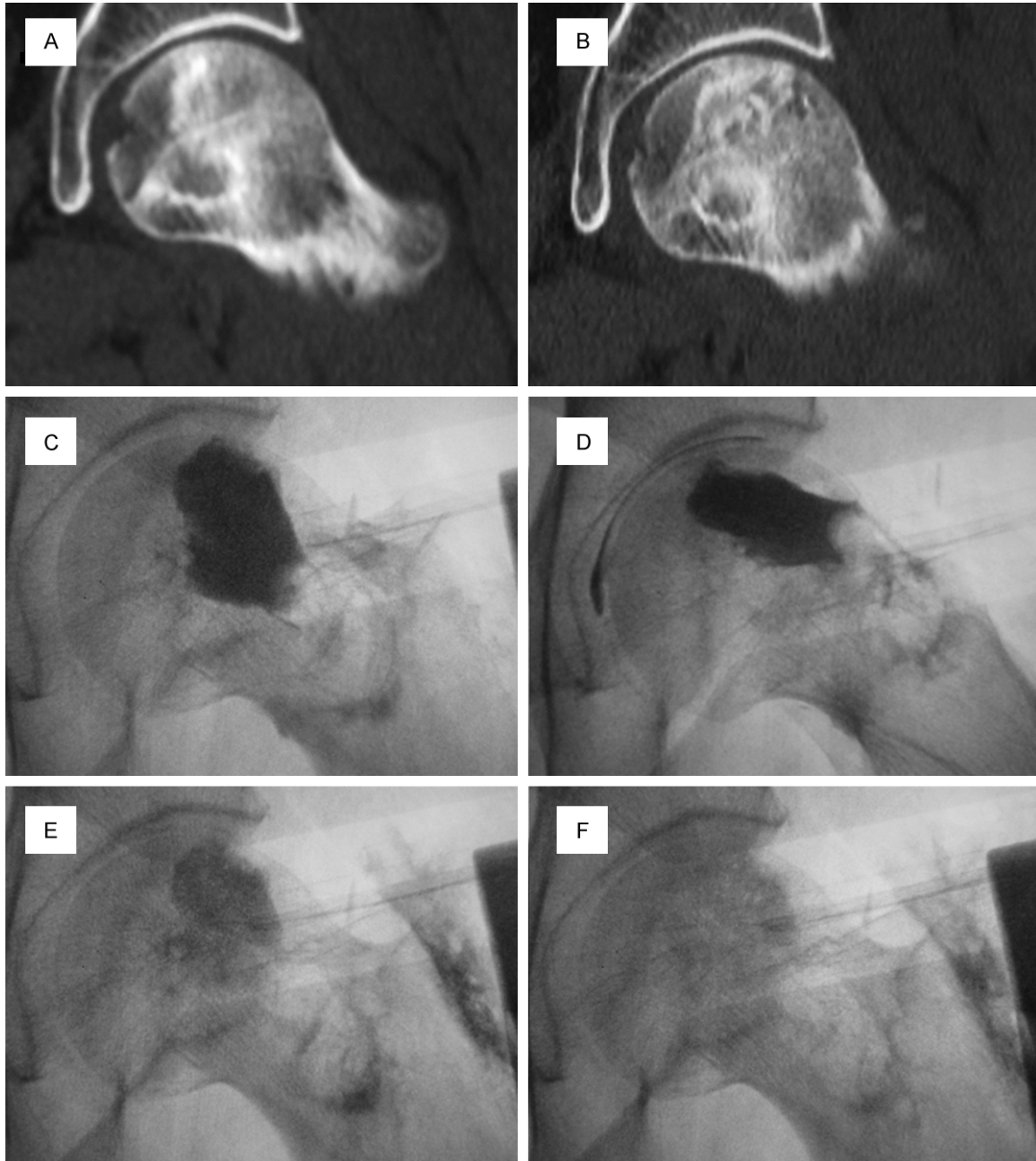


Figure 3. A 46-year-old male patient with bilateral NONFH (Left was in Ficat II and right was in Ficat Stage I). The debridement and cancellous bone grafting procedure with ICVG was performed in the left hip, and core decompression with venography was performed in the right hip. The osteonecrosis extent in the preoperative CT (A), bone grafted extent in the postoperative CT (B) and clearance extent by ICVG (C, D) matched with each other well. A full view of the operative cavity with three empty points was observed (C), and little contrast material remained after 35 minutes (F), which an indicated excellent improvement in the intraosseous circulation. The contrast material empty procedure was the same as previously described (C, E, F).

tomically, the empty beginning points comprised the normal intraosseous artery supply areas, and their distributions were correlated with four femoral head arterial supplies, the lateral epiphyseal arteries, the medial epiphyseal

artery, the superior metaphyseal arteries, and the inferior metaphyseal arteries [6]. Thus, 4 empty beginning points at most may be expected on ICVG images. Clinically, the number of empty beginning points directly influenced the

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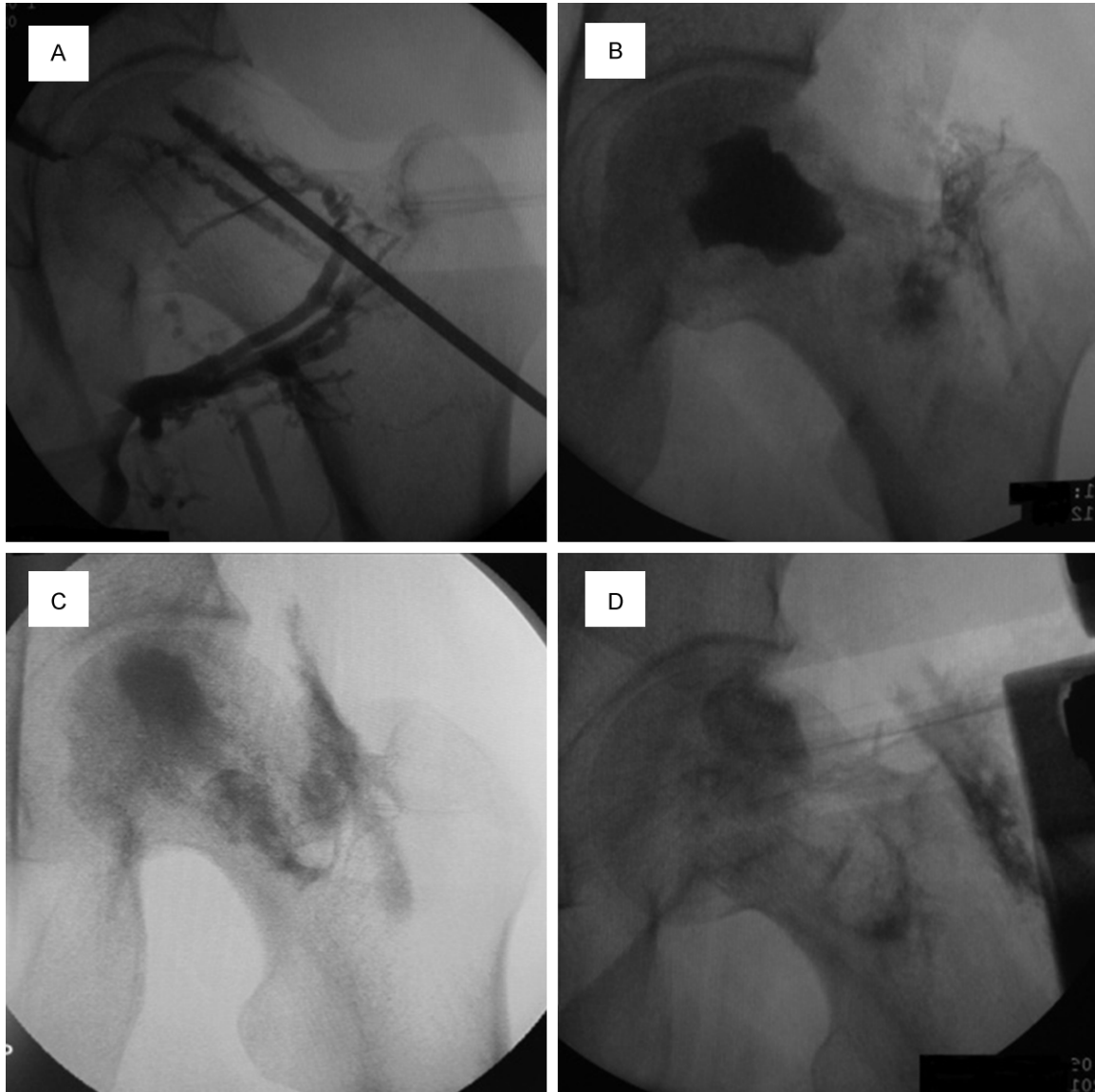


Figure 4. Differences between ICVG and venography were demonstrated. Venography (A) of the proximal femur indicated the named extraosseous veins in several seconds; however, ICVG indicated the contrast material moved from the cavity via the intraosseous cancellous bone into the extraosseous venous plexus and ultimately disappeared in every cavity fading case (B-D). A and D represent the cases in **Figures 3B and 1** and C in **Figure 2**.

time cost and the amount of residual contrast material. According to our observation, fewer than 2 empty beginning points will have no or delayed cavity fading, which indicated insufficient intraosseous circulative improvements. Therefore, more necrotic and sclerotic bone had to be removed toward the four arterial supply areas. The arterial supplies may be directly evaluated via empty points and indirectly evaluated via the visualization of intraosseous and extraosseous veins [7]. Thus, contrast material movements may occur from the operative cavity to the extraosseous veins.

ICVG exhibited a different venous drainage pattern compared with a previous study in two aspects. The time cost of the empty procedure in ICVG was decades of minutes; however, a previous study was decades of seconds. Moreover, the contrast material diluted into the surrounding bone walls at the beginning, then moved via the lateral base of the femoral neck into the extraosseous venous plexus in the superior-medial of the great trochanter, and ultimately disappeared in the ICVG images. However, the contrast material was empty via four extraosseous veins in the previous study

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[8]. The likely explanation for this difference was that the former occurred under normal intraosseous pressure, whereas the latter occurred under high pressure injection.

In conclusion, ICVG was an effective technique that did not require a special instrument to evaluate the operative bone cavity extent and circulation without complications with the exception of the limited delay procedure time.

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Disclosure of conflict of interest

None.

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