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Revascularization of femoral head ischemic necrosis with vascularized bone graft: a CT scan experimental study

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Abstract. An ischemic necrosis of the femoral head was induced in 15 mongrel adult dogs using the technique described by Gartsman et al. [10]. Five weeks later, a free vascularized rib graft was transferred into the previously induced ischemic femoral head. High resolution computed tomographic scanning was used to evaluate revascularization 4, 8 and 12 weeks after grafting. The femoral head exhibited new vessel formation throughout the study. Arterial terminal branches arising from the rib graft medullary and periosteal circulations extended beyond the rib graft, entered the head, and reached the subchondral plate. Even where the rib graft did not replenish the central core of the head, there was vascular supply from the grafted bone's vascular tree. These results suggest that a free vascularized bone graft is able to revascularize an experimentally induced ischemic femoral head necrosis.

Key words: CT scan – Osteonecrosis – Hip – Bone grafts – Revascularization – Animal research

Treatment of ischemic necrosis of the femoral head remains controversial. Many surgical procedures have been proposed, but no operation has been shown to be truly satisfactory in preventing collapse of the femoral head [1, 3, 6, 12, 14, 19, 21, 25, 26, 28]. Both free and pedicled vascularized bone autografts have been used to manage the condition [4, 8, 9, 15, 18, 20, 23, 27]. These approaches provide physiologic stimulation of neovascularization and new bone formation, an excellent source of blood to the ischemic bone, which would greatly improve its circulation and, it is hoped, revascularize the femoral head [2, 7, 12, 16, 17, 22]. If a new blood supply were to be established, the ischemia would resolve.

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Vascularized fibular grafting for ischemic necrosis of the femoral head has also been used in animal research. Previous experimental studies from this laboratory have proven the feasibility of this procedure [11]. Also, computed tomographic (CT) scanning has been successfully used to study the intrinsic circulation of free vascularized bone grafts in dogs [13]. Therefore, the aim of this study of a canine model was to evaluate the effect on vascularity of a free vascularized rib graft in previously induced ischemic necrosis of the femoral head using a precise imaging technique. For this purpose we employed high resolution CT.

Materials and methods

Fifteen skeletally mature male and female mongrel dogs weighing 22–33 kg were studied. Surgical procedures have been described in a previous report [13]. Briefly, in the first stage the left femoral head was devascularized using the technique described by Gartsman et al. [10]. Five weeks later, an anterior rib graft 6–8 cm in length was harvested from the ninth left rib. The graft was based on the periosteal circulation from the intercostal pedicle [13]. The left hip was operated upon using an anterolateral approach, and the bone wax previously placed into the femoral neck canal was removed. A 1.5 × 2-cm core was drilled from the lateral aspect of the proximal end of the femur – just distal to the greater trochanter – through the middle part of the trochanteric and neck zones to the center of the femoral head. The graft's anterior tip was placed into the capital hole and the posterior end fixed by an appropriate Blount staple to the lateral femoral cortex. The graft's vascular bundle was then exteriorized through the femoral lateral cortical hole, and microvascular anastomoses were made between the posterior intercostal pedicle and the caudal gluteal bundle (Fig. 1).

Dogs were killed in groups of five at 4 weeks (group 1), 8 weeks (group 2), and 12 weeks after the graft operation (group 3). Immediately, the left proximal third of the femur was harvested and the Blount staple removed. After the patent vessels were located, the graft's vascular pattern was perfused with a washing solution of 50 ml saline with 5 ml 1% sodium heparin. A perfusion pump injected this solution at a constant pressure of 120 mm Hg. After the vascular tree was washed, a radiographic dye of micro-

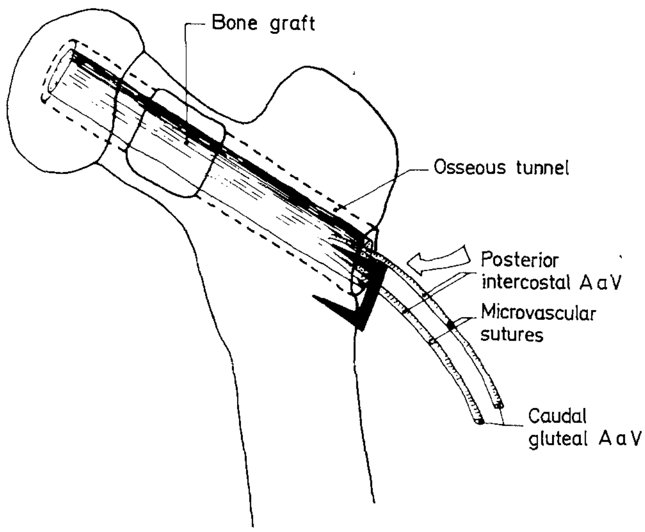

Fig. 1. Drawing of second operative procedure. The rib graft is housed in the central core of the previously induced femoral head necrosis. Graft vessels are anastomosed to the host's vessels (Reproduced from [13])

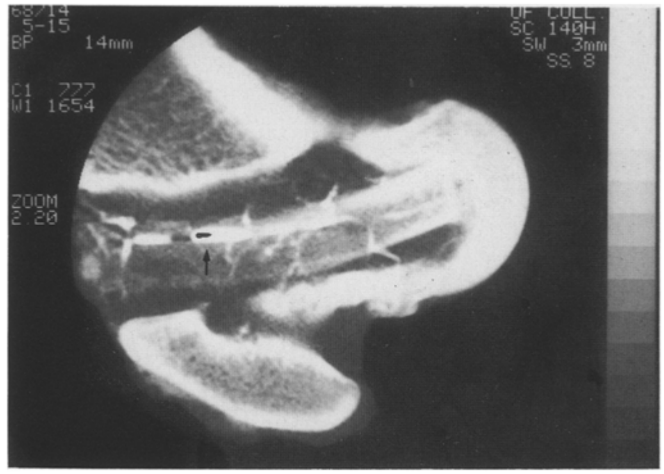

Fig. 2. Group 1, CT scan coronal view. Posterior intercostal artery is patent (*arrow*), but no vessels enter the head of the femur. (Slice width 3 mm; CT magnification ×2.20)

Table 1. CT scan program used in the experiment

Scan mode	Normal body
Position	Coronal, sagittal
Sample density	High
Scan diameter	140 H
Scan speed factor	30 s
Collimator aperture	Ultrafine
Slice width	3 mm, 10 mm
Tilt	0.0 degrees
Swivel	Variable
Zoom factor	2–4.14
Reconstruction filter	C
Rotation angle	0.0 degrees
Image matrix	512×512

nized barium sulphate (Micropaque, Picker Corporation, Highland Heights, OH) was injected at the same pressure.

The femoral samples were studied with a high resolution CT scanner, model Exel 2002 Scint. In each sample, 10–15 slices, spaced 1–2 mm to each other, were obtained coronal and sagittal to the femoral neck. The sequential study included the femoral head, subcapital area, the femoral neck, and the trochanteric zone. A CT scan program for this study was developed (Table 1), and an industrial fine-grain film was used. The CT scan analysis determined the femoral head cancellous bone, crescent sign appearance, shape of the femoral head, and the interphase with the rib graft. Vessels within the proximal femur were evaluated for origin, caliber, spread, and distribution.

Results

Group 1

At 4 weeks, we could see fusion of the intracapital rib tip within the femoral head. In both sagittal and coronal planes, callus formation between the femoral bone and the rib graft was clearly appreciable (Figs. 2, 3). At this early stage the scan for all the dogs showed a patent

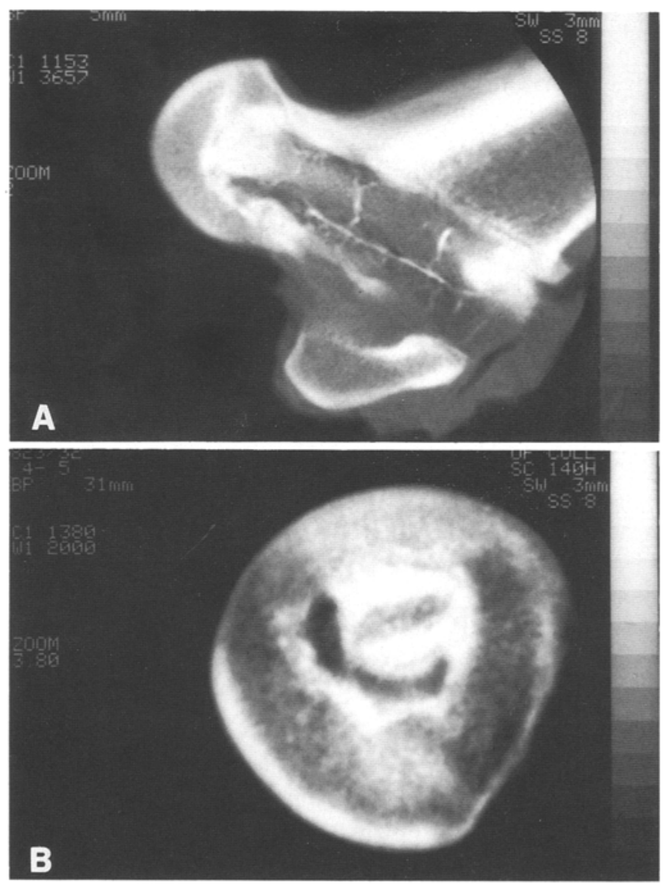

Fig. 3 A, B. Group 1. **A** Even though the feeding artery of the graft is patent, no vascular ingrowth within the femoral head is appreciable. Note consolidation of the intracapital graft tip within the femoral head. (Slice width 3 mm; CT magnification ×2). **B** The interphase between the head and the graft exhibits bone callus formation, but no vessels are seen within the head of the femur. (Slice width 3 mm; CT magnification ×3.80)

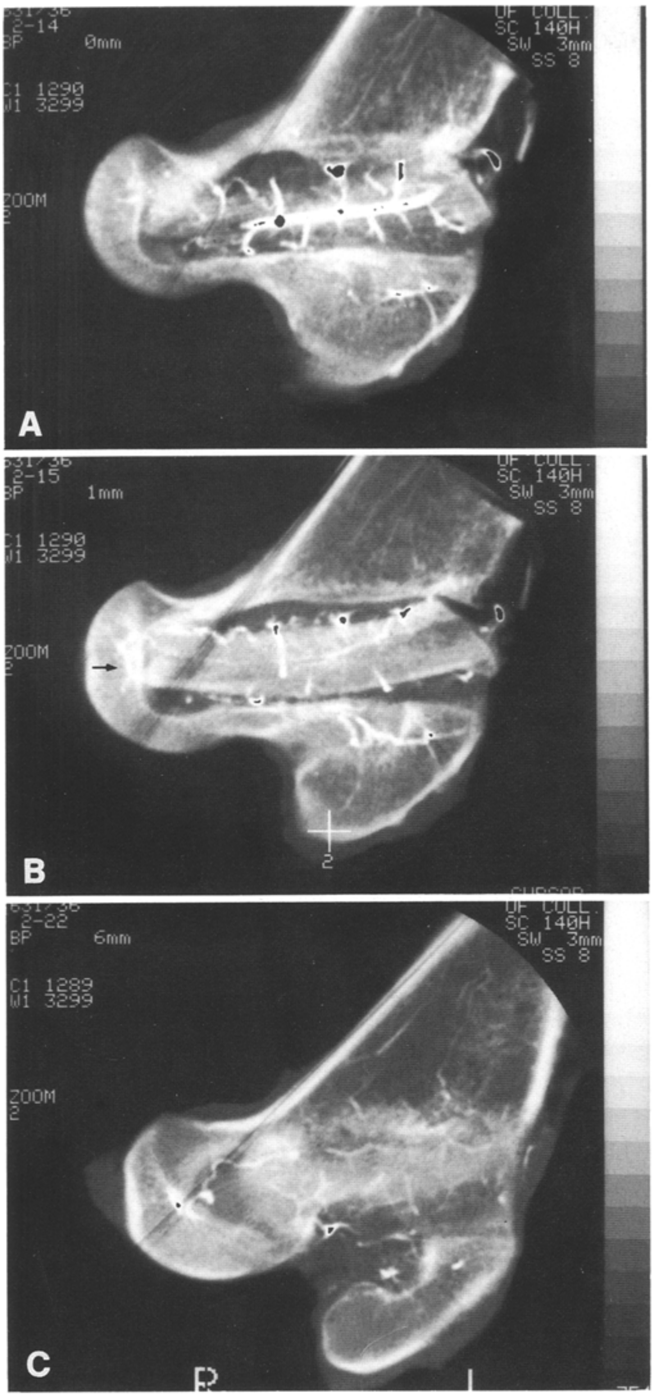

Fig. 4A–C. Group 2, CT scan serial study. **A** The thick trunk of the posterior intercostal artery is clearly appreciable, as well as gross secondary branches. Some vessels extending from the graft periosteal system enter the femoral head. **B** Graft cortices are diffused, and the scan densities of the graft and the femoral head are similar. The graft end resting beneath the femoral head shows consolidation. Periosteal radicles along the course of the rib graft are also observable. The distal medullary artery of the rib crosses the border between the grafted bone and the femoral head, entering the latter (*arrow*). **C** This film shows the distal end of a periosteal branch within the femoral head. (Slice width 3 mm; CT magnification ×2)

posterior intercostal artery running along the course of the rib graft. Some vessels dependent on the posterior intercostal artery formed periosteal branches, but these were few in number and limited in extent. The medullary vessels of the rib graft were also seen. However, neither the periosteal nor the medullary vessels reached the femoral head, as shown in Figs. 2 and 3.

Group 2

After 8 weeks, films showed further incorporation of the rib graft within the structure of the femoral head. Cortices were diffused, and the femoral head bone was continuous with the graft bone. The graft end resting beneath the femoral head hole showed fusion (Figs. 4B, 5C, D). Also, the head remained round, and no subchondral crescent sign was seen (Figs. 4, 5). There was an intense proliferation of vessels, largely periosteal, although frequently both rib vascular systems were connected to each other, forming vascular networks from which second order vessels emerged. Vascular growth was directed toward adjacent zones, such as the greater trochanter, femoral neck, and subcapital areas. Both distal branches of the periosteal circulation and the distal medullary artery of the grafted rib crossed the head/graft interphase, reaching the femoral head (Fig. 4B, C). In the sagittal plane, vascular branches arising directly from the posterior intercostal artery reached the femoral head bone and even extended toward the subchondral plate (Fig. 5C, D). These branches usually appeared as gross single, straight vascular trunks divided into secondary branches. They turned toward different areas of the femoral head, following a radiant path. Each vessel arose perpendicularly at different levels from the graft rib's major artery, leaving the nourishing artery every 4–8 mm (Fig. 5).

Group 3

At 12 weeks, as after 8 (group 2), the rib graft's intracapital end showed fusion within the femoral bone. Continuity between rib and femoral head was observed (Figs. 6A, 7B). Since there were patent vessels, the atmosphere around the rib graft remained open (Fig. 7A). The posterior intercostal artery was patent, as were the periosteal and medullary vascular systems of the rib. Both systems exhibited anastomoses between each other, as shown in Fig. 7A, D. New vessel formation coming from the posterior intercostal artery or the periosteal network produced thick arterial trunks. These trunks and the distal medullary artery entered into the femoral head, crossing the head/graft interphase (Fig. 6B). In the sagittal slices (Fig. 7), terminal branches from the posterior intercostal artery or from its periosteal network were seen spreading into the femoral head. These vessels reached the subchondral plate, even in areas where the central core of the head had not been replenished by the vascularized graft (Fig. 7C, D). The new

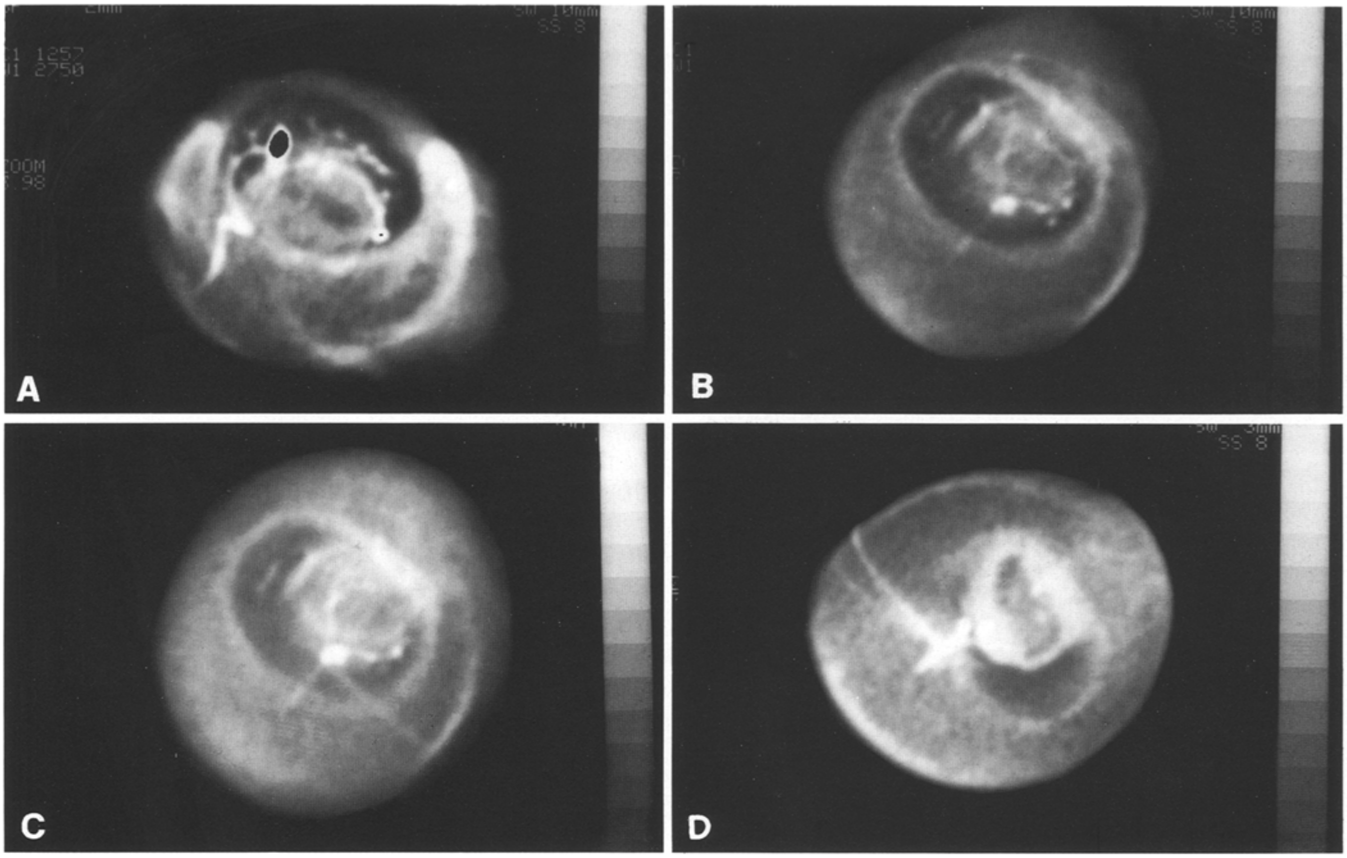

Fig. 5A–D. Group 2. Sagittal sequential study of the dog in Fig. 4. **A** Section from the distal cervical zone. Patent posterior intercostal artery and circumferential periosteal ring that tend to combine with two longitudinal arteries. A thick arterial branch dependent on the periosteal ring runs toward the posterior cancellous femoral bone. **B** Subcapital level (8 mm distal to the preceding slice). Both the periosteal and the medullary vascular circulations are patent. In addition, some communications are present, joining both systems. **C** Section taken at the middle part of the femoral head. Two radial vessels arise from a periosteal longitudinal branch; one of them reaches the subchondral plate. (**A–C** Slice width 10 mm; CT magnification ×3.98). **D** Femoral head level. Bone graft exhibits consolidation and there is no evidence of crescent sign. Two gross parallel arteries emitted by a periosteal branch of the graft reach the femoral head's subchondral plate. (Slice width 3 mm; CT magnification ×3.84)

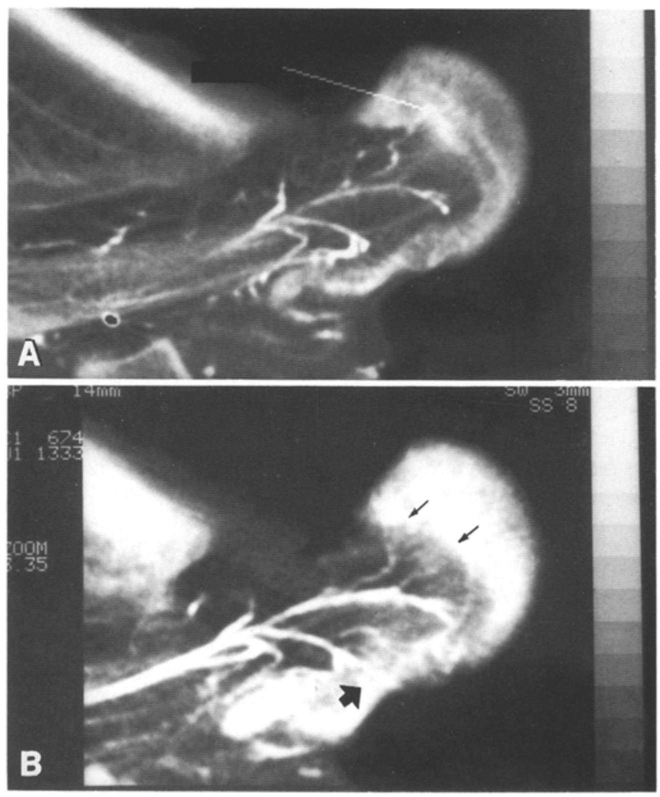

Fig. 6A, B. Group 3. CT scan of coronal series of the proximal end of the femur. **A** There is continuity between the donor and host bones (*broken line*). Several periosteal terminal branches arising from the posterior intercostal artery extend toward the femoral head and terminate within the intracapital graft end, the head of the femur and the subcapital area. (Slice width 3 mm; CT magnification ×2.20) **B** The gross trunk of the posterior intercostal artery is clearly appreciable running along the course of the rib graft. Its terminal end runs toward and enters the superior pole of the femoral head. Another two branches dependent on the graft's feeding artery spread toward the center and the inferior pole of the head (*small arrows*). A pair of branches arising from the posterior intercostal artery reach the upper subcapital area (*large arrow*). (Slice width 3 mm; CT magnification ×3.35)

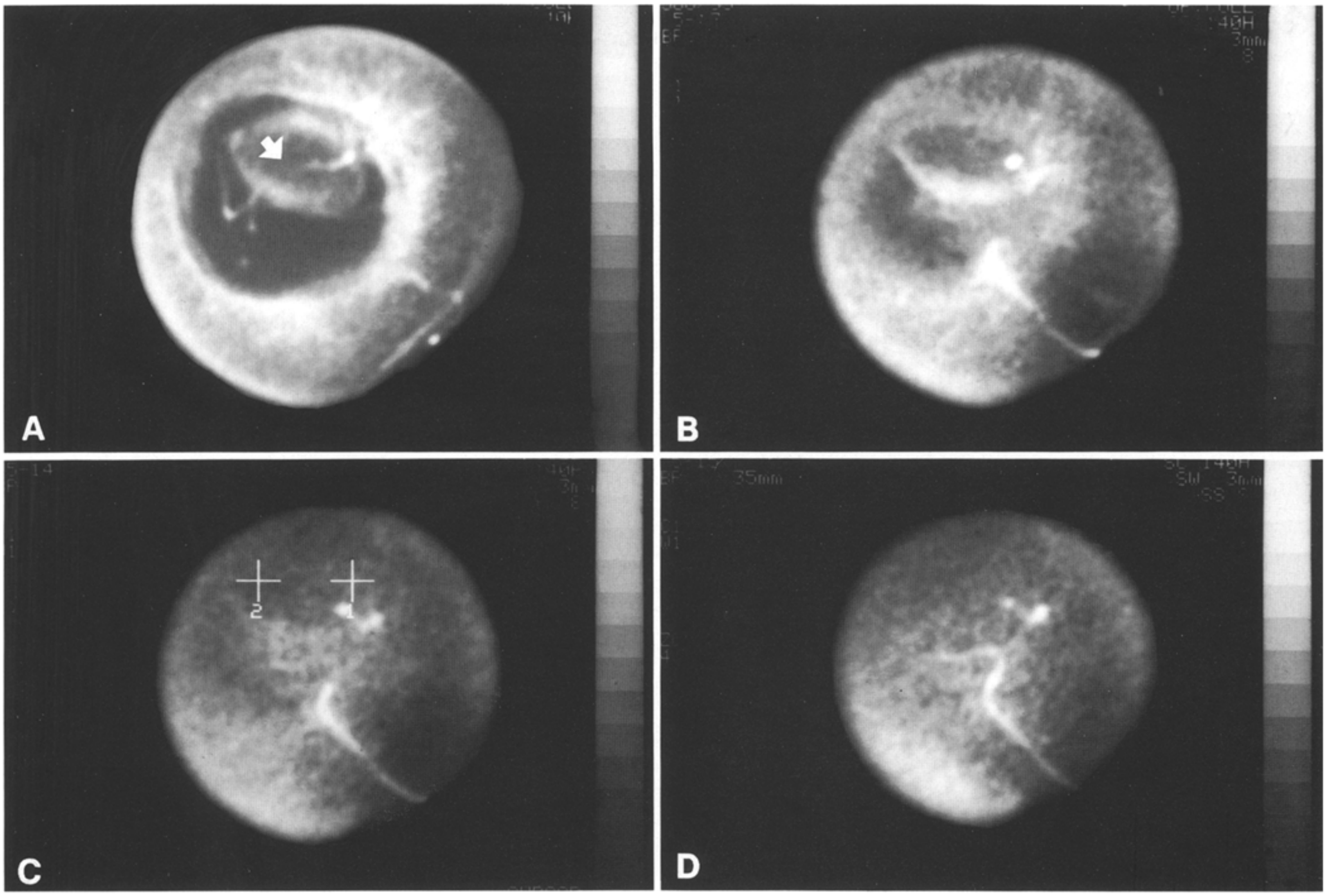

Fig. 7A–D. Group 3. Series of femoral head level sagittal slices. **A** The periosteal and medullary vascular systems communicate with each other by a branch which traverses the rib (*arrow*). In the inferior right quarter of the head, an arterial branch reaches the subchondral plate. **B** The graft distal medullary artery remains patent at the rib's endosteal surface. A gross arterial trunk from the periosteal system enters the femoral head and extends distally into the subchondral plate. **C, D** Even where the rib graft does not replenish the central core of the head, there are some terminal branches from both the periosteal and the medullary vascular systems of the graft beyond the graft/host border. In **C**, a branch runs more than 5 mm (distance between the *crosses*) to reach the subchondral plate. In **D**, radiant and transverse arteries in different directions are also appreciable. (Slice width 3 mm; CT magnification ×4.14)

vessels were distributed through the subchondral plate and extended as much as 6–8 mm (Fig. 7C).

Discussion

Since most conservative surgical procedures proposed for ischemic necrosis of the femoral head have not been highly successful in preventing late segmental collapse of the femoral head, another physiologic alternative must be attempted [1, 3, 6, 12, 14, 19, 21, 25, 26, 28]. Theoretically a vascularized bone graft would provide all the tissues the ischemic bone needs to be repaired: living cells and patent vessels [2, 7–9, 11–13, 15, 17, 18, 20, 23, 27, 29]. This study has demonstrated the existence of a source of neovascularization (patent vessels) toward the ischemic bone from the vascularized rib graft.

To our knowledge, this is the earliest CT angiographic evidence of revascularization of ischemic necrosis of the femoral head using a free vascularized bone graft. These angiographs demonstrate a patent posterior intercostal artery directed toward the femoral head and the medial third of the rib graft. Several authors have pointed out that this is the most valuable sign of a good prognosis for the revascularized hip [8, 18, 23, 27]. These vessels promote neovascularization into the ischemic bone followed by new bone formation [8, 15, 23, 27]. Although in the earliest follow-up period (4 weeks) there was no extension of vessels into the host femoral head, we could visualize several gross arteries entering the head soon after. These truly "new nutrient arteries" arose from the rib graft's posterior intercostal artery, its periosteal network, and its medullary cavity vascular pattern. They crossed the graft/host bone border, spreading beyond this point into the head. These gross, single arteries were distributed in different directions, reaching the subchondral plate. According to some authors [2, 5, 7, 16, 22, 24], if the subchondral plate disruption could be avoided, no segmental collapse would be expected. We share this opinion [11, 12].

The new nutrient arteries provided a new vascular and cellular source toward the previously avascular bone. A free vascularized bone graft has all the requirements of a potentially high osteogenic tissue: living bone (osseous and allied cells) and patent vessels (blood supply and vascular wall atmosphere) [13, 29]. Thus after increasing the blood supply into the ischemic bone, a reparative process will begin, and the normally inexorable fate of the segmental collapse will be arrested or at least delayed. Furthermore, the vascularized graft, which bridges the center of the femoral head and the intertrochanteric region, could support the weight-bearing femoral head surface, preventing collapse [7, 12, 18, 22, 23, 27].

In this way, our free vascularized bone graft transferred to an ischemic necrosis of the femoral head produces an extensive new vascular formation within the avascular tissue. The results of this experimental study are encouraging; further investigation will define the best clinical application for free vascularized bone graft in the ischemic necrosis of the femoral head.

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