A histological study of the necrotic area after transtrochanteric anterior rotational osteotomy for osteonecrosis of the femoral head

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We studied nine patients who had had a transtrochanteric anterior rotational osteotomy, as developed by Sugioka, for osteonecrosis of the femoral head. At a mean of 2.5 years after the initial operation we carried out a histological study of the previously necrotic femoral head which had not shown collapse of the new primary weight-bearing site. In seven joints, there was proliferation of fibrous tissue in the dead trabeculae with vascular ingrowth. New bone covering dead trabeculae created the characteristic appearance of 'creeping substitution'. However, these changes were limited and did not extend over the entire necrotic area. Dead bone remained in all the cases. In the other two heads we did not observe proliferation of fibrous tissue or vascular ingrowth, only dead trabeculae and dead bone marrow.

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Osteonecrosis of the femoral head is often found in relatively young people and its treatment should attempt to preserve the hip in view of the high rate of failure of replacement arthroplasty in young patients.¹⁻³ The technique of transtrochanteric anterior rotational osteotomy (TRO), was developed by Sugioka⁴ as a joint-preserving procedure which prevents further deformity by transposing the necrotic area from a site of primary weight-bearing to a secondary area. According to Sugioka⁴ the procedure also improves congruency of the joint and promotes bone regeneration within the necrotic area. Long-term satisfactory results have been reported.^{5,6} Apart from two patients studied by Sugioka et al⁵ there have been no histological

studies of postoperative regeneration of the necrotic area. We have therefore carried out a histological study of the regeneration process after TRO by collecting biopsy samples from this site.

Patients and Methods

Between 1989 and 1999 we performed TRO on 28 joints in 24 patients with idiopathic osteonecrosis of the femoral head. According to Sugioka⁴ if the ratio of the intact area of the posterior part of the femoral head to the total articular area of the surface, as seen in a lateral radiological view, was 33% or higher, operation was indicated. After operation the ratio of the transposed intact area of the articular surface area of the femoral head to the weight-bearing surface of the acetabulum, as observed on an antero-posterior (AP) radiograph, was expected to be 36% or higher.

Since 1993, we have performed superselective angiography before operation on 18 hips in 15 patients to identify the nutrient arteries of the femoral head.⁷ Of these patients, nine men consented to have bone biopsies at the time of removal of the screw. Their hips were graded according to Ficat's method,⁸ and six joints were classified as stage 2 and three as stage 3. In all joints the area of osteonecrosis was classified as I-c, according to the Japanese Ministry of Health and Welfare classification.⁹ The time from surgery to bone biopsy ranged from two to four years with a mean of 2.5 years and the mean period from bone biopsy to clinical assessment was 1 year 2 months (6 months to 2 years). There were no cases of collapse of the new weight-bearing site. Progression of collapse in the necrotic portion, which had become a secondary weight-bearing site, was observed in eight patients. The extent of the collapse was measured by comparing the lateral view at the time of biopsy with the immediate postoperative lateral view on radiographs (Table I, Figs 1 and 2).

Clinical assessment was undertaken using the system of Merle d'Aubigné and Postel,¹⁰ grading pain, mobility and walking ability with scores from 0 to 6. Before surgery the mean score was 11.3 ± 1.1 (10 to 12). This improved (Wilcoxon signed-rank test, $p < 0.01$) to a postoperative score at the time of biopsy of 15 ± 1.5 (13 to 17). The pain score improved from 2.3 ± 0.4 to 5.2 ± 0.8 , the mobility

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Fig. 1a

Fig. 1b

Radiographs showing anteroposterior (AP) (a) and lateral (b) views of a hip immediately after operation.

Fig. 2a

Fig. 2b

AP (a) and lateral (b) views of the same hip at the time of biopsy 2 years and 4 months after operation. The biopsy was performed through the hole of the screw (black arrow). Progression of collapse in the necrotic area can be seen on the lateral view (white arrow).

Table I. Details of the nine patients (all men) who had bone biopsies at the time of removal of the screw after TRO

Case number	Age at operation (yr)	Aetiology*	Ficat ⁸ stage at operation	Ratio (%)		Postoperative period at operation (mth)	Progressive collapse of necrotic area (mm)
				Preop [†]	Postop [‡]		
1	52	S	2	52	50	48	
2	34	S	2	38	49	26	<3
3	39	S	2	47	48	24	<3
4	38	A	3	38	42	28	<3
5	25	A	3	40	43	28	≥3
6	33	S	2	37	43	30	≥3
7	39	A	3	35	48	24	<3
8	39	A	2	33	40	26	<3
9	37	A	2	40	44	24	<3

* S, steroid induced; A; alcohol associated

[†]preoperative ratio of intact area of the posterior part of the femoral head to total articular surface on the lateral view of the radiograph

[‡]postoperative ratio of transposed intact articular surface of the femoral head to the weight-bearing surface of the acetabulum on the AP view of the radiograph

score from 4.9 ± 0.6 to 5.0 ± 0.5 and the walking score from 4.4 ± 0.7 to 4.8 ± 0.6 .

Tissue preparation. After removal of the screws bone was collected, using a trephine, from the tip of the screw hole at the osteochondral junction under fluoroscopic control (Fig. 2). The specimen was fixed in 4% formalin, decalcified, embedded in paraffin and stained with haematoxylin and

eosin. In addition, in two patients (cases 3 and 6), before the bone biopsy, tetracycline was twice administered orally to double label the bone. Non-decalcified specimens were prepared with a Villanueva bone stain.

Histological examination. The histological examination was carried out on a single section from each specimen using image analysis (Mac Aspect; Mitani Corporation,

Fig. 3

Case 4. Photomicrograph of the necrotic area. Fibrous tissue accompanied by vascular ingrowth is seen within the dead trabecula. Osteoblasts lay down new bone over necrotic trabeculae ('creeping substitution'). (D, dead bone; N, new bone, haematoxylin and eosin $\times 100$).

Fig. 4

Photomicrograph of the necrotic area in case 3. Tetracycline fluorescence indicates new mineralisation near the surface of dead trabeculae (Villanueva stain $\times 100$).

Tokyo, Japan). The proportion of dead trabeculae was calculated in the centre of the necrotic zone in a area of $15\,000\,000\,\mu\text{m}^2$. Bone trabeculae were considered to be dead if there was a uniform loss of lacunar osteocytes or if there were only osteocyte ghosts present in a zonal area of trabecular bone.¹¹ Three observers measured each specimen three times, and the averages were calculated.

Results

In all nine patients, a boundary between the healthy and necrotic area, corresponding to increased radiodensity, was seen on histological examination at the distal end of the biopsy specimens. In this zone, thickened trabeculae and viable osteocytes were seen in all cases, but the proliferation of fibrous tissue and blood vessels was scanty in the trabeculae.

In the necrotic area, a proliferation of fibrous tissue and vascular ingrowth was noted in the dead trabeculae in seven of the nine patients. In these seven, new bone laid down by osteoblasts over necrotic trabeculae created the

characteristic appearance of 'creeping substitution' (Fig. 3).^{12,13} This appearance did not involve the entire necrotic area, with dead bone remaining in all cases. In the remaining two patients, the proliferation of fibrous tissue accompanied by vascular ingrowth was not seen; only dead trabeculae and dead bone marrow were present. In all nine, the proportion of dead trabeculae ranged from 14.7% to 86.9% (Table II). Only one patient (case 3) showed successful tetracycline labelling (Fig. 4). The proportion of dead trabeculae did not significantly correlate with either the preoperative or postoperative ratios. There was a significant correlation between the ratio of dead trabeculae and progressive collapse (over 3 mm) of the necrotic area (Mann-Whitney U test, $p < 0.05$).

Discussion

Sugioka et al⁵ described two patients in whom the femoral head was examined following total hip replacement eight years and six years and five months after TRO. In both patients necrotic bone had been replaced by new bone. The histological findings could have been produced by the effects of osteoarthritis and could not be attributed only to the effects of TRO. Our study focused on histological changes in the necrotic area of the femoral head and was conducted relatively early after the osteotomy. The results, therefore, can be considered to be reliable in assessing the direct effects of TRO on bone regeneration.

In seven of nine patients new fibrous tissue was present in part of the dead trabeculae, as was the formation of closely adjacent bone. In none of the patients, however, was the entire necrotic area replaced by new bone, indicating that bone regeneration is an extremely slow process.^{14,15} Although the weight-bearing stress placed on the necrotic area should have been reduced after TRO in which the Ficat stage was 2 or greater, the presence of a thick

Table II. Histological findings in the nine men who had had TRO

Case	Mean ($\pm$ SD) ratio of dead trabeculae (%)	Fibrous tissues with vascular ingrowth at necrotic area
1	27.9 $\pm$ 4.5	Moderate
2	77.4 $\pm$ 4.6	Moderate
3	16.4 $\pm$ 2.8	Slight
4	14.7 $\pm$ 2.8	Moderate
5	85.1 $\pm$ 5.2	None
6	86.9 $\pm$ 4.0	None
7	55.2 $\pm$ 4.6	Moderate
8	50.6 $\pm$ 4.3	Moderate
9	45.9 $\pm$ 4.6	Moderate

osteosclerotic area at the boundary between the necrotic and healthy areas indicated that there was no significant increase in vascular ingrowth towards the necrotic bone.¹⁶

Early postoperative collapse of the new weight-bearing site observed after TRO carried out in countries other than Japan, has been attributed to race-dependent differences in the anatomy of the hip, particularly differences in the state of the artery to the posterior column at the time of rotation of the femoral head.^{17,18} It is also possible that the nutrient arteries of the femoral head were not adequately identified and preserved. We believe that if precise preoperative measurements of the necrotic area are made, and if the nutrient arteries of the femoral head are preserved during surgery, the part of the femoral head transposed to the weight-bearing site will not collapse in the early postoperative stage.^{7,19} In those patients in whom collapse of the new weight-bearing site was prevented, some collapse of the anterior necrotic portion transposed from the primary weight-bearing site was seen. In such cases, progression of osteoarthritis develops because of anterior instability of the femoral head.^{6,7}

Bone regeneration in the necrotic area is extremely slow after TRO and the progression of collapse of the necrotic area of the femoral head cannot be prevented entirely, regardless of its anterior transposition. Therefore, to prevent osteoarthritis due to progression of the necrotic process, it may be necessary to add a mechanical reconstruction such as a morsellised and impacted bone graft^{20,21} or a free vascularised fibular graft^{22,23} to this procedure.

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