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Computed tomography with multiplanar reformation and three-dimensional image reconstruction in the preoperative evaluation of adult hip disease

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Summary. *Computed tomography (CT) with multiplanar reformation and three-dimensional (3D) image reconstruction was used pre-operatively to outline the bony morphological changes and femoral-acetabular relationships in 25 adult patients suffering from hip disease. Diagnoses included ischaemic necrosis of the femoral head, osteoarthritis, rheumatoid arthritis, calcium pyrophosphate dihydrate (CPPD) crystal deposition disease, previous trauma and chronic dislocation. Polyethylene models of the femora and acetabula were constructed from three-dimensional contouring of CT data and compared with resected specimens in patients subjected to subsequent total hip arthroplasty. Information provided by this imaging technique was useful in both selecting and guiding the most appropriate surgical procedure and it was found that models depicted the actual bony contours with reasonable accuracy. CT combined with multiplanar reformation and 3D analysis may be the optimal pre-operative means of assessment of the diseased adult hip.*

Résumé. *La tomodensitométrie (TDM) avec reconstruction multiple et tri-dimensionnelle (3 D) des images a été utilisée avant l'intervention afin de visualiser les modifications de la morphologie osseuse et les rapports entre le cotyle et la tête du fémur chez 25 sujets adultes présentant une hanche pathologique. Les diagnostics étaient nécrose de la tête fémorale, arthrose, arthrite rhumatoïde, chondrocalcinose, séquelles de traumatismes et de luxation congénitale. Des modèles en polyéthylène du fémur et du cotyle ont été réalisés à partir des données tridimensionnelles fournies par la TDM et comparées avec les pièces opératoires réséquées chez les patients traités par arthroplastie totale. Les informations apportées par cette technique d'imagerie ont été utiles à la fois pour indiquer et effectuer le meilleur procédé opératoire et on a trouvé que les modèles représentaient les véritables contours osseux avec une précision satisfaisante. La TDM avec reconstruction multiple et tri-dimensionnelle (3 D) pourrait être le meilleur moyen pré-opératoire d'évaluation d'une hanche pathologique chez l'adulte.*

Key words: *Computed tomography, Image reconstruction, Hip disease*

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Introduction

The hip joint is commonly affected by a variety of disorders in adults. Reconstructive surgery is often indicated to relieve or prevent pain, for diminished function, deformity and progressive articular damage [24]. The operative options available to the orthopaedic surgeon include total joint arthroplasty, hemi-arthroplasty, cup arthroplasty, osteotomy, arthrodesis and excision arthoplasty [9, 24]. The choice of the most appropriate operation depends on many factors including the age and activity level of the patient, the nature of the underlying disease process, susceptibility to generalised sepsis and secondary joint infection, the severity of symptomatology and the anticipated duration of post-operative rehabilitation [9, 24].

More important from a technical standpoint are the morphological relationships of the femoral head and acetabulum and the amount and integrity of available bone stock on both sides of the joint [17]. Conventional radiography, tomography and contrast arthography are imaging techniques which have been employed previously for morphological assessment [20, 21]. Computed tomography (CT) has been specifically used in the preoperative determination of femoral bone density in patients selected for double cup arthroplasty [4, 13]. This report describes the use of multiplanar reformation and three dimensional (3D) image reconstruction of CT-acquired data in the pre-operative assessment of a variety of hip disorders in adults.

Materials and methods

Twenty-five men aged from 32 to 78 years with hip disease were studied. Diagnoses included ischaemic necrosis of the femoral head (22 joints), osteo arthritis (7 joints), rheumatoid arthritis (4 joints), calcium pyrophasphate dihydrate crystal deposition disease (2 joints), previous trauma (2 joints) and chronic hip dislocation (1 joint). Thirteen patients had bilateral involvement and 2 had undergone previous contralateral total hip arthroplasty.

Each patient underwent conventional frontal and lateral radiography of the diseased hip(s), followed by CT. Image data acquisition was derived from a Technicare 2060 scanner using 2 mm slice thickness and incrementation. Individuals with contralateral orthopaedic implants were positioned obliquely with the craniocaudal axis angled relative to the scanner table, in order to avoid image degradation from streak artefacts. This enabled the most diseased portions of all the femoral and acetabular joint surfaces to be adequately studied. Multiplanar reformation and 3D image reconstruction of CT-acquired data were undertaken using a Cemax 1000 image processor[1]. Based upon CT date and 3D contouring, disarticulating polyethylene models of each acetabulum and proximal femur were constructed and made available to the surgical team preoperatively. The surface morphology of these models was then compared with that of the resected specimens in the patients.

Results

Both radiologists and orthopaedic surgeons felt that the multiplanar reformations and 3D images contributed valuable pre-operative information regarding the degree of articular surface deformity, the extent of osteophytosis and bone fragmentation (Figs. 1–4) and the availability and condition of residual bone stock on both sides of the joint (Figs. 2, 3). The positional relationship between the femur and acetabulum were well shown by these techniques, and were particularly important in chronic hip dislocation (Fig. 4). Besides demonstrating the pattern of femoral head migration in the coronal plane (superior, medial, lateral or axial), as shown on conventional frontal radiographs [21], CT with multiplanar reformation enabled relative movement in the sagittal plane to be documented (Figs. 4, 5).

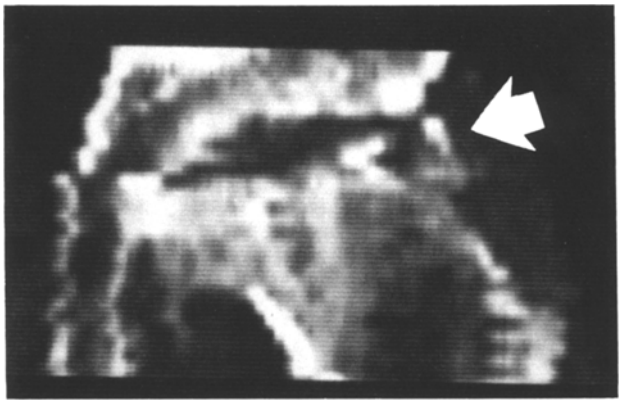

Fig. 1. Advanced osteoarthritis. Reformatted image in the coronal plane demonstrates marked flattening of the femoral head in association with superior migration, osteophytosis, and fragmentation (*arrow*). Such images can be obtained in any desired plane from axially-acquired CT data within several seconds

In cases of ischaemic necrosis, valuable preoperative information was obtained demonstrating the extent of infarction and the degree of subchondral bony collapse. The imaging manipulations were better than conventional axial CT in identifying and quantifying areas of depression involving the articular surface of the femoral head (Figs. 6, 7). Subchondral fractures through necrotic bone, corresponding to the crescent sign of conventional radiography [21], were also more easily recognised.

The geographical pattern of ischaemic necrosis related to marginal buttressing, zonal lucency representing the reactive fibrous interface and sequestration of necrotic bone [21] was equally well appreciated on axial CT images, multiplanar reformations (Fig. 6) and 3D sections (Fig. 8a).

Although CT coronal, sagittal and oblique reformations also provided better information regarding the position and size of subarticular cysts (Figs. 4b, 5, 6), they offered no advantage over conventional radiography in assessing joint space narrowing. Compensatory bony buttressing and peri-articular erosions were well demonstrated by multiplanar reformation and 3D image reconstruction.

The three-dimensional surface contours and sections and polyethylene models were found to accurately represent the actual configuration of acetabular and femoral specimens removed at

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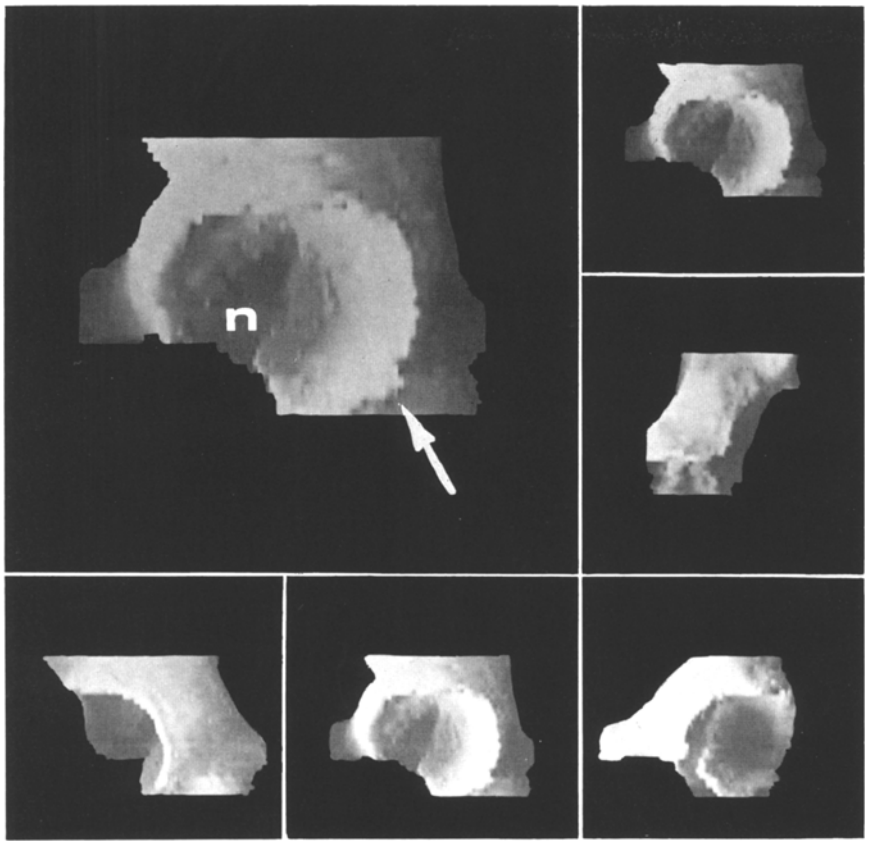

Fig. 2. Mild osteoarthritis. 3D surface contour images of the acetabulum with the femur selectively removed reveal marginal osteophytosis (*arrow*) and permit optimal assessment of available bone stock. The acetabular notch (*n*) is well depicted. Such images allow viewing of the anatomy from any desired angle

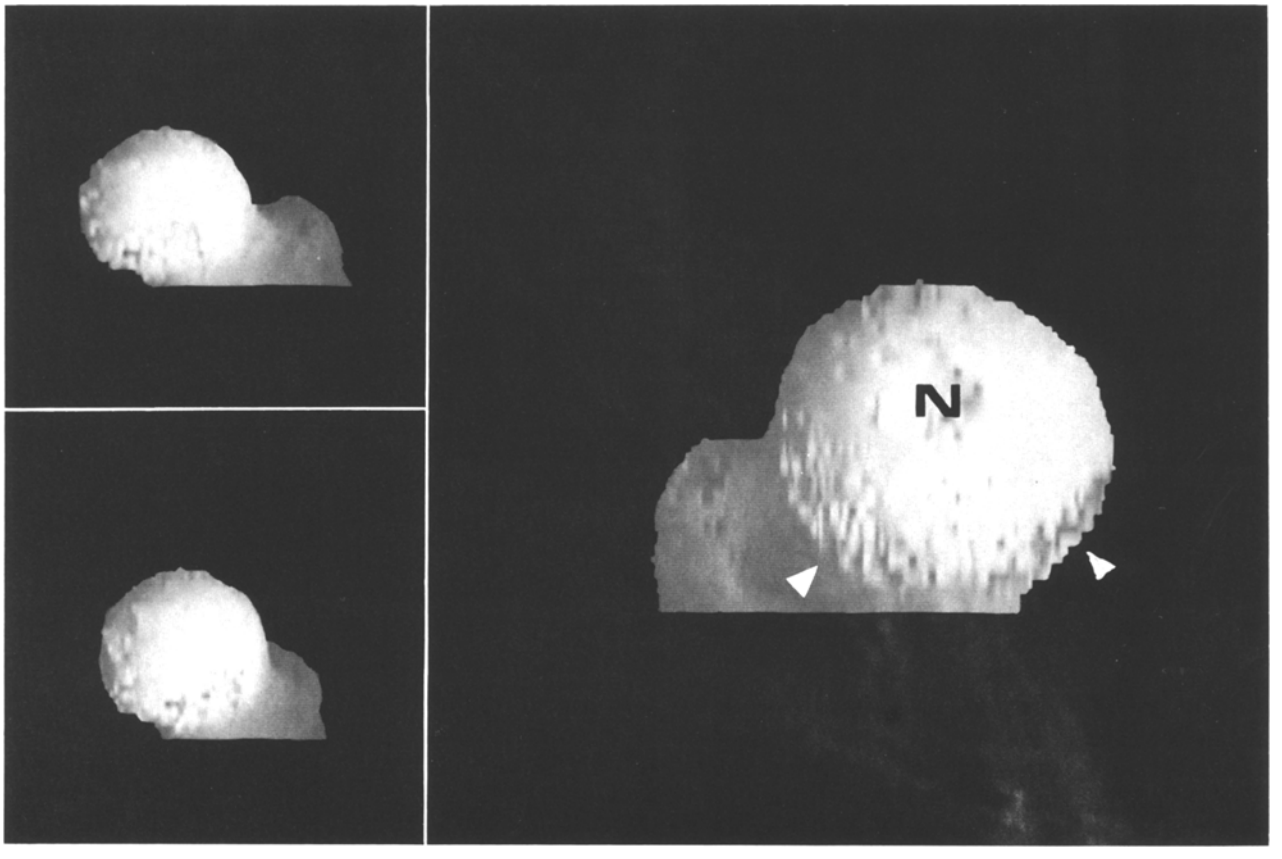

Fig. 3. Osteoarthritis. 3D surface contour images of the proximal femur following selective removal of the acetabulum reveal the normal fovea centralis *N*) and marginal irregularity related to mild osteophytosis (*arrowheads*)

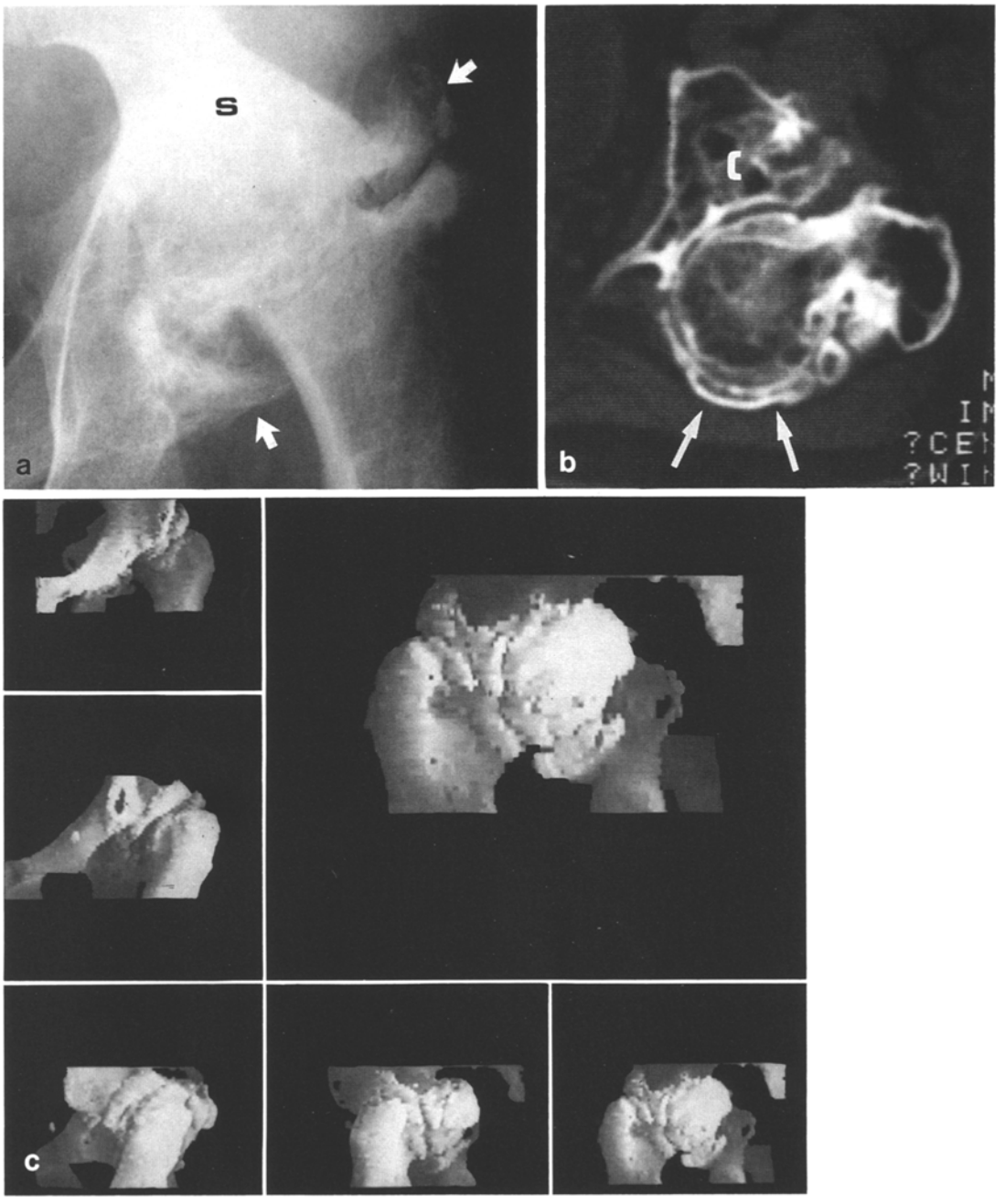

Fig. 4a–c. Chronic hip dislocation; **a** Conventional frontal radiograph of the left hip demonstrates obliteration of the joint space superiorly related to marked sclerosis [S] and cephalad migration of the femoral head. Prominent osteophytosis and fragmentation are also evident (*arrows*); **b** Axial CT image confirms the findings in **a**, but in addition reveals marked posterior subluxation of the femoral head. A thin rim of compensatory acetabular bone has formed posteriorly (*arrows*), and subchondral cysts (*c*) are also noted; **c** The abnormal femoral-acetabular relationship and secondary bony alterations are optimally depicted on 3D surface contour images

subsequent operation (Fig. 8). The 3D slices of each joint employing variable thicknesses and planes of interest accurately demonstrated the integrity of subarticular bone. The operative team, including surgeons-in-training, found the models (Figs. 9, 10) useful for practising anticipated procedures including osteotomy and placement of prostheses.

Discussion

Previous musculo-skeletal applications of multiplanar reformation and 3D image reconstruction

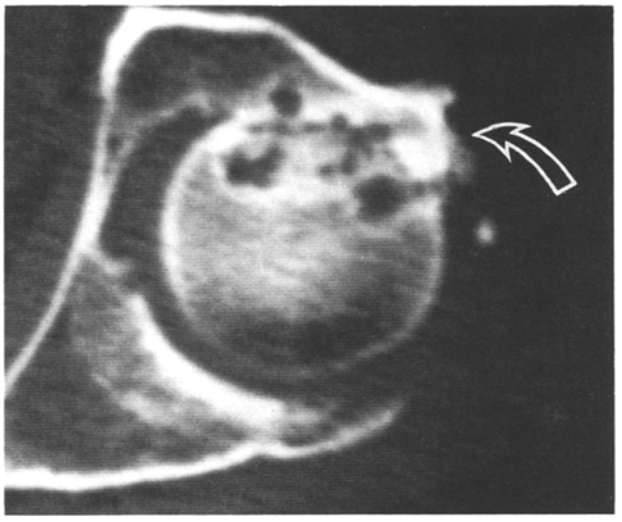

Fig. 5. Osteoarthritis. Axial CT image of the left hip demonstrates anterior migration of the femoral head relative to the acetabulum, related to the localisation of typical degenerative changes including joint space loss, subchondral cysts, and sclerosis (*arrow*)

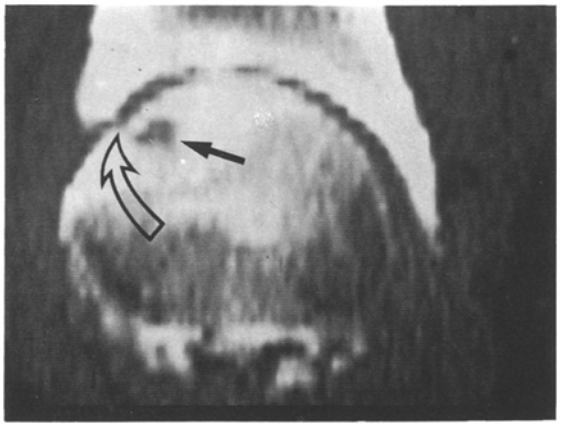

Fig. 6. Ischaemic necrosis of the femoral head. Reformatted image in the sagittal plane reveals characteristic increased density of the weight-bearing aspect, in association with a subchondral cyst (*straight arrow*) and subtle collapse of the articular surface (*curved arrow*). The latter finding was not evident on conventional radiographs

of CT data have included pre- and post-operative assessment of cranio-facial malformations, temporo-mandibular joint display, temporal bone imaging, depiction of vertebral column deformities, characterisation of acetabular fractures, and optimal demonstration of anatomy at other complex sites including the wrist and knee [2, 10, 16, 22, 27, 28]. We and others have previously described the specific use of these techniques in the pre-operative evaluation of ischaemic necrosis of the femoral head [23]. We now report the use of these

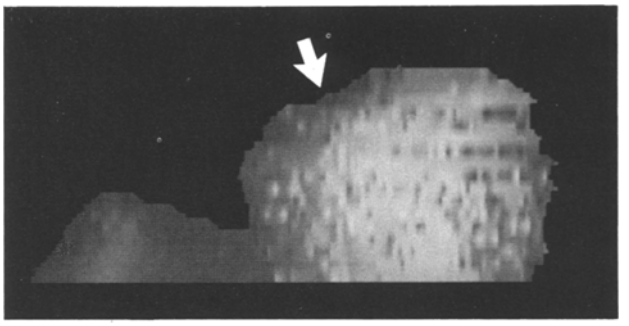

Fig. 7. Ischaemic necrosis of the femoral head. 3D surface contour image of the proximal femur with the acetabulum removed demonstrates collapse of the weight-bearing surface (*arrow*) related to the underlying disease

techniques in the pre-operative assessment of adult hip disease in general. Several authors have previously applied multiplanar imaging at this site [6, 8].

When the surgeon has decided that operation is necessary in adult hip disease he relies on diagnostic imaging studies to help select the most appropriate procedure and plan its technical aspects. In our experience, CT with multiplanar reformations and 3D image reconstruction is the best method for assessing the bone stock on both sides of the joint. These software manipulations of CT data should also be useful in delineating other alterations in contour of the joint surface, such as those which occur following anterior dislocation [5].

Accurate pre-operative information of the extent of infarction and the degree of collapse in ischaemic necrosis of the femoral head is important in the surgical management of patients with this disorder [11, 15, 18, 25]. Conventional radiography is often inadequate because of the limited projections of the femoral head which can be obtained and the obscuring of the head by adjacent acetabular bone [21]. Conventional tomography is valuable [21], but yields images which can be difficult to interpret due to blurring of bone outside the plane of interest; the radiation dose is also relatively high. CT optimally depicts the extent of infarction [3, 4, 13], but axial images poorly demonstrate associated collapse of the articular surface, particularly when it is not severe. Since multiplanar reformation and 3D image reconstruction of CT data can identify, quantify, and accurately positions areas of collapse involving the ischaemic femoral head, they have proved useful in both selecting and planning the appropriate operation. Previously, evaluation of the extent of necrosis has been performed using crude arc measure-

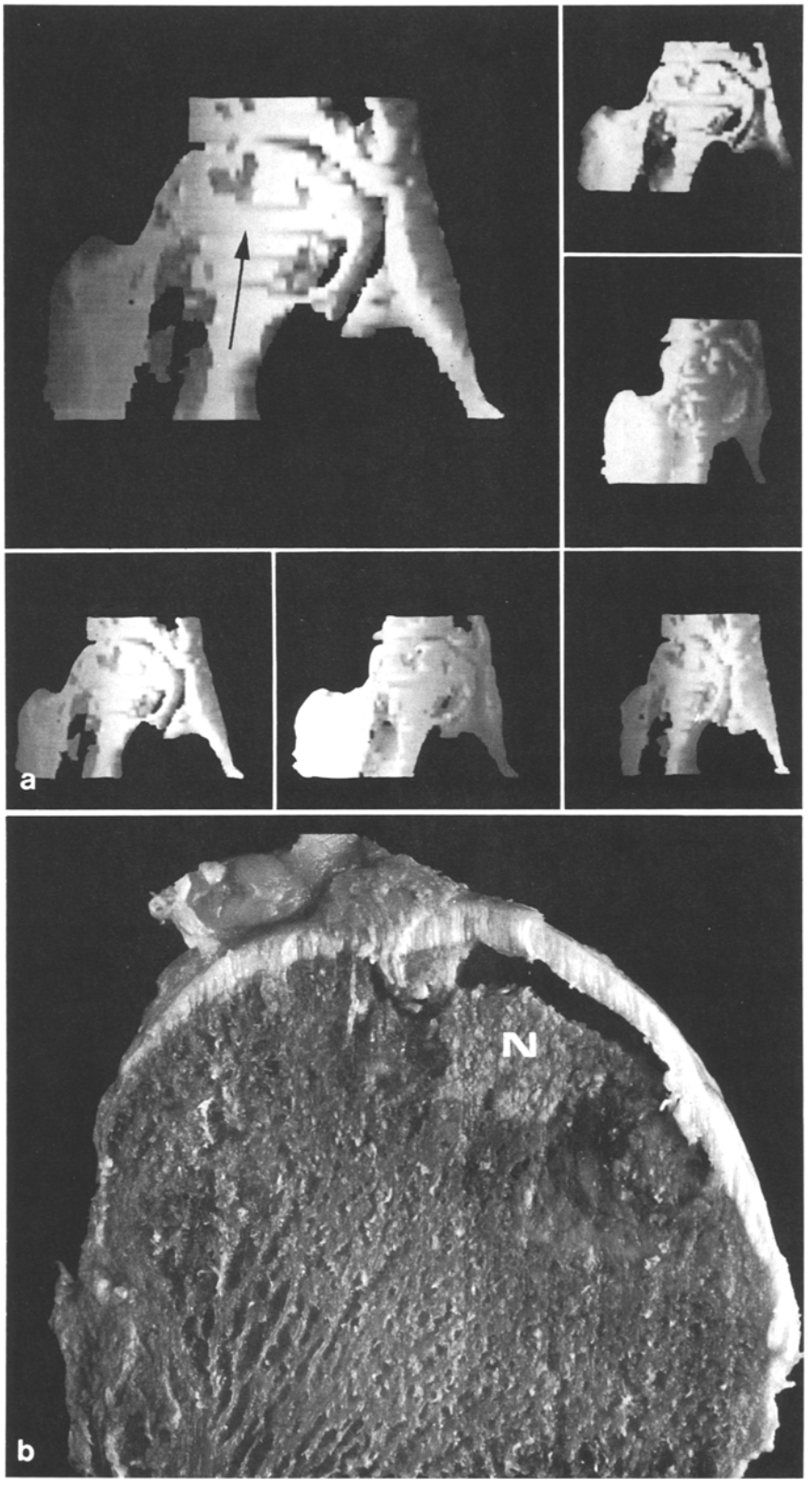

Fig. 8a, b. Ischaemic necrosis of the femoral head. **a** 3D sectional images in the coronal plane reveal deformity of the weight-bearing aspect related to collapse of the articular surface. Alternating areas of lucency and increased density are noted in the subchondral necrotic zone (*arrow*). Such images can be generated in any desired plane and specified thickness; **b** Corresponding photograph of section through resected specimen confirms the imaging abnormalities (N = zone of necrosis and collapse)

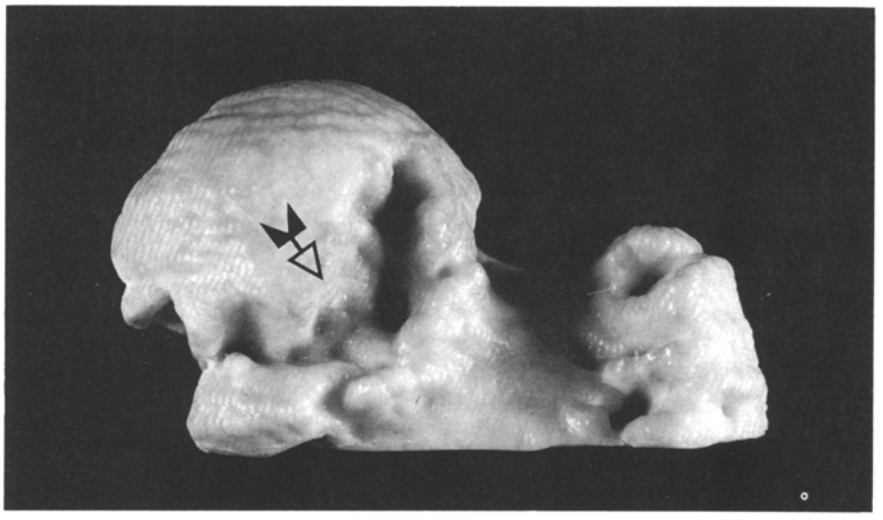

Fig. 9. Post-traumatic deformities of the femoral head. Polyethylene model of the proximal femur constructed from axially-derived CT data reveals a prominent cleft (*arrow*) near the head-neck junction related to a previous injury which correlated well with findings at surgery

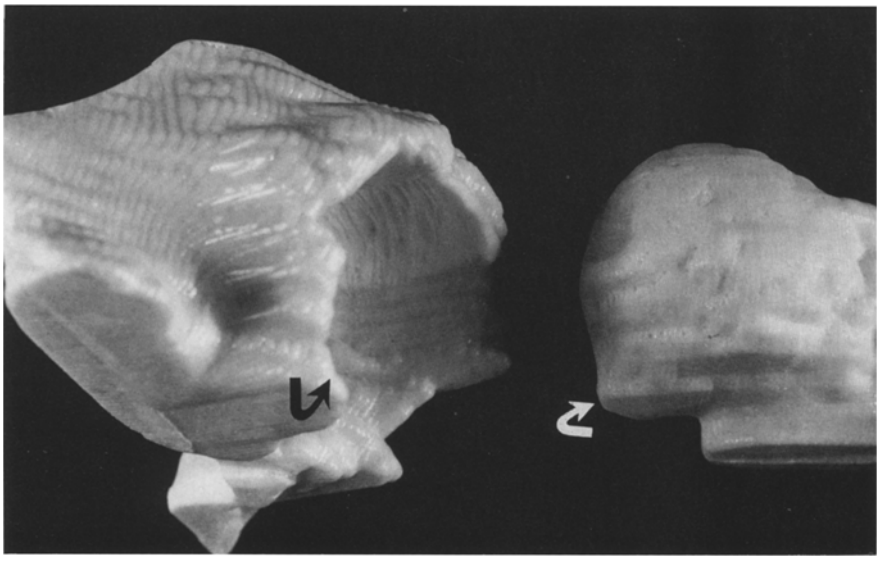

Fig. 10. Osteoarthritis. Disarticulating polyethylene models of the acetabulum and femur depict marginal osteophytosis (*arrows*) and are useful in surgical planning

ments derived from frontal and lateral conventional radiographs [11].

The ability to construct physical models of bone by 3D contouring of CT-acquired data represents a major advance in the surgical planning. Using similar techniques, successful construction of cranial prostheses from CT data has recently been achieved [14]. In our experience, 3D polyethylene models were beneficial in displaying bony anatomical relationships and in enabling the surgical team to practise the intended procedure. With appropriate software manipulation, data acquired by cross-sectional imaging techniques may in the future provide the orthopaedic surgeon with specific pre-operative information regarding details of technique.

In order to obtain optimal multiplanar reformations and 3D images, two technical requirements must be met. CT data must be obtained contiguous or overlapping intervals using the thinnest possible slices, and the patients must remain still between sections. Although this technique takes longer adequate information may be obtained reasonably quickly. Our examinations have averaged 25 slices in patients with contralateral implants and 35 slices in those who have not had a previous operation, enabling more extensive study without encountering streak artefacts.

Multiplanar reformation and 3D image reconstruction do not add diagnostic information which is not already present on axial CT images. A noticeable loss of spatial resolution is inherent

in the contouring process which is utilized for the latter. Nevertheless, these techniques present CT-acquired data in a format which optimises visualization of spatial relationships. Consequently, based upon our limited clinical experience, we consider CT combined with multiplanar reformation and 3D analysis to be the best method for pre-operative evaluation of hip disease in adults.

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