Arch Orthop Trauma Surg (2000) 120 : 88–95

ORIGINAL ARTICLE

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Cone prosthesis for the hip joint

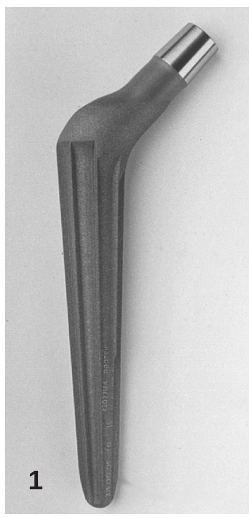
Received: 22 March 1999

Abstract The shape of the proximal segment of the femur must be taken into account when implanting femoral endoprostheses, especially those intended for cementless anchorage. Numerous femoral prostheses are available for the proximally broadly extending, "trumpet-shaped" morphology. However, the femur often has a narrow, more cylindrical configuration, as is frequently seen with dysplastic hip joints, but variants of the anatomical constitution or ethnic variants are also found. Conventional femoral prostheses with a proximal transverse oval or rectangular cross-section are often incorrectly positioned in those cases because they can fracture the narrow bones. In many instances, even a pathological anteversion attachment cannot be adequately corrected. The cone prosthesis is ideal for this morphology when pre-operative planning indicates good contact between the bone cortex and the middle third of the prosthetic stem. The tapered anchorage of the cone stem in the medullary cavity reamed to a cone shape promotes primary stability, which is a fundamental prerequisite for the osseointegration of a coarse blasted titanium implant. The sharp longitudinal ridges on the prosthetic stem, which tend to cut into the bone, ensure extensive rotational stability, which explains why thigh pain is not associated with the cone prosthesis. The cone prosthesis has proved its worth in 635 implants performed over 9 years, with highly satisfactory clinical and X-ray results. The surgical technique is relatively straightforward, and complications are rare. The patients' subjective satisfaction is particularly remarkable. The success of the operation lies in correct preoperative planning, which ensures that the morphology of the selected femur guarantees contact between the bone cortex and the middle third of the prosthetic stem.

Introduction

The narrow, cylindrical morphology of the femur represents an important anatomical variable which can complicate or even render impossible the implantation of a conventional total endoprosthesis. The following criteria are particularly relevant.

Given the narrow, cylindrical configuration of the proximal segment of the femur, the diameter of the medullary cavity is correspondingly narrow. Furthermore, the proximal end of the femur in dysplastic hips is arranged in an anteversion position of 60° or more. This morphology continues distally as far as the level of the lesser trochanter. Conventional femoral prostheses, which have a broad, transverse oval profile, do not fit into the cylindrical medullary cavity and are also turned into a pathological anteversion position through the bone cross-section on implantation. This problem is avoided thanks to the round stem cross-section of the tapered prosthesis (Figs. 1, 2).



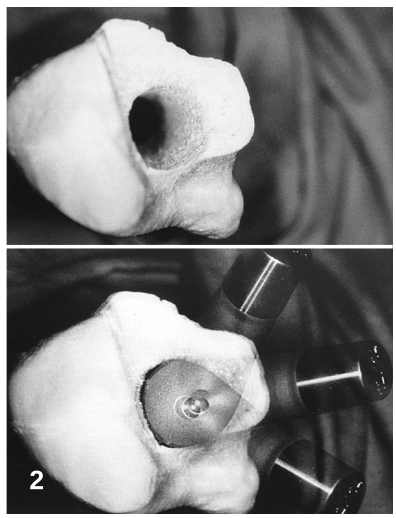


Fig. 1 Cone prosthesis. The titanium implant has a cone stem with a tapered angle of 5°. Eight sharp longitudinal ridges are evenly distributed over the entire circumference of the prosthetic stem. The titanium surface is coarse blasted for osseointegration

Fig. 2 The round stem facilitates unimpeded rotation during implantation to adjust the anteversion angle

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Another problem is frequently associated with a dysplastic femur. Medullary cavity deformity with bony scars capable of forming a significant barrier can occur in such cases following previous intertrochanteric or subtrochanteric osteotomies. Even this problem is easier to overcome with the cone prosthesis because the tapered seat in the often very hard bone is prepared for the prosthetic stem with sharp reamers, which are easier to use than the conventional rasps.

The implant

The cone prosthesis is designed for cementless anchorage and is therefore manufactured from the biocompatible titanium-aluminium-niobium alloy (PROTASUL-100*). The surface of the stem is coarse blasted for extensive osseointegration.

The cone stem has a tapered angle of 5° and eight longitudinal, relatively sharp ridges that are evenly distributed over the entire circumference and tend to cut into the bone on implantation. This principle ensures extremely stable anchorage, and rotational stability in particular. This rotational stability obviously explains why thigh pain is unknown with tapered prosthetic anchorage.

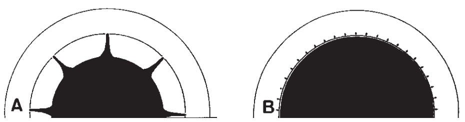
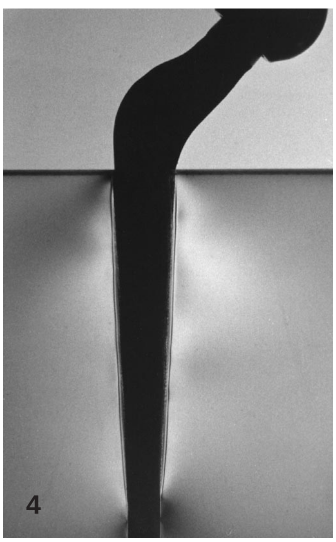


Fig. 3 Cross-section of the prosthetic stem. **A** The sharp longitudinal ridges tend to cut into the bone, thus providing a high degree of rotational stability. The ridges trigger intermittent transmission of load with high mechanical pressure, thus promoting osseointegration. There is a space between the ridges for the rapid revascularisation of the medullary cavity. **B** In comparison, a tapered stem without longitudinal ridges would continuously convey load to the entire circumference with relatively low mechanical pressure. The stem core is inevitably thicker for the same external diameter, thus producing greater rigidity



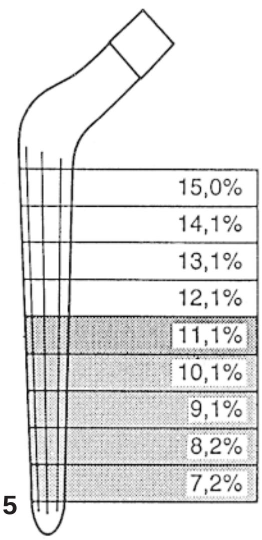


Fig. 4 The photo-elastic model displays continuous contact and continuous transmission of load to the tapered anchorage

Fig. 5 The tapered stem tends towards a more proximal transmission of load on geometrical grounds: the supporting surface per unit of length is greater in the proximal section of the stem with a greater diameter than in the thinner, distal section of the stem

The ridges intermittently carry load to the bone under high mechanical pressure, thus promoting stability and osteointegration. The space between the ridges, where the implant does not come into direct contact with the bone cortex, facilitates revascularisation of the medullary cavity because blood vessels can grow here prior to bone resorption (Fig. 3a). Another more beneficial effect of the longitudinal ridges lies in the reduction of the core cross-section, which makes the prosthetic stem somewhat more elastic. In comparison, a tapered stem without longitudinal ridges would have a larger core diameter (Fig. 3b), which would make the prosthetic stem far more rigid. A further consequence would be the continuous conduction of load to the contact surfaces with low mechanical pressure.

The CCD angle of the cone prosthesis is 135°, the neck length increasing with the diameter of the stem. The neck of the prosthesis has a standard 12/14 taper to accommodate ceramic or metal ball heads, each available in different neck lengths.

With tapered anchorage, the cone prosthetic stem is driven into the tapered medullary cavity. This produces continuous contact between the implant and the bone so that the size of the load transmitted depends on the extent of the contact surface. Strength is therefore conducted proximally because, with a taper, the surface per unit of length increases with the diameter (Figs. 4, 5), i.e. the supporting surface is greater per unit of length in the proximal section of the stem with a larger diameter than in the distal section [4, 5].

Long-term experience has shown that this conduction of load with tapered anchorage creates biomechanical conditions which are conducive to the structural adjustment of the bone. After a matter of months, the trabecular structure of cancellous bone adjusts to the mechanical load given by the prosthesis without triggering proximal stress protection (Fig. 6).

Sharp reamers with the diameters of the respective prosthetic stems are available for tapering the medullary cavity. The dimensions of the reamer are accurately geared towards those of the implant. There is a slight deviation only in the region of the tip of the reamer and prosthetic stem, where the reamer has a tapered angle of 2° over a length of 40 mm. Thus, in cases where the medullary cavity is very narrow, the prosthetic bed is reamed slightly more near the tip such that, in these very rare instances, solid jamming of the stem tip and any ensuing rigid, distal conduction of load is avoided (Fig. 7).

The cone prosthesis is available in 12 stem diameters ranging from 13 to 24 mm in order to suit individual anatomical conditions.

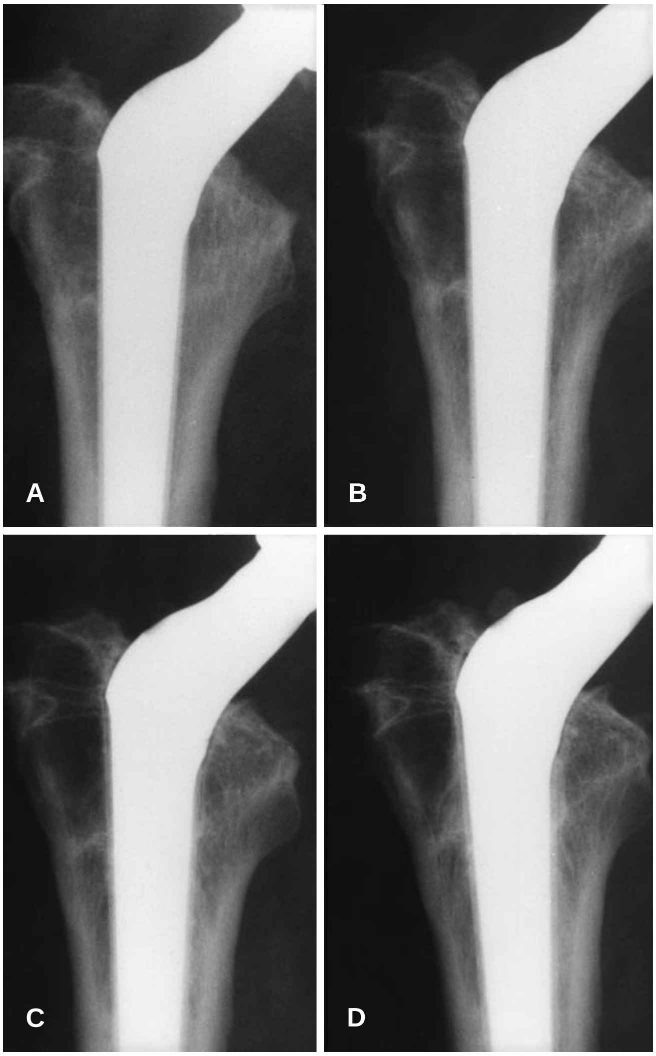


Fig. 6 The biomechanically conducive transmission of load during cone anchorage facilitates and accelerates the structural adjustment of the bone to the new mechanical situation. **A** X-ray shows the original bone structure 2 weeks after implantation. **B** Remodelling of the bone structure is evident after as little as 3 months. **C** New trabeculae of bone formed in the direction of the mechanical stresslines after 1 year. **D** Remodelling complete after 3 years. Proximal bone atrophy did not occur due to the proximal transmission of load

Preoperative planning

Preoperative planning facilitates the actual procedure and improves the quality of the surgery because the individual stages involved do not have to be considered and "attempted" during the operation. All the details are available at the start of surgery, having been planned in advance.

Preoperative planning requires good quality X-rays with a magnification scale of 1.15:1, upon which the planning templates are based. In order to obtain this magnification scale, the hip joint is assumed to be 10 cm above the tabletop of the X-ray apparatus, with a distance of 5 cm between the tabletop and flat surface of the film. A magnification scale of 1.15:1 is achieved with a distance of 115 cm between the focus of the X-ray tube and the film. In very obese patients, the bone can be higher above the tabletop. In such cases, either the distance between the X-ray and the film must be increased or a reference body of a specific length must be defined at bone level at the same time as the bone on the X-ray film. The magnification scale can be calculated from the ratio between the actual length of the reference body and the length shown on the film.

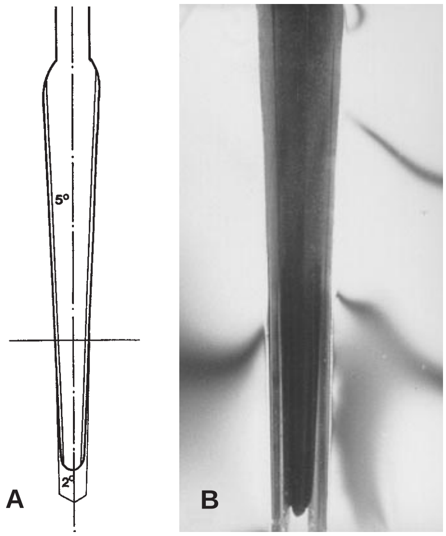


Fig. 7 **A** The tapered reamer has a tapered angle of 5° consistent with the cone prosthesis. The reamer has a tapered angle of 2° over a length of 40 mm only near the tip of the stem where more bone is reamed off. This prevents the tip of the prosthesis from becoming jammed with a distal conduction of strength in limiting indications. **B** A space between the tip of the stem and the prosthetic bed can be seen in the photo-elastic model

The first stage in the planning process involves the selection of suitable implants for the acetabulum and femur with planning templates on the original X-rays.

When selecting the cone prosthesis, care must be taken to ensure that the configuration of the femur guarantees close contact between the middle third of the prosthetic stem and the bone cortex, with the tip of the stem being unrestricted in the medullary cavity (Fig. 8).

It is especially important to select the correct stem diameter. The commonest mistake is to select a stem diameter which is too small, thus leading to subsidence of the prosthesis with tapered anchorage. The outline of the planning template accurately reflects the implant dimensions. When selecting the diameter, it should be borne in mind that a thin layer of bone will be removed with the reamer and that the sharp longitudinal ridges will tend to cut into the bone on implantation. Therefore, on selecting the correct stem diameter, the contour of the prosthetic stem on the planning template must overlap the inner contour of the bone cortex on the X-ray by 1 mm on both sides in the region of the centre third of the stem (Fig. 8).

A planning drawing offers numerous advantages, especially when prepared personally by the surgeon. Based on the sketches of the individual stages, the operator can

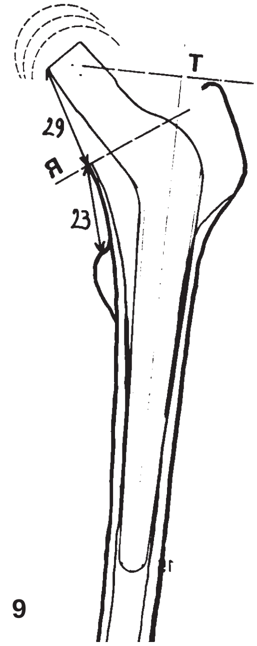


Fig. 8 Preoperative planning: the cone prosthesis with the appropriate stem diameter is selected using the planning template. The prosthetic stem must be in close contact with the femoral bone cortex in the middle third, the contour of the template overlapping that of the bone cortex by 1 mm on both sides. The tip of the prosthetic stem must not come into contact with the bone cortex

Fig. 9 The contour of the femur and the prosthesis, the resection surfaces and the reference distances are entered on the planning drawing

“mentally” plan the procedure in advance, having a mental picture of each stage involved. Finally, the outcome of the surgery is directly apparent from the sketch.

Initially, the cup implant with the centre of rotation is marked on the outline sketch of the pelvis. The current and corrected position of the tip of the greater trochanter is marked in order to check leg length. With the planning template, the contour of the cone prosthesis selected is incorporated in the planning drawing together with the resection line of the femoral neck and the trochanter reference line (Fig. 9). The planning sketch is then placed on the X-ray and the contour of the femur carefully transferred. The tip of the greater trochanter on the X-ray thus lies on the previous marking for the intended position of the trochanter and is generally tangent to the trochanter reference line, provided that leg length does not have to be altered.

Finally, the distance between the resection line and the proximal edge of the lesser trochanter is measured to give the resection plane of the femoral neck. When reconstructing severely deformed hips, other reference points can be marked on the drawing and their distances measured. All longitudinal measurements must be carried out according to the template scale that takes the X-ray magnification scale into account. All measurements must be entered on the plan so that they can be read off during surgery.

Surgical procedure

The tapered prosthesis can be implanted via all standard surgical approaches. After dislocating the femoral head, the neck of the femur is initially resected to clear the way for the implantation of the prosthetic cup. The scheduled distance from the lesser trochanter to the femoral neck resection plane is measured and the osteotomy position marked on the femoral neck. Osteotomy is then performed here with an oscillating saw. However, only the median 2/3 of the femoral neck cross-section is cut through as a complete cut could take the osteotomy into the greater trochanter. The residual lateral third of the femoral neck is cut through with a chisel positioned distally on the medial surface of the greater trochanter.

Once the prosthetic cup has been implanted, the femoral canal is opened on the osteotomy surface of the femoral neck and a curved sensor known as the “medullary

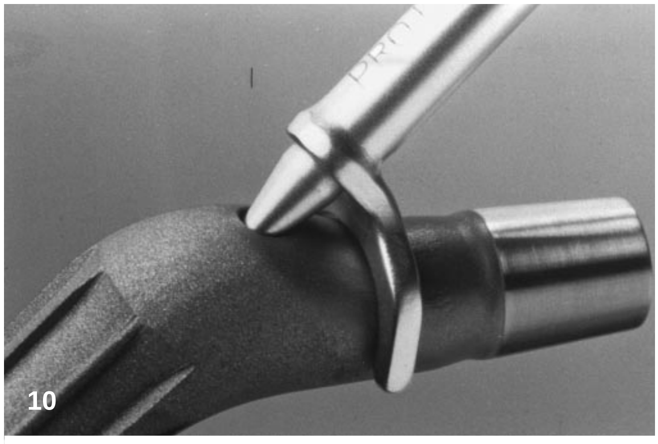


Fig. 10 Impactor for the cone prosthesis. The central flush pin is inserted into the flat borehole on the shoulder of the prosthesis in order to insert the prosthesis and drive it into position. The fork-shaped section is placed around the neck of the prosthesis to check the rotation of the cone prosthesis

Fig. 11 Photograph taken during surgery: care must be taken to prevent the neck of the prosthesis from sitting on the bone cortex during extensive correction of pre-existing anteversion. A fissure 10 mm deep and 3 mm wide should remain. Bone substance may have to be removed using a fine chisel to ensure this

Table 1 Investigation of the first 100 cone prostheses implanted

1991–1994	n = 635
15.4.91–12.8.92	n = 100
Women	84
Men	16
Age (years):	
Youngest	18
Oldest	79
Average	51
Lost to follow-up	3

cavity probe" is inserted. This instrument is used to check that access to the medullary cavity is not obstructed and confirms the anticipated direction of the medullary cavity. This device can also be used to check that the medullary cavity is not obstructed at the required depth or whether any obstacles are present such as a bone barrier secondary to earlier osteotomy. The tapered reamer is then introduced by gradually increasing the diameter. It must be noted that the cone prosthesis has a straight stem which is supposed to lie in the longitudinal axis of the medullary cavity. The reamers must therefore run in close contact

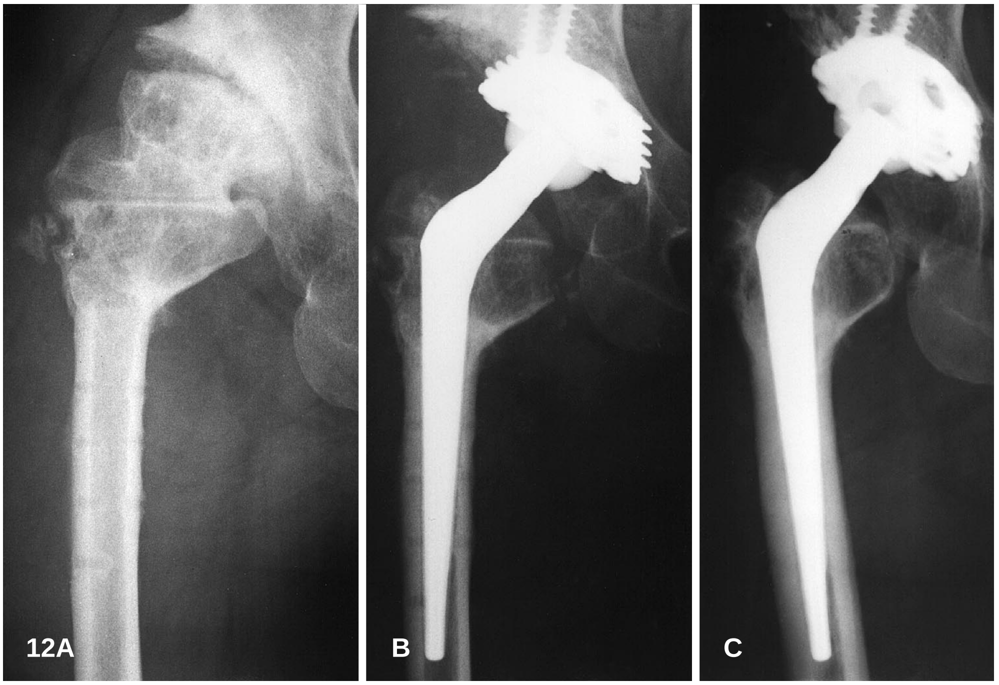


Fig. 12 Case study. **A** Severe congenital dysplasia of the right hip joint in a 39-year-old woman. Condition following intertrochanteric osteotomy. **B** Condition 1 week after implantation of a cone prosthesis. **C** Condition 7 years after surgery

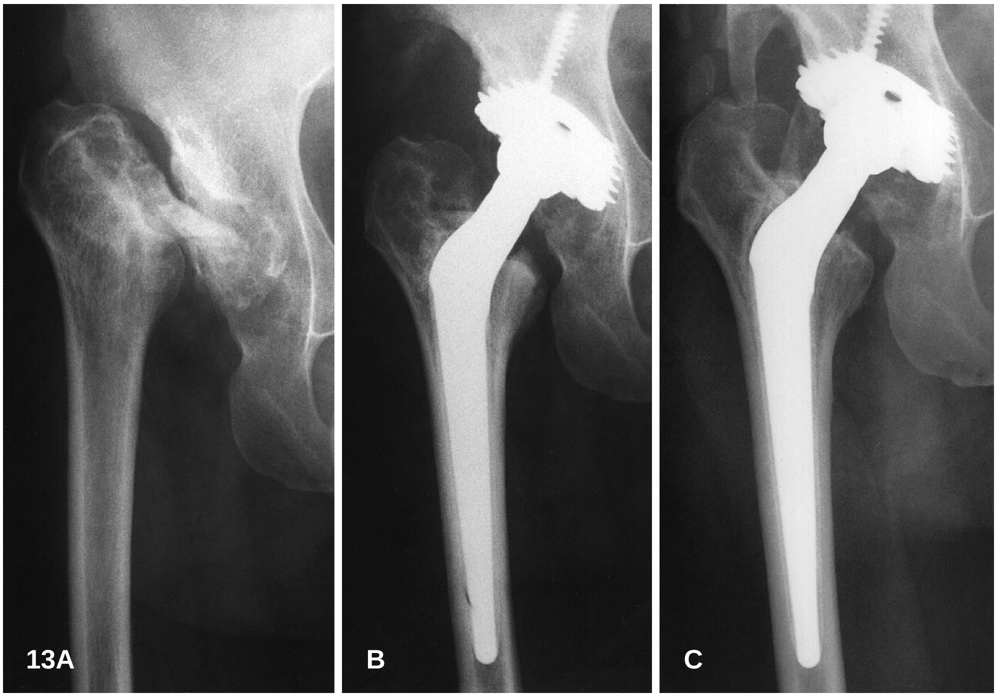


Fig. 13 Case study. **A** Severe osteoarthrosis of the right hip secondary to congenital dislocation in a 39-year-old man. Condition after avascular necrosis of the femoral head following conservative repositioning. **B** Condition 3 weeks after implantation of a cone prosthesis. **C** Condition 7 years after surgery

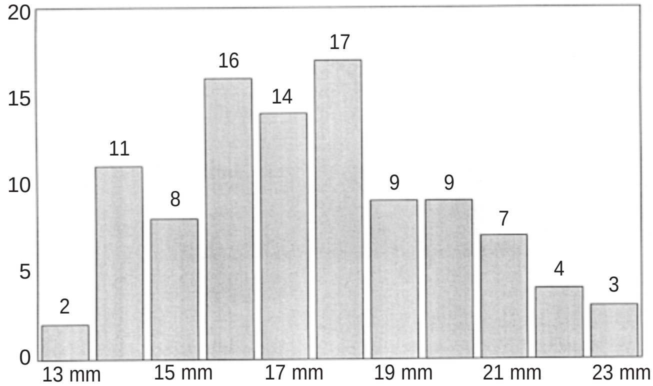


Fig. 14 Distribution of the stem diameter of the cone prosthesis in this investigation

with the greater trochanter in the longitudinal axis of the femur as otherwise varus misalignment may occur.

The stepwise extension of the medullary cavity using the tapered reamers is complete when there is powerful frictional resistance and the scheduled distance to the osteotomy margin is reached at the mark indicating the penetration depth of the reamer. In addition to preoperative planning, this is the definitive test to ensure the adequate diameter of the prosthetic stem. On removing the last reamer from the medullary cavity, the bone meal adhering to the reamer indicates the position and length of the tapered bone bed in the femur.

The tapered prosthesis is then driven into the medullary cavity and turned 10°–15° in the desired anteversion position using the fork-shaped impactor (Fig. 10). The anteversion angle can be checked relatively accurately against the lower leg bent at a right-angle. Test repositioning is, however, required for definitive checking purposes. The prosthesis is driven in only so far with the hammer until stability allows test repositioning. A short manipulating head is placed on the prosthetic taper, and test repositioning is carried out. If the anteversion angle has to be corrected, the prosthesis can be loosened slightly after redislocation and turned in the required direction. If the repeat test reposition shows the appropriate degree of anteversion, the prosthesis is definitively anchored until the scheduled distance between the osteotomy margin and the medial rim of the prosthetic taper is reached. Stable anchorage can also be confirmed acoustically from the sound of the hammer blows. If the test reposition were not carried out until the prosthesis had been finally anchored, it could prove difficult to loosen the prosthesis in order to correct the anteversion.

If a larger anteversion angle is corrected with the prosthesis in the case of hip dysplasia, the neck of the prosthesis may sit on the dorsal bone cortex of the femoral neck, thus triggering a misleading stability phenomenon even before the tapered stem is firmly positioned in the tapered bone bed. This phenomenon must be avoided at all costs as it can cause prosthetic imbalance with a pendulum movement in the stem region. A fissure approxi-

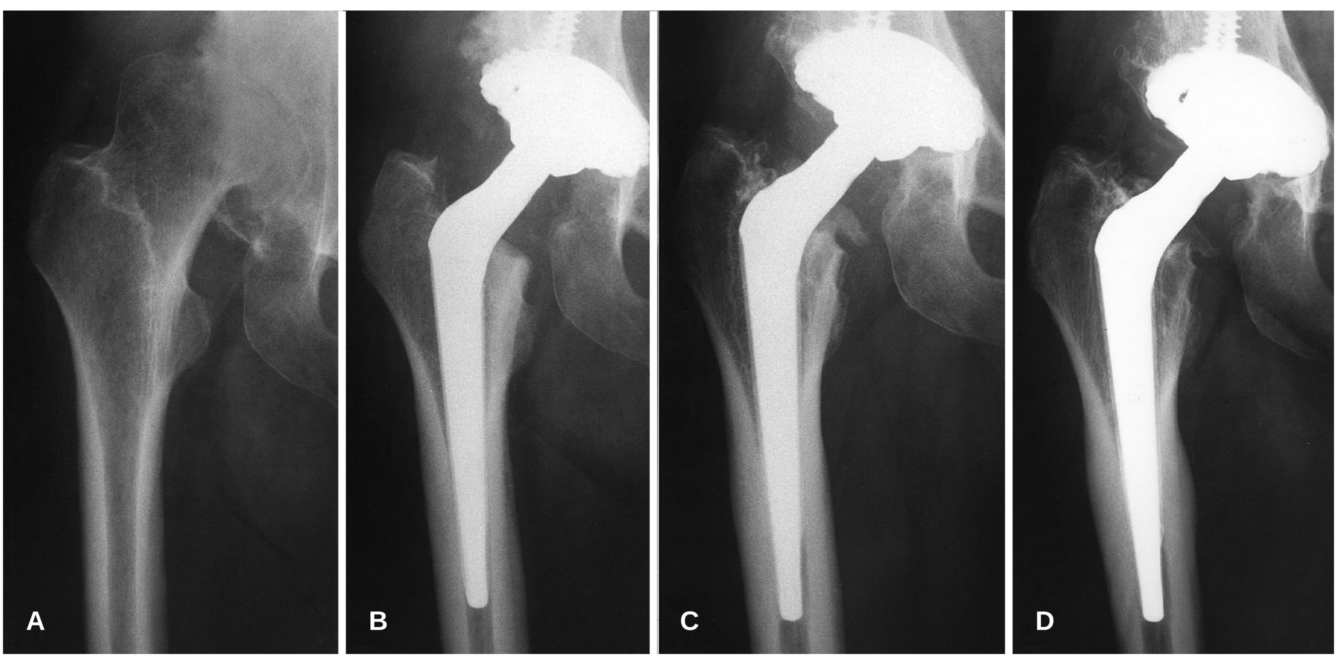


Fig. 15 X-ray of a cone prosthesis with the tip of the stem firmly jammed. **A** Severe, painful, dysplastic degenerative disease of the right hip joint in a 52-year-old woman. Slight, trumpet-shaped configuration of the proximal segment of the femur with a very narrow medullary cavity and thick bone cortex. **B** Postoperative findings 4 weeks after implantation of a cone prosthesis. The tip of the prosthesis is firmly jammed in the narrow medullary cavity. The middle third of the prosthetic stem is not in adequate contact with the bone cortex. **C** One year after the implantation, thickening of the bone cortex in the distal third of the stem as a reaction to the distal transmission of load and a movement-induced fissure between the prosthesis and the bone in the proximal third of the stem. **D** General ossification of the movement-induced fissure 5 years after implantation. Distal thickening of the bone cortex persists. Clinically unchanged, the hip functions normally, without pain, with freedom of movement and unrestricted walking ability

mately 10 mm deep and 3 mm wide must always remain between the concavity of the neck of the prosthesis and the bone cortex or should otherwise be created by cutting off bone substance (Fig. 11).

Results and discussion

In total, 635 cone prostheses were implanted between 1991 and 1994. The present study is based on an investigation of the first 100 hips subjected to surgery up to August 1992. Three hips were not available for follow-up: two patients could be contacted only by telephone, and one patient presented with delayed infection 3 years post-surgery and was excluded from the study on those grounds (Table 1).

Eighty-four prostheses were implanted in female patients and 16 in male patients. This striking ratio can be attributed to the fact that surgery was performed mainly in patients with dysplastic hip joints – a phenomenon which is more common in women. Moreover, there was a geographical spread of congenital hip dysplasia in the region served by the hospital (Figs. 12, 13). The age of the patients was relatively low, which is again consistent with congenital hip dysplasia, and certainly a factor to be taken into account when assessing the noticeably good results obtained. The average age of the patients was 51 years, the youngest being 18 and the eldest 79.

The right hip was affected in 59 cases and the left hip in 41 cases, with no predilection for one side compared with the other. Seven patients were given cone prostheses in both hips. Metal-on-metal pairings were used for 39 hip joints. All cone prostheses were exclusively used in combination with cementless cup implants. The tapered screw cup was implanted in 77 hips, the monoblock primary cup in 13 hips, the standard cup in 1 hip and inforcement cups in 9 hips. The standard cup was rarely used due to the fact that this implant was not available until August 1992, whilst in later series, 56% of implants were standard cups compared with only 30% tapered screw cups. Stems with diameters of 16, 17 and 18 mm were most widely used (Fig. 14).

At the beginning of this surgical procedure, insufficient attention was paid to the fact that rigid contact with the bone in the middle section of the stem is essential for the implantation of cone prostheses, the tip of the stem remaining free. In 21 of the 97 prostheses implanted, the tip of the stem was jammed solidly into the narrow medullary cavity. In 6 of these 21 prostheses, a narrow fissure appeared between the stem of the prosthesis and the bone in the region of the proximal third during the first 12 months. This filled with bone tissue over subsequent years, albeit very slowly (Fig. 15). This fissure can be attributed to the fact that a rigid distal conduction of load occurred when the tip of the stem became firmly lodged, with slight oscillation in the proximal section of the stem on load transmission. In accordance with the distal application of load, the bone cortex thickened in the vicinity of the stem tip. None of the 6 patients presented with subjective disorders. Nevertheless, this is an adverse phenomenon because the prosthetic stem could, at least in theory, sustain a fatigue fracture. Apart from this vibrating phenomenon in 6 cases, the clinical and

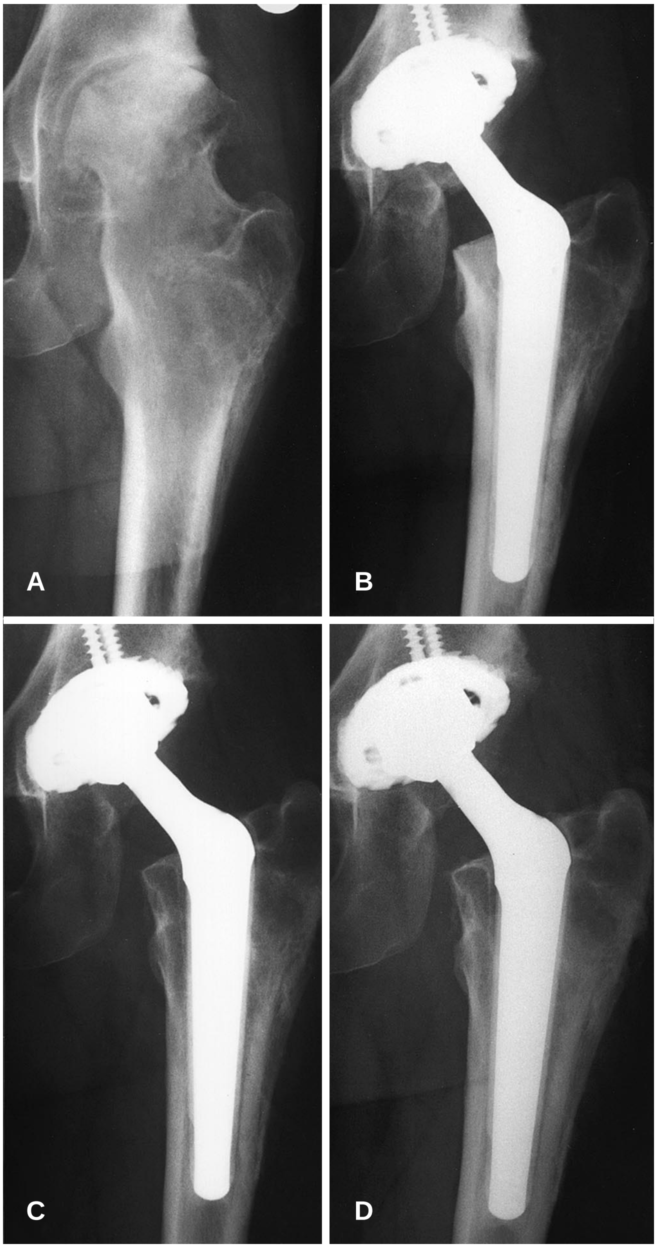


Fig. 16 Subsidence of the cone prosthesis with subsequent restabilising and osseointegration. The single case in this investigation: **A** advanced degenerative disease of the left hip joint in a 36-year-old man weighing 100 kg and with a very demanding physical occupation. Condition 15 years after intertrochanteric valgisation-flexion osteotomy due to segmental necrosis of the femoral head. **B** Condition 2 weeks after implantation of a cone prosthesis, with metal articulation on inadequate anchorage of the middle third of the stem in the bone cortex. **C** The prosthesis has subsided approximately 2 mm without pain 1 year after implantation and 9 months after placing full weight on the joint. **D** Solid, homogeneous osteointegration without subsequent subsidence of the prosthesis despite continuous severe physical occupational exertion and no symptoms of pain 5 years after implantation

Table 2 Subsidence of the cone prosthesis

	n
2 mm followed by osteointegration	1
5 mm (infection)	1

Table 3 The clinical course of pain

	n
Severe pain	0
Mild on walking long distances	5
No pain	92

Table 4 Complications

	n
Haematoma (aspirated)	4
Haematoma (revised)	0
Ectopic bone	6
Brooker 1	2
Brooker 2	1
Brooker 3	3
Palsy (partial, reversible)	3
N. femoralis damage	1
N. peronaeus damage	2
Fibrous stiffening	1
Late infection (removal of prosthesis)	1

X-ray results were highly satisfactory. If correctly implanted, the cone prosthesis does not show any tendency towards subsidence. Subsidence of 2 mm was apparent on the X-ray of only one very active patient with a body weight of 100 kg. This subsidence did not advance in subsequent years but rather was followed by highly stable osseointegration (Fig. 16). Evidence of more severe subsidence (5 mm) was apparent in only one patient in whom an infection developed 3 years after surgery (Table 2).

The clinical course of the symptoms was particularly encouraging. All patients presented with severe pain prior to the operation, otherwise they would not have undergone surgery. At follow-up 92 of the hip joints were pain-free, even after walking for long distances or following considerable physical exertion. Patients complained of slight pain in 5 hip joints after walking long distances, the pain being subjectively localised in the soft tissue scars secondary to repeat previous surgery. No cause of pain was apparent from the X-rays. Severe pain was not experienced in any hip joint (Table 3).

Complications

No significant complications occurred apart from one case of delayed infection 3 years after surgery. Reversible nerve damage was observed in three hip joints, affecting the femoral nerve on one occasion and the peroneal nerve on two occasions. This damage had completely regressed within a year. Movement was considerably hampered after surgery due to scarring in one hip joint that was extremely stiff at the outset. Given the long-term history of this patient, repeat revision surgery was not attempted (Table 4). Postoperative haematoma had to be aspirated in 4 hip joints. Peri-articular ossification was observed in 6 hip joints, but only 3 of these reached grade 3 on the Brooker Index.

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