VALGUS OSTEOTOMY IN SEVERE OSTEOARTHRITIS OF THE HIP

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One hundred and fifty consecutive valgus osteotomies (Pauwels II), performed by P. Maquet for very severe osteoarthritis, have been analysed and followed up for three to ten years with an average of six years. The quality and the persistence of the results depended mainly on the morphology of the osteoarthritic hip. A clinically and radiologically satisfactory result was attained when the stresses in the joint had been reduced by improving the congruity of the joint surfaces and thus increasing the area of the weight-bearing surfaces, in particular by using the cephalic medial osteophyte to take part of the load. In forty-nine cases of osteoarthritis secondary to dysplasia, subluxation, or congenital dislocation with a neo-acetabulum, valgus osteotomy gave 77 per cent good results, with 83 per cent pain-free hips, this result being maintained for at least ten years for women operated on before fifty years of age.

The results in primary osteoarthritis, occurring in young middle age (eighty-three patients) are interesting. When the hip was extruded by acetabular and cephalic osteophytes, good results were obtained in 60 per cent with 81 per cent pain-free hips. In protrusive osteoarthritis and coxa profunda (eighteen hips), valgus osteotomy only slightly improved the mobility but long-lasting relief of pain was obtained in 78 per cent. The causes of failure were lack of mechanical improvement, osteoarthritis resulting more from biological disturbance than from mechanical causes, and the influence of age.

In severe osteoarthritis of the hip, a total replacement is efficient and frequently advised. However, this procedure is considered with reluctance in many cases. This happens when the surgeon is faced with a young woman handicapped by a severe dysplasia, since failure of the arthroplasty is to be expected in the long term; or with an elderly person in poor health where the risks of such radical surgery are high. Therefore it is worth exploring all the possibilities of intertrochanteric osteotomy in severe osteoarthritis.

Varus osteotomy (Pauwels I) is rarely indicated in a severely deformed hip where the femoral head is flattened and enlarged by a medial osteophyte. When such a hip is placed in abduction, the femoral head, instead of turning within the acetabulum, pivots on the lateral edge as if on a fulcrum (Pauwels 1959). This decreases the load-transmitting area and increases the stresses.

McMurray's osteotomy, which produces no significant change in the neck–shaft angle, may give good results even if the joint space has completely disappeared, but only if there exists a large area of articular congruity (Ferguson 1971; Knott 1971; Morsch 1971; Mueller 1971; Müller 1971; Nissen 1971). A group of 500 patients, who were operated on in the Hôpital Cochin in Paris and have been followed for between two and ten years, has confirmed the long-term success of this procedure (Postel et al. 1972). Another study of ninety patients who have been submitted to tenotomy of the adductor, adductor and psoas muscles (hanging hip operation) performed by Paul Maquet at the Clinique Ste Elisabeth, Liège, and followed up for an equivalent period shows that we can equally expect good results from other operations which diminish the load on the hip, as long as sufficient weight-bearing surfaces exist (Massias and Mazas 1966; Mensor and Scheck 1968; Castaing et al. 1973; Radin, Maquet and Parker 1975).

In 1955 Pauwels proposed his valgus osteotomy (Pauwels II). The principle consists of using the medial osteophyte of the femoral head as part of the articular weight-bearing surface by opening the neck–shaft angle: this increases the articular congruity and decreases the stresses in the superolateral aspect of the acetabulum. In the present study, we limit our concern to the results of this operation, which has been performed in all cases by P. Maquet in Liège (Belgium).

Any analysis of functional results poses two problems. On the one hand, if one considers only those patients who were re-examined a long time after operation it results in a selection of cases, since early failures, dissatisfied patients and those who refused to attend the follow-up examination will have been omitted. On the other hand, a review of all the hips


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operated on, whatever the length of the follow-up, fails to show the long-term results precisely.

We have reviewed 150 osteotomies carried out from 1967 to 1969 with a follow-up of at least three years. During that period a total of 225 valgus osteotomies were carried out. The reliability of our analysis could therefore be questioned. We have tried to estimate this reliability by an analytical breakdown of 100 osteotomies consecutively carried out during the year 1968. In this group we found seven elderly patients who died after operation (only one in the first three months); five patients who were lost to follow-up after the first three months but had not developed any complication; nine patients reviewed within one or two years and whose functional results seemed satisfactory; twelve patients whose results seemed less good than average or poor, five of whom have now been given a total hip replacement; and sixty-seven patients followed up for more than three years. This therefore shows that 33 per cent of the patients we operated on were not followed up for more than three years and their results are certainly inferior to the overall results. However, they cannot significantly decrease the figure of good results among the 150 cases reviewed after three years: this was 68 per cent (103 out of 150), which compares with 62 per cent for all patients reviewed however long the follow-up.

During this period, varus osteotomies represented 20 per cent and valgus 80 per cent of the osteotomies for severe osteoarthritis; forty-three of the 150 patients who submitted to a valgus osteotomy were more than sixty-five years old.

OPERATION

Mechanical principle of the valgus osteotomy. This operation aims at decreasing the compressive stresses in the joint in three ways (Pauwels 1975).

Enlargement of the articular load-bearing surface. Rotation of the femoral head enables the medial aspect of the head to take part of the load and thus the joint pressure is shared between the acetabular roof, and the acetabular osteophytes. There need be no fear that the valgus osteotomy will increase articular stresses, for the opening of the neck–shaft angle shortens the lever arm of the gluteal muscles. The very considerable enlargement of the bearing surface (because of the better congruity) makes negligible any possible increase of the transmitted force due to the postoperative coxa valga.

A cam-like effect of the medial osteophyte of the femoral head on the deep surface of the acetabular roof may occur. This gives lateral widening of the joint space, which had previously been overstressed and where narrowing, cysts and sclerosis had predominated. Some flattening of the articular surfaces through functional adaptation can then enlarge the weight-bearing surface of the joint (Fig. 1).

Decrease of the load on the joint. A large "tenomytomy" is carried out systematically in any Pauwels II osteotomy: the adductor muscles are severed as well as the iliopsoas, the gluteus medius and the gluteus minimus.

Change in direction of force. In protrusive osteoarthritis a properly planned Pauwels II osteotomy reduces the stresses concentrated in the bottom of the socket by changing the direction of the overall force acting on the hip (Fig. 2).

Besides the mechanical effects, the biological effect after any intertrochanteric osteotomy intervenes with resulting vascular trophic changes in the femoral head. The consolidation of the osteotomy occurs in two or three months. Full weight-bearing on the operated limb is not allowed until the sixth month: two crutches are used at first, allowing about 20 per cent of normal weight-bearing. One crutch is recommended during the subsequent six months. This partial unloading of the joint seems to enhance the regeneration of the articular tissues.

Indications. The morphology of the joint (congruity, situation and magnitude of the osteophytes) constitutes the main indication for an osteotomy: this will be discussed later. The radiological texture of the joint also determines the possibility of repair. This "healing" of the articular lesions usually occurs when there are cysts, sclerosis and large osteophytes. On the other hand, when chondrolysis or osteolysis predominates, without any osteophyte, a valgus osteotomy is usually doomed to fail.

The mobility after operation depends to some extent on the range of movement beforehand. A gain of mobility may occur but must not be expected in all hips. The reappearance of a joint space and the disappearance of painful muscle contractures allow a better range of adduction and abduction and an average of 20 degrees improvement in flexion. Rarely, the range of movement is decreased after operation. A
stiff hip, however, is no contraindication for an osteotomy because the relief of pain may justify this operation.

**Operative technique.** Pauwels valgus osteotomy is performed if full adduction of the leg provides the desired congruity of the joint surfaces. To determine the precise size and shape of the wedge to be resected, Maquet uses a paper tracing of the contours of the joint. He thus graphically investigates the maximal enlargement of the bearing surfaces and avoids any translocation of the femoral shaft in relation to the pelvis which could interfere with the mechanical axes of the lower limb.

After division of the adductor and ilioptosus tendons through a medial incision, the upper extremity of the femoral diaphysis is approached posterolaterally. A bone wedge with a lateral base is resected from the intertrochanteric zone, its size corresponding exactly to the planned change in the neck-shaft angle. The osteotomy surfaces are compressed together with a purpose-built compression hook, using an eccentric tightening device. The stability of the osteosynthesis allows the patient to stand up and walk, using two crutches, starting from the second day.

**Complications.** Complications are unusual and are not serious. Four per cent developed haematoma, some of which became infected, but without consequences on the joint: the infection subsided in all of them, after removal of the implanted metal. In 4 per cent the osteosynthesis was not satisfactory, allowing a recurrence of 10 or 15 degrees of varus; some justified early reoperation, not from fear of non-union, but to ensure the mechanical efficiency of the osteotomy. Three per cent developed thrombotic complications.

**ANALYSIS OF RESULTS**

**Criteria.** For each anatomical and clinical type of osteoarthritis, the results were analysed according to four criteria.

"Objective" clinical result (Merle d'Aubigné 1970). We attribute a rating from 0 to 6 each to pain, mobility and gait. The total of the ratings allows classification into three categories: very good results (17 and 18 out of 18), good (16, 15, 14) and poor (under 13).

**Radiological result.** All the cases of osteoarthritis that we studied were severe, and characterised by a narrowing of the joint space by more than 50 per cent, abnormal sclerosis in the femoral head and in the roof of the acetabular socket, and cysts. The radiological result is considered as "very good" if these three signs disappear and if the new joint space is wider than 2 millimetres. The result is "good" if two signs disappear, the third one remaining unchanged. All the other cases are "unsatisfactory".

**Relief of pain.** Pain is the main complaint and its complete relief is the principal purpose of the operation even if the range of movement is not normal.

"Subjective" result. This reflects our opinion about the improvement obtained with this operation, taking into consideration the patient's condition before intervention, and the prognosis: a "very good" objective result can be considered only as subjectively "good", if the radiograph shows any signs of degradation.

**Follow-up.** The assessment of pain and the subjective evaluation relate only to the latest examination carried out between three and six years after operation. It seemed essential to determine the evolution of the objective clinical and radiological results of the osteotomies in order to appreciate the prognosis of the operation and the time when degradation might occur. Therefore we have examined the patients at both three and six years after operation.

**Results related to the type of osteoarthritis.** The aim of our analysis was to establish, for every type of osteoarthritis, which improvement could be achieved by a Pauwels II osteotomy, and to delineate the indications for this operation. We have separated the cases of osteoarthritis into three groups with well-defined clinical and radiological characteristics and distinct prognoses.

<table>
<thead>
<tr>
<th>Type of osteoarthritis</th>
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<th>Sex</th>
<th>Percentage of good results</th>
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<td>Clinical ('objective')</td>
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<td>Dislocation 8</td>
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**Fig. 3**

Radiological and clinical classification of the results of the 150 osteoarthritic hips studied.
CLASSIFICATION OF RESULTS

Osteoarthritis due to hip dysplasia

Hip dysplasia mainly affects women (forty-seven out of forty-nine hips), and the high stresses which the joint undergoes lead to osteoarthritis. Nineteen patients were operated on before the age of fifty, sixteen between the age of fifty and sixty, and only fourteen after the age of sixty. Often both hips were abnormal (in thirty-seven cases the opposite hip was dysplastic). Insufficient cover of the femoral head was a constant element, but an anatomical coxa valga was not always present. The femoral head was extruded, due primarily to the insufficient cover but also due to the osteoarthritic remodelling which resulted in osteophytes on the head and in the base of the socket. The dysplastic head remained in a shallow acetabulum in twenty-two hips, and subluxed upwards in nineteen. Genuine dislocations occurred in eight patients, with the femoral head articulating within a neo-acetabulum, above the anatomical acetabulum.

This early osteoarthritis was severe and the operation was generally proposed when the pain occurred after less than a twenty-minute walk with a crutch, and when the joint was stiff (rating 11 out of 18). Extensive radiological signs, predominating in the superolateral aspect of the acetabular roof were the rule. Operation. Sometimes the mobility of the joint in the coronal plane is very restricted and then the valgus created at operation may be greater than the maximum possible compensating adduction. The joint space is opened laterally, thus reducing the stresses on the superolateral area of subchondral sclerosis. Of the twenty-eight such hips on which the Pauwels II osteotomy was carried out only five showed persistent abduction. In the others, considerable improvement in mobility and complete regression of the deformity were observed, as well as the reappearance of a large joint space.

Results. Pain was immediately relieved. A year later one could observe a moderate but real improvement of flexion and extension, averaging 20 degrees. At the same time the joint space appeared enlarged on the radiograph. An unsightly limp sometimes persisted after the first year but caused little discomfort and gradually disappeared. Three years after operation the objective clinical results were very good or good in 77 per cent of cases, and the radiological results very good or good in 92 per cent (half of these patients recovering a normal joint space) (Fig. 3). Six years after operation the overall result was still satisfactory: 55 per cent very or good clinical results, 63 per cent very good or good radiological results and 83 per cent of the operated joints still remained painless. According to our "subjective" evaluation of the later results, 70 per cent of the hips were significantly improved.

Prognosis. In this group the early results are dependent on the accurate determination and resection of the wedge. The other factors affecting prognosis are apparent only after five or six years.

Minor factors. The results are unaffected by the severity of the dislocation (Figs. 4 and 5), whether the osteoarthritis occurs in a dysplastic joint (with an acetabulum in an anatomical position), in a subluxated joint, or even in a dislocated joint with a neo-acetabulum. The osteoarthritis is caused by mechanical factors and in every case a sufficient enlargement of the bearing surfaces provides a comparable improvement. The shallow acetabulum seems to be of minor importance and we have not noticed any significant difference between the results with a shallow or deeper socket. The severity of the osteoarthritis certainly does not contraindicate a Pauwels II osteotomy. Even if a joint space was completely absent, it frequently reappears provided that a sufficient reduction of the articular stresses has been achieved by the osteotomy.

Major factors. When the joint pressure is sufficiently decreased by the operation, a new equilibrium exists between the stresses and the biological resistance of the articular tissues. In a young woman this balance may persist, while in an older woman, degradation may occur some years later.

We can separate our patients into three groups, according to their age at operation: for the patients under fifty the favourable results at the third year are unchanged at seven and a half years; for the patients between fifty and sixty we notice, at seven years, a slight clinical degradation (1 point out of 18) but the radiological investigations occasionally foreshadow degeneration; for many patients over the age of sixty the radiological investigation shows, starting in the fifth year, some signs of degradation associated with a clinical
worsening. Therefore, for the same degree of osteoarthritis, the results are the same for all patients three years after operation. Those patients operated on under the age of fifty have a good chance of maintaining their initial results for seven or ten years or even more. Over the age of fifty the persistence of the good result is more uncertain.

We also notice that severe osteoarthritis of the opposite hip and the failure to obtain a real improvement of congruity at operation (three hips) both give a poor prognosis.

![Figures 6, 7, 8, 9](image)

Results of a Pauwels II osteotomy on a primary osteoarthritis with osteophytes. Figure 6—Severe osteoarthritis at the age of sixty years. Figure 7—Marked improvement obtained by operation still apparent after five years. Figures 8 and 9—Progressive degradation of the clinical and radiological results, noticed seven and ten years after operation.

**Primary osteoarthritis**

This type of osteoarthritis occurs in patients near the age of sixty, without any morphological anomaly. It seems to be due to some biological defect of the tissues making them unable to withstand normal stresses. We have distinguished two clinically identical but radiologically different types of primary osteoarthritis. In one the evolution is very slow, the narrowing of the joint space and the subchondral sclerosis being associated with the formation of a large osteophyte which progressively extrudes the head. In the other the evolution is faster, and the head remains perfectly centred, without osteophytes.

The “centred” hip, with congruity between the head and the acetabulum, cannot be improved by a Pauwels II osteotomy but the hips “remodelled by osteoarthritis” can, after operation, take part of the load on the cephalic osteophyte, thus lowering the articular stresses.

Primary osteoarthritis occurred in patients over sixty years of age in two out of three cases (see Fig. 3). It was slightly more frequent in women (fifty-one out of eighty-three patients) and severe, the walking ability being restricted to twenty minutes, despite one or two crutches. Yet the range of movement was slightly better than in osteoarthritis from dysplasia. **Osteoarthritis with joint remodelling** (fifty-nine hips). If the evolution is slow, the development of osteophytes is more important. They can be moderate (Figs. 6 to 9), remodelling the medial aspect of the head (thirty-one hips); or they can be extensive, progressively extruding the femoral head (twenty-eight hips). Initially, it may be difficult to differentiate between secondary osteoarthritis from dysplasia and primary osteoarthritis. Yet we tend to consider this condition as primary osteoarthritis because of the age when it appears, because of the lack of any proximal subluxation, and especially when there is radiographic evidence of osteoarthritic remodelling of a non-dysplastic hip. **Operation.** The common characteristic of these two types of primary osteoarthritis is the possibility of improving the congruity of the weight-bearing surfaces by a Pauwels II osteotomy. In both types, the sclerosis in the acetabular roof is predominantly at the lateral edge (thirty-three times out of thirty-nine). The valgus osteotomy is adapted to the anatomical and radiological form of the individual case. Overcorrection was decided upon on thirty-six occasions and an abduction deformity persisted for a year after operation in seven patients and for five years in two of them. **Results.** There was improvement in many patients but in 14 per cent (eight out of fifty-nine) there was early failure, the only benefit being the relief of pain for one to two years. At three years after operation there were very good or good radiological results in 78 per cent, but in only 60 per cent were the clinical results very good or good because of the persistence of some limping. At five years the results were slightly worse since only 49 per cent had good clinical results and 54 per cent good...
radiological results. At the last examination there were good "subjective" results in 56 per cent although 81 per cent of hips were free of pain. Thus, the good results seemed progressively to diminish with time, and only the relief of pain persisted for a long period.

"Centred" hips, without osteophyte (twenty-four hips). The symptoms are the same as in the remodelling form of primary osteoarthritis, but the condition evolves rapidly, without osteophytes. Sclerosis of the lateral side of the acetabular roof predominated in only eleven hips. Despite the abduction radiographs showing that for this type a varus osteotomy was unsuitable, Maquet carried out a Pauwels II valgus osteotomy hoping to achieve some improvement by a change of load-bearing areas.

Results. These have been unsatisfactory. In nine hips, there was neither clinical nor radiological improvement even early after operation; only the pain was partially relieved for a few months. At three years, clinical or radiological results were rated very good or good in only one hip out of three. Even among the improved hips, some late degeneration occurred and at the last examination only 29 per cent of hips were free of pain, and 21 per cent "subjectively" satisfactory.

A Pauwels II osteotomy is therefore not recommended for primary centred osteoarthritis occurring in patients who are more than sixty years old.

Protrusive osteoarthritis
This is a rare form, observed in only eighteen of our 150 hips (12 per cent), with distinct clinical and radiological features. Women are more commonly affected (fourteen women, two men) and the condition is tolerated for a long time. The range of movement is restricted in the coronal plane, and initially pain is only moderate. This accounts for the average age of the patients at operation being sixty-one years with a range of forty-eight to seventy-two years. The condition was bilateral in fifteen cases, but there have only been two bilateral valgus osteotomies.

The radiographs show degrees of evolution. In simple medial osteoarthritis there is narrowing of the joint space medially and sclerosis in the bottom of the acetabulum. When osteoarthritis is more severe, progressive deepening of the acetabulum occurs, the head is projected medial to the "ilio-ischiatic" line, producing a coxa profunda (Figs. 10 to 13) or a genuine protrusive osteoarthritis, the articular stresses being concentrated in the depth of the acetabulum; in one third of our hips (six out of eighteen) there was a coxa vara, which might have been a causative factor.

Operation. The maximum valgus that the articular configuration allowed was achieved at operation. In fourteen hips it was greater than adduction before operation. In eight hips an abduction deformity persisted at the end of one year, because the range of movement was only moderately improved in the coronal plane, even when the other symptoms had disappeared. Four deformities persisted at six years, with two good and two bad clinical results.

Results. There were only three hips (17 per cent) with completely and immediately unsatisfactory results. The other fifteen results remained favourable at the last examination with only one exception. Pain was relieved in 78 per cent, but the overall objective results were slightly less satisfactory because of the limited range of movement.

At the three-year follow-up only 66 per cent of the overall objective results were very good or good, and 72 per cent of the radiological results were very good or good, but the "subjective" evaluation gave an improvement of 66 per cent over the state before operation.

Prognosis. The existence of a coxa vara does not seem to influence the prognosis. The severity of the osteoarthritis or of the protrusion is not a contraindication for a
valgus osteotomy. However, we know that if the hip is very protruded it will not significantly regain movement in the coronal plane. The valgus change must be moderate, in order to avoid creating an abduction deformity. The severity of the condition does not prevent the relief of pain, the regression of the medial subchondral triangular sclerosis or of the cysts, and the reappearance of the joint space.

**DISCUSSION**

The valgus intertrochanteric osteotomy is a helpful procedure in cases of severe osteoarthritis. It is a conservative method which can give lasting improvements. Complications after operation are rare and benign. In this series there has been no mortality from the operation; early walking, starting on the second day, results in a very low incidence of phlebitis, and we have not had a case of fatal embolism. Septic accidents are no more frequent than those of total hip prostheses, and their consequences are less severe: the rare cases of sepsis remain extra-articular and heal without functional consequences. There are few mechanical accidents, no cases of non-union, and bony union is achieved in ten to twelve weeks. If revision becomes necessary, a total prosthesis can be implanted since the shape of the femur will still accommodate a normal prosthetic stem. Tenomyotomy has only a temporary effect and does not prevent stabilisation of the prosthetic hip by the gluteal muscles. Severe osteoarthritis, or a restricted range of movement, does not contraindicate a Pauwels II osteotomy.

A joint space often reappears on the radiographs even after a complete absence and can be as wide as 5 millimetres. Post-mortem examinations of patients who had undergone a satisfactory Pauwels II osteotomy have shown areas of fibrocartilage similar to hyaline cartilage (Endler 1972). The reappearance of a large joint space usually accompanies the disappearance of abnormal subchondral sclerosis and associated cysts, an improvement in the range of movement, and a lasting relief of pain. This relation of clinical and radiological results is also observed in degeneration: the recurrence of radiological signs of osteoarthritis, without any loss of function in the course of the following two or three years is exceptional.

The Pauwels II osteotomy is efficient only if it brings about a reduction and a better distribution of the articular stresses in the hip. In cases of osteoarthritis in which the stresses are evenly distributed (even narrowing of the joint space, no triangular sclerosis in the acetabular roof), the operation can neither improve the congruity of these concentric articulations nor enlarge the articular bearing surfaces; it may shorten the lever arm of the gluteal muscles. The failure of valgus osteotomy in such hips is obvious if one compares the results of the two groups of patients with primary osteoarthritis who are comparable as far as aetiology (no dysplasia), the severity of the condition and the age are concerned. They differ only in the radiological appearance of their hips. The hip joints extruded by osteophytes, that can be improved by a Pauwels II osteotomy, give 60 per cent very good or good results at three years and 81 per cent pain-free hips at five years, while the concentric hips only give 33 per cent very good or good results at three years and 29 per cent pain-free hips at five years.

The improvement achieved by this operation is the result of a new balance between the articular stresses and the "biological" resistance of the tissues. If osteoarthritis is merely the consequence of mechanical anomalies, sufficient reduction of the articular stresses will entail very satisfactory and lasting results. This occurs in osteoarthritis developing from dysplasia. In contrast, primary osteoarthritis seems to result from a biological defect in the joint tissues, without any alteration in mechanical stress. In some of these hips a Pauwels II osteotomy may reduce and distribute the stresses better. However, the biological abnormalities persist. This explains why the results which may initially be satisfactory, may be of shorter duration than those in secondary osteoarthritis.

Thus, if we compare the two groups of patients with identical radiological features (extruded femoral head) but different causes (extrusion due either to dysplasia or to primary osteoarthritis), we observe rather different results: 77 per cent very good or good clinical objective results after three years in secondary osteoarthritis, but only 60 per cent very good or good results after three years in primary osteoarthritis.

The new balance between the stresses and biological resistance seems to be more precarious if the patient is older although advanced age is no contraindication to the operation. For the same lesions we may obtain the same results during the first three years after the operation, whatever the patient's age; however, results initially satisfactory may remain satisfactory for longer if the patient is younger. If we study the group with secondary osteoarthritis we observe that, at the seventh year after operation, there is no degradation among the patients under fifty, but a slight radiological degeneration among patients between fifty and sixty, and a significant degeneration among those over sixty years of age. Thus the overall results in patients over sixty show a failure rate significantly higher than in younger patients. One must remember the predominance in this age group of patients who were operated on for primary osteoarthritis.

For the patient over sixty, the indication for a valgus osteotomy must be carefully considered: one may hesitate to propose the inconvenience of two crutches for six months to an old man when a total hip prosthesis would offer an excellent immediate result. In elderly people the Pauwels II osteotomy would therefore be used in three particular circumstances: in protrusive
valgus osteotomy in severe osteoarthritis of the hip

REFERENCES


