We analysed one surgeon’s attempt to reconstruct the hip in 66 patients (84 hips) with chronic dislocation and to restore the height of the centre of rotation above the transverse teardrop line, the body-weight lever arm, the abductor lever arm, and the abductor angle to normal. The outcome was assessed using a patient profile at 0, 10 and 20 years, a clinical assessment of pain, mobility and the range of active movement. We measured the work done by active movement against gravity, radiological signs of loosening, migration and subsidence, and the need for revision. We used survival at ten years and revision as the endpoint.

The incidence of complications was higher than in arthroplasty for primary osteoarthritis of the hip, but the outcome was considered satisfactory. The advantages of a flanged cemented socket were demonstrated. A custom-made, laterally reduced, Charnley extra small CDH femoral prosthesis was used in certain cases.

Pauwel’s application of the ‘Theory of moments of forces’ to the hip inspired Sir John Charnley to adopt a lateral approach to the hip, with medial displacement of the centre of rotation, and lateral transplantation of the trochanter. Such a reconstruction of the hip showed that a greater force was applied to the hip by the abductor muscles than by the weight of the body. This raises the question: does a mechanically advantageous reconstruction improve the outcome?

Several authors have addressed this question. Johnston, Brand and Crowninshield developed a three-dimensional model showing that medial and inferior displacement of the centre of rotation reduced the load on the hip and inferred that this would reduce the incidence of implant failure. Yoder et al followed 116 low friction arthroplasties (LFAs) between six and 12 years and showed a higher incidence of loosening of the femoral component when the centre of rotation was placed 30 mm superior and lateral to the normal position. Delp and Maloney used a three-dimensional model to demonstrate that inferior displacement of 20 mm maximised the isometric abductor moment, whereas superior displacement of 20 mm decreased it. Pagnano et al reviewed 145 total hip arthroplasties (THAs) for Crowe type II hip dysplasia. They found that placing the centre of rotation 15 mm superior to the normal position increased the rate of revision of both the cup (p < 0.01) and the femoral component (p < 0.04). Stans et al reviewed 70 THAs for Crowe type III dysplasia and found that placing the centre of rotation within 10 mm of the normal position, or even more medially, was associated with less loosening of the socket (p = 0.016). Superior or lateral displacement greater than 10 mm increased the incidence of loosening of the socket in their series.

Our study shows how a surgeon is able to reconstruct a dislocated hip by reducing the height of the centre of rotation above the transverse teardrop line (TTDL), reducing the body-weight lever arm, increasing the abductor lever arm and reducing the abductor angle (Fig. 1).

Patients and Methods

Between 1972 and 2000, 118 LFAs were carried out for arthritis secondary to chronic dislocation of the hip. Cases followed for five or more years were selected for study; five of those included had failed within five years; 11 LFAs (nine patients) who died before a five-year follow-up were excluded. None of these had required a revision, and the cause of death was unrelated to their operation. The remaining 84 LFAs (56 women and ten men) were followed for a mean of 11 years (maximum 23 years) and are the subject of this study.
There were 35 Hartofilakidis low and 49 Hartofilakidis high dislocations. There were 48 unilateral and 18 bilateral cases. The left hip was affected in 56% of cases. All the patients were from Northwestern Ontario, which has a population of 244,100, 15% of whom are Native Americans of the Ojibway or Cree tribes. In our series, 64.3% of patients were from these two tribes. The mean age was 47 years (22 to 72). The mean weight was 69.2 kg (44 to 97.3). The mean BMI was 27.1 (15.9 to 39). In 25%, the BMI was ≥ 30, and these were considered obese. Some operative procedures had previously been carried out on 19 hips (22.6%). Other factors included alcoholism (27), diabetes mellitus (nine), rheumatoid arthritis (four), systemic lupus erythematosus (two), cerebral palsy (three), hemiparesis (two), arthrogryposis (one) and poliomyelitis (one).

Each case was assessed before operation using Charnley’s modification of the method described by d’Aubigné and Postel. This assessment included active movements against gravity, the patient’s weight and height, the use of walking aids and analgesics and their ability to work. After operation, each case was assessed annually. Anteroposterior radiographs, centred on the symphysis pubis, with the feet slightly internally rotated, were taken before and after surgery and then annually. These radiographs were measured using an engineer’s caliper, with a vernier scale, and a protractor to determine the forces acting about the hip when standing on one leg (Fig. 1).

In unilateral chronic dislocation, one leg is short, the pelvis shows hemiatrophy and there is a compensatory spinal scoliosis. Because of this asymmetry, the vertical midline of the pelvis was assumed to lie on a line joining the centre of the second sacral vertebra with the symphysis pubis. The horizontal reference was the TTDL. The centre of rotation of the femoral or prosthetic head was determined using a translucent silhouette with concentric circles and a central pinhole. The significant abductors were considered to be gluteus medius and minimus acting on the trochanter and the anterior fibres of gluteus maximus and tensor fascia lata acting on the iliobial tract. The resultant force of the abductors was assumed to run from a radiographic point, 2.5 cm cephalad and 2.5 cm medial to the anterior superior iliac spine, and tangential to the lateral surface of the greater
trochanter. Linear measurements were corrected for radiological magnification.

Knowing the length of the abductor lever arm, the body-weight lever arm, and the corrected body-weight (body-weight \times 0.844), the abductor force can be calculated:

\[
\text{Abductor force} = \text{Corrected body-weight} \times \text{Body-weight lever arm/Abductor lever arm}
\]

Applying the theorem of the ‘Triangle of forces’, the joint force and its direction can be determined:

\[
\text{Joint force} = \sqrt{a^2 + 2\,a\,b\,\cos \theta + b^2},
\]

in which \(a\) is the abductor force (kg), \(b\) the body force (corrected body-weight in kg), and \(\theta\) is the angle of abductor force (degrees).

Gravitational acceleration was omitted for simplicity. These calculations represent an approximation of the principle forces, acting in the coronal plane, at the moment of equilibrium when standing on one leg. They do not reflect the varying magnitude or direction of the joint force in normal walking or other activities. Some such simplified concept is required to achieve a mechanically advantageous reconstruction.

Using anthropometric tables the work done in the active movements of straight leg raising (SLR), and abduction against gravity (AAG), may be calculated as follows:

\[
\text{Work done (SLR)} = x\,y\,\sin \alpha
\]

\[
\text{Work done (AAG)} = x\,y\,\sin \beta
\]

in which \(x\) is the weight of the leg (body-weight \times 0.156), \(y\) the length of the limb from the centre of rotation of the hip to the centre of gravity of the leg (lower limb length = body-height \times 0.530; hip to centre of mass = lower limb length \times 0.477), \(\alpha\) the angle of SLR in degrees and \(\beta\) the angle of AAG above the horizontal. The decision to express active movements as work done was made because a patient with a high BMI has to do more work to lift the leg through a given number of degrees than a patient with a low BMI. In 22 of the 84 patients with chronic dislocation of the hip, the contralateral hip was considered to be radiologically normal.

To test the validity of the above measurements, the pre-and postoperative measurements of the 22 normal untreated hips were compared. A positive correlation and reliability was found suggesting that the method was adequate for the purposes of this study (Table I). The mean values of the 22 normal hips also provided a standard to which those with chronic dislocation could be reconstructed. Where the measurements in the reconstruction equalled the normal values (± SD) or better, it was considered successful. The mean body-weight and the abductor and joint forces were calculated from the corrected body-weight using the two equations (Table II). The data were entered into a SPSS 1 computer programme (SPSS Inc., Chicago, Illinois) to facilitate statistical analysis.

The d’Aubigné and Postel system assesses pain, mobility and the passive range of movement on a scale of 1 to 6 (6 being normal and 1 the worst). The sum of these three scores is sometimes used as a clinical assessment with 18 reflecting the normal. In chronic dislocation of the hip, or paralysis of the leg, the summation of passive movements is frequently rated 5 or 6, erroneously suggesting that function is normal. Active movements against gravity, SLR from the supine position and AAG from a true lateral horizontal position, reflect function better. A new ‘clinical assessment’ out of 18 was devised, substituting the active movements SLR (0˚ = 0, 5˚-30˚ = 1, 35˚-60˚ = 2, ≥65˚ = 3), and AAG (0˚ = 0, 5˚-20˚ = 1, 25˚-40˚ = 2, ≥45˚ = 3), for the passive movements.

Radiological assessment was based on studies by DeLee and Charnley, Hodgkinson, Shelley and Wroblewski, Sochart and Gruen, McNeice and Amstutz. The acetabular component was considered ‘loose’ if there was any continuous, three-zone demarcation of the bone/cement interface, ‘migrated’ if the cup changed position on sequential radiographs and ‘revised’ if a revision had been carried out, or was required. The femoral component was considered ‘loose’ if there was any bone/cement demarcation in three or more of the seven zones, ‘subsided’ if the stem had subsided more than 5 mm and ‘revised’ if revision had been carried out, or was required.

The following information was not available: case 1, patient’s height; cases 9, 11, 17, 22, 25 and 83, preoperative radiographs.

**Complications**

**Dislocation.** There were three early dislocations (3.6%) within three months of surgery. In one case no reduction or further surgery was attempted. The other two were successfully treated by closed reduction. There were five late dislo-

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**Table I.** Pre- and postoperative measurements in 22 normal hips

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean</th>
<th>SE</th>
<th>SD</th>
<th>Correlation coefficient</th>
<th>Reliability coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height centre rotation above TTDL* (mm)†</td>
<td>13.4</td>
<td>0.47</td>
<td>2.21</td>
<td>0.8697</td>
<td>0.9300</td>
</tr>
<tr>
<td>Body-weight lever arm (mm)</td>
<td>90.7</td>
<td>1.04</td>
<td>4.89</td>
<td>0.8576</td>
<td>0.9230</td>
</tr>
<tr>
<td>Adductor lever arm (mm)</td>
<td>48.3</td>
<td>1.09</td>
<td>5.10</td>
<td>0.8733</td>
<td>0.9322</td>
</tr>
<tr>
<td>Adductor lever arm angle to vertical</td>
<td>25.0°</td>
<td>1.08</td>
<td>5.06</td>
<td>0.8121</td>
<td>0.8951</td>
</tr>
</tbody>
</table>

*TTDL, transverse teardrop line
†Compare Yoder et al mean height 14 mm (8 to 20) SD 3

---

**Table II.** Forces in 22 normal hips

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean Corrected body weight force</th>
<th>Correlation coefficient</th>
<th>Reliability coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean calculated abductor force</td>
<td>113.8 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean calculated joint force</td>
<td>153.1 kg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
cations (6.0%), between three months and 4.5 years; one was revised for recurrent dislocation, one was associated with a migrated socket which required revision, and three were successfully treated by closed reduction. Thus two dislocations (one early and one late), led directly to failure of the operation.

Reattachment of greater trochanter. Of the 84 trochanteric osteotomies, 14 (16.7%) did not heal by bony union; 12 had a fibrous union (<2 cm displacement) which did not appear to affect function; one patient had bilateral nonunion which gave a Trendelenburg gait.

Fracture of the femoral shaft. There were six fractures (7.1%) occurring between five months and eight years after the operation; two involved the femoral stem, and were associated with loosening which required revision of the stem; four occurred distal to the stem and revision was not required.

Nerve injuries. There were three partial sciatic nerve palsies (3.6%); one had a persistent foot-drop but no sensory dys-

Table III. Height of centre of rotation above transverse teardrop line

<table>
<thead>
<tr>
<th></th>
<th>Mean preoperative height (n = 78)</th>
<th>Mean postoperative height (n = 84)</th>
<th>Mean lowering centre of rotation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>56.6 (27.1 to 92.9)</td>
<td>12.3 (0.3 to 36.8)</td>
<td>43.3 (2.1 to 88.6)</td>
</tr>
<tr>
<td>Case 1</td>
<td>71.1</td>
<td>9.0</td>
<td>62.1</td>
</tr>
<tr>
<td>Case 2</td>
<td>71.7</td>
<td>10.6</td>
<td>61.1</td>
</tr>
<tr>
<td>Case 3</td>
<td>91.0</td>
<td>7.6</td>
<td>83.4</td>
</tr>
</tbody>
</table>

*number too small for significance
†between one and six years

Loosening. This occurred in 23 cups (27.4%), between one and 20 years, and in 14 femoral components (16.7%) between two and 20 years after operation. Migration occurred in 14 cups (16.7%) between one and 20 years, and subsidence in three femoral components (3.6%) between three and ten years. Revision for aseptic loosening was carried out in 17 cups (20.2%) between three and 20 years after operation and in nine femoral components (10.7%) between four and 14 years.

Death. One patient died early (12 hours). Autopsy revealed that a colloid cyst in the third ventricle of the brain had prolapsed, causing acute hydrocephalus. The remaining eight deaths (11 LFAs) occurred between six and 23 years after the operation and were unattributable to the surgery.

The surgeon’s objective was to achieve a mechanically advantageous reconstruction. In five cases (one deep infection, one unreduced early dislocation, one revised recurrent dislocation and two trochanteric nonunions) the failure was attributed to errors in surgical technique. These five cases were excluded from the analysis of results and only the 79 cases, in which the mechanical soundness of the reconstruction could be judged, were considered.

Results

Changes in the patients’ profile over 20 years are shown in Table IV. With age, the patient increases in weight,
decreases in stature and is increasingly classified as a C case in which his ability to walk is adversely affected by cardiovascular, respiratory, neurological, psychiatric, or other factors. There was, however, a substantial decrease in the need for walking aids and analgesics, and an improved capacity for work.

The mean preoperative clinical assessment of 8.5 out of a possible 18 (n = 76, SD 1.9, SE 0.2) improved to a mean postoperative score of 13.5 (n = 76, SD 1.9, SE 0.2), p < 0.01. The mean preoperative work done in straight leg raising of 170.7 kg/cm (n = 74, SD 143.1, SE 16.6) improved to a mean postoperative score of 289.1 kg/cm (n = 74, SD 134.3, SE 15.6), p < 0.01. The mean preoperative work done in active abduction against gravity of 17.8 kg/cm (n = 74, SD 39.2, SE 4.6) improved to a mean postoperative score of 115.7 kg/cm (n = 74, SD 76.7, SE 8.9), p = 0.01.

The survivorship at ten years, with revision of the cup as an endpoint, was 81.6%, SE 4.9. The survivorship at ten years, with revision of the femoral component as an endpoint, was 86.6%, SE 4.5. The combined survivorship at ten years, with revision of either component as the endpoint, was 79.1%, SE 5.1.
The mechanical advantage achieved is shown in Table V. A significant improvement in each of the mean values was achieved; between 72.2% and 97.5% of cases were corrected to the mean value of the 22 normal hips ± SD, or better. Furthermore, the simplified and approximate calculations of the abductor and joint forces show that Charnley’s approach to the hip and subsequent reconstruction, increases the efficiency of the abductors and decreases the load on the joint. The number of cases in this study was too small to demonstrate whether the theoretical mechanical advantage achieved, improved the outcome. Bottoming out of the cup increased the incidence of revision of both the cup (p = 0.031) and the stem (p = 0.014). The introduction of the flanged off-centre CDH cup (n = 40) compared with the original off-centre bore cup (n = 22), which had no flange, reduced the incidence of bottoming out (p = 0.001).

Discussion

A striking feature of this study was that 64% of the cases occurred in Native American patients, who represent only 15% of the population. The high frequency of perinatal dislocation of the hip in the Native American population has been attributed to a genetic predisposition and an environmental factor. Important references are McKusick’s Online Mendelian Inheritance in Man,18 and Salter’s 1968 paper on the influence of the tigonagan or swaddling board.19

Reconstruction of established dislocation of the hip is technically difficult and has a high complication rate. Nevertheless, an improvement in the clinical assessment, the ability to do work in the form of active movements against gravity and the survivorship to an endpoint of revision, suggest that this can be a rewarding procedure (Fig. 2a).

The surgeon’s attempt to achieve a theoretically desirable reconstruction (22 normal hip values ± SD, or better) was reasonably successful, but we had too few cases to determine if such a reconstruction produces a better outcome. Between 200 and 300 similar cases would be required to resolve this issue.

The flanged socket prevents bottoming out, pressurises the cement until polymerisation is complete and reduces the incidence of revision of both the cup and stem.20,21 A solution to the problem of the extremely narrow medullary canal commonly found in high congenital dislocations, was a custom-made modification of the Charnley, extra small CDH femoral prosthesis, reduced by 2 mm laterally. This was used in three cases in this study, and in seven subsequently. In most of these cases, an osteotomy was made of both the greater and the lesser trochanters, and the femur was shortened until the femoral head could be reduced without difficulty or risk to the sciatic nerve. The trochanters were then reattached, distal to their original positions, with correct rotation of the femur and muscle tension (Fig. 2b). This narrow stem is manufactured from Ortron 90 (Thack-ray), a stainless steel alloy with improved stiffness and resistance to corrosion. There have been no failures of this implant during seven years.

There is still a high incidence of failure to treat early dislocation of the hip effectively in Native American patients in Northwestern Ontario. Analysis of reconstruction of the hip with regard to the height of the centre of rotation above the TTDL, the body-weight lever arm, the abductor lever arm, and the abductor angle, suggests that improvement towards a normal value increases the efficiency of the abductors and decreases the load on the hip. The quality of the result was assessed by noting changes in the patient profile over 20 years by measuring the work done in active movements against gravity, observing radiological signs of loosening, the need for revision and the ten-year survival. Either the need for revision or survival beyond ten years defines the endpoint. This study offers evidence in support of the hypothesis that “mechanically sound reconstruction improves the outcome”. Although intuitively correct, this, however, remains unproven.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References


