We analysed the gait characteristics of 15 patients with prosthetic reconstruction of the proximal femur after resection of a malignant bone tumour using stride analysis and measurement of oxygen consumption. Compared with normal volunteers their gait was slower, with less cadence and reduced stride length. The mean net energy cost of free walking was 141% of normal. The degree of asymmetry of the single-limb support time correlated with the free-walking velocity and the net energy cost. If they used a single cane the subjects walked with less cadence, longer stride length, and prolonged single-limb support times. The net energy cost of walking and asymmetry of the single-limb support time had a negative correlation with the strength of the hip abductor muscles. Their walking performance was better than that of six subjects who had hip disarticulation.

Patients and Methods

We studied six men and nine women with a median age of 24 years (16 to 47), who had undergone prosthetic reconstruction of the proximal femur. The median interval from the operation to the study was 27 months (12 to 76). Six patients had an osteosarcoma, four a Ewing’s sarcoma, four a chondrosarcoma and one a malignant fibrous histiocytoma. Six tumours were right-sided and nine left.

All patients had an intra-articular resection of the hip. The median length of the femur resected was 21 cm (8 to 28) which was a median of 51% (30 to 74) of the length of the bone. One patient had a total hip replacement and 14 had a bipolar implant. The abductor muscles were anchored to the lateral aspect of the prosthesis and sutured to the vastus muscles or the fascia lata whenever possible.

Six patients who had had a disarticulation of the hip for treatment of a malignant tumour and 20 normal volunteers were also studied.

Oxygen consumption was determined using the Douglas-bag technique. We measured the net energy cost (ml O₂/m/kg) and the proportion of predicted maximum aerobic capacity.

Stride characteristics were evaluated using a VA-Rancho Footswitch Stride Analyser (Pathokinesiology Laboratory, Rancho Los Amigos Medical Centre, Downey, California). We measured free-walking velocity, cadence, stride length, gait cycle time, double-limb support time, and the right and left single-limb support times.

Statistical analysis. We carried out statistical analysis using the Statview 4.5 statistical package (Abacus Concepts Inc, Berkeley, California). A correlation coefficient (r) was determined as a measure of the relationship between the variables. Differences between groups were analysed by the Student t-test. A p value of < 0.05 was considered significant.
Table I. Comparison of the energy cost and stride characteristics of the 15 patients who had proximal femoral replacement with the six patients who had hip disarticulation and the 20 normal volunteers (values are expressed as mean ± sd)

<table>
<thead>
<tr>
<th></th>
<th>Proximal femoral replacement</th>
<th>Normal volunteers</th>
<th>p value*</th>
<th>Hip disarticulation</th>
<th>p value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy cost (ml O₂/m/kg)</td>
<td>0.24 ± 0.03</td>
<td>0.17 ± 0.02</td>
<td>&lt; 0.0001</td>
<td>0.29 ± 0.06</td>
<td>0.024</td>
</tr>
<tr>
<td>Aerobic capacity (%)</td>
<td>37.2 ± 12.3</td>
<td>22.9 ± 5.8</td>
<td>&lt; 0.0001</td>
<td>43.1 ± 8.9</td>
<td>0.31</td>
</tr>
<tr>
<td>Free-walking velocity (m/min)</td>
<td>63.9 ± 9.7</td>
<td>80.6 ± 9.8</td>
<td>&lt; 0.0001</td>
<td>50.6 ± 9.5</td>
<td>0.003</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>101 ± 8.5</td>
<td>111 ± 5.7</td>
<td>&lt; 0.0001</td>
<td>81.6 ± 5.3</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>1.26 ± 0.16</td>
<td>1.44 ± 0.16</td>
<td>0.004</td>
<td>1.29 ± 0.22</td>
<td>0.87</td>
</tr>
<tr>
<td>Double support (% gait cycle)</td>
<td>20.2 ± 3.5</td>
<td>21.1 ± 3.7</td>
<td>0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asymmetry (s)‡</td>
<td>0.09 ± 0.08</td>
<td>-</td>
<td>&lt; 0.0001</td>
<td>0.28 ± 0.11</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

* p values between replacement of the proximal femur and normal control
† p values between replacement of the proximal femur and hip disarticulation
‡ single-limb support time difference between unaffected and affected limbs

Results

The mean net energy cost of free walking and the percentage of maximum aerobic capacity of the patients were 141% and 162% of those of the control group, respectively (Table I). The patients walked significantly slower than the control group with less cadence and a reduced length of stride. As shown in Figure 1 the free-walking velocity of the patients had a negative correlation with the net energy cost (r = -0.55, p = 0.05).

The patients had a lurching Trendelenburg gait. All had a shorter single-limb support time on the affected side. The mean asymmetry of the single-limb support time, which is the difference between the unaffected side (0.52 ± 0.07) and the affected side (0.42 ± 0.06), was 0.09 s (0.01 to 0.22). As shown in Figure 2 there was a significant negative correlation between free-walking velocity and asymmetry of the single-limb support time (r = -0.67, p = 0.006). Figure 3 shows that the net energy cost had a significant positive correlation with the asymmetry of the single-limb support time (r = 0.8, p = 0.001).
The change of the stride characteristics when using a walking aid was examined in five patients (Fig. 4). They walked with less cadence and had a longer stride length when using a cane, so that the walking velocity was not significantly changed. Both single-limb support times were prolonged and the asymmetry was significantly reduced.

The walking performance of the patients was superior to that of those who had had hip disarticulation (Table I). They walked significantly faster, had less asymmetry and used less energy. The net energy cost of walking had a significant negative correlation with the strength of the residual hip abductor muscles ($r = -0.75, p = 0.012$). There was a weak negative correlation between asymmetry of the single-limb support time and the strength of the abductor muscles ($r = -0.62, p = 0.05$). There were no significant correlations between the gait characteristics of the patients and the length of the proximal femur which had been resected.

**Discussion**

Prosthetic reconstruction of the proximal femur after resection of malignant bone tumours offers several advantages. After operation, most patients were able to return to a nearly normal lifestyle. However, even those who did not complain of symptoms had abnormal gait patterns and their functional evaluation, according to a non-parametric system, was less than satisfactory. Gait analysis provides information about functional impairment, and gives numerical measures of the functional outcome for each reconstructive procedure. To our knowledge, a detailed gait analysis of patients who had undergone limb-sparing surgery for malignancies of the proximal femur has not been described.

Energy cost, based on the measurement of oxygen consumption, is the best evaluation of overall gait performance of patients who have had a major alteration in the function of the lower limb. Higher-level amputees had a less efficient gait than those with a lower level of amputation. The walking of patients who had prosthetic knee reconstruction after resection of a malignant tumour was more efficient than those who had had an above-knee amputation. Our study has shown that the walking efficiency of

<table>
<thead>
<tr>
<th>Mean (%)</th>
<th>p value</th>
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<tbody>
<tr>
<td>Velocity</td>
<td>99.4</td>
</tr>
<tr>
<td>Cadence</td>
<td>94.8</td>
</tr>
<tr>
<td>Stride length</td>
<td>105.0</td>
</tr>
<tr>
<td>Double-limb support</td>
<td>93.8</td>
</tr>
<tr>
<td>Single-limb support time affected</td>
<td>110.0</td>
</tr>
<tr>
<td>Single-limb support time unaffected</td>
<td>106.0</td>
</tr>
<tr>
<td>Asymmetry</td>
<td>73.8</td>
</tr>
</tbody>
</table>

Fig. 4

The changes in the gait characteristics of five patients who used a single cane, with 100% representing no change with the use of a cane. The bar represents the 95% confidence interval.
patients with prosthetic hip reconstruction after tumour resection was significantly better than that of patients who had disarticulation of the hip. The maximum aerobic capacity of the patients was well below the 50% cut-off limit, above which sustained walking is not feasible without fatigue.

In our study, the degree of asymmetry of the single-limb support time correlated with the free-walking velocity and the net energy cost of walking. A close relationship between the asymmetry of the single-limb support time and the gait performance of patients has also been found in megaprosthetic knee reconstructions and after periacetabular resection of tumours. The asymmetry of single-limb support time is considered to be an important index of the gait capability of the patients.

The effect of walking aids on the gait of patients who had limb-sparing surgery has rarely been studied. We have shown that the patients with replacement of the proximal femur walked less asymmetrically when they used a cane. In an analysis of patients who had resection of the acetabular ring support by a cane was sufficient to abolish a Trendelenburg gait. These studies indicated that the regular use of a cane is beneficial to the patients to reduce the mechanical stress on the bone-implant interface, which may lead to failure of the prosthesis, and to improve the characteristics of walking.

The strength of the hip abductor muscles correlated with the net energy cost and symmetry of the walking. Patients with good abductor strength walked less asymmetrically and used less energy. We believe that the decrease in strength of the abduction of the hip in our patients was due mainly to the loss of muscle attachment to the femur. Suturing the soft tissues or tendons to a metal prosthesis cannot result in a biological, permanent stable fixation.

In current techniques of reconstruction, the formation of a continuous fibrous tissue sleeve, consisting of gluteal muscles, tensor fasciae latae and vastus muscles surrounding the prosthesis, may be more important for the long-term functional outcome. In an attempt to establish a lasting tendon-to-prosthesis attachment, a custom tendon anchor fixation system, with excellent biomechanical properties has been developed. Direct fixation of the gluteus medius tendon and a segment of the bone to the prosthesis can give a higher isometric abductor muscle force. Formal gait analysis may give a more critical evaluation of the functional advantages of such innovations.

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


