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# ENERGY COST DURING AMBULATION IN TRANSFEMORAL AMPUTEES: A KNEE JOINT WITH A MECHANICAL SWING PHASE CONTROL VS A KNEE JOINT WITH A PNEUMATIC SWING PHASE CONTROL

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**ABSTRACT. The aim of the study was (i) to evaluate the preference of transfemoral amputees for a 4-bar linked knee joint with either a mechanical swing phase control or a pneumatic swing phase control, and (ii) to compare the energy expenditure in transfemoral amputees using a prosthesis with a mechanical swing phase control with that of the same amputees using a prosthesis with a pneumatic swing phase control. The study included 28 unilateral transfemoral amputees amputated for reasons other than chronic vascular disease. All patients had a prosthesis with a knee joint with mechanical swing phase control (the Otto Bock 3R20) before entering the study. The amputees changed their knee joint to one with pneumatic swing phase control (the Tehlin knee joint) at random either after the first or second assessment. The amputees were asked for their preference at the second and third assessments. The energy expenditure while walking at speeds of 2 and 3 km/h was measured at each assessment. After having tried both knee joints, 19 patients preferred the Tehlin knee, 6 patients preferred the Otto Bock 3R20, and 3 patients had no preference. The energy expenditure measurement showed that walking with the Tehlin knee required more energy than walking with Otto Bock 3R20. Because of the limited number of patients included in the study and the fact that a double-blind design was impossible to achieve, conclusions should be drawn with caution.**

*Key words:* transfemoral amputation, prosthesis, knee joint, energy expenditure.

## INTRODUCTION

Although knee joints with a pneumatic or hydraulic control were introduced as early as in the 1960s (4), knee joints with such designs became more commonly used only in the 1980s. The hydraulic units were thought to improve the gait in young transfemoral amputees (5). However, only a few studies (2, 3) have reported on this topic.

The present study evaluated the preference of transfemoral amputees for a 4-bar linked knee joint with either a mechanical swing phase control (Otto Bock 3R20) or a pneumatic swing phase control (Tehlin knee) (see technical addendum). Furthermore, the energy expenditure of walking with the two knee joints was studied in order to investigate whether the knee joint preferred by the amputees was also the one which required less energy while walking.

## MATERIALS AND METHODS

### *Subjects*

The study included 28 unilateral transfemoral amputees living in the north of the Netherlands. All gave informed consent. The amputees had no other major diseases of the lower extremities. Some had problems of back ache or problems with the non-prosthetic leg which, however, did not cause disturbances of the gait. There were no skin problems of the stump.

The characteristics of the patients are summarized in Table I. The residual limb length shown in this table was measured as the distance from the trochanter major to the distal end of the femur.

Seventeen patients had been amputated for traumatic reasons, 10 patients because of a malignant tumour and one patient because of an acute arterial occlusion without signs of chronic vascular disease.

All patients had an Otto Bock 4-bar linked knee with a mechanical swing phase control (3R20) before entering the study. All but two had a Multiflex foot. Two patients had an Otto Bock Lager foot. Sixteen patients had a Quadrilateral socket, 12 patients a (modified) NML socket. Some of the patients used a pelvic suspension: 9 patients used a Silesian bandage, 3 patients an elastic sleeve (TES-belt®). Fit and alignment of the prosthesis were checked and found to be satisfactory. The shoes used by the amputees were the same throughout the entire study.

Table I. *Characteristics of the amputees in patient groups 1 and 2*

| | Patient group | | | |
|---|---|---|---|---|
| | 1 | | 2 | |
| | Mean | (range) | Mean | (range) |
| Age (years) | 40 | (15–63) | 42 | (23–63) |
| Time since amputation (years) | 13 | (2–43) | 23 | (6–48) |
| Residual Limb Length (cm) | 22 | (12–30) | 21 | (13–35) |
| Weight (kg) | 78 | (66–106) | 84 | (59–110) |
| Height (m) | 1.79 | (1.60–1.91) | 1.80 | (1.65–1.99) |
| *n* male/female | 12/2 | | 12/2 | |

Four patients walked with a stick, even for short distances.

*Methodology*

The patients were divided at random into two groups (see Fig. 1). The knee joints in the prostheses of the amputees of the first group were replaced by one with a pneumatic swing phase control, the Tehlin knee joint, after the first assessment. The prostheses of the amputees of the second group were not changed after the first assessment. In this group the cosmetic cover was removed and restored after some walking in the workshop at the first assessment, in order to ensure that the amputees were unaware of the true status (old or new) of the knee joint. The true status was revealed to them only after the second assessment. It was impossible to use a double-blind design.

After the second assessment, at least 2 weeks after the first, the amputees in the first group had their old Otto Bock knee joint reinstalled in their prostheses. The knee joints of the amputees in the second group were now replaced by the Tehlin knee.

A third assessment was made at least 2 weeks after the second assessment.

The knee joints were replaced by an experienced prosthetist. An adaptor was used for the positioning of the Tehlin knee. At each assessment photographs were taken using standardized methods.

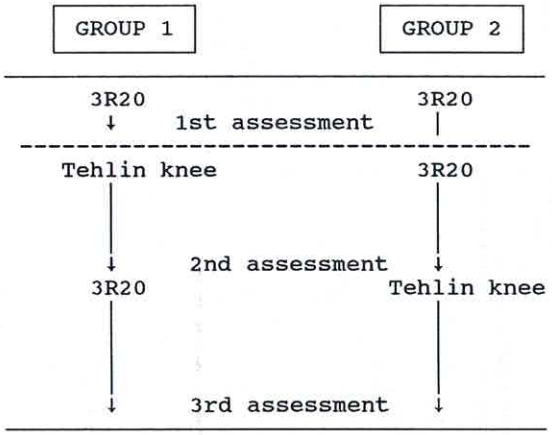


*Fig. 1.* Design of the study.

*Data collection*

Each amputee was assessed three times: twice with the knee joint with mechanical swing phase control (the first and third assessments in group 1, and the first and second assessments in group 2) and once with the knee joint with pneumatic swing phase control (the second assessment in group 1, and the third assessment in group 2).

At the second and third assessments the amputees were asked about their preference with regard to the type of knee joint and the reasons for this preference.

Energy expenditure was measured at all three assessments. The amputees did not eat any food or drink coffee or tea 2 hours before the measurements and did not drink alcohol 24 hours before the measurements. The assessments were performed between 10 a.m. and 12.30 a.m. Oxygen uptake was measured using an Oxycon gas analyzer (Mijnhardt), with the patients walking on a treadmill. During the test, the patients breathed air through a rubber mouthpiece, connected with the Oxycon gas analyzer, while the nose was kept closed using a spring clip. The Oxycon gas analyzer calculated, among other things, the following mean variables: $V(O_2)$ L/min, $V(CO_2)$ L/min, and Respiratory Coefficient. The amputees first sat for 6 minutes and then walked for 6 minutes at speeds of 2 and 3 km/h, with 6 minutes of rest in between. The mean value of the last 2.5 minutes of each run was taken as the measured value at that speed. Depending on the Respiratory Quotient (RQ), the energy consumption per litre $O_2$ (EE) was estimated (1) and the energy expenditures per second and per kilogram body weight (P) were calculated at each speed, using the following equation:

$$P(J/s \cdot kg) = \{V(O_2)(L/min) \times EE(J/Liter\ O_2)\}/\{60 \times BW\ (kg)\}$$

where V $(O_2)$ = oxygen uptake, EE = energy uptake per litre of oxygen (depending on RQ) and BW = body weight.

Before the test the amputees were asked to walk on the treadmill for some minutes in order to get used to the situation. Every amputee held on to the bars while walking on the treadmill, for the sake of preventing falls.

The room was air conditioned, with a temperature between 20°C and 22°C and a relative humidity between 60% and 70%.

*Statistical analysis*

The data from the second and the third assessments were analysed as cross-over design with two treatments and two periods. We used the nonparametric Mann-Whitney U-test

Table II. *Patient preference*

| Patient group | Assessment 2 | | | Assessment 3 | | | |
|---|---|---|---|---|---|---|---|
| | *n* | Tehlin | 3R20 | *n* | Tehlin | 3R20 | No preference |
| 1 | 14 | 10 | 4 | 13 | 9 | 3 | 1 |
| 2 | | | | 14 | 10 | 2 | 2 |

for the energy expenditure data and the Presscott test for preference data. *p*-values below 5% were considered significant. The energy expenditure data are presented as means and standard deviations.

## RESULTS

One patient in group 1 refused to participate in the study some days after the first assessment, because he felt so unsafe on the new knee joint that he was afraid to fall. He was excluded from the energy expenditure analysis.

Two patients, both in group 1, were unable to walk on the treadmill at a speed of 3 km/h. Only the energy expenditures during sitting and walking at a speed of 2 km/h were measured in these 2 patients.

Table II presents the preference data.

In group 2, 3 patients preferred the "second" knee after the first assessment and one patient the "first" knee, although the knee joints had not been changed. In the total group of 28 patients, 19 patients preferred the Tehlin knee, 6 preferred the Otto Bock 3R20 and 3 had no preference; the difference in preference is significant ($p < 0.01$).

The main reason mentioned by the amputees for preferring the Tehlin knee was that they walked more easily and/or faster with this knee in comparison with the Otto Bock 3R20. The main reason mentioned for preferring the 3R20 was that bending the knee joint without weight-bearing on the prosthesis was very easy with the Tehlin knee, which gave them an unsafe feeling.

Fig. 2 shows the data of the energy expenditure

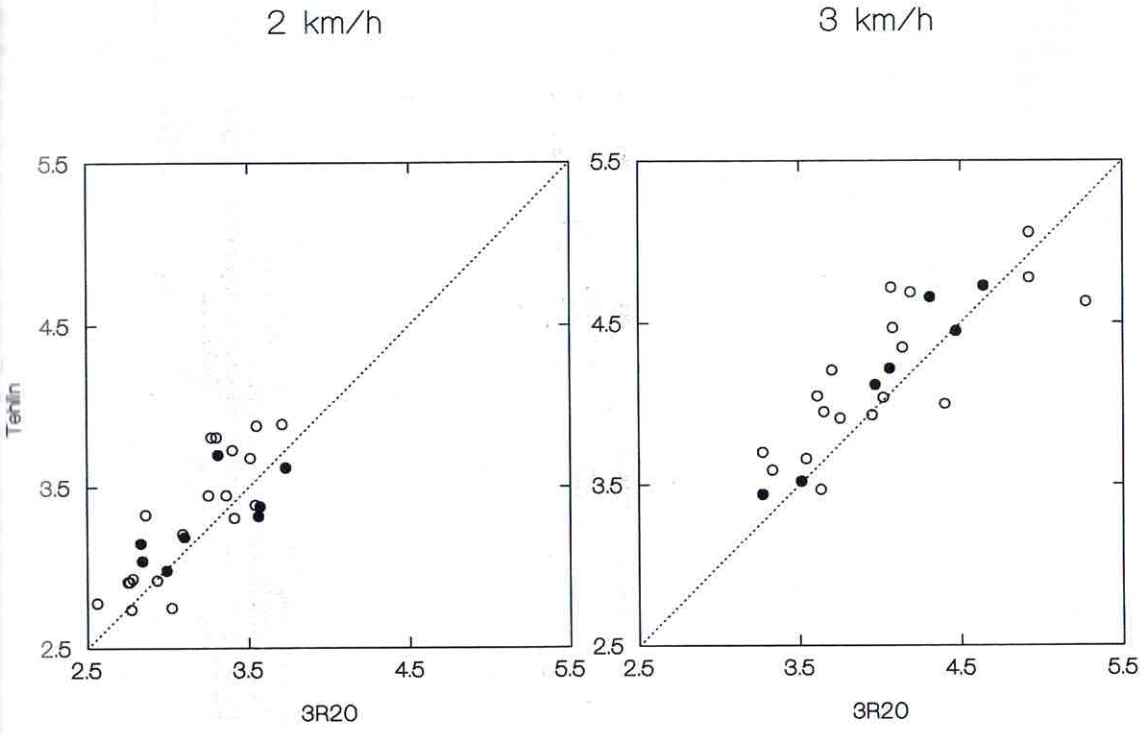


*Fig. 2.* The energy expenditure in J/s.kg for the two knee types. Each dot represents one amputee. ○ = preference for Tehlin knee; ● = no preference for Tehlin knee.

Table III. *Mean energy expenditure (and standard deviation) in J/s · kg during sitting and walking in both patient groups with a prosthesis with a knee joint with mechanical swing phase control (Otto Bock 3R20) or pneumatic swing phase control (Tehlin knee)*

| | | | Energy expenditure | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Sitting | | 2 km/h | | 3 km/h | |
| Patient group | Assessment | Knee joint | Mean | (sd) | Mean | (sd) | Mean | (sd) |
| 1 | 1 | O.B.3R20 | 1.08 | (0.25) | 3.36 | (0.35) | 4.05 | (0.41) |
| | 2 | Tehlin | 1.05 | (0.20) | 3.28 | (0.38) | 4.11 | (0.56) |
| | 3 | O.B.3R20 | 1.05 | (0.19) | 3.08 | (0.35) | 3.96 | (0.65) |
| 2 | 1 | O.B.3R20 | 1.09 | (0.17) | 3.53 | (0.47) | 4.32 | (0.43) |
| | 2 | O.B.3R20 | 1.07 | (0.12) | 3.27 | (0.31) | 4.08 | (0.43) |
| | 3 | Tehlin | 1.10 | (0.15) | 3.33 | (0.37) | 4.23 | (0.39) |

during walking with the Tehlin and Otto Bock 3R20. There are no differences between the amputees who finally preferred the Tehlin knee and who finally preferred the Otto Bock 3R20 or had no preference.

The energy costs during sitting and walking are summarized in Table III.

The analysis of the energy expenditure at the second and third assessments revealed a significant difference between the two types of the knee at 2 km/h ($p = 0.005$; 95% confidence interval (CI) for the difference Tehlin – 3R20 is $0.26 \pm 0.16$), at 3 km/h ($p = 0.012$; 95% CI is $0.29 \pm 0.23$), but not at the sitting position ($p = 0.8$; 95% CI is $0.03 \pm 0.09$) (Table IV).

This analysis did not reveal any significant difference between assessments 2 and 3. The energy cost at the first assessment was, however, significantly higher than that at the later period with the same (3R20) knee: in group 1 at 2 km/h ($p = 0.002$) and in group 2 at 2 km/h ($p = 0.004$) and at 3 km/h ($p = 0.007$).

The photographs taken of the prosthesis showed that in some patients the Tehlin knee seemed to be positioned in a more stable position. It was hard to quantify the difference in position of the two knee joints because the photographs were not fully comparable, even though they had been taken in a standardized way.

## DISCUSSION AND CONCLUSIONS

The present study evaluated the preference of transfemoral amputees for a 4-bar linked knee joint with either a mechanical swing phase control or a pneumatic swing phase control. Furthermore, the energy cost while walking with the two knee joints was measured. The knee joint with mechanical swing phase control was the Otto Bock 3R20, while the linked knee joint with pneumatic swing phase control was the Tehlin knee.

Having used both knee joints, 19 patients preferred the Tehlin knee, 6 patients preferred the Otto Bock 3R20 and 3 patients had no preference. Although one of the main reasons for preferring the Tehlin knee was that it seemed to make walking easier, this was not

Table IV. *Mean difference between the third and second assessments (with standard deviation) in energy expenditure (J/s · kg) and p-values of Mann-Whitney U-test between groups 1 and 2*

| | Sitting | | | 2 km/h | | | 3 km/h | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 3rd–2nd assessment | | | 3rd–2nd assessment | | | 3rd–2nd assessment | |
| Patient group | *n* | mean | (sd) | *n* | mean | (sd) | *n* | mean | (sd) |
| 1 | 13 | 0.00 | (0.14) | 13 | –0.20 | (0.20) | 11 | –0.15 | (0.31) |
| | | * | | | * | | | * | |
| 2 | 14 | 0.03 | (0.08) | 14 | 0.07 | (0.23) | 14 | 0.15 | (0.28) |
| *p-value | 27 | 0.81 | | 27 | 0.005 | | 25 | 0.01 | |

related with a lower energy expenditure during walking. The data actually showed the opposite: the energy cost with the Tehlin knee was found to be higher. It may be concluded that the choice of the amputee in favour of the Tehlin knee was made because of some kind of favourable differences other than energy cost.

The higher energy expenditure with the Tehlin knee might be explained by the fact that most patients were more familiar with a prosthesis with an Otto Bock 3R20 than with the Tehlin knee. However, excluding those patients who ultimately preferred the 3R20 (who may have been the patients who could not get used to the Tehlin knee) did not alter the results.

In some patients the Tehlin knee seemed to be placed in a more stable position than the Otto Bock 3R20. The difference in energy expenditure with both knees may have been caused by a difference in the position of the knee joints in the prosthesis however, it is not likely that this would have caused a significant difference.

The energy expenditure while walking on the treadmill was lower when the test was repeated after some weeks. This decrease in energy cost may be due to the fact that the amputees were more familiar with the test situation and with walking on a treadmill during the second and third tests. At each assessment they walked on the treadmill for some minutes before the oxygen consumption was measured. This may have been too short. However, allowing the amputees to walk for a longer period each time before the real measurement was started, would have been too tiresome for some of them.

Only a small group of patients were included in the study. Moreover, a double-blind design was impossible to achieve in this study. So, conclusions have to be seen in the light of these limitations. Further observations are therefore needed before a well rounded recommendation can be given in the choice of prosthesis.

This study focused on energy cost and can therefore not easily be compared with the studies by Godfrey et al. (2) and Murray et al. (3), which compared gait variables measured by means of gait analysis.

In conclusion, the present study, comparing the Tehlin knee with the Otto Bock 3R20, showed that most amputees preferred the Tehlin knee because it made walking easier and/or faster. It seems that the amputees made their decisions based on issues other than energy expenditure rate.

### TECHNICAL ADDENDUM

Otto Bock 3R20: 4-bar linkage, mechanical friction on proximal and distal axis, spring for extension aid; Otto Bock, Duderstadt, Germany.

Tehlin-knee: 4 bar linkage, pneumatic cylinder with separate adjustment for swing phase flexion and extension resistance, spring for extension aid; Teufel, Stuttgart, Germany.

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