

Establishment of consistent gait after fitting of new components

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Abstract—Since the time required for a person with an amputation to become familiarized with a prosthesis after a change of a component is not known, the gait of a single subject, a man with a through-knee amputation, was examined with two different knee mechanisms interchanged in the same prosthesis. Several parameters were analyzed to determine when the subject's gait had stabilized sufficiently to permit confident assessment of the appropriateness of the knee mechanisms. At least one week of functional walking was required before a clinical decision could be made about the suitability of the component. For the purposes of research, it was deemed preferable to try knee mechanisms for at least 3 weeks to be sure pertinent gait parameters stabilized.

Key words: *amputees, artificial limb, biomechanics, gait, knee joint, prosthesis design.*

INTRODUCTION

In both the clinical setting and the research environment, prosthetists make assumptions about gait quality outcomes after prosthetic components have been fitted or alignment has been altered. Often, these judgments are made after only brief practice sessions by the person being tested. The subjective nature of these assessments, or the assumptions on which later measures are based, are questionable. This is due, in part, to the unacceptably low sensitivity of visual observation (mean sensitivity = 22.2 percent) as reported by Saleh and Murdoch in 1985 (1); to

the broad range of alignments and components tolerated by many people with amputations (2); and to the fact that some measures, such as pressures and torques, are not readily observable.

This study posed the question: if different components are to be compared to ensure optimal gait outcomes, when can the prosthetist be confident that gait performance is stable and, thus, make the decision to accept or reject a component?

METHOD

A single case study with repeated measures was used to investigate this question. The subject was an active 26-year-old man who had a through-knee amputation as a result of a motor vehicle accident 9 years prior to the study. He leads an active life as the father of two small children and in his employment in fitting and maintaining domestic and industrial appliances. The subject used a Teh Lin® pneumatic knee mechanism in his prosthesis for 3 years. Prior to that he had always been fitted with an Otto Bock® 3R21 knee mechanism. The test prosthesis was fabricated to resemble the subject's usual limb as closely as possible while allowing easy knee unit substitution.

Two test knee units were used in the prosthesis. The first was an Otto Bock® 3R46, a polycentric unit with hydraulic swing control, and the second was a 3R30, a similar Otto Bock® unit with friction swing control.

The subject wore the test prosthesis with the hydraulic knee in place for 4 weeks. Sagittal and posterior data collections were taken immediately after fitting and then each week for the next 3 weeks, at the same time of day and week as the initial collections. The friction controlled

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knee unit was then fitted, replacing the hydraulic unit, and the process repeated. The manufacturer's recommendations for correct knee unit alignment were followed and no other components altered.

After the initial test period on each knee mechanism, the subject chose to continue wearing the prosthesis with the friction knee as his regular limb, making it possible to take a further series of five data collections at weekly intervals commencing 13 weeks later.

Data were collected using a Selspot® Movement Monitoring System linked with an AMTI® force platform; the subject traversing the walkway at his preferred walking speed. A total of 325 data collections were taken and calculation of the joint forces, moments, and powers were made using a link segment model (3).

Data from five walks taken on each collection day were averaged and the coefficient of variation (CV) calculated for each of the measured parameters.

Thirteen trials were available for comparison, grouped into three conditions:

1. hydraulic knee trials taken Weeks 0 to 3 (condition 1)
2. friction knee trials taken Weeks 4 to 7 (condition 2a)
3. friction knee trials taken on Weeks 21 to 25 (condition 2b).

Differences both within and between conditions were examined. Key parameters selected for closer examination, including CV, were:

- vertical ground reaction force
- step and stride kinematics
- preferred walking speed
- vertical heel rise
- knee angular velocity
- time taken to reach peak vertical force.

Statistical Analysis

Because the data to be analyzed were time series, the coefficient of variation (CV) is used to demonstrate the variability of the signal from the mean. The CV was calculated according to Winter (4) and expressed as a percentage:

$$CV = \frac{\sqrt{\frac{1}{N} \sum \sigma_i^2}}{\frac{1}{N} \sum |X_i|} \times 100$$

WHERE N = number of intervals over the period
 X = mean value of variable at i th interval
 σ_i = standard deviation of variable X about X_i

RESULTS

Both within and between conditions there was no significant difference in preferred walking speed (mean for condition 1 = 1.47 ms^{-1} ; condition 2a = 1.45 ms^{-1} ; condition 2b = 1.47 ms^{-1}), and the vertical ground reaction force showed low variability (CV = 7–12 percent).

For condition 1 the analysis revealed a reduced stance time in the last trial (**Figure 1**). This reduced stance time remained for the first trial in condition 2a, but stance time increased for the following two trials. The final trial in this condition showed stance time had reverted to first trial duration (**Figure 2**).

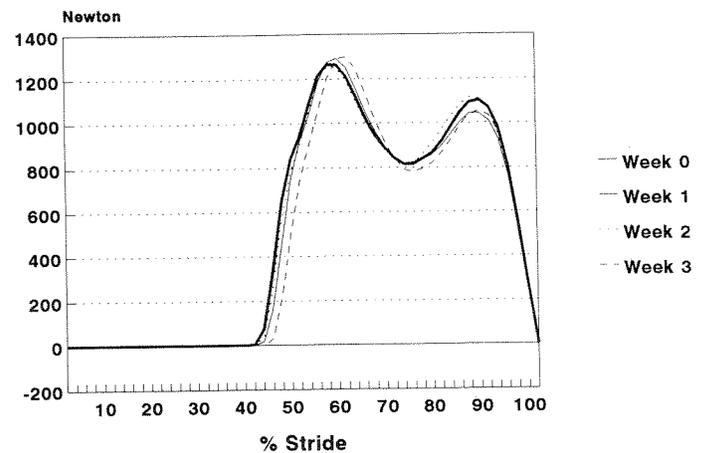


Figure 1.
Vertical ground reaction force, condition 1: hydraulic knee.

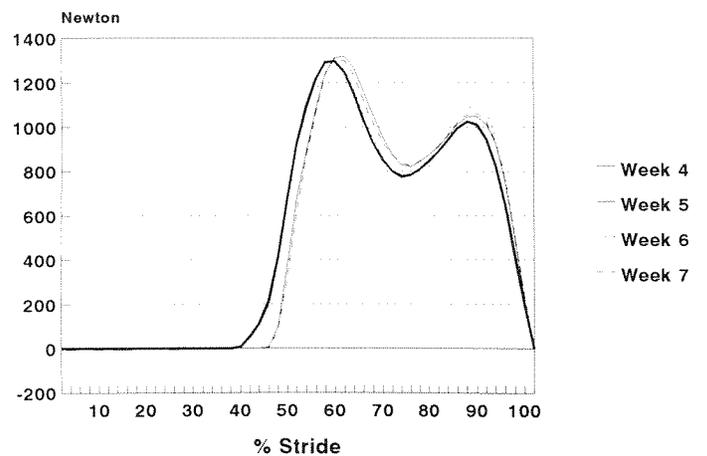


Figure 2.
Vertical ground reaction force, condition 2a: friction knee.

Stance phase duration for condition 2b (Figure 3) was consistently at the lower range.

In the graph of the knee angular velocity for condition 1 (Figure 4), an established pattern across all trials can be seen. The graph shows similar peaks and a negative velocity prior to toe-off. For condition 2a (Figure 5), the pattern is similar to condition 1 immediately after fitting the friction knee mechanism, but changes to a different 'standard' pattern for this knee over time.

When condition 1 was compared with condition 2a the following changes were noted:

- the time taken to peak load (T_1 , Figure 6) was shorter

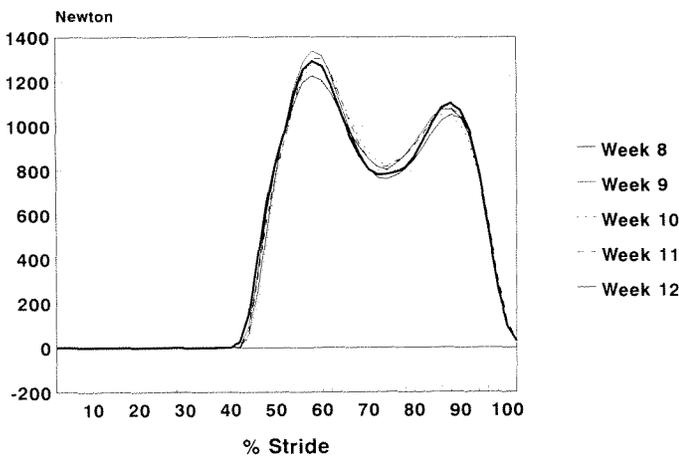


Figure 3. Vertical ground reaction force, condition 2b: friction knee.

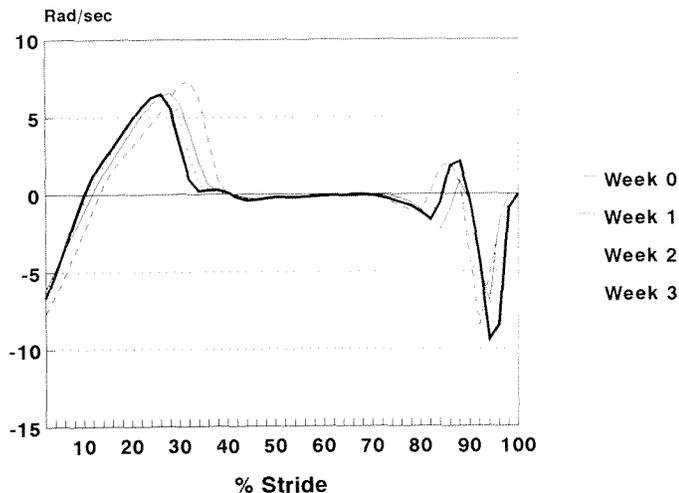


Figure 4. Knee angular velocity, condition 1: hydraulic knee.

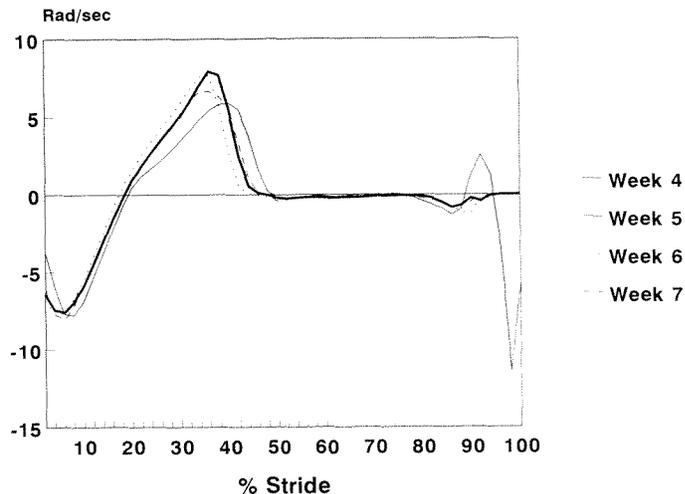


Figure 5. Knee angular velocity, condition 2a: friction knee.

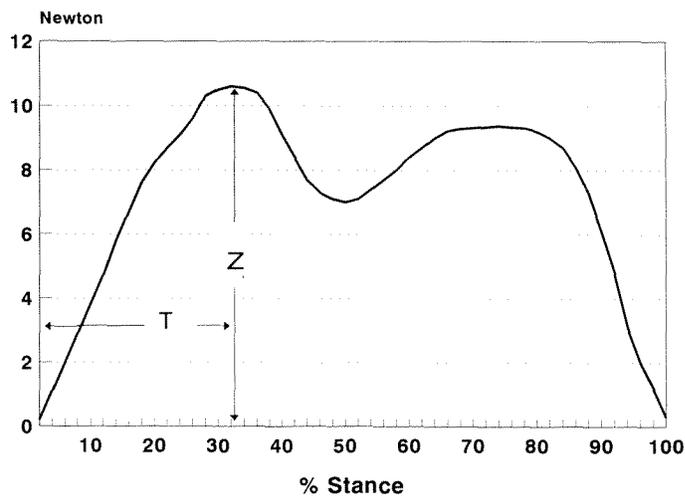


Figure 6. T_1 : time taken to reach first peak vertical ground reaction force.

- the vertical ground reaction force had a lower CV, although both were near the normal limits of 10 percent (4)
- the knee angular velocity had a lower CV
- the hip moment recorded for had a lower CV.

Only the hip power displayed a higher CV for condition 1.

When comparing condition 2a with condition 2b, the following values reduced:

- the average T_1 (condition 2a = 61 percent stride, condition 2b = 58 percent stride)

- the knee angular velocity CV (condition 2a = 55 percent, condition 2b = 26 percent)
- the knee angle CV (condition 2a = 17 percent, condition 2b = 15 percent)
- the CV of the vertical ground reaction force (condition 2a = 12 percent, condition 2b = 7 percent).

DISCUSSION

Figures 4 and 5 indicate a 'settling in period' where Week 1 data differ noticeably from Weeks 2 to 4 on the second test knee mechanism. It can be presumed, therefore, that the subject needed to wear the altered prosthesis for at least one week before a decision about the effectiveness of the change could be supported. This time is needed to allow for adapting to the new component by modifying a practiced gait pattern. The increased stance phase duration recorded in the middle two trials of condition 2a further indicates that maximal gait quality measurement requires at least 3 weeks of practice before gait stability can be assumed.

While clinical decisions may be made after one week it is suggested that, for purposes of research, an altered limb should be worn for at least 3 weeks to ensure that consistent walking performance is obtained.

The reduction in variability of the vertical ground reaction force from 12 percent to 7 percent (**Figures 2 and 3**) between condition 2a and condition 2b indicates improvement in walking consistency over the 21 weeks, but it is not suggested that this extended time is necessary before decisions can be made about gait stability.

The accepted global measure of gait quality (5), walking speed, was not sensitive enough to reveal the inconsistency brought about by the changing of the knee unit. This indicates that this measure cannot be used in a clinical setting in the short term to demonstrate acceptance of prosthetic changes. Prosthetic stance time and T_1 were better indicators of gait consistency, both becoming ex-

tended after each knee unit substitution and reducing as time progressed.

More difficult to measure, but equally useful as a gauge of gait stability, was the prosthetic knee angular velocity. This pattern also did not stabilize until after a settling-in period.

Although with the hydraulic knee the subject demonstrated a higher quality gait, as evidenced by the smaller T_1 and less variable knee angular velocity, he elected to continue using the prosthesis with the friction knee. This somewhat surprising result may be explained by the increased variability in hip power for condition 1 (hydraulic knee), which indicates a high energy input at the hip when this knee unit is used.

CONCLUSIONS

From the data presented in this study, it can be demonstrated that the subject became more consistent in his walking pattern the longer he used the prosthesis.

It is thus recommended that prostheses that have been altered should be worn for at least one week before consideration is given to accepting or rejecting the changes made. Further, for research purposes, a period of 3 weeks familiarization on the prosthesis is more appropriate.

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