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AN EXPERIMENTAL STUDY OF THE KINEMATICS OF A MODIFIED ABOVE-KNEE PROSTHESIS

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ABSTRACT
The users of the modern prostheses, such as the so-called "intelligent" prostheses or computer-controlled prostheses, still can not climb stairs as nonamputees do. Rising from a chair is also very difficult activity for a transfemoral amputee. The underlying reason for this unresolved problem of stair climbing with an AK prosthesis lies in the need to introduce an external source of energy, which would provide the user with the energy required to lift the body when climbing stairs. To solve this problem, a small linear actuator was installed in an existing Endolite above-knee prosthesis. Connected to an external hydraulic power system, the new prosthesis allows its user to climb stairs. This paper deals with the kinematics of such a modified prosthesis.
Keywords: above-knee prosthesis, hydraulic actuator, kinematic analysis

1. INTRODUCTION
Prosthetic technology has advanced to a remarkable degree in the past two decades, driven largely by amputees' demand. Today, otherwise healthy individuals with mid-calf amputation should be able to participate in a full range of normal activities, to walk without any perceptible limp, and to engage in recreation and sports [1]. Current above-knee prostheses enable their users to walk, stand and sit fairly comfortably [2]. A lack of muscles limits an above-knee amputee's other activities. Stair-climbing and other similar elevation-related activities are some of the greatest problems that such persons are still faced with [3]. Development of prosthetic walk to approximate the complexity of the normal walk requires improvement of intelligent control versus the classic methods. For the transfemoral amputee the loss of the knee is undoubtedly significant problem with respect to control and security, and also energy consumption. The modern above-knee prostheses make walking much easier for amputees. Substantial study is given to the knee and ankle joint of the prosthesis [4,5].
To date, the problem of climbing stairs for a transfemoral amputee has not been resolved. The users of the modern prostheses still can not climb stairs as nonamputees do. Rising from a chair is also very difficult activity for a transfemoral amputee. The underlying reason for this unresolved problem of stair climbing with an AK prosthesis lies in the need to introduce an external source of energy, which would provide the user with the energy required to lift the body when climbing stairs. This approach is usually disregarded due to the presumption of a need for a robust external source of power, which would be unacceptable to the user. To solve this problem, a small linear actuator was installed in an existing Endolite above-knee

prosthesis. Connected to an external hydraulic power system, the new prosthesis allows its user to climb stairs. This paper deals with the kinematics of such a modified prosthesis.

2. THE EXPERIMENT

The above-knee prosthesis ENDOLITE type SFEUK (Stanceflex Uniaxial Knee Chassis) was used for this testing. Using this type of prosthesis it was easy to build in a new hydraulic cylinder by substituting its damper in the knee joint, without causing any destruction of the prosthesis structure. The existing damper in the knee joint is substituted with a specially constructed hydraulic cylinder. The prosthesis is made of new materials (composites), so it has a low mass. This is very important due to the possibility of future changes in mass, as it permits a change of mass within an allowed range. The constructive conception of the hydraulic cylinder was defined, but the mechanical and hydraulic characteristics (force, pressure, flow rate) have been defined previously with consideration to the available space and connection points in the existing prosthesis.
The modified above-knee prosthesis was attached to a frame that prevented the prosthesis from falling over during testing. The frame was made from aluminum bars attached to each other with connector plates and screws.
The prosthesis's "foot" was attached to the frame. For the experiment, two types of feet were used – one with a flexible joint between the foot and the lower leg (StanceFlex) and one with a rigid joint.

2.1. Instrumentation

The position measuring system POLARIS (Northern Digital Inc., Ontario, Canada) was used in the kinematic analysis of the movement of the upper half of the prosthesis. A passive measuring system was used for the experiment. Clusters of infrared reflective markers were attached to the prosthesis. Three clusters of markers, each with three markers, were placed: one on the prosthesis' frame, another on the lower leg, and the third on the upper leg just above the knee (Fig.1).

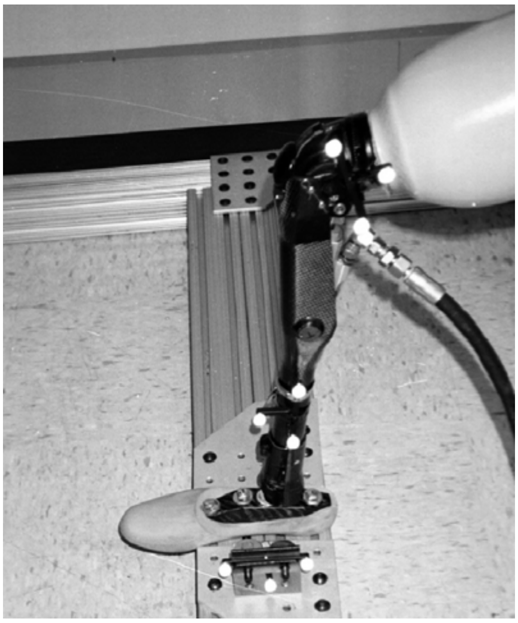

Figure 1. Prosthesis with markers attached

2.2. Experimental preparations

The linear actuator installed in the knee of the prosthesis was connected to an Enerpac hydraulic system. The prosthesis was placed within the POLARIS measuring range so that all three marker clusters could be tracked at once. Through such positioning of the prosthesis, several important parameters could be determined throughout the movement of the prosthesis: the lower leg axis, the knee joint angle, and the weight positions at the upper part of the prosthesis.

2.3. Experimental testing

The experimental testing of the above-knee prosthesis was carried out in the following manner: oil released from a valve in the hydraulic system moved the linear actuator in the knee of the prosthesis, which then lifted the upper part of the prosthesis until it reached a vertical position.

Once this had occurred, the oil was channeled back into the reservoir through a duct and the upper part of the prosthesis returned back to its original lowered position.

The experiment tested the effect of the joint between the foot and the lower leg of the prosthesis. First the rigid joint was tested, then the flexible joint.

Also tested were the motion kinematics of the above-knee prosthesis during a stair-climbing simulation and during a simulation of rising from a chair. The difference between this two motions lies in different body positions which produces different moments in the knee and ankle joints. Mass disposition during the rising from a chair produces greater forces and moments in the prosthesis.

3. RESULTS

The results of the tests using a rigid joint and flexible joint between the foot and the lower leg of the prosthesis are shown in Figures 2 and 3. Figure 2 shows the motion of the upper part of the prosthesis during the simulated stair-climbing and the motion of the upper part of the prosthesis during the simulated rising from a chair with a rigid joint between the foot and lower leg of the prosthesis. The time duration for stair climbing was 0,95 s and recording was done over 16 frames. The time endurance for rising from a chair was 1,20 s and recording was done over 22 frames. Figure 3 shows the motion of the upper part of the prosthesis during the simulated stair-climbing and the motion of the upper part of the prosthesis during the simulated rising from a chair with a flexible joint between the foot and the lower leg of the prosthesis.

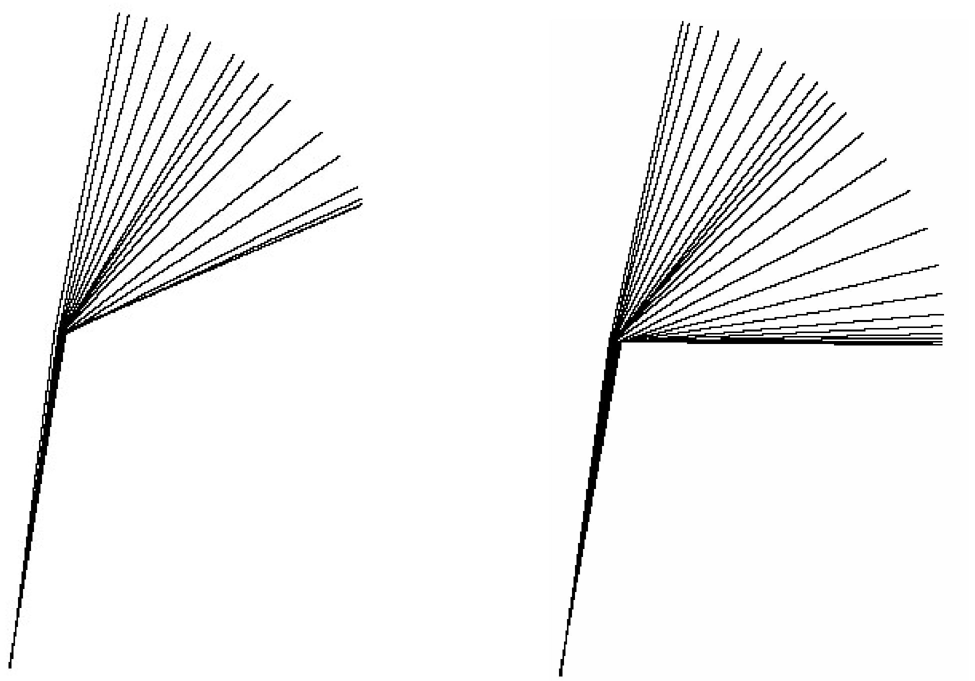

Figure 2. Simulated stair-climbing with a rigid joint between the foot and lower leg of the prosthesis (left), simulated rising from a chair with a rigid join between the foot and lower leg of the prosthesis (right)

The time duration for stair climbing was 1,06 s and recording was done over 19 frames. The time duration for rising from a chair was 1,34 s and recording was done over 24 frames.

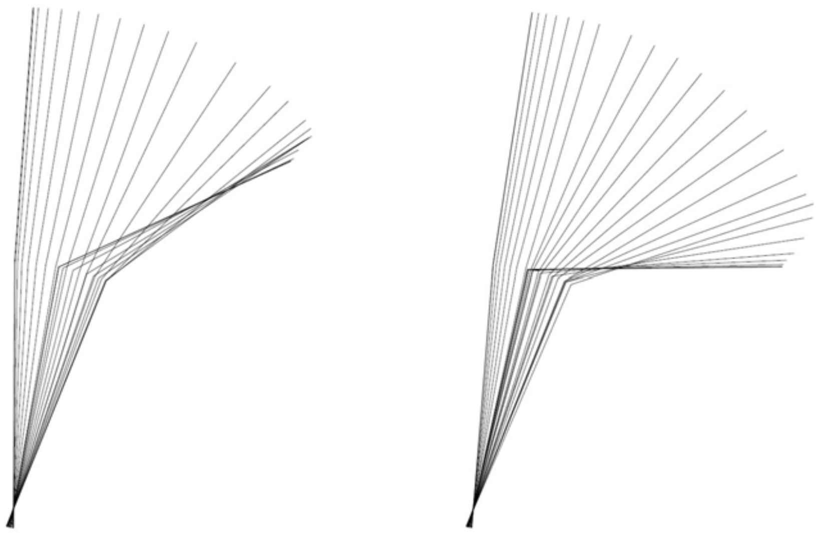

Figure 3. Simulated stair-climbing with a flexible joint between the foot and lower leg of the prosthesis (left), simulated rising from a chair with a flexible joint between the foot and lower leg of the prosthesis (right)

4. ANALYSIS OF THE RESULTS

The experiment showed that there is no significant difference in the motion kinematics of the above-knee prosthesis when climbing the stairs and when rising from a chair. The only notable difference is in the amount of time required during the simulation of rising from a chair. The experiment showed a considerable difference in the motion kinematics of the two types of joint between the foot and lower leg. The flexible joint allows a much greater freedom of rotation in the knee of the prosthesis, which may be more comfortable for a user, but could also cause stability problems during use. Also shown was that the available degrees of flexibility are not sufficient for stair-climbing. In the experiment, the maximum angle created was 6^o, whereas an angle of 15^o is necessary for stair-climbing.

5. CONCLUSION

The experiment very convincingly demonstrated the expected motion kinematics, which were unable to be represented adequately in a visual medium due to the very short duration (0.8 – 1.2 s)

Furthermore, the experiment showed the great difference in the motion kinematics of the above-knee prosthesis with a rigid foot-to-lower-leg joint and the prosthesis with a flexible joint.

The experiment also showed that a new solution is necessary to the problem of finding a suitable type of joint between the foot and lower leg if successful stair-climbing is desired. The task required from a new foot model would be to ensure proper dorsal flexion in the ankle during stair climbing. As the kinematics of an amputee should approximate the normal kinematics, it is also necessary to add a hydraulic cylinder in the ankle. Its role would be to create a proper dorsal angle for foot positioning and provide a moment needed for lifting the body.

6. REFERENCES

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