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An Above-Knee Prosthesis for Rock Climbing

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INTRODUCTION

Rock climbing is a dangerous, but challenging activity in which ascents of vertical cliffs are attempted. It is considered a truly challenging activity where danger is a constant element. Very often, the alpinist can balance on a mere inch or two of rock with his feet, while his hands explore a still more precarious hold. For the rock climber, the challenge is not the height of the ascent, but the degree of difficulty of the climb, which can range from easy to very severe. Physical endurance, powerful leg and arm muscles, as well as efficient footgrips and handholds are required to deal with chimneys and crevices, particularly in the case of very steep rocky surfaces.[1]

A small number of lower limb amputees have taken up rock climbing and find it to be a positive experience. In general, they report that this sport provides an opportunity to develop their courage, patience, and presence of mind, and more importantly, a way to overcome fears, prove their ability, and heighten self-esteem through the pursuit of an unusual and challenging activity.[2]

The literature relating to the development of special prosthetic and orthotic devices for rock climbing is scarce. For the below-knee amputee, ice climbing crampons have been adapted to clip to the prosthetic shank.[2] An ankle-foot assembly which provides motion in all planes was also found to be helpful, especially when climbing over typically rough terrain.[3] Above-knee amputees generally prefer to climb without their prosthesis and to rely on specially adapted forearm crutches for added grip and stability.[3] The disadvantage of this method of rock climbing resides in the limited use of the hands for handholds and the necessity for the amputee to carry his prosthesis on his back for use on level surfaces.

When rock climbing with their prostheses, certain problems were brought forward by above-knee amputees. In summary, these are: the ineffectiveness of the footgrip when using an above-knee prosthesis; the forefoot of the prosthesis catching in crevices; the inability to use knee grips; the relative knee instability in certain situations; and movement restrictions due to limited outward rotation of the leg and foot. The bulk of the exoskeletal knee joint assembly and shank also hampers movements and close contact of the body with the rocky surface. For the person with a very short above-knee residual limb, the use of a pelvic band and single axis hip joint further limits performance because of hip movement limitation. In addition, the weight of the prosthesis, due to certain components and reinforcements, imposes upon the amputee extra energy expenditure when lifting the prosthesis and excessive friction between the residual limb and the prosthesis, thereby causing residual limb irritation and breakdown. Consequently the

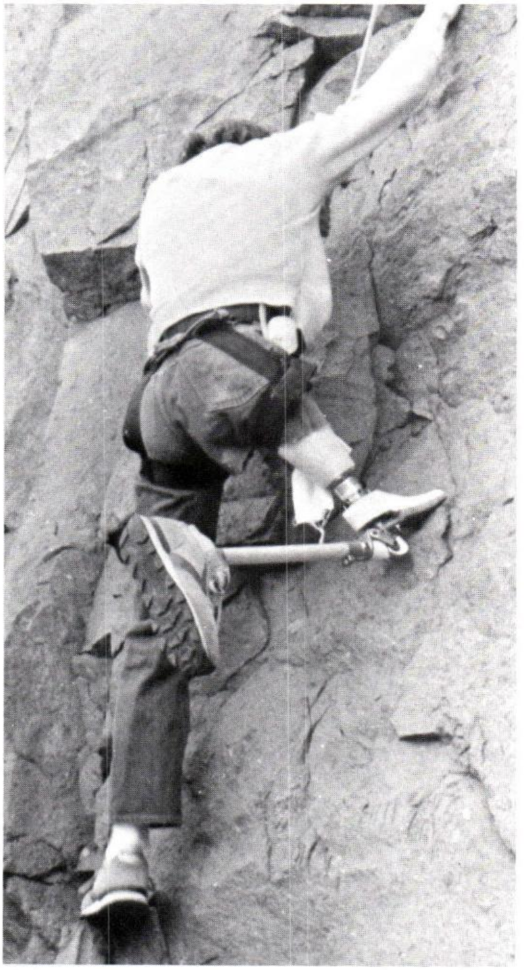

Figure 1. The above-knee prosthesis for rock climbing provides grip close to the residual limb.

above-knee amputee may climb only easy to moderately difficult rocky surfaces. In order to surmount these problems, a rock climbing prosthesis (RCP) was designed specifically for the above-knee amputee.

Modifications were made to an above-knee prosthesis for a very short residual limb previously equipped with a pelvic band, single axis hip joint, exoskeletal single axis, constant friction knee unit, and SACH foot. The rock climbing prosthesis allows greater mobility, is less bulky and lighter, provides grip close to the residual limb (Figure 1), improves stability and footgrips, and avoids hooking of the forefoot in crevices.

FABRICATION OF THE RCP

The RCP prototype includes a conventional socket, a modified pelvic band, a thigh rotation system, a foot assembly close to the knee (upper foot), a modular polycentric knee, a titanium shank, and a SACH foot (lower foot).

Socket and Suspension

A conventional polyester resin socket was used. To allow greater hip flexion, the anterior wall of the socket was lowered by 2.5 cm (one inch). Due to the shortness of the residual limb (length of 17.5 cm or seven inches) initial flexion of the socket of ten degrees and abduction of five degrees were provided.

For added strength and more efficient suspension, a stainless steel pelvic band was preferred to the silesian band (Figure 2). It was fit with a four-way hip joint (ACME #3J-7704-00). Hence, hip movements in the frontal and saggital planes were permitted. Adjustable elastic bands were anchored anteriorly and posteriorly on the socket and band in order to avoid protrusion of the residual limb out of the socket when climbing. The anterior strap extended from the midline of the anterior wall of the socket at the level of the ischial seat, up to the pelvic band (Figure 2). To counter-balance the initial abduction of the socket, the posterior strap was anchored 2.5 cm (one inch) medial to the midline of the posterior wall and 2.5 cm (one inch) below the proximal brim of the socket. All attachments were reinforced with fiberglass.

Thigh Rotation System

In certain rock climbing conditions, the climber must bear weight on the medial border of the shoe. This maneuver involves, to varying degrees, movements at the hip, knee, and ankle joint. The lower limb amputee fitted with an above-knee prosthesis, has limited range of motion in the horizontal plane since no rotation is possible at the knee and ankle joints. Further limitation is introduced by the use of a pelvic band. Hence, to obtain a medial

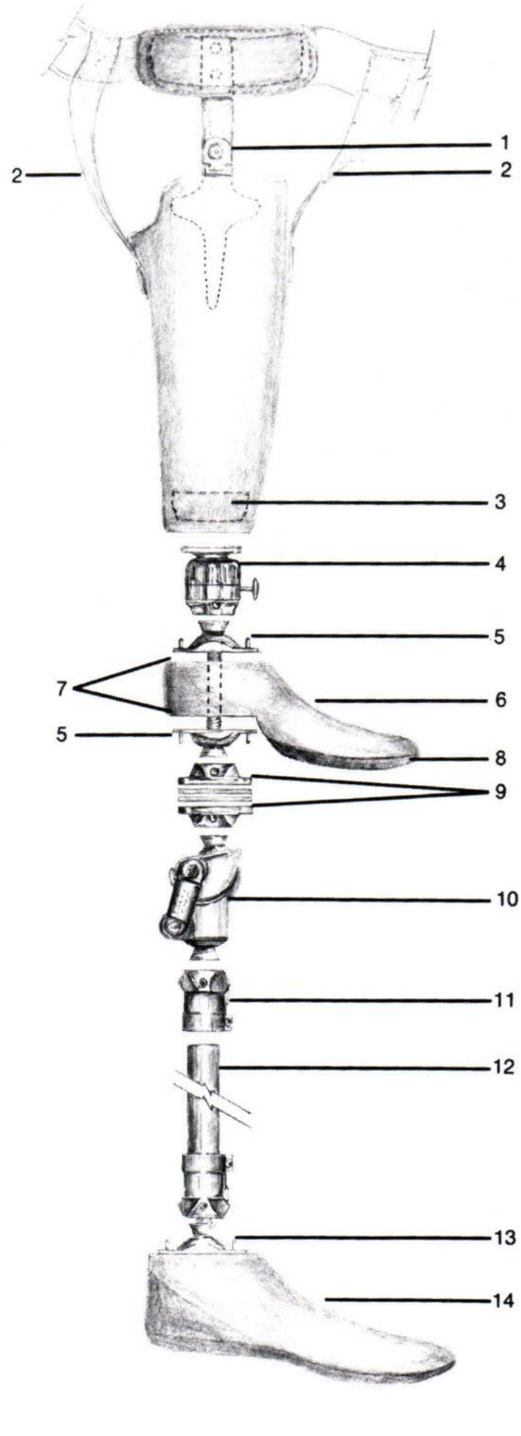

Figure 2. Exploded view of the components of the RCP:

1. **Multi-axial hip joint**
2. **Elastic bands**
3. **Plastic adaptor plate**
4. **Thigh rotation system**
5. **Titanium SACH foot adaptor**
6. **SACH foot with denuded keel (upper foot)**
7. **Fiberglass reinforcements**
8. **Anti-skid rubber sole**
9. **Titanium rotatable socket adaptors**
10. **Modular two-bar linkage knee unit**
11. **Tube clamp adaptor**
12. **Titanium modular shank**
13. **SACH foot adaptor**
14. **SACH foot**

footgrip, the amputee rock climber must twist his trunk away from the rocky wall, increasing risk of a fall. As illustrated in Figure 2, a manually controlled thigh rotation system (Otto Bock #4R45) was fit under the socket with a plastic adaptor plate (Otto Bock #5R1). It allows up to 110 degrees of external rotation of the limb and locks in the neutral position (Figure 3). The release lever is incorporated into the thigh rotation system. For amputees with longer residual limbs, this lever can be extended proximally close to the hip, so that trunk flexion is not necesary to reach it.

Grip Close to the Residual Limb: The Upper Foot

Grip close to the residual limb is made possible through the insertion, at a 90 degree angle, of a SACH foot (Otto Bock #1S10) between the thigh rotation system and the knee unit. Modifications were made to the ankle-foot unit (Figure 1). The rubber of the posterior part of the foot was stripped off and the wooden keel was denuded (Figure 2). The wooden keel was then reinforced with two layers of fiberglass (Figure 2). Two titanium modular SACH foot adaptors (Otto Bock #2R31=M10) were molded in the fiberglass coating and screwed to the keel above and below the keel of the upper foot, thereby eliminating any possibility of torsion at that level (Figure 2). A 0.6 cm (1/4

Figure 3. The thigh rotation system allows up to 110 degrees of external rotation.

inch) rubber anti-skid sole was glued under the anterior part of the foot (Figure 2).

Knee Unit

Two titanium rotatable socket adaptors (Otto Bock #4R51) were superimposed and screwed under the upper foot to provide anchorage for the knee unit. A stainless steel two bar linkage modular knee joint (Otto Bock #3R19) was selected (Figure 2). This knee joint unit allows up to five degrees of knee hyperextension for improved knee stability in stance and is provided with an extension aid. Moreover, when the knee is brought into full flexion, it may be maintained in this position, against gravity (Figure 1). Thus, accidental hooking of the lower foot in crevices is avoided.

Shank and Foot

The lower part of the RCP consists of a titanium long tube (Otto Bock #2R38), attached to the knee unit with a titanium tube clamp adaptor (Otto Bock #4R52) and to the SACH foot by a titanium SACH foot adaptor (Otto Bock #2R31=M10). Altogether, the use of titanium reduces considerably the weight of the prosthesis and compensates for the added weight of the pelvic band.

FUTURE PLANS

The rock climbing prosthesis was clinically tested with a 25 year old above-knee amputee, and was found to improve his rock climbing capabilities. With the RCP, the above-knee amputee rock climber is provided with greater mobility and with foot and knee grips acting in different planes. Therefore, the climber has full use of his hands and ascents of steeper walls can be attempted. On more even ground, normal gait is possible with no special adjustment required (Figure 4). Yet certain problems still have to be resolved, one being that of cosmesis and social acceptance of the RCP, since the upper foot is

Figure 4. With the RCP, normal stance and gait are possible.

permanently fixed to the prosthesis and protrudes anteriorly. Ideally this upper foot should be removable and could take the shape of an incurved anti-skid metallic blade which can be attached when needed. A second problem relates to the protection of the knee unit. Since the knee is not covered, it is liable to rub on the rocky surface and be damaged. In addition, it is not protected against rain and water running off the rock.

CONCLUSION

An above-knee prosthesis for rock climbing was developed. It provides two important features: grip close to the knee and full outward rotation of the leg for grip on the medial border of the shoe. It consists of a conventional socket, multiaxial pelvic band and thigh rotation system placed under the socket to increase mobility, a protruding foot above the knee axis for grip close to the knee, a modular polycentric knee, and a SACH foot. Titanium components were used in order to reduce the overall weight of the prosthesis.

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