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Some Biomechanical Evaluations of the ISNY Flexible Above-Knee System with Quadrilateral Socket

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INTRODUCTION

Biomechanical functions of above knee sockets can be divided into two parts. The first is to encase or contain the residual limb, and the second is to bear the weight of the amputee.

The shape of the residual limb depends on muscle activity during each gait phase. The conventional hard above knee socket cannot alter itself with these changes. If we use a flexible socket to encase the changing limb, which is held by a hard weight bearing frame, the amputee should feel more comfortable in this socket (Figure 1), also the fit of a suction socket will be more complete in it. So it can be assumed that the ISNY (Icelandic-Swedish-New York) socket has been developed in this context.

Over 70 prostheses incorporating the ISNY flexible above knee socket have been fabricated in our facility. The patients' subjective evaluations to the sockets are very good. In this study, we have attempted to evaluate and study biomechanically three above knee amputees (Table 1) with regards to the socket shape and degrees of adduction of the femur.

METHOD

Using three linear motion transducers (potentiometer), we have measured the movement of the socket walls. Three transducers were attached to the central point of the socket walls at right angles to the anterior, lateral, and posterior sides (Figures 2, 3, and 4). The data gained from the transducers were recorded by a data-corder, transmitted to an A/D converter, processed by micro-computer, and drawn on sheet paper automatically by the X-Y plotter. Using foot switches which are attached to the prosthetic and normal shoe soles, we recorded the stance-phase of each leg with time. The system is shown in Figure 5. Measurements were made for a ten meter walk, which was repeated five times (Figure 6).

Results of our study, which showed changes of the socket shapes measured by the linear motion transducers, were almost the same for the three amputees, so we have displayed only the result of subject H (Figure 7).

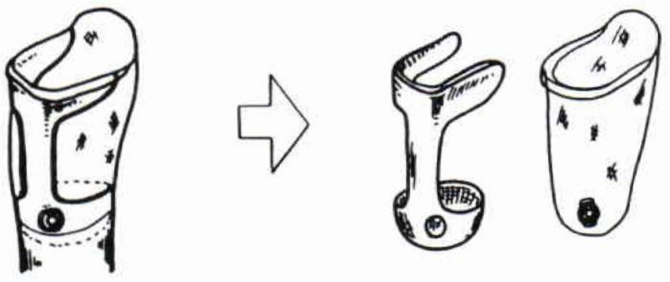
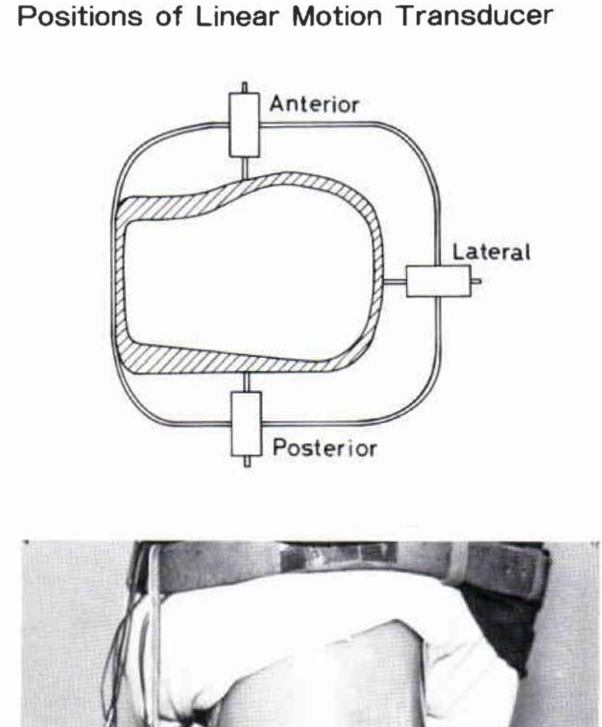


Figure 1. (left) Components of the ISNY Flexible Socket System, including completed system, rigid frame, flexible socket.

Figure 2. (below) Cross-sectional view showing initial position of transducers on anterior, lateral, and posterior walls.



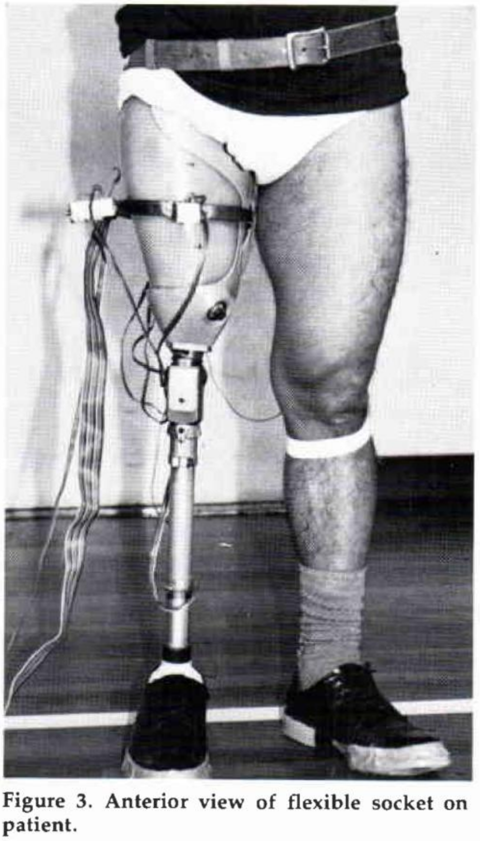


Figure 3. Anterior view of flexible socket on patient.

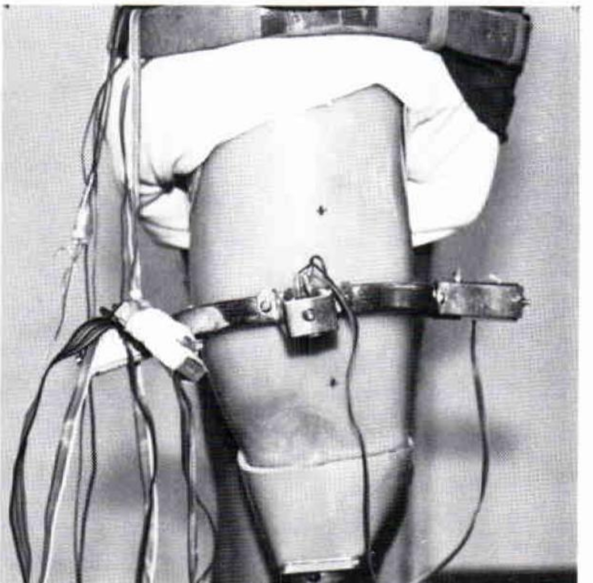


Figure 4. Lateral view of flexible socket on patient.

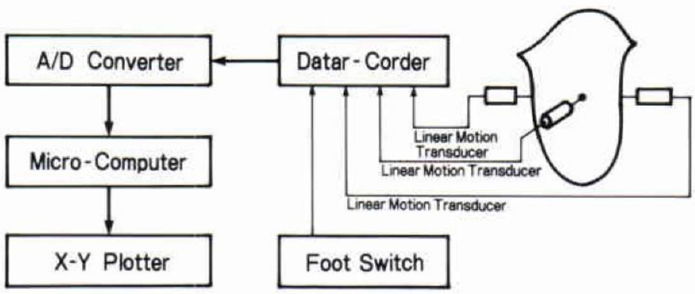


Figure 5. (left) Schematic illustrating recording system for socket data.

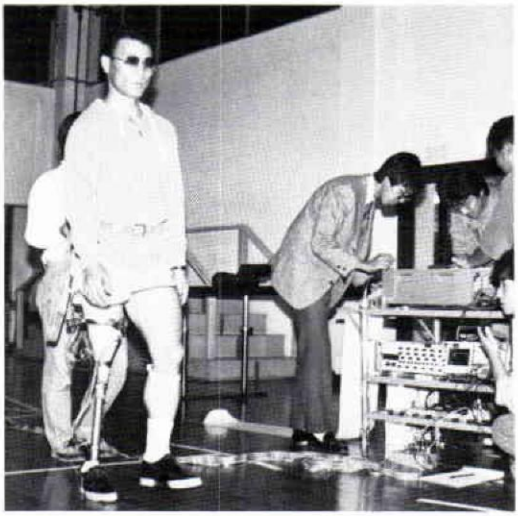


Figure 6. A demonstration of the study in progress.

Subject	Length of Stump	Age	Years after Amputation
T	14 cm	36	20
H	23.5cm	36	24
S	25 cm	39	21

Table 1. Statistics of the three amputees in the study.

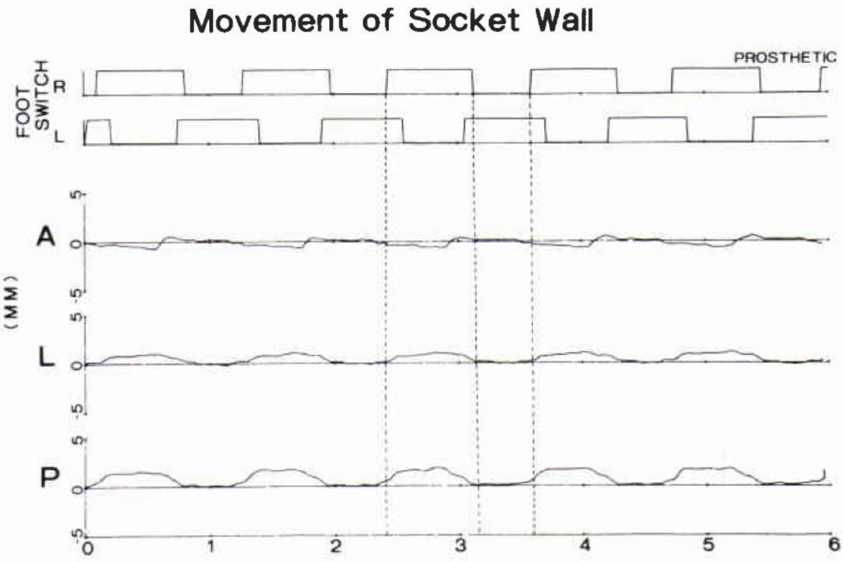


Figure 7. Graph of data plotting millimeters of motion (Y) vs. time (X).

RESULTS

The upper position of Figure 7 shows which side is in the stance phase, and the lower position shows changes of the socket walls—anterior, lateral, and posterior—corresponding to the walking cycle.

The vertical axis shows deviation expressed in millimeters. The positive direction shows expansion of socket, and negative direction shows shrinkage. The horizontal line shows time in seconds; in this case, the anterior wall shrinks from the beginning of stance phase and continues to the push off phase of stance. This subsequently reverses to expansion before gradually returning to a neutral position. From the middle of swing phase, to near the start of stance phase, the lateral and posterior walls expand. There is a gradual decrease from push off and a return to neutral position at the beginning of swing phase.

The mentioned results are illustrated in Figure 8; broken lines show the socket of the prosthesis in a relaxed state. The solid lines indicate the prosthetic socket shapes at various points during gait. At heel contact, the socket anterior wall collapses and the posterior wall expands. At mid-stance, the lateral wall expands, while at push-off the anterior wall expands and the previously expanded posterior wall reduces. At toe-off, the socket shape returns to a relaxed position.

These findings explain the change in socket shape. At heel contact, the posterior residual limb musculature expands; at mid-stance, the femur pushes the socket wall outward to hold the pelvis in a horizontal position; and at push-off, the anterior musculature expands to swing the leg forward, all of which corresponds to our expectations.

The amount of deviation related to the movements of the socket walls was not so great. In this case, the maximum deviation was 1.6mm, but for the other subjects the maximums were 5.0mm.

Femoral Adduction

The degree of adduction of the femur in the flexible socket might be supposed to be much smaller, so we inspected this by x-ray. We found that there is no difference between a flexible socket and a hard socket concerning the degree of adduction of the femur (Figures 9 and 10). The flexible sockets were, of course, duplicates of the hard sockets.

At this point, it seemed necessary to take the whole lateral wall movement, and measure it more precisely. To do this, we attached four transducers onto the lateral wall, from the proximal area to the distal (Figure 11). The movement of the lateral wall at each point was recorded automatically, by the same measuring system, and the result is shown in Figure 12. We as-

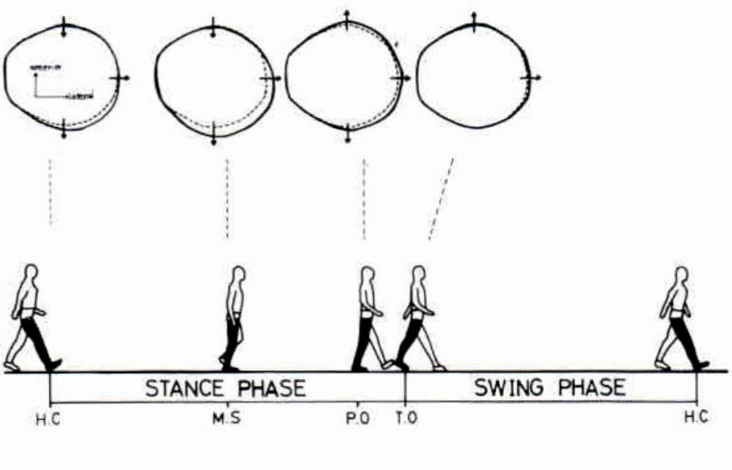


Figure 8. (left) Graphic representation of the data with phase of gait during which it is observed."

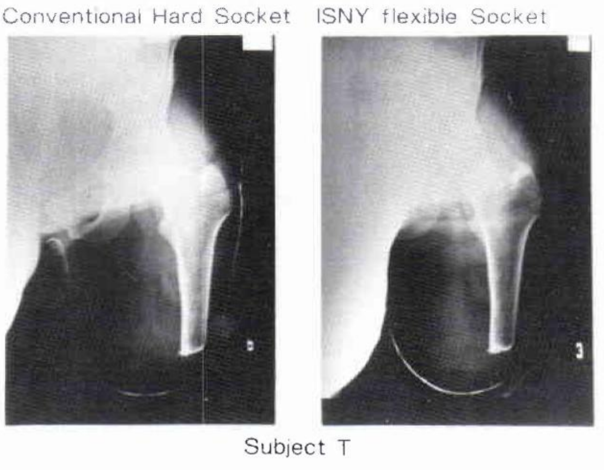
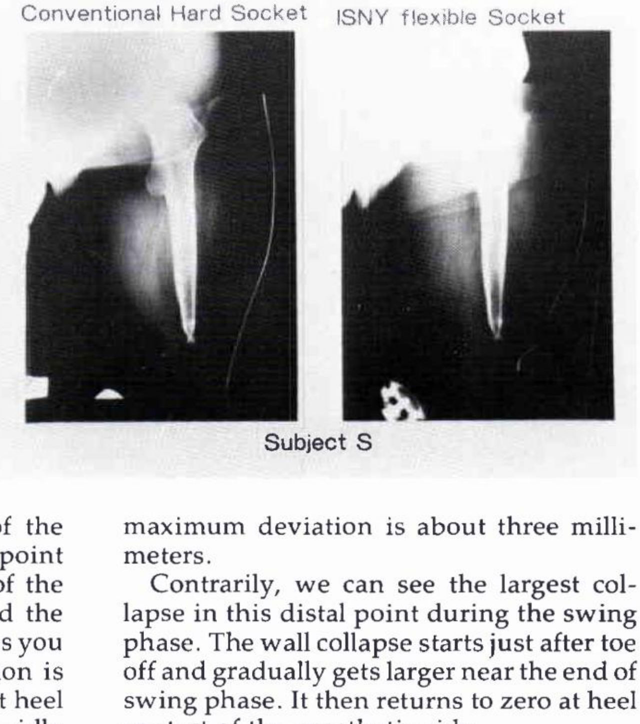


Figure 9. (left) Adduction angle of femur in subject T.

Figure 10. (right) Adduction angle of femur in subject S.



sumed that the largest expansion of the lateral wall can be seen at the lowest point at the stance phase. The level arm of the femur will push at this point toward the outside direction the strongest. But, as you see in Figure 12, the biggest deviation is seen in the proximal second point. At heel contact, the lateral wall expands rapidly and continues expanding until push off, where it gets its maximum deviation (in this case five millimeters). The socket wall then shrinks rapidly until toe off, where it returns to a zero level. The expanding of the most distal point is not so large as compared with the proximal second point. It expands also in the stance phase, but the maximum deviation is about three millimeters.

Contrarily, we can see the largest collapse in this distal point during the swing phase. The wall collapse starts just after toe off and gradually gets larger near the end of swing phase. It then returns to zero at heel contact of the prosthetic side.

We can see some shrinkage of the lateral wall at the most proximal point, but in this case, the pattern of movement is a little different compared with the most distal point. In the proximal point, the shrinkage starts at mid-swing phase, gets largest around heel contact of the prosthetic side and continues to midstance, where it re-

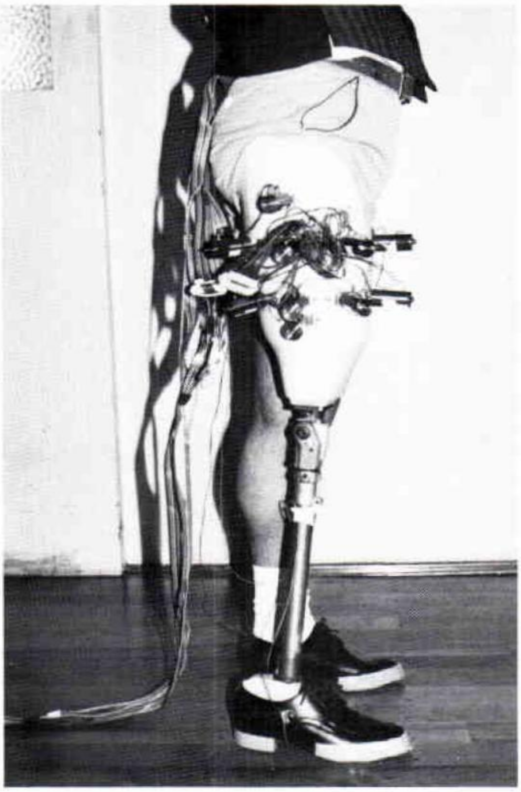


Figure 11. Lateral view, showing socket with four transducers placed along lateral wall.

turns to zero. From these results, it can be concluded that the lateral wall of the ISNY flexible socket has sufficient strength to hold the femur in the initial adducted position. In addition, the lateral wall movements of the flexible socket correspond to the changes in the residual limb's soft tissue shape. If the socket wall movements were caused by the lever arm movement of the femur, our result would be completely different.

Socket Wall Thickness

The socket wall thicknesses seem to be unequal for each area. This is caused by the manufacturing procedures. We cannot overlook this fact when speaking about the socket wall movements. We have measured the thickness of the flexible socket using a micrometer for 29 points. That corresponds to four different height levels, each eight points from medial, anterior, lateral, and posterior. We used three positive models and we made three sockets for each model. The material used is four millimeter polyethylene, which is vacuum-formed by a standard method. The results of these nine sockets were not much different, and a case is demonstrated in Figure 13. The numbers

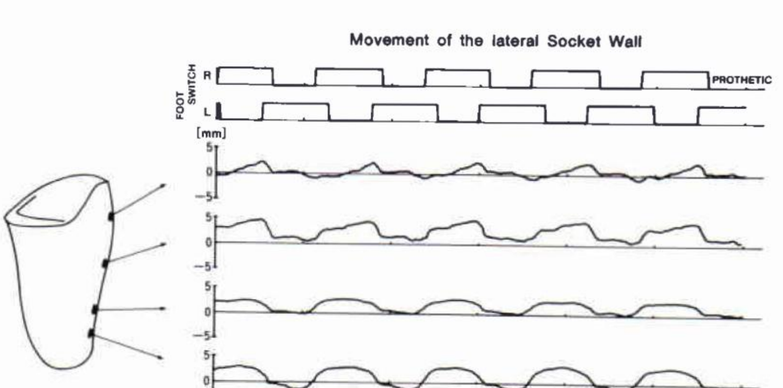


Figure 12. Motion of lateral wall during gait.

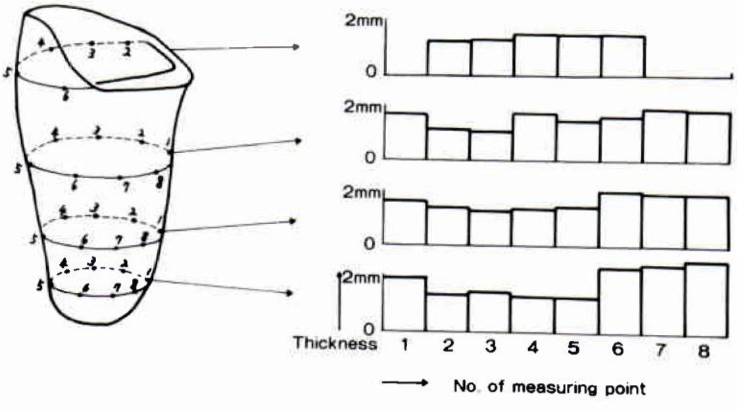


Figure 13. Socket wall thickness at various points.

show measuring points: Number 1 medial, Number 3 anterior, Number 5 lateral and Number 7 posterior, and the even numbers are midpoints in between. The maximum thickness is seen in the most distal point at the posterior side. The minimum is seen also in the most distal point, but at the lateral side. The measurements are 2.5 millimeters maximum and 1.2 millimeters minimum, or approximately a ratio of two to one.

Generally, the anterior and lateral walls are thinner than the posterior and the medial walls. We found that the socket movement of the lateral wall was largest at the second most proximal point, and the thickness of this point is almost similar to the lower points. Therefore, we can say that socket movement of the lateral wall is not a function of the thickness of the socket wall, but rather a function of the change in shape of the soft tissues of the residual limb. Although the lateral wall is thinnest, its strength is sufficient to hold the femur in the original adducted position.

SUMMARY AND CONCLUSION

The ISNY flexible above knee system with a quadrilateral socket has been evaluated biomechanically using linear motion transducers and x-ray. We found that the socket shape changed strictly in response to the muscle activity predominant in each phase of gait. The adduction degree of the femur in the flexible socket compared with a hard socket was almost the same.

AUTHORS

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