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A new biomechanical method for determination of static prosthetic alignment

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Abstract

A new static alignment method for trans-tibial prostheses is suggested using the individual load line as a reference.

Standing posture and static alignment of 18 experienced trans-tibial prosthetic users with good walking ability were determined and compared with 20 healthy persons. The individual load line was defined by means of the new Otto Bock alignment system "L.A.S.A.R. Posture".

The sagittal standing posture of trans-tibial amputees and non-amputees differs. Normally only a prosthesis worn by the trans-tibial amputee and dynamically aligned over an extended period of time satisfies biomechanical rules of alignment. In contrast, prostheses aligned during one session in the traditional subjective manner seem to lack any recognizable biomechanical systematics. Initial results suggest the knee centre should be 10 to 30mm behind the load line, depending on patient's weight. This knee position is independent on the type of the prosthetic foot.

Introduction

The quality of rehabilitation of trans-tibial amputees with prostheses is influenced by different factors. From the prosthetic or biomechanical point of view at least four important inter-related factors can be noted: the prosthetic socket, the type of the prosthetic foot selected, prosthetic alignment (Pinzur *et al,* 1995; Solomonidis, 1991), and the integration of the prosthesis into the amputee's motor activity.

The present article deals with prosthetic alignment. Preliminary results from trans-tibial fittings will be presented in which the static alignment was not based on a fixed reference line but related to the measured load line.

From clinical practice it is known that the optimization of prosthetic alignment can take several weeks from the first dynamic alignment to the final definitive fitting. The dynamic optimization of the prosthesis is a very time-consuming and subjective process requiring excellent skills and many years of experience of the prosthetist. In dynamic alignment the practitioner must rely on his visual perception during the gait trials as well as feedback from the amputee, along with his experience, to refine the alignment interactively (Zahedi *et al.,* 1986).

Although many manufacturers of prosthetic components give static alignment recommendations from clinical experience using theoretical alignment reference lines, these general guidelines do not reflect individual differences. Furthermore, there is a worldwide controversy regarding different alignment guidelines (Radcliffe, 1994; West, 1987). The possibility of applying biomechanically determined measurements to prosthetic alignment is the subject of this paper.

Method

Static prosthetic alignment was determined using the Otto Bock alignment system "Laser Assisted Static Alignment Reference (L.A.S.A.R.) Posture". Figure 1 shows a trans-

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Fig. 1. Measuring the static alignment of a trans-tibial amputee with the "L.A.S.A.R. Posture" system.

tibial amputee standing on the alignment platform.

The "L.A.S.A.R. Posture" alignment system measures the vertical component of the ground reaction force acting on the force plate of the platform. Thus the patient's weight and the location of the weight bearing line in static standing with both feet on the force plate can be determined. If only one side, e.g. the prosthetically fitted limb, is standing on the force plate, the force of that side and the resultant load line will be measured.

In addition to the force plate, the apparatus contains a projection system, electronics with a stepper motor, and the service and display unit (Fig. 2). The force plate includes 4 sensor cells located in the corners of the force plate. The microprocessor determines the centre of pressure and the amount of ground reaction force. The electronics triggers the stepper motor whereupon it moves a semiconductor laser to the centre of the measured forces. Optics located in front of the laser convert the pinpoint laser beam into a bright line. The laser line is then projected on the person being measured illustrating where the centre of pressure is located. Thus, the location of the vertical ground reaction force is visibly indicated on the amputee.

If the distance between a certain point of the body and the load line is to be measured, the laser beam can be moved to this position by pressing a button on the service unit. The distance between this body point and the load line, and the vertical force vector are indicated on the display.

In prosthetics the distance between components and the load line in the sagittal plane is useful for the static alignment. For measuring posture as well as alignment, distances of the following points from the reference line, shown in Figure 3, were recorded: the middle of the shoulder, the greater trochanter, the knee centre - defined by Nietert (1977), and the lateral malleolus.

In the frontal plane, the distance to the load line was determined from the middle of the ankle joint and knee joint.

Patients

The alignment measuring process was performed on 18 trans-tibial amputees. The posture of the amputees and static prosthetic alignment were determined on the definitive, long-term prostheses customarily worn by the patients as well as on the test prostheses. The test prostheses used the same socket as the definitive prostheses; only the prosthetic feet were changed. All test prostheses were dynamically aligned by an experienced prosthetist. Several different prosthetic feet were tested in succession.

During the alignment measuring process the patients wore their customary shoes.

Tables 1, 2 and 3 list patient's data, amputation cause, and the foot types.

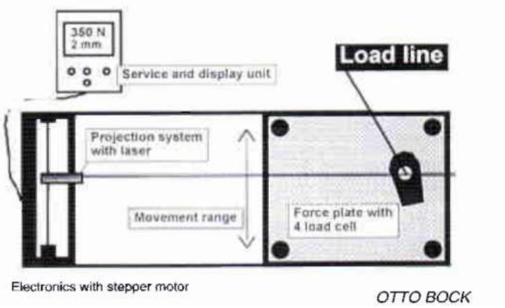

Fig. 2. Elements of the "L.A.S.A.R. Posture" alignmen system.

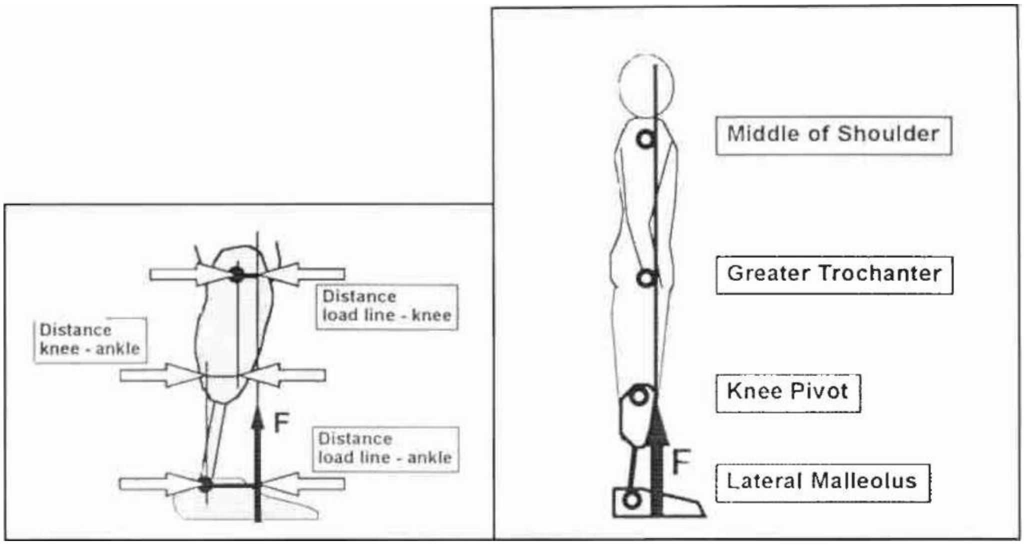

Fig 3. Sagittal plane reference points for the trans-tibial amputee, F-ground reaction force.

For this investigation, experienced users were selected who had worn a prosthesis for many years and could walk a significant distance. For this reason, amputees with circulatory impairment were not included in the investigations. The amputees had comfortable sockets and no joint pain or range of motion abnormalities.

For reference, 20 non-amputees aged 17 to 53 years were also measured.

Table 1. Amputation cause

Trans-tibial amputees	
Number:	18 trans-tibial amputees
Aetiology:	13 Trauma
	(2 as little child)
	3 Malformation
	1 Tumour
	1 Other

Results

Posture in the sagittal plane

Measurements in the sagittal plane from the middle of the shoulder, the greater trochanter, the knee joint centre and the lateral malleolus are shown in Figure 4.

The measured data show clear differences between the posture of non-amputees and the prosthetically fitted side of trans-tibial amputees. The posture of the non-amputated

Table 3. Prosthetic feet of the definitive fitting of the trans-tibial amputees

Amputee s habitual foot type		
Number:	18 trans-tibial amputees	
Foot size:	24-28	
Foot type:	Dynamik 1D10	9
	Dynamic pro 1D20	2
	Quantum foot	1
	Multiflex	3
	Flexwalk	3

Table 2. Patient's data

Trans-tibial amputees Number: 18 trans-tibial amputees				
	Age(y)	Body mass(kg)	Height (cm)	Amp. period(Y)
Mean	39 0	77.5	177	169
Stand, dev.	8.7	13.8	13	100
Minimum	18	57	163	2
Maximum	65	106	190	36

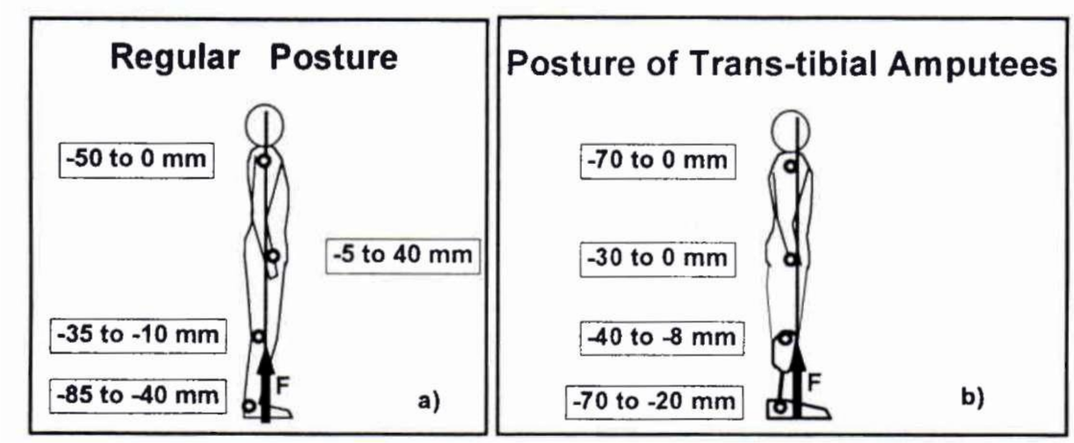

Fig. 4. Range of the positions from the middle of the shoulder, greater trochanter, knee centre and lateral malleolus; a) non-amputees, b) trans-tibial amputees with their definitive prosthesis.

side of the trans-tibial amputee is similar to that of the non-amputee.

The altered position of the hip joints seems to be most significant. Instead of a slightly anterior position of the greater trochanter with reference to the load line typical of the non-amputee, the trans-tibial amputee shifts his posture so that this anatomical point falls behind the load line (Fig. 5).

Figure 6 indicates the measured mean values and standard deviations of the measured points for all 18 trans-tibial amputees with their definitive prosthesis. The average posterior position of the ankle with reference to the load line is 50mm, that of the knee 18mm. that of the greater trochanter 16mm, and that of the shoulder 35mm.

In the frontal plane, the load lines of the trans-tibial amputee as well as of the non-amputee run approximately through the middle of the ankle joint and the knee joint of each leg.

To investigate possible interdependencies of the different joint positions, the linear coefficients of correlation were measured in pairs. For the non-amputees no relationship could be discerned. Table 4 shows on the other hand, that the trans-tibial amputees had a statistically significant correlation between the knee and ankle position, with a coefficient of correlation of R=0.53.

According to the linear correlation analysis, there are no interdependencies between the

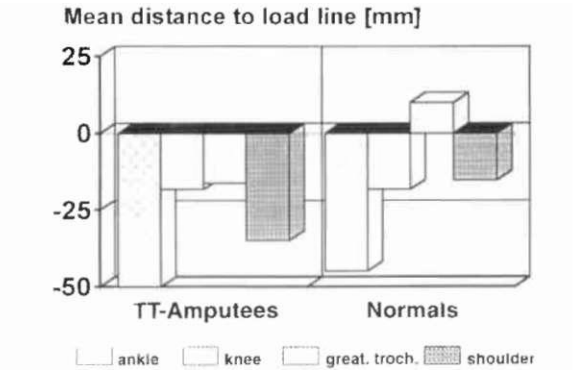

Fig. 5. Comparison of the posture of trans-tibial amputees and non-amputees using the mean values of the sagittal position of ankle, knee, greater trochanter and shoulder.

Table 4. Coefficients of correlation of the different joint positions for trans-tibial amputees

	Knee	Greater trochanter	Shoulder
Ankle	0.53	0,06	-0.31
Knee		-0.04	-0.08
Greater trochanter			0.22

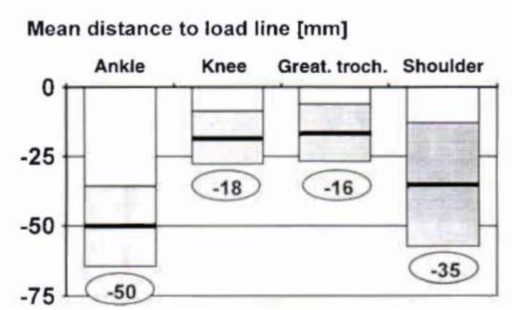

Fig. 6. Mean value and standard deviation of the position of the shoulder, the greater trochanter, the knee joint and the lateral malleolus of the trans-tibial amputees.

Table 5. Coefficients of correlation for the different joint positions versus body mass and height for trans-tibial amputeees

	Body mass	Height
Ankle	-0.20	-0.06
Knee	-0.44	0.01
Greater trochanter	-0.26	-0.12
Shoulder	0.01	-0.04

body height and the joint position for trans-tibial amputees. However, body mass has a significant influence on the distance between the knee and the load line (R= -0.44). The heavier the trans-tibial amputee, the greater the posterior position of the knee with reference to the load line (Table 5).

Static prosthesis alignment

Static prosthetic alignment in the sagittal plane is reflected in the inclination of the pylon and determined by the horizontal distance between the knee centre and the ankle.

According to the scatter diagram of Figure 7, the horizontal distance between the knee centre and the load line is independent of the horizontal distance between the knee and the ankle. The knee position with reference to the load line, and thus the acting lever of the ground reaction force at the knee joint, is independent on the characteristics of the prosthetic foot.

On the other hand, the ankle distance from the load line shows a highly significant relation to the distance between knee and ankle (R= -0.75). The sagittal plane inclination of the below-knee pylon is therefore determined primarily by the position of the foot.

Table 6 Coefficients of correlation for the knee joint-ankle-distance versus the joint positions, body mass and body height for trans-tibial amputees

	Knee-Ankle
Ankle	-0.75
Knee	0.17
Greater trochanter	-0.10
Shoulder	0.30
Height	0.09
Body mass	-0.11

Furthermore, Table 6 verifies that prosthetic alignment is neither correlated with the body measures nor with the hip position nor with posture of the upper body. The distance between knee and ankle of the trans-tibial prosthesis is influenced during standing by the variation in foot anteroposterior shift.

The distance ankle-knee, and thus the ankle position, is finally correlated with the foot type, as Figure 8 describes.

Further parameters correlating with the foot type used by the trans-tibial amputee could not be identified.

Following changes in the components of the prosthetic foot optimal prosthetic alignment assessed subjectively during one test session only did not reveal any recognizable alignment relationships.

Discussion

The lengthy and difficult process of obtaining a qualitatively satisfactory prosthetic alignment led to consideration of the fitting methodology. It is obvious that present prosthetic alignment recommendations differ from each other

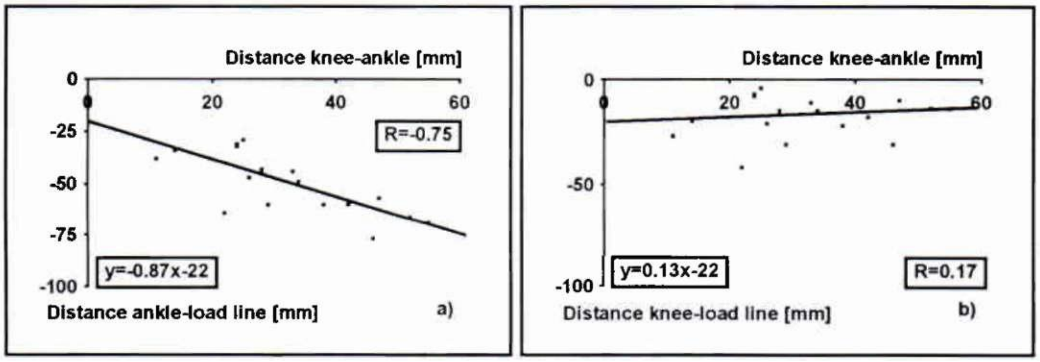

Fig. 7. Scatter diagram between the knee-ankle-difference and a) the ankle position and b) the knee position for trans-tibial amputees

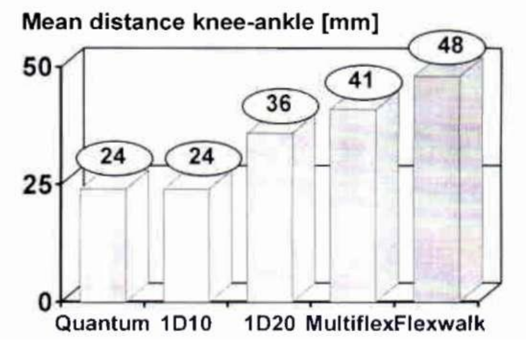

Fig 8. Mean ankle-knee distance for the different foot types.

considerably (e.g. TKA-line, German alignment). From the biomechanical point of view, this can be understood only if prostheses contain different components. These different components have different characteristics leading to different properties during walking, e.g. different dorsal resistances of the feet in the temporal course of the gait cycle. If prostheses contain the same components and the same socket, a different biomechanical alignment with the same functional result cannot be explained. Also, in clinical practice it can be noted that prosthetic alignments become more and more similar after a longer period for acclimatization even if the prostheses were assembled before dynamic alignment according to different static alignment recommendations (Marmaras and Bach, 1995; Radcliffe, 1994: West, 1987).

Forces and moments are not visible. However, they define the fundamental function of a prosthesis during standing and walking. For optimization of prosthetic alignment, visual information about the force and moment situation seem to be desirable for the prosthetist (Wilson ***et al,*** 1979). With the "L.A.S.A.R. Posture" alignment system, the vertical ground reaction force can be precisely determined and indicated on the standing patient. Measuring the static alignment then becomes possible. Forces and lever arms can be considered. This offers a new biomechanical insight; prosthetic alignment is not exclusively dependent on prior custom. With the "L.A.S.A.R. Posture" alignment system a tool is now available for making prosthetic alignment or individual posture visible in the selected plane. The basis is the vertical ground reaction force acting on the leg during standing.

Posture measurement of non-amputees shows that the ground reaction force falling along the middle of the ankle, the knee centre, the greater trochanter and the middle of the shoulder often described in the literature is not correct.

In addition, it appears that prostheses with different feet do not show any alignment consistency after brief alignment trials. Prostheses worn by the amputee for a longer time seem to have more consistent alignments. This is supported by practical experience showing that prostheses can be optimally aligned using subjective methods only over a longer period of time. Thus, the amputee is not able after only a short wearing time to evaluate the quality of the alignment (Solomonidis, 1991; Zahedi, 1986). Possibly this new procedure could offer a starting point for achieving a good fitting result in a more verifiable way and in a shorter time.

The results thus far encourage continued testing of these ideas in practice to refine the results presented here. Also applications for other areas of practice are worth considering: orthoses, compensation for leg lengths discrepancy, etc.

Non-amputees maintain their balance during standing using ankle control. The ground reaction force running behind the hip joint allows stabilization of the hip joint during standing by ligament or muscular force acting anterior to the joint. The trans-tibial amputee uses the gluteal and the posterior thigh musculature during standing for controlling stability and balance of the knee joint. Therefore, the trans-tibial amputee has not only altered gait characteristics (as known from clinical gait analysis) but, compared with the non-amputee, also different posture balance.

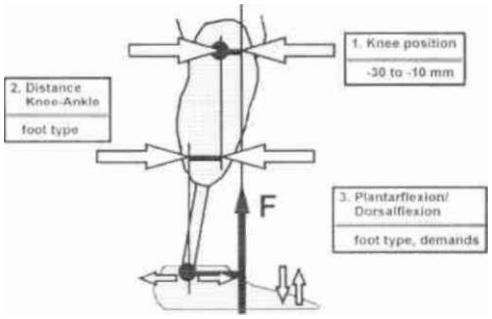

Fig 9. Biomechanically derived alignment recommendation for trans-tibial prostheses

Conclusions

The present investigation attempted to determine prosthetic alignment for trans-tibial amputees biomechanically. As the investigation was made on a relatively small number of amputees, it requires further verifications of the results presented. However, it has suggested a new static alignment method for trans-tibial amputees' prostheses, as outlined in Figure 9:

1. determine the load line on the prosthetic side remembering that the knee centre should be located 10 to 30mm behind the load line;
2. the posterior position of the ankle (distance ankle-knee) is made depending on the foot selected (compare with Figure 8);
3. dorsal and plantar flexion of the foot have to be adjusted depending on both foot type and patient's weight (individual requirements) considering the knee location.

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