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Measuring Technology

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The 3D L.A.S.A.R. – A New Generation of Static Analysis for Optimising Prosthetic and Orthotic Alignment

The technology of the „L.A.S.A.R. Posture" measuring device has made a substantial contribution to determining and optimising the static alignment of technical orthopaedic devices for the lower limbs in the last two decades. Based on its fundamental principles, the „3D L.A.S.A.R" measuring device was developed. This article describes the enhanced functions and the resulting added benefit for O&P professionals in everyday fitting routine.

Key words: alignment, static, prostheses, orthoses

Introduction

Restoring the ability to stand and walk is the major goal of rehabilitation after a lower limb amputation [1]. To achieve this, every leg amputee – regardless of the mobility grade – needs a prosthesis that can bear loads stably when standing and in the stance phase when walking. On the other hand, there must be sufficient ground clearance in the swing phase to allow the lower leg to swing through freely. These fundamental requirements can be met only with biomechanically correct prosthetic alignment. This alignment has a sustained effect on the quality of the prosthesis, and ultimately on the amputee's quality of life. For example, step symmetry, joint loading and oxygen consumption when walking depend on the prosthetic alignment [2, 3]. Prosthetic alignment is conducted in three phases in fitting practice:

1. Workshop or bench alignment (precise assembly of the prosthesis, in general according to the manufacturer's instructions)
2. Static prosthetic alignment (adjustment of the prosthesis on the standing patient)
3. Optimisation of dynamic alignment (fine adjustment after a gait analysis)

This article discusses mainly static prosthetic alignment, alignment requirements and the options for objectifying alignment using the L.A.S.A.R. technology. The acronym „L.A.S.A.R" stands for „laser-assisted static alignment reference".

Experience with the L.A.S.A.R. Posture static measuring system

Measuring the static situation requires tools that make the forces and torsional moments that act when standing visible. L.A.S.A.R. Posture was introduced 20 years ago as the first measuring device to enable objective static prosthetic alignment under workshop conditions. The device determines the centre of pressure and projects the vertical component of the ground reaction force onto the standing person using a vertical laser line (Fig. 1). Distances of this line from alignment reference points – for example joint pivot points – can be measured [4]. When the person being measured is standing with both legs on the force measurement plate, the body's centre-of-gravity line is measured and when the person stands with one leg on the force measurement plate and the other leg on the height compensation plate, the load line is displayed.

The intensive scientific support for this method with a number of studies and the constant scrutiny of the benefit of this completely new technology in practice have led to clear recommendations for biomechanical prosthetic alignment from below-knee to the

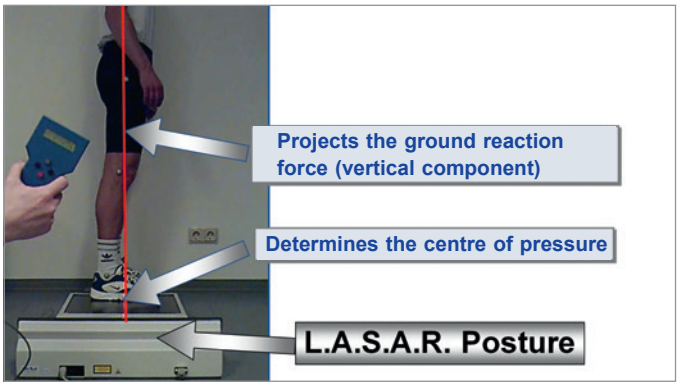

***Fig. 1** Basic principle of L.A.S.A.R. Posture*

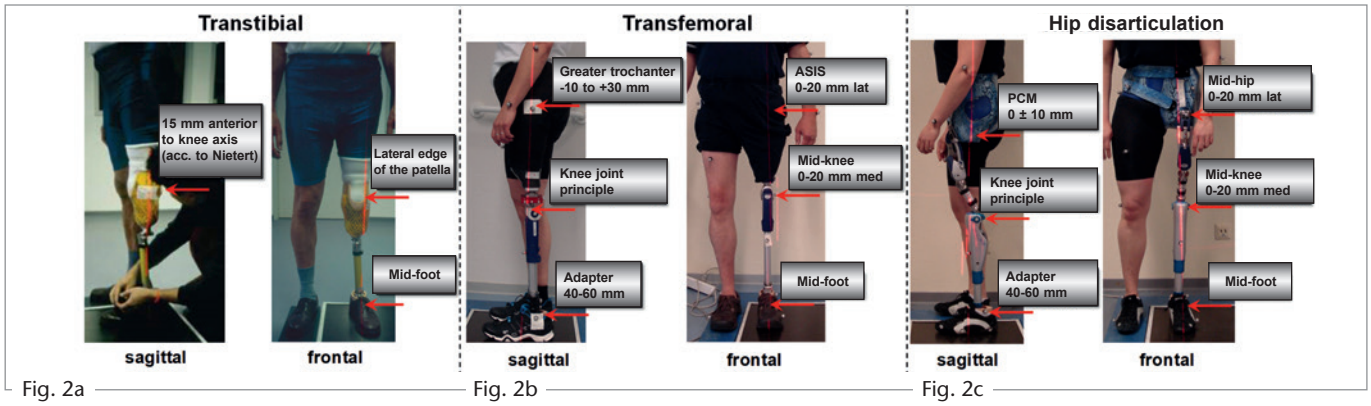

***Fig. 2** Static situation of the biomechanically correct prosthetic alignment for the lower limb. The amputation levels „Transtibial" (2a), „Transfemoral" (2b) and „Hip disarticulation" (2c) are displayed in the sagittal and frontal plane. Depending on the amputation level, the load line determined using a force measurement plate (red line) runs at the indicated distance to the reference point.*

pelvic socket prostheses. The recommendations vary widely depending on the level of amputation, as shown below.

Prosthetic alignment for a transtibial amputation

The alignment of the transtibial prosthesis has a sustained effect on the function of the preserved knee joint when standing and walking [5]. The biomechanical objective is to achieve physiological knee function. There have been many studies of the biomechanical principles of prosthetic alignment and the effect on knee function when standing and walking [4-7]. These principles were implemented in practical instructions for alignment that have become established in patient care on a daily basis all around the world. For individualised alignment, O&P professionals use modern measuring technology for the static analysis and observe the amputee while walking. Care is taken to ensure that the gait pattern exhibits physiological knee function and that the corresponding static criteria (Fig. 2a) are met.

Prosthetic alignment for knee disarticulation and transfemoral amputation

The alignment has a sustained effect on the safety and function of the prosthesis when the knee disarticulation and transfemoral amputee stands and walks. The biomechanical objective is to achieve safe knee function. To restore the ability to stand and walk, it is essential to match the prosthetic foot to the hip joint with the appropriately flexed and adducted residual limb. This ensues from the mechanical principles of locomotion. The knee joint is positioned between the prosthetic foot and the socket in accordance with the functional principle. The technical functioning of the joint itself can be influenced by the prosthetic alignment only to a very limited extent [8].

Transfemoral prostheses are first assembled and precisely adjusted in the alignment device. The manufacturers of the prosthetic components usually specify the positioning of the foot and knee joint. Adduction and flexion of the socket are specified individually. Limitations of hip joint movement due to a flexion contracture must also be accommodated. In most cases, after the precise assembly of the prosthesis, the adjustment of plantar flexion on a standing patient is sufficient to meet the static criteria (Fig. 2b). However, the prerequisite is that the proximal area of the socket is designed so that the force can be transmitted between the prosthesis and the body at the centre and not at the edges. The difference between the load line and the centre-of-gravity line should be no more than 15 mm in the sagittal plane. In the walking test, the flexion and adduction position of the residual limb and the transverse rotation of the knee joint are checked and corrected if necessary. Clearly asymmetrical step lengths indicate incorrect socket flexion.

Prosthetic alignment for hip disarticulation

The alignment affects the safety and function of the prosthesis when a hip disarticulation amputee stands and walks. The biomechanical objective is to achieve safe knee function and at least the basic function of the hip joint. To restore the ability to stand and walk, it is essential to match the prosthetic foot, the knee and the hip joint to the pelvic socket.

Extensive studies have shown that the partial centre of mass (PCM) is the key reference point for prosthetic alignment [9,10]. This makes the prosthetic alignment independent of the design of the pelvic socket. Hip joint, knee joint and prosthetic foot are adjusted to this reference point in the alignment device with the pelvic socket in neutral position. The static alignment consists solely of adjusting the plantar flexion to meet the alignment criteria (Fig. 2c). During the walking test, the adduction and rotation position of the pelvic socket to the hip and knee joint must be checked.

The new 3D L.A.S.A.R. with its additional functions and information

Technical properties

Ongoing further development of electronic components such as microcomputers, sensors and high-resolution camera chips enabled the technical principle of the L.A.S.A.R. Posture to enter the digital world. The new 3D L.A.S.A.R. is a measuring system consisting of a two-part force measurement plate equipped with sensors, four 5-megapixel CMOS cameras, a central computer unit and a tablet as control element (Fig. 3a).

The two measuring plates of the 3D L.A.S.A.R. are equipped identi-

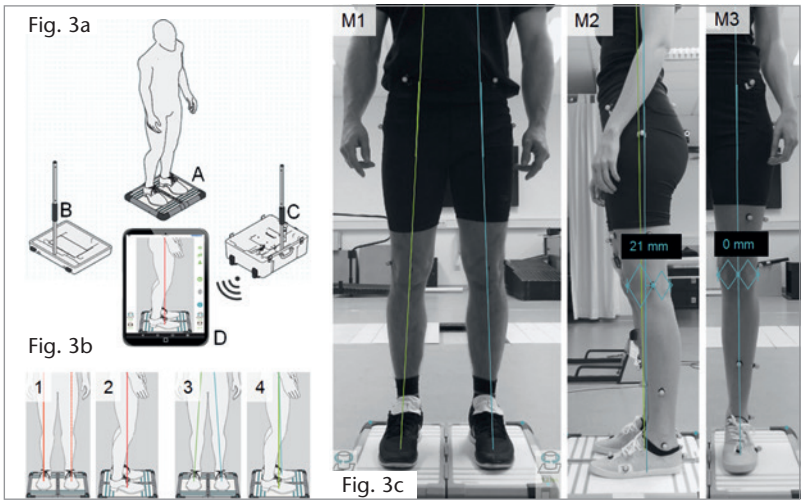

Fig. 3a *Schematic representation of the basic components of the 3D L.A.S.A.R. (**A**: Force measurement plate with sensors, **B and C**: Four cameras in two holders, **C**: Computer unit, **D**: Tablet control panel).*

Fig. 3b *Schematic representation of the measuring situations (legacy mode [2D] in the frontal plane [1] and sagittal plane [2]; 3D mode in the frontal plane [3] and sagittal plane [4]).*

Fig. 3c *Representation of actual measurements in 3D mode (**M1**: measurement in the frontal plane, **M2**: measurement in the sagittal plane with a digital 60/40 gauge superimposed, **M3**: measurement in the frontal plane with a digital 50/50 gauge superimposed).*

cally with four load cells and three force sensors each on the basis of full-bridge strain gauges. Relevant load parameters of the two legs are registered simultaneously. In addition to the resulting centres of pressure on the measuring plates and the vertical ground reaction force components, the acting horizontal forces can be measured. It is also possible to measure the torsional moments around the vertical axis of the coordinate system of the ground reaction force. From this information, the vertical components of the ground reaction force – also known as load lines – can be displayed on the tablet simultaneously for both lower limbs (legacy mode in 2D) (Fig. 3b). By including the horizontal forces, the ground reaction force vectors at the support point can also be determined and displayed on the tablet optionally in the sagittal or the frontal plane (3D mode). To determine the distances between the load lines or force vectors and the reference points (e.g. pivot axis of the knee joint), virtual measuring instruments or distance gauges can be inserted into the saved image (see Fig. 3c: M2 and M3). The image can be zoomed to allow precise positioning of these measuring aids.

For the first time, the digital rendering of the measured values allows them to be stored and used for documentation and analysis of the static situation even after the measuring session. In addition to the images and data of the measured situation, fields for comments can be inserted, for example with notes for the next steps of treatment. Data storage is based on a password-protected SQL database in which images and patient data can be stored securely. The database is stored on an SD card. The SD card can be exchanged to allow several users to work on one device with their own databases. Before beginning operation of the measuring system, the cameras and the force measurement plate are aligned with each other in a defined position. A frame displayed on the tablet assists this positioning. After the cameras have registered the LEDs that light up in the corners of the force measurement plate, an integrated calibration algorithm adjusts the vectors displayed graphically on the tablet to the forces measured. This makes it possible to display on the tablet a projection of the ground reaction forces – scaled for size, angle, and position and accurate to the millimetre – onto the person being measured. A button on the control panel of the tablet allows the view to be switched from the sagittal to the frontal plane.

Advantages for optimising static alignment

A major advantage of the 3D L.A.S.A.R. is that it allows the static load of both lower limbs to be viewed and analysed simultaneously. Unfavourable static load situations can be detected at a glance and the alignment can be optimised immediately without the patient needing to move to a different standing position on the device. After modifying the alignment configuration of the device on one limb, the static effect on the other limb becomes visible immediately. From the additional information in 3D mode on the actual course of the force vectors, the real distances between the vectors and the respective reference points can be determined, allowing a precise measurement of the static load.

To assist in the optimal customised static alignment of the orthopaedic device (e.g. a TT or TF prosthesis), tutorials on prosthetic alignment or reference values for various prosthesis components are available in a menu point in the tablet software. The static situation that is displayed on the tablet can be explained to the patient and the next steps for optimisation can be discussed. For training larger groups, the system has an additional interface for projecting the tablet display onto a different screen.

Initial experience with the 3D L.A.S.A.R. in a comparison group of non-amputees

For practical application in prosthetics and orthotics, orientation to the average values of healthy subjects is helpful in many cases. When using the conventional L.A.S.A.R. Posture, it was important to note that the measured values represented the distances from the vertical line of action of the force to the reference points. With the 3D L.A.S.A.R., the distances between the line of action of the „real“ force vector and the reference points can now be measured. To check the differences of the measured values of the two L.A.S.A.R. Posture versions and obtain reference values for using the 3D L.A.S.A.R., a group of 50 neurologically and orthopaedically unremarkable subjects (29 ± 8 years,

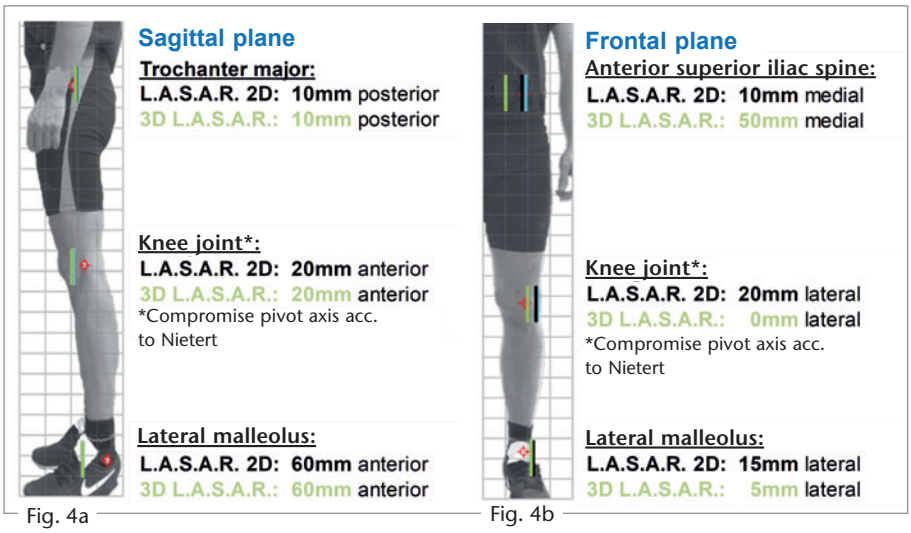

Fig. 4 *Averaged distances between reference points and load line and force vector, presented for the health comparison group (n = 100);*

a: *sagittal plane,* ***b:*** *frontal plane.*

177 ± 9 cm, 73 ± 10 kg, male: n = 31, female: n = 19) were examined using both L.A.S.A.R. versions. For a standardised baseline situation, the subjects were instructed to stand on the measuring device with their normal stance width before the values were measured on the L.A.S.A.R. Posture. As an additional criterion, the feet were to be placed at the same level in anterior-posterior direction The individual stance width was measured. In the subsequent measurement on the 3D L.A.S.A.R., the positions of the feet could therefore be reproduced. The results were averaged for both legs, resulting in mean values for 100 limbs (Fig. 4).

As anticipated, there were relatively small deviations in the sagittal plane, with a slight increase from distal to proximal. For the distance between the line of action of the force and the compromise pivot axis of the knee joint that is often important in practice [11], a mean distance of approx. 20 mm with a standard deviation of 15 mm was measured with the 3D L.A.S.A.R. The deviations are considerably more pronounced in the frontal plane. This is explained by the two-legged support of the body, which is associated with higher horizontal forces than in the sagittal plane. The mean values of the comparison group of non-amputees exhibit a high standard deviation, which is an indication of the known large individual differences. Despite this, these values are useful and can be used as reference parameters.

To illustrate this, Figure 5 presents a measurement with the 3D L.A.S.A.R. in both modes using a single example. The situation measured in the legacy mode yields information in the frontal plane identical to that of the L.A.S.A.R. Posture. In 3D mode, the distances increase from distal to proximal (lateral malleolus: approx. 10 mm; anterior superior iliac spine: approx. 40 mm). At the knee joint, the load line measured with the L.A.S.A.R. Posture is positioned approx. 15 mm to 20 mm lateral (comparable with 3D L.A.S.A.R. in the legacy mode: approx. 20 mm); the actual line of action of the force vector, measured in 3D mode, passes nearly through the centre of the knee.

Initial experience with the 3D L.A.S.A.R. and recommendations for prosthetic alignment after transtibial and transfemoral amputation

To establish the basis for reference data of transtibial (TT) and transfemoral (TF) amputees, a total of 15 subjects (5 TT: 43 ± 11 years, 174 ± 9 cm, 73 ± 16 kg, male: 3, female: 2; 10 TF: 46 ± 10 years, 176 ± 8 cm, 87 ± 13 kg, male: 8, female: 2) were recruited. They had previously been fitted with transtibial prostheses [4-7] or transfemoral prostheses [12] in accordance with Blumentritt's known recommendations for alignment The measurements were made separately for the affected and the healthy limb, both with the L.A.S.A.R. Posture and with the new 3D L.A.S.A.R. This resulted in values for the following measuring situations:

– L.A.S.A.R. Posture
– 3D L.A.S.A.R. in legacy mode
– 3D L.A.S.A.R. in 3D mode

The resulting recommendations for the distances between the load line (L.A.S.A.R. Posture, 3D L.A.S.A.R. in legacy mode) or the force vector (3D L.A.S.A.R. in 3D mode) and the respective reference points are summarised in Figure 6 (TT) and Figure 7 (TF). This results in the following key conclusions for practice:

Alignment of transtibial prostheses

The values measured with the L.A.S.A.R. Posture and the 3D L.A.S.A.R. in legacy mode are nearly identical for both the

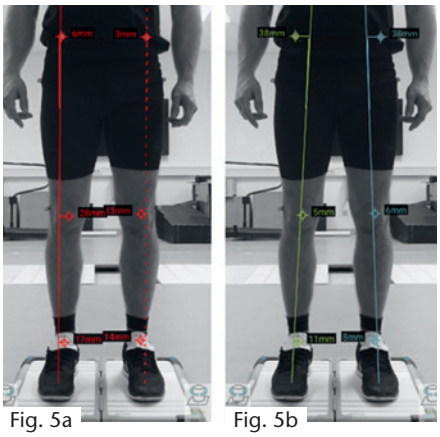

Fig. 5 *Frontal projection of the line of force of the vertical ground reaction force (****a****: legacy mode, corresponding to information of the L.A.S.A.R. Posture) and actual frontal line of force of the force vector (****b****: 3D mode); single example*

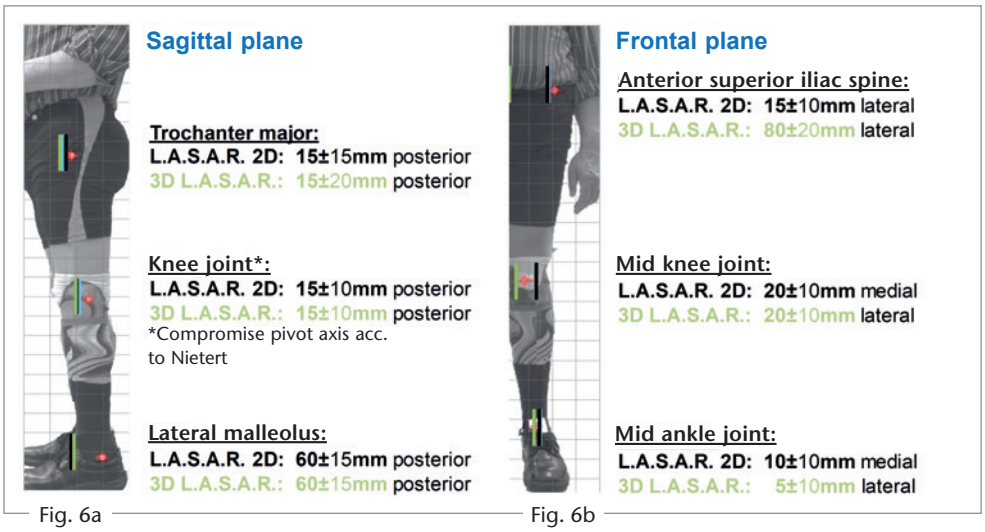

Fig. 6 Averaged distances between reference points and load line and force vector, presented for TT amputees, indicating possible setting ranges;

***a**: sagittal plane, **b**: frontal plane.*

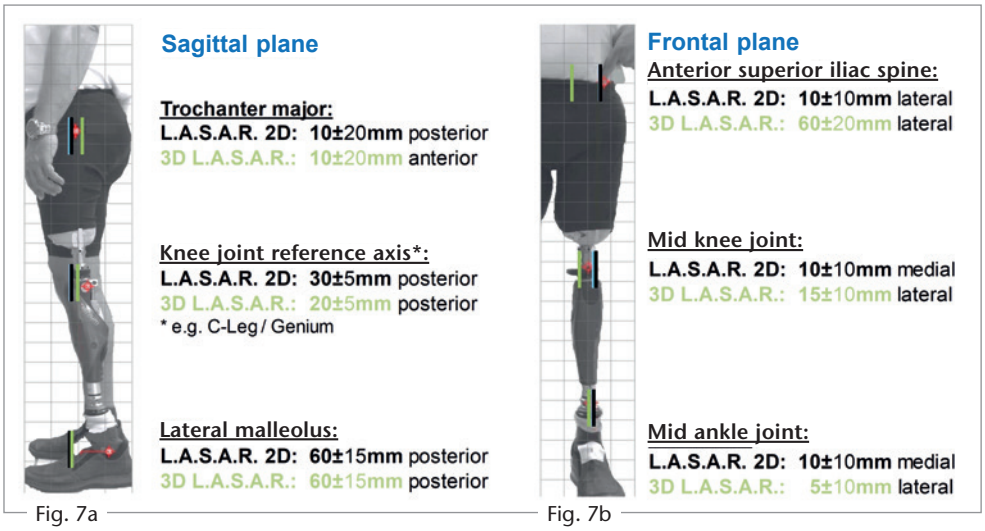

Fig. 7 Averaged distances between reference points and load line and force vector, presented for TF amputees, indicating possible setting ranges;

***a**: sagittal plane, **b**: frontal plane.*

prosthesis side and the preserved limb in both planes (sagittal and frontal), (Fig. 6). It can therefore be concluded that the existing recommendations for alignment of TT prostheses using the L.A.S.A.R. Posture are directly transferable to the 3D L.A.S.A.R. in legacy mode. This applies to the distances between the load line and the reference points lateral malleolus (ankle joint), the compromise pivot axis of the knee joint (knee joint), greater trochanter and anterior superior iliac spine.

The values in 3D mode (3D L.A.S.A.R.) deviate from those in legacy mode, but the deviations in the sagittal plane are small with good prosthetic alignment due to the comparatively small horizontal force. The deviations in the frontal plane are more pronounced, especially on the prosthesis side. Here, the force vector at the knee runs along the medial edge of the patella (L.A.S.A.R. Posture and 3D L.A.S.A.R. in legacy mode: lateral edge of the patella) and approx. 80 mm medial of the iliac spine (L.A.S.A.R. Posture and 3D L.A.S.A.R. in legacy mode: 0 mm to 20 mm medial).

Alignment of transfemoral prostheses

As with transtibial prostheses, the values measured with the L.A.S.A.R. Posture and the 3D L.A.S.A.R. in legacy mode are nearly identical for both the prosthesis side and the preserved limb in both planes (sagittal and frontal), (Fig. 7). The existing recommendations for alignment using the L.A.S.A.R. Posture are thus also directly transferable to the 3D L.A.S.A.R. in legacy mode for TF prostheses. This applies to all distances between the load line and the respective reference point lateral malleolus (ankle joint), knee joint, greater trochanter and anterior superior iliac spine.

However, the values in 3D mode (3D L.A.S.A.R.) deviate from those in legacy mode for both planes (sagittal and frontal). On the prosthesis side, the result is that the distances in the sagittal plane between the force vector and the knee joint or greater trochanter are approx. 5 mm to 10 mm smaller and the course of the force vector on the prosthesis side is thus somewhat more posterior than in the healthy comparison group. This may indicate a specific feature of TF prostheses in which the force transmission point in the proximal socket can be posterior to the greater trochanter.

In the measurements of TF amputees in 3D mode with the 3D L.A.S.A.R., the force vectors in the frontal plane pass at the level of the anterior superior iliac spine approx. 10 mm further medial

Knee joint	2D	3D
3R40/41	45 mm	35 mm
3R15/49	40 mm	30 mm
3R90/92	40 mm	30 mm
3R95	45 mm	35 mm
3R60	10* mm	0* mm
3R20/36	35 mm	25 mm
3R106	35 mm	25 mm
3R80	35 mm	25 mm
C-Leg	30 mm	20 mm
Genium	30 mm	20 mm

Greater trochanter:
L.A.S.A.R. 2D: 10±20mm posterior
3D L.A.S.A.R.: 10±20mm anterior

Knee joint reference axis*:
L.A.S.A.R. 2D: (Tabelle 2D) posterior
3D L.A.S.A.R.: (Tabelle 3D) posterior

Lateral malleolus:
L.A.S.A.R. 2D: 60±15mm posterior
3D L.A.S.A.R.: 60±15mm posterior

Fig. 8 *Recommendation for distances between reference points and load line or force vector in the sagittal plane for TF amputees, presented for different types of knee joints, indicating possible setting ranges at the level of the lateral malleolus and greater trochanter.*

than in the healthy comparison group. It is assumed that on the prosthesis side, due to the further medial force transmission point at the socket, greater horizontal forces act in mediolateral direction, which must also be compensated by the contralateral side. The force vectors thus tend to be closer to the centre of the body.

Specific recommendations for distances between the force vector and the reference axis of the knee joint in the sagittal plane can also be given for the 3D L.A.S.A.R. for different types of knees. These recommendations are summarised in Figure 8 in addition to the known ones for the L.A.S.A.R. Posture.

With the 3D L.A.S.A.R., nearly identical distances between the respective reference points and the load line (legacy mode) and force vector (3D mode) are found in the sagittal plane on the contralateral side for both amputation levels (TT and TF). The existing recommendations regarding the static of the preserved leg thus remain valid.

Notes on optimising static alignment in 3D mode

The simultaneous display of both force vectors allows two different effects to be observed separately in the sagittal plane:

- The horizontal distance between the vectors on the force measurement plate is caused by the distance between the centres of pressure (see Fig. 9b in legacy mode and 9c in 3D mode). This can be adjusted, for example, by changing the plantar flexion position of the foot component.
- The distance between the vectors at the level of the greater trochanter may be due to an unnatural hip moment in the sagittal plane and/or transverse plane or be caused by unnatural pelvis rotation. This is often caused by unfavourable socket positions in these planes (Fig. 9d).

The goal of optimising static alignment in the sagittal plane is that

1. The force vectors are at the recommended distance from the reference points,
2. The positions of the centres of pressure at the level of the force mesurement plate in anterior-posterior direction are identical or at most 20 mm apart,
3. The force vectors on the prosthesis side and the preserved limb are nearly identical in the sagittal plane.

If these criteria are met, it can be assumed that both the preserved joint structures and the prosthesis components are appropriately loaded in accordance with biomechanical criteria and that no unnaturally large horizontal ground reaction forces act that can cause tension in the residual limb-socket interface and pelvic region. The impact of the horizontal forces on the actual course of the ground reaction forces can be detected directly only in the 3D mode of the 3D L.A.S.A.R. (Fig. 9c and 9d)

In the frontal plane, the centres of pressure should be in the centre of the foot and the force vector at the recommended distance from the centre of the knee joint and the anterior superior iliac spine – according to the data for the respective amputation level. Figure 10 shows a schematic representation of the natural static situation in legacy mode (Fig. 10a) and in 3D mode (Fig. 10b). In Figures 10c and 10d, there are extraordinarily high horizontal ground reaction forces that lead to a strong slope of the force vectors which can be visualised in this way only with the 3D L.A.S.A.R. In these cases, severe tension in the pelvic region can be assumed.

Conclusion

Compared with the L.A.S.A.R. Posture, the 3D L.A.S.A.R. allows additional parameters and information on the static optimisation of prosthetic and orthotic alignment to be used, thus improving the quality of patient care. Simultaneously, there are new options for documentation and subsequent analysis. This gives rise to additional benefits for O&P professionals in routine practice for producing and orthopaedic devices for the lower limb that comply with biomechanical principles. The documentation options will also facilitate the dialogue with patients and reimbursers regarding the quality of care.

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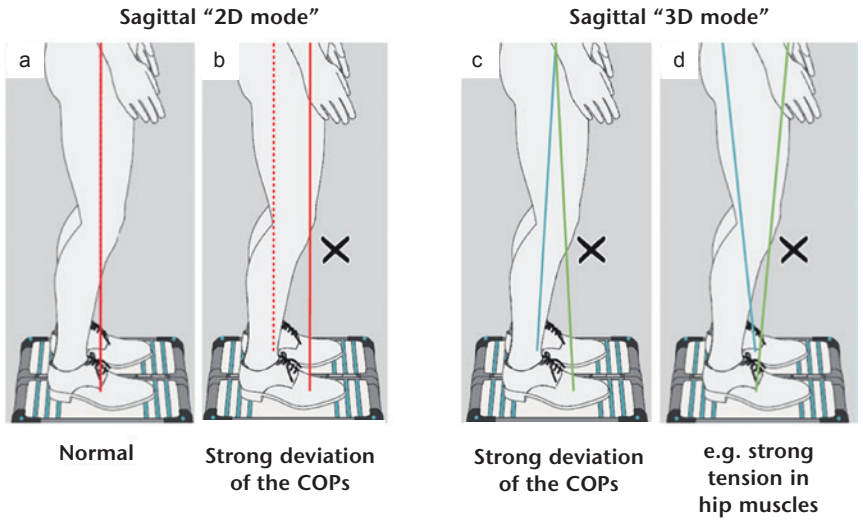

Fig. 9

Fig. 9 *Schematic representation of the static situation in legacy mode and 3D mode in the sagittal plane;*

a: *normal static situation for both limbs;*

b: *large difference in the anterior-posterior position of the centres of pressure and load lines (unfavourable static situation);*

c: *large difference in the anterior-posterior position of the centres of pressure and force vectors (unfavourable static situation);*

d: *identical position of the centres of pressure, but different slope of the force vectors (unfavourable static situation).*

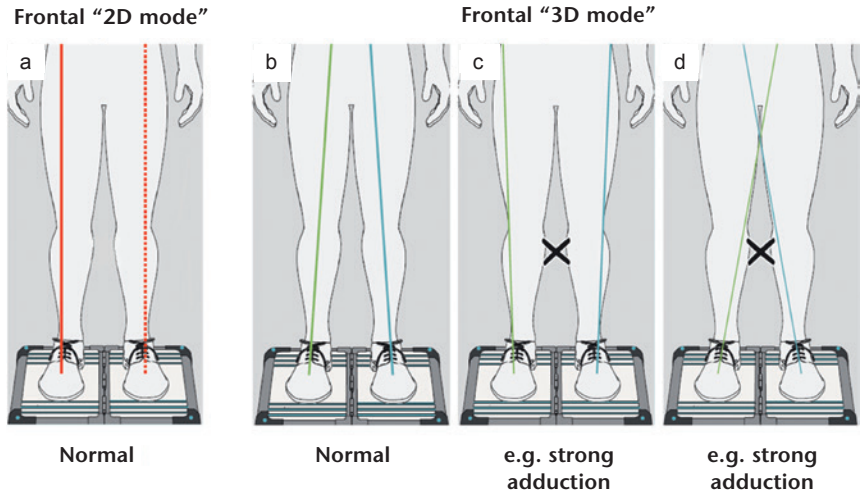

Fig. 10

Fig. 10 *Schematic representation of the static situations in legacy mode and 3D mode in the frontal plane;*

a, b: *normal leg static for both limbs;*

c: *optimal position of the centres of pressure, but strong lateral slope of the force vectors (unfavourable static situation);*

d: *optimal position of the centres of pressure, but strong medial slope of the force vectors (unfavourable static situation).*

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