

BETTER FITS FOR LOWER-LIMB PROSTHETICS

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INTRODUCTION

For healthy normal humans, walking requires very little thought or effort. In ambulation the regulation of ground reaction forces is a painless, precise, and economical motion requiring minimal thought.¹⁴ This is not necessarily the case for those with prostheses, especially the 70% of prosthetics users in the United States who are older adults.³ Every year 2% of seniors require an amputation - most of which are the result of cancer, peripheral vascular disease, obesity, and especially diabetes.²

In the United States, 20.8 million people have diabetes, and more than 60% of non-traumatic lower-limb amputations (~82,000) occur within this population.¹ This makes diabetes the leading cause of non-traumatic lower-limb amputations. An added concern for prosthetists and orthotists are the 21% of the diabetic population that are over the age of 60.¹

As the body ages, there are many physical changes that can affect proprioception and muscle action – two conditions essential for smooth gait. Awareness of surroundings and muscle actions can be affected by slower reflexes, stiffer joints, sarcopenia, nerve degeneration, cognitive impairments, and decreases in perception and responses.^{16,2} This decrease in nerve function is a concern as the current method of fitting a prosthetic requires patient feedback about the “feel” of the limb during ambulation as the clinician makes observations about its function.⁸ This system becomes even more subjective, and reliant on the clinician’s eye, when the patient is incapable of providing accurate or reliable feedback due to physical or mental deterioration.

Numerous studies have cited the importance of proper alignment in prostheses as it has a significant impact on the amputee’s walking ability.^{4,5} Alignment determines how forces are transmitted through the prosthetic limb and how it cooperates with the sound limb. Improper alignment may result in increased loading and undue stress on the residual limb.^{4,5} Problems arise when the patient is unable to notice alterations in the prosthetic limb that occur during a normal fitting. This leaves clinical observation of the gait pattern as the predominant method of assessment; the clinician must draw correlations between their biomechanical knowledge and their observations.^{4,14} Through no fault of the prosthetist, a fitting often becomes a trial-and-error system attempting to find the best dynamic alignment.^{7,8} The imprecision in this system may result in less than optimal stability and mobility for the patient as there is no quantitative information about the functioning of the prosthesis during locomotion.^{14,7}

Limitations in Current Alignment Methods

Those involved in the prosthetic selection and fitting process have adapted numerous technologies to combat this imperfect methodology. Some have used x-rays to determine the load line, though this use is limited to static loading only.¹³ Others, with access to comprehensive gait laboratories, have used 3D-motion analysis systems to understand the intricacies of locomotion. This type of system does have many uses, but it is expensive. In addition, many prosthesis wearers alter their gait when instrumented; hence, costing the gait lab time and money running trials that may not yield

accurate results. Data resulting from such a system is complex; it remains to devise an objective and accurate means to extract the most useful information for prosthetic alignment.

Most gait systems offering integrated kinetic and kinematic analysis present data in one of two manners: either post-performance delayed by a few minutes or possibly days, or graphical and numeric reports separated from the visual image of the patient's ambulation.¹¹ Current devices do not meet the demands of the prosthetic care teams. New methods and technologies need to be more quantitative and objective. Development of technology that is easy to implement and affordable and coupling it to readily understood principles of alignment will move the alignment process in the necessary direction and improve functional outcomes.

FORCE-LINE VISUALIZATION

A real-time force-line visualization device offers visual, straightforward, uninstrumented, reliable data for proper prosthetic alignment. Force-line visualization (also known as: force vector visualization or video vector generation) is a method of superimposing the ground reaction forces onto a real-time video image of the patient during ambulation. This system allows a clinician to see the force vector relative to the leg's position at any instant in time. This offers a quick visual indication of the magnitude and location of those forces.¹⁴ The clinician can determine where the ground reaction force is in relation to the ankle, knee, and hip. Force-line visualization offers the benefits of slow motion playback video united with the graphical representation of the ground reaction forces. The clinician can watch the changes in the force-line as the patient walks, and then review the performance and the forces at each stage of the gait cycle. Gait abnormalities are easy to spot, prosthetic adjustments can be made, and their effects can be quickly evaluated.¹⁰

With little capital investment, this system can provide quantitative data for precise, immediate clinical decisions.^{10,14} Force-line visualization systems were first devised in the late

1970s. Two groups were working on the idea at roughly the same time. T.M. Cook and B.A. Cozzens worked for Moss Rehabilitation in Pennsylvania while R.E. Major, G.K. Rose, and J.H. Tait designed a system for the Orthotics Research and Locomotor Assessment Unit (ORLAU) in the United Kingdom. The first systems were comprised of at least one force plate, a vector display signal generator (often an oscilloscope), a vector display, at least one video camera, and a viewing beam splitter to superimpose the force-line onto the real-time image.^{13,14} These early systems strove to meet the requirements of orthotists, prosthetists, physicians, and physical therapists, but technology at that time did not allow for easy to use nor commercially viable systems.

Force-Line Operation

A literature review indicates that approximately every ten years the idea of a force-line visualization system is revisited. Computers and advanced electronics have allowed refinements to the original force-line visualization idea. Now data from the force plates and feeds from the video cameras are directed into a PC, and then graphically combined into one overlapped image. For the current systems to operate correctly, the edges of the force plate(s) are parallel to the planes of the cameras (frontal and sagittal). The location of the force plate is then marked in the camera video display and the visualization software (the plate appears as a trapezoid on the monitor). As the patient walks across the plate, the force vector is altered from the coordinate system of the plate to the coordinate system of the computer monitor.¹¹ In most systems, the vector display is updated every 20ms, giving a sample rate of 50 frames per second.¹³ The force vector denotes the location of the center of pressure and the magnitude of that force. As the patient moves through each stage of the gait cycle, the vectors change in height and angle giving a real-time video of the forces acting on the patient's leg during locomotion.

During double-limb stance, the magnitude of the force-line is greater than the patient's body

weight. As the opposite limb swings forward into mid swing, the force-line decreases to less than the body weight. It returns to greater than the body weight during push-off. In addition, the center of pressure moves from the heel to the metatarsals as the foot rocks from heel-strike to toe-off. The angle of the line also changes in relation to the acceleration and deceleration of the center of gravity. With very little training, a clinician can see and interpret how the forces move through each joint - similar to the TKA line prosthetists are already familiar with.

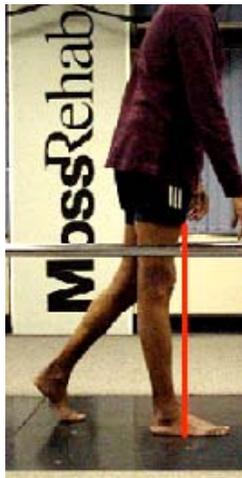


Figure 1. A force-line anterior to the knee is associated with knee extension.

Benefits

With each improvement in the design, force-line visualization proves its worth. Hospitals, laboratories, and rehabilitation centers that use force-line have touted its value as a clinical, research, and educational tool that supports evidence-based treatment decisions.^{7,12} It has been extensively used in identifying postural patterns, planning and evaluating lower-limb or joint surgeries, and gait analysis for orthotics and prosthetics. Proper use of force-line can improve the fidelity of the information used in prosthetic alignment. In alignment, it can reduce the clinician's reliance on patient feedback as the clinician can see how the forces are transmitted through the limb or prosthesis.

According to P.J. Rowe and J.H. Tait and G.K. Rose, force-line visualization aids a clinician

in “diagnosis, prescription, and treatment” of lower-limb ailments and is of “considerable value in the decision regarding the treatment to be given and the assessment of the results of such treatment.”^{12,13} Alignment through observation only operates on a strictly kinematic basis; whereas, force-line adds a kinetic element to the procedure. The clinician can perceive the effects of adjustments to a prosthetic knee and any inappropriate muscle actions. The video file can be saved for reference as well as shown immediately to the patient to increase understanding of his or her gait patterns as affected by the prosthesis. Not only will the patient's understanding increase, but also that of biomechanics students and researchers as they can now see the previously invisible ground reaction forces.^{12,15} New or different prosthetic components can be more readily learned and utilized using force-line visualization. In a review of available gait instruments by R.K. Begg, R. Wytch, and R.E. Major, force-line visualization is “the most useful clinically since it produces a real time display, is simple to operate, and interpretation of the data is easier than other systems available.”¹⁵

J. Stallard and P.J. Woollam used a transportable ORLAU system to evaluate 61 orthotics patients. They were able to improve biomechanical alignment in 68% of the assessments; in only two cases were they unable to make a “positive outcome.”⁹ Though this study was completed on orthotics and not prosthetics, it is significant for any clinician. The physiotherapists and specialists that did the initial alignments expressed approval of immediate feedback on their adjustments and that the system gave them confidence in their decisions.⁹

Current Systems

Besides the ORLAU system, there are several other systems in existence. H. Lanshammar developed the Vifor system in Sweden. He shows frontal and sagittal views of the ground reaction forces in ergonomics and knee joint loading.⁶ The original Cook system at MossRehab has been re-designed now using a

laser representation of the force. It is used daily for prosthetics and orthotics adjustments. In Australia, Begg designed a system for prosthetics and sports purposes.¹¹ Currently there are only two commercial providers of force-line visualization systems: MIE Medical Research Ltd. (Pro-Vec) and BTS Bioengineering (Digivec). The problem with these existing systems is that they tend to be difficult to use, cumbersome to set up and integrate with existing lab equipment, and lacking in display quality and available views. The limitations on the adoption of force-line appears to be their cost and availability.¹² Though ideal for prostheses and orthoses alignment, force-line is not accurate enough for applications requiring precise calculations of joint moments.^{12,14} Despite these drawbacks, force-line would be an invaluable tool in any clinic as force plates and video cameras are readily available.

Future Endeavours

In order to make this technology more accessible, there needs to be a commercial supplier of a complete force-line visualization system. In conjunction with MossRehab, Bertec is researching the feasibility of producing a user-friendly, economical system with increased sensitivity and accuracy to allow for more quantitative data. Currently views are limited to frontal and sagittal cameras, while this new system is expected to allow camera placement anywhere in the room. It is our goal to make this beneficial technology available to clinics with limited budgets and personnel.

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