Capabilities

Communicating the Science of Prosthetics and Orthotics

NORTHWESTERN UNIVERSITY

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Contents

Scholarly Research of Young People in the Northwestern University Rehabilitation Engineering Research Center and the Prosthetics Research Laboratory

This issue of *Capabilities* mostly features the research and development work of young people connected with the laboratory as undergraduate students, graduate students, post-doctoral fellows, and staff members. Research laboratories in research universities are greatly enhanced by young students who bring energy, enthusiasm, fine minds, and new techniques to the labs. When these traits are coupled with the specialized knowledge and wisdom of older mentors, a formidable research force is engendered.

Typically we have two or three undergraduate students engaged in independent studies each year that provide research experience and undergraduate credit. Topics often are preliminary in nature, rather like small pilot studies, or the students may look into the improvement and/or calibration of scientific instruments that are so important in a research enterprise. Another reason for undergraduate opportunities is to expose the students to rehabilitation research at an early age. In particular, it provides opportunities for persons with disabilities to learn about disability research during their undergraduate years. We have had four NIDRR-Scholars supported by the National Institute on Disability and Rehabilitation Research (NIDRR). These scholars, who have disabilities that may involve use of prostheses or orthoses, usually spend a summer in our labs. One is now an M.S./Ph.D. candidate with us. One is a practicing orthotist and one has been accepted into medical school.

Currently our program has twelve graduate students, of which five are Master's students and seven are Ph.D. candidates. Besides support as Research Assistants and Teaching Assistants, they receive support from a wide range of sources. One has and another has had a Whitaker Foundation Graduate Fellows in Biomedical Engineering. One is a National Defense Science and Engineering Graduate Fellow and two have been Mauch Fellows. One has had a fellowship from the National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM), and another has had a Greek Government Fellowship (IKY). Six have or have had fellowships from Northwestern University (five Walter P. Murphy fellowships and one Royal E. Cabell fellowship). Graduate students almost double the man-power of our research team and they greatly expand our research capabilities.

Over the last three years we have had three post-doctoral fellows working in our laboratory. They too have greatly enhanced our research force. One is an outstanding engineering Ph.D. and the other two are certified in prosthetics and orthotics (P&O) as well as having Ph.D.s. One is from Switzerland and one from Australia. To some extent they represent the future in P&O research when prosthetists and orthotists with research degrees will become more prevalent. Already, one of our Ph.D. students has obtained her certification in prosthetics and will receive her Ph.D. in June. We feel fortunate to have three people in our center with doctoral degrees who are also qualified in prosthetics and orthotics. They bring a new dimension to P&O research.

Dudley S. Childress, PhD
Director, Northwestern University PRL & RERP

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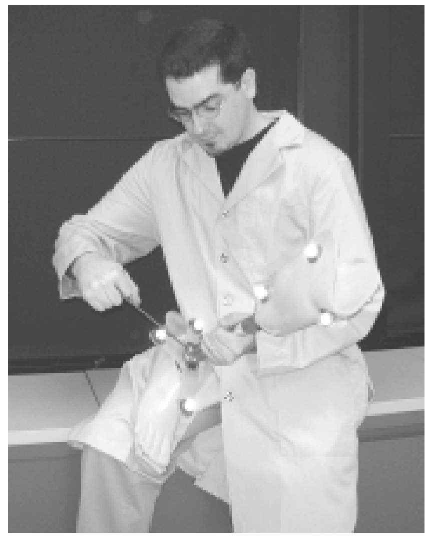
Human Ambulation Studies Up and Running at Northwestern University Prosthetics Research Laboratory and Rehabilitation Engineering Program

By Andrew H. Hansen, PhD

The number of human ambulation research personnel at NUPRL & RERP has increased dramatically over the last five years. With this increase has come a wealth of new ideas, some which take our scientific inquiries in new directions, and some which branch from the investigations of previous and veteran researchers in our laboratory.



Andrew Hansen,PhD, works with a component of a lower limb system as part of his research in areas of human ambulation

Some new directions of research in our laboratory include studies examining lower limb orthoses, studies of new prosthetic components, studies of gait initiation and termination, and studies investigating spinal movements during walking. Many other projects investigate new aspects of previous research including work on shock absorption properties in walking and studies of effective rolling shapes that walking systems utilize. The research in these areas has led to ideas regarding prosthesis alignment of different kinds of prosthetic feet and the development of a new prosthetic foot for use in low-income countries.

A great deal of the research in human ambulation studies at NUPRL & RERP ties into the development and examination of simple conceptual models of walking that can be used to understand non-disabled walking and the ambulation patterns of persons who use prostheses and orthoses. The goal of this work is to more thoroughly understand both non-disabled and disabled walking in order to more effectively evaluate current prostheses and orthoses and to develop prostheses and orthoses that more appropriately mimic biologic function, i.e. ones that are more "biomimetic".

On the following pages, the students and staff conducting research in the area of Human Ambulation describe their specific projects and how they fit into the overall research scheme. ❖

Gait Characteristics of Persons with Bilateral Transfemoral Amputation

By Brian Ruhe

Ruhe is studying the gait characteristics of persons with bilateral trans-femoral amputation. I feel that studying the compensatory actions of the hip and trunk while using two above knee prostheses may be helpful in enhancing the function of prostheses for people with unilateral amputations as well.

Ruhe has studied five people with bilateral trans-femoral amputation using the VA Chicago Motion Analysis Research Laboratory (VACMARL) computerized motion analysis systems at NUPRL & RERP. The data he has collected supports the hypothesis that persons with bilateral trans-femoral amputation use similar compensatory actions to functionally ambulate. He is gathering data attempting to understand what these compensatory movements are actually doing for the individual. When a complete understanding of amputee gait can be derived, better prosthetic components can de developed to simplify the act of walking for this population.

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Roll-Over Shape Studies

By Andrew H. Hansen, PhD

Our laboratory has been examining the effective rocker (or cam-like) shapes that locomotor systems conform to during walking. We've named these effective geometries "roll-over shapes" because they are the shapes that are taken as the body rolls over the stance leg in walking. We have measured the roll-over shapes of non-disabled locomotor systems and believe they can be compared directly with their prosthetic or orthotic counterparts. For example, one of the roll-over shapes we examine is the ankle-foot roll-over shape. The ankle-foot roll-over shape shows the effective rolling cam that the ankle and foot contribute to create during the roll-over part of walking.

Our initial findings from non-disabled persons' walking measurements suggest that the undamaged physiologic ankle-foot system adapts to walking speed changes, shoe heel height changes, and to different amounts of carried weight to maintain a generally invariant roll-over shape. We believe these findings are relevant to design and alignment of prosthetic feet and ankle-foot orthoses, which act to replace or augment functionality of the missing or disabled ankle-foot systems of their users.

The information gained from roll-over shape studies and from theoretical walking models developed in our laboratory has led to the development of a prosthetic foot, the Shape&Roll® Prosthetic Foot, and to the development of a computerized alignment system for different kinds of prosthetic feet, the Roll-over Shape Alignment System (ROSA™ System). Work is ongoing toward the refinement of the ROSA™ System. At its current stage, it is able to predict alignments of different kinds of feet based on a starting alignment of one foot by an experienced prosthetist. We hope to eliminate the need for the starting alignment in future versions of the system.

Most gait analysis studies are performed on level ground. However, in reality, persons must traverse a wide variety of terrains. Furthermore, persons who use prostheses encounter many problems when walking on non-flat terrains. For these reasons, our laboratory studied the gait of non-disabled persons walking on inclined and declined surfaces. This was done in an attempt to understand the adaptations that are made by the undamaged physiologic locomotor systems when walking on a variety of ramps. Our main finding was that the roll-over shape of the knee-ankle-foot system changed in orientation to accommodate the ramp's surface. We believe the specific findings from non-disabled walking will help to define design constraints for the future development of prosthetic and orthotic systems that are more auto-adapting to the terrain their users walk over.

Further Development of the Shape&Roll® Prosthetic Foot

By Sophie Lambla, MS

I am presently involved in a research project concerning the development of the Shape&Roll® prosthetic foot. Since I started in October 2002 as a Research Engineer at NUPRL, my work has focused mainly on the improvement of the cosmetic shell of the Shape&Roll® foot.

Unfortunately, many people think that the cosmetic part of a prosthesis is not as important as the function of the prosthesis. However, an attractive cosmesis may assist the integration process for a new user as it makes the appearance of a prosthesis less apparent and helps them blend in with his/her surrounding environment. It may also help to build a better self-esteem; thus the development of the cosmetic shell is important.

During the past three months, I evaluated different materials and designed new molds for the cosmetic shell. I also designed a new compression mold for the Shape&Roll® foot to accommodate for smaller sizes.

Michel Sam, MS, developed a process to make the cosmetic shell for the Shape&Roll® prosthetic foot. To fabricate a cosmetic shell, a negative mold of a human foot is taken using a bath of therapeutic wax. This wax mold is modified in order to correctly position the keel and determine the thickness of the shell. The negative wax mold is then filled with

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plaster, with the keel in place. An aluminum piece is attached to the keel at the place the pylon will be later attached: this piece will maintain the keel in place within the future silicone mold. The removal of the wax gives us the positive plaster mold of the original human foot. Using sculpting techniques, a 2-part silicone negative mold of this plaster foot is made. When this mold is finished, the plaster is broken out. Some clay is placed on the top of the keel to reduce the weight of the

Sophie works with plaster, polyurethane and other materials to create a shell to make the Shape&Roll prosthetic foot more attractive.

future shell, then the keel (with the clay) is placed in the silicone mold, and finally a polyurethane shell is made. When a satisfactory shell is obtained, the inside of the shell is replicated with silicone, so as not to use the clay anymore. This insert in silicone permits us to save time and helps to fabricate a clean, clay-free shell. Pigments are added to the polyurethane in order to obtain a flesh-like color.

At theinitial stage of development, the cosmetic shell would tear easily once a cut was made. To solve this problem, two nylon stockings cover the keel and the silicone insert and a unidirectional fiberglass reinforcement is placed below the ankle, over the stockings, to stop tearing.

Polyurethanes of different hardnesses have been tried out to improve durability. Two polyurethanes with a higher hardness than the one originally used are being investigated. Indeed, the texture and the tensile strength are better. The shell seems to be resistant to tearing and very flexible at the same time. To determine which one will be used, we have to test the shells in the fatigue-testing machine.

Further improvements have been made on the mold itself and the insert. Instead of using silicone for the mold and the insert, the original polyurethane used for the shell is now used. Using polyurethane lowers the cost substantially. Moreover, this type of polyurethane is easier to find in low-income countries than silicone.

However, using an insert made out of polyurethane creates a new problem: it is hard to remove the keel and the insert without destroying the shell. At the moment, a dilatancy technique using vacuum and sawdust is being evaluated to replace the insert. If this technique works, the keel can be easily removed once the shell is made, by releasing the vacuum and removing the sawdust.

As mentioned earlier, a new compression mold has been designed to accommodate for smaller sizes of prosthetic feet. The original mold permits us to make Shape&Roll® prosthetic feet from sizes 7 to 12. The new mold permits us to make Shape&Roll® prosthetic feet from sizes 3 to 6.

The goals over the coming months are to test the durability of the two materials chosen for the cosmetic shell, determine mixing ratios for three different colors of cosmetic shell, and design new compression molds for children and new compression molds with heel height compensation.

Developing a Computer Model to Aid in Aligning Lower Limb Prostheses

By Pinata Hungspreugs, MS

The prosthetic fitting process can be time and cost consuming, especially for clients with high levels of amputation, such as shoulder and hip disarticulations. In 1992, the Prosthetics Arm Design and Simulation System (PADSS) was developed to assist prosthetists with selection of upper limb prosthetic components that would fit their clients' needs. This software program was updated in 2000 using a commercially available 3D human simulation program called Jack by Electronic Data Systems (EDS), chosen because of its advanced graphics of human models and because of its Windows operating platform, which is more familiar to users than the Sun Sparc platform on which the original PADDS

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operated. By using the modified version of Jack, a prosthetist would be able to create a 3D computer model of his or her client by specifying sex, weight, and applicable measurements from the residual limb needed to perform a prosthetic fitting. Once the human model is created on the computer, the desired prosthetic components are chosen and placed on the human model in the desired configuration. The PADSS is then able to show the prosthetist areas on the body that the client can touch (contact map) and volume in space that the client can reach (workspace volume). This program allows prosthetic students to practice fittings virtually, acts as a visual communication tool between the client and prosthetist, and can be used to assess new prosthetic designs or configurations. Currently this software is being tested and modified. Future plans include obtaining feedback from prosthetists on its design and interface, comparing results from the PADSS to that of actual fittings by prosthetists, and making the program more robust.

A similar program would be beneficial for lower limb prosthetic fittings. After selecting from a library of prosthetic components and placing them in the desired configuration and alignment, a computer model would be able to simulate the client walking with the prosthesis. Components could be changed or realigned quickly on this virtual model to obtain gait results close to that of the client's sound limb, or to that of an able-bodied subject. A program like this might be able to reduce the prosthetic fitting time and cost, facilitating the fitting process for both the prosthetist and the client.

Unfortunately, the mathematics and computer computation involved in simulating prosthetic gait of this detail can be extremely complicated and time consuming. We are currently analyzing simpler models that will help us to better understand the mechanics of walking both in able-bodied and prosthetic gait. The roll-over shape created by the ankle and foot is being studied using both physical and computer models. Simple wooden rocker feet attached to Aircast® walking casts have been created that can be worn by non-disabled subjects. Because the casts inhibit movement of the ankle-foot complex, the user must rely on the rocker feet shapes alone and the motions of the knee and hip joints to progress forward.

We expect to see gait patterns similar to those of persons with below-knee amputations. By limiting the motion of the ankle and foot in non-disabled subjects, we can better determine how accurately our rocker foot models can simultate able-bodied gait patterns. By varying the arc lengths, the radii, and the positioning of the rocker feet, we can study the effects of these variables on gait patterns. Without ankle and foot compensations for these changes, we may be able to examine how a person adapts to different roll-over shape parameters. These studies could also give us some further insight to the differences in prosthetic foot types and alignment (Hansen et al, 2000). They may also help us to further understand changes in gait while walking up or down inclines (Hansen, 2002).

Pinata Hungspreugs demonstates the rocker feet designed to test hypostheses about gait patterns of persons with lower limb amputations.

Computer models are being used to determine how accurately simple models can simulate real human motion. The computer models are being developed to accompany the physical experiments explained in the previous paragraph. These models are based upon the motion of rocker-based inverted pendulums and simple inverted pendulums. Changing the arc length radius or the fore-aft position of the foot can be easily executed using computer models, and the simulations can then be compared to human motion data. Other simulations are being created to analyze the effects of roll-over shape parameters at faster than normal walking speeds.

Basic ideas between the interplay of the swing leg to the stance leg are also being studied using computer models. For example, the relationship between heel strike of the swing leg to the roll-over shape of the stance leg is being analyzed. By exploring these models and comparing them with gait data of both able-bodied persons and persons who use protheses, we may be able to determine what type of models can accurately model human motion. We feel that the combination of computer modeling and experimentation may permit us to develop prostheses that will enable amputees to ambulate more efficiently, and create simulation programs that can help prosthetists choose or design prostheses that are optimized for their clients.

Hansen AH (2002). Roll-over Characteristics of Human Walking With Applications for Artificial Limbs. PhD Thesis. USA: Northwestern University.

Hansen AH, Childress DS, Knox EH (2000). Prosthetic Foot Roll-over Shapes with Implications for Alignment of Transtibial Prostheses. Prosthetics and Orthotics International 24:3, 205-215.

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Gait Initiation andTermination

By Steve Miff, MS

In May, 1863, Oliver Wendell Holmes wrote in the Atlantic Monthly:

"The two accomplishments common to all mankind are walking and talking."

Although the two activities described by Holmes appear to the common observer as mundane, daily routines, they are complex motor acts requiring significant coordination. Walking, for example, is a dynamic activity that amalgamates bones, muscles, joints, ligaments, and the central nervous system to create a coordinated movement that translates the body from one position to the next.

"Quiet" standing and walking (e.g., at a constant mean velocity) are considered "steady-state" activities – meaning, on average, the body is neither accelerating (speeding up) nor decelerating (slowing down). Various aspects of steady-state walking have been analyzed extensively, by numerous researchers, in an attempt to better understand both healthy and pathological gait.

Human locomotion, however, is not entirely a steady-state progression, but rather consists of three components: starting, walking at a constant speed, and stopping. The dynamic processes of starting and stopping are much more complex since the human body needs to accelerate and decelerate, respectively, often in a limited amount of time. As a result, the skills necessary to maintain stability, weight transfer, foot clearance, etc. become more critical during these transition phases than during the steady-state conditions. Such requirements become even more significant in people with a lower limb amputation, where one or multiple joints are missing. Although a large number of scientific studies have examined the various characteristics of steady-state locomotion, only a limited number have analyzed how a person initiates and terminates gait.

The focus of my research is to understand how acceleration and deceleration are achieved during gait initiation and termination, in both non-disable ambulators and in people with lower limb loss. To gain such understanding, able-bodied walkers and people with a below-knee amputation have been assessed and compared using gait analysis techniques conducted in the VA Chicago Motion Analysis Research Laboratory (VACMARL). The data collection and analysis involved the use of a real-time capture, eight-camera motion measurement system that is used to measure walking kinematics (joint angles). In addition, six force platforms embedded in the walkway were used to measure the related ground reaction forces created by the subject's walking and an Electromyography (EMG) system was used to record lower extremity muscle activation patterns.

We believe that the process of gait initiation can be characterized by two distinct phases: a passive initial forward fall, followed by an active process that leads to steady-state walking. Preliminary results suggest that during gait initiation, humans start by falling forward like an inverted pendulum on a rocker in order to generate forward momentum. This initial forward fall is similar for non-disabled walkers and for people with lower limb loss falling forward on their prosthesis. This determination has lead to the conclusion that the ankle and the foot are only used to create an appropriate "roll-over" shape. Therefore, a biological foot and ankle may be matched in function by a prosthesis (a passive element.)

These preliminary results suggest that the acceleration during the first step of gait initiation is primarily due to a forward fall, and not the result of a "push" at the ankle, as has been described in previous research articles. Results also suggest that the second step of gait initiation is a dynamic process that consists of input of energy from the original stance leg ankle and hip during the first double support. This input of energy generates additional forward momentum bringing the body to the desired steady-state velocity within two steps. In addition, results also indicate that in many aspects rapid gait termination is a "mirror image" of gait initiation.

The goal of this research is to develop a more complete knowledge and a better understanding of gait initiation and termination. Learning the relationships between various gait parameters, and focusing on some of the dysfunctional aspects created by a lower limb amputation, enable us to better understand the dynamic processes of gait initiation and termination and to design more functional prosthetic components for persons with lower limb amputations. In turn, these more functional components may allow amputees to walk with greater stability, improved comfort, and at faster speeds.

Research investigations in lower limb and walking areas are funded by the NIDRR of the Department of Education under grant number H133E980023. The authors also acknowledge the use of the VACMARL of the VA Chicago Health Care System, Lakeside Division, Chicago, IL.

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Gait analysis of bilateral amputees with different ankle components

By Po-Fu Su

The purpose of this investigation is to determine if the provision for prosthetic ankle motion in bilateral lower-limb amputees significantly improves their pattern of walking. This project will use quantitative gait analysis, performed in the VA CMARL, to determine how prosthetic components that provide ankle motion affect walking performance in persons who have bilateral trans-tibial or trans-femoral amputations. We will investigate if increased ankle motion enables bilateral amputees to achieve greater freely-selected and maximum walking speeds, take longer step lengths, reduce their trunk sway, and walk with more efficient patterns of pelvic motion with significant reduction or elimination of compensatory actions such as hip-hiking.

Po-Fu Su works in the VACMARL analyzing data about performance of prosthetic ankle components.

All subjects will initially be fitted with Seattle Lightfoot II feet and will walk on them for at least 2 weeks. After their first gait analysis to establish baseline, the subjects will be fitted with either Endolite Multiflex Ankles or Otto Bock Torsion Adapters as their first set of prosthetic ankle components. Endolite Multiflex Ankles allow ankle plantarflexion/dorsiflexion and inversion/eversion while Otto Bock Torsion Adapters provide up to 20 degrees of internal/external rotation. Subjects return for the second gait analysis two weeks later and afterward they are fitted with the second set of prosthetic ankle components. A third gait analysis is performed 2 weeks later, after which the subjects will be fitted with both sets of prosthetic ankle components. The fourth and final gait analysis is performed two weeks later.

Questionnaires are also administered to the amputee subjects after each gait analysis session to document their subjective evaluations of walking with the different prosthetic configurations. From the data collected during the different gait analysis sessions we will calculate and compare a number of measures within subject, within groups of subjects and between groups of subjects. These measures include ankle, knee and hip joint rotations, temporal-spatial parameters of walking, and kinetic variables such as joint moments and powers.

The results from this study will aid in identifying limitations in current prosthetic technology that inhibit normal patterns of walking in all lower-limb amputees, including both unilateral and bilateral, and may lead to the development of more functional prosthetic technology. Additionally, information from the characterization of the walking patterns of bilateral lower-extremity amputees will increase knowledge and understanding about the ambulation potential of this small, but significant, population of persons.

The Role of the Spine in Walking

Regina Konz, M.S.

Current understanding of the role that the spine plays in walking is limited because typical gait analysis models either disregard the upper body entirely or, if the spine is included,regard the spin as a single rigid structure. Data on segmental spinal movements associated with walking are scarce. Exploring how spinal motion contributes to walking forms the basis of my doctoral dissertation. In collaboration with surgeons from the Northwestern Memorial Hospital Department of Neurosurgery, Dr. Stephen Ondra and Dr. Aruna Ganju, I am conducting two studies that we hope will help us improve our understanding of how spinal motion contributes to gait: (1) Analysis of Able-Bodied Spinal Motion During Walking and (2) Analysis of Pathologic Spinal Motion During Walking. Dr. Dudley Childress, Dr. Steve Gard, Dr. Stefania Fatone, and Ms Rebecca Stine are also involved in these investigations.

The overall purpose of these studies is to increase our understanding of the spine's role in walking and determine what effects limiting spinal motion has on walking. We will analyze the spine's contribution to gait in both able-bodied adults and adults with spinal pathologies that result in mal-

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alignment and reduced spinal motion. Thus far we have developed a multi-segment spinal model, based on spinal regions, to analyze spinal motion in able bodied adults during walking and evaluate the effects that restricted spinal motion may have on gait. In this study, motion of the spine in able-bodied adults is restricted by the application of a customized, fiberglass body jacket, similar to a Thoraco-Lumbo-Sacral Orthosis (TLSO).

Preliminary data from three able-bodied subjects suggests that pelvic obliquity and rotation are diminished when

Gina Konz, now studying the role of the spine in walking, was one of the NUPRL & RERP personnel who set up the VA Chicago Motion Analysis Laboratory (VACMARL).

spinal motion is restricted by the TLSO. A slight increase in vertical ground reaction force magnitude when the spine was restricted, combined with decreased pelvic obliquity, could indicate a reduction in the shock absorbing capabilities of a restricted spine. The reduction in pelvic rotation may explain the shorter step lengths taken by individuals restricted with the TLSO. To achieve faster walking speeds with restricted spinal motion, cadence was increased. Additionally, data are being processed and analyzed to quantify the motion of spinal regions during gait and to validate the effectiveness of constraining the spine with a TLSO.

Restriction of motion may also occur in persons with spinal pathologies. Walking is affected to varying degrees by spinal disorders, such as mild curvatures, and more severe spinal pathologies requiring surgical instrumentation. Trunk imbalance may occur when deformities hamper the spine's ability to compensate for postural changes, in many cases exhibiting clinically observable gait deviations. If a deformity exceeds the spine's compensatory abilities the use of orthoses or surgical intervention and fusion may become necessary. While these methods may correct the deformity and balance the head over the sacrum, they alter the normal flexibility of the spine. It is unclear what effect this may have on an individual's gait.

Gait data from twenty subjects between 18 and 80 years of age with spinal pathologies are being collected using noninvasive procedures routinely employed in clinical gait analysis. Some of these subjects may require spinal surgery to correct the deformity, in which case, they will undergo gait analysis both pre- and six months post-operatively. Data from the first gait analysis (pre-operative and unbalanced spinal motion) will be analyzed separately and then compared to the post-operative data (stabilized and balanced spinal motion). By increasing our understanding of the effects of pathological spinal motion, we may be able to assist in the pre-treatment decision making process so that normal alignment and balance are restored with minimal negative effects on gait.

Comparing Shock-Absorbing Prosthetic Components in Unilateral Transfemoral Amputees

By Sara Koehler

The aim of this project is to compare two different prosthetic components—a stance-phase knee flexion unit and a shock-absorbing pylon—on the basis of their ability to provide shock absorption and to enhance limb function during gait. Currently, one of the main limitations of lower-limb prostheses is their inability to provide sufficient shock absorption during gait. Because most prosthetic knees are designed to remain fully extended during the loading response phase, shock absorption normally provided by physiologic mechanisms in able-bodied walking (such as stance-phase knee flexion) is lost.

One particular class of prosthetic knee components provides stance-phase knee flexion for the purposes of duplicating normal knee action during gait. It is thought that by restoring normal knee action during the loading response phase, some shock absorption will also be restored. By comparison, shock-absorbing pylons address this issue by increasing prosthetic compliance, thereby increasing comfort during gait. Shock-absorbing pylons attenuate impact forces through axial shortening as load is rapidly transferred to the prosthesis during gait. However, since these pylons shorten during the entire prosthetic stance phase of walking, this may cause dynamic leg length discrepancies and increase the potential for tripping during the swing phase of the contralateral leg.

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Both shock-absorbing pylons and stance-phase knee flexion units provide shock absorption, but the operation of the stance-phase knee flexion units is considerably more complex. Since each mechanism is different in its design and operation, this study will attempt to identify parameters related to limb compliance and comfort level when walking with each component. Potentially, this study will establish guidelines for choosing one type of shock-absorbing prosthetic component over the other.

The testing protocol for this study requires each subject to be fitted with the same prosthetic foot component and undergo a gait evaluation with both the stance-phase knee flexion unit and the shock-absorbing pylon. Sufficient time to adapt to each component is allowed between each gait analysis. Following data collection, gait parameters are analyzed in order to compare the performance between the two shock absorbing components. Some of the parameters considered will be: ground reaction forces, walking speeds, temporal and spatial parameters, and the timing and magnitude of stance-phase knee flexion of transfemoral amputee subjects walking with and without the shock-absorbing prosthetic components.

The patterns of walking from the research subjects will be compared with data from able-bodied persons to determine if the provision for shock absorption improves walking performance. In addition, the timing and operation of the pylon mechanics and the mechanical properties of the stance-phase knee flexion unit will be investigated. Hopefully, the findings from this study will lead to the design of new prosthetic components that may increase comfort and improve walking performance in transfemoral amputees as well as prevent joint and back problems common to people who walk on stiff prostheses.

Sara Koehler is studying the function of shock absorption components when used by individuals with unilateral lower limb amputation.

Shock absorption during walking

By Georgios Bertos, MS

Lower-limb amputees experience high forces that are transmitted through their prostheses to their trunk during walking. These shock forces are not only uncomfortable and unhealthy for the amputee but may also contribute negatively to the quality of the gait. We believe shock absorption is a fundamental aspect of normal and pathological walking which if not set properly can result in poor and injurious gait. We also believe that the current prostheses of the market may not supply the right shock absorption to the persons who walk with them. One of the reasons for this is that there is no clear understanding of appropriate shock absorption for non-disabled and disabled walking.

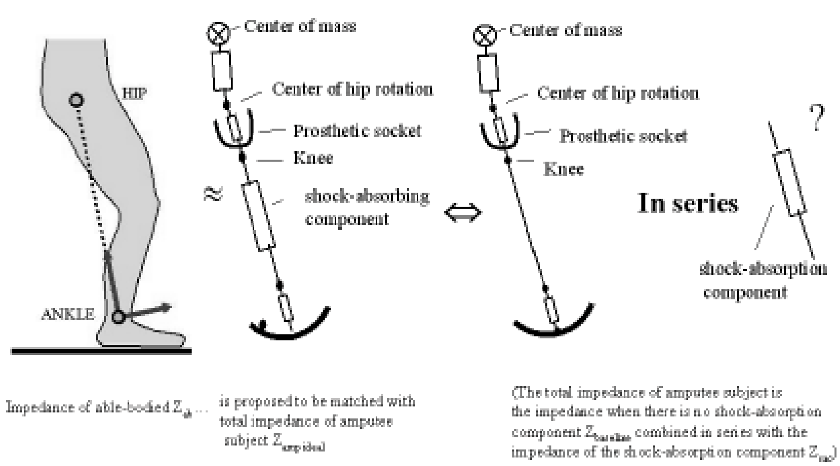

Figure 1: We will design a shock absorption device which when superimposed with the prosthetic leg without shock absorption will match the characteristics of shock absorption during able-bodied walking.

First of all, in order to improve shock absorption during walking we need a quantified measure of "shock absorption". We believe that mechanical impedance as defined in mechanical engineering can serve that purpose. We have analyzed able-bodied walking data and have developed an identification method based on steady-state analysis to estimate the mechanical impedance of the locomotor system (legs and hip) during walking. We have built the "walker", a mechanical model in order

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to verify the theoretical model of shock absorption we propose. (See Front Cover) Using the same identification method we have also estimated the impedance of unilateral above the knee amputees (wearing no shock absorbption components) during walking. Based on engineering principles, we believe we can design a shock absorption device which will compensate for the difference in mechanical impedance between the able-bodied and above the knee prosthetic walking. (Fig 2). We are in the process of designing and testing prototype prostheses based on this acquired theoretical knowledge which could improve the comfort and the gait of persons wearing them.

Continuing Work on Shape&Roll Prosthetic Foot and C-Leg

By Margrit Meier, PhD

At the moment I am involved in two main projects: (1) the development of the Shape&Roll® prosthetic foot and (2) the testing of the C-leg®, a computerized prosthetic knee joint.

Shape&Roll® Prosthetic Foot Project

First of all I would like to introduce Sophie Lambla, our new member of the Shape&Roll® project development team. Sophie is a research engineer from France and is the successor of Michel Sam, MS, who has left our laboratory in order to continue his career as a medical student. Sophie is mainly working on the Shape&Roll® foot project and introduces her work in more detail in her section. Because the Shape&Roll® prosthetic foot project has been presented in the Autumn Issue of *Capabilities*, I will mention it here only briefly: After the successful completion of the field trial in El Salvador, we are now in the stage of fine-tuning the foot so that hopefully it can be released in the near future. Fine-tuning includes the testing of different attachment possibilities, the creation of an appropriate cosmetic shell and its fatigue testing. We are also looking into the development of Shape&Roll® prosthetic feet for children.

C-leg® Project

A primary goal for prosthetists when fitting above-knee amputees is to provide them with good control over their prosthetic knee mechanisms. Poor control can lead to sudden collapse of a prosthesis and hence to unexpected falls. The introduction of computer-controlled prosthetic knee joints created new control possibilities, while providing additional benefits for amputees. What sets the C-leg® system apart from other microprocessor-controlled knee joints, is its hydraulic knee unit with computer-controlled swing and stance phase. By integrating the stance phase into the computer controlled process, it becomes possible to monitor and regulate knee motion during the entire walking cycle. This control appears to provide effortless adaptation to changes in walking speed, a feature that contrasts with conventional knee joints. In addition, the C-leg® would appear to increase stance phase security because knee sensors detect velocity and direction of rotation and pylon sensors gather moment data on the pylon due to ground reaction forces. Tthe mechanism should not allow the knee to buckle at an inappropriate time.

Previous investigations of microprocessor-controlled knee joints have reported mixed results, ranging from data showing clear benefit for amputees to those that suggest there is no difference at all when compared to conventional knee mechanisms. Objective evidence is needed to determine if there is significant benefit when prescribing these expensive microprocessor-controlled knee mechanisms over the high-performance passive knee units that cost significantly less.

One of our objectives of this study is to use quantitative gait analysis to investigate the general performance and maneuverability of the C-leg®. The results will be compared with the function of two high-performance passive knee joints: A single axis knee joint with a hydraulic unit and a multiple axis knee joint. The single axis knee is a hydraulic device that is commonly prescribed in the United States. It is somewhat similar to the C-leg®, but stance and swing phase are mechanically controlled, not electronically. The multiple axis joint has a small hydraulic unit offering swing phase and limited stance flexion control.

We plan to recruit 15 unilateral transfemoral amputees, aged between 40 and 60 years. The participants will receive a copy of their current prosthesis as a test-prosthesis. They will be permitted to accommodate to each knee unit for 4 weeks prior to a gait analysis session. All participants will be requested to fill out a questionnaire for each mechanism in order to provide subjective feedback from the users. The participants will undergo three gait analysis sessions, each with one of the aforementioned knee mechanisms. Each gait analysis session will be divided into three components: (1) Level walking at the slowest, normal and fastest walking speeds, while kinematic and kinetic data will be recorded; (2) Time taken to ascend and descend a stair flight of 10 steps; and (3) time taken to perform an obstacle course over different terrains. All of these sessions will be tested with and without a dual-task test in order to quantify the mental load when walking with the different knee joints. During each of these sessions, heart rates will be monitored in order to objectively compare the participant's walking effort. By having the amputees walk both with the conventional knee joints and the C-leg®, it should be possible to identify the strengths and weaknesses of the computerized knee joint and to determine if it provides significant benefits over the simpler, less expensive joints. ❖

Research Projects Place New Emphasis on Orthotics

Stefania Fatone, PhD

Research and technological advancements in the field of orthotics has lagged behind prosthetics for many years. We are attempting to address this by investigating a number of different aspects of orthosis performance. I am currently involved in three areas of orthotics research. The following is a brief description of each of these projects.

Stefania Fantone works with a router to prepare an orthosis for testing with a subject.

"An Investigation of Foot Alignment and Support in Ankle Foot Orthoses (AFOs)"
Investigators: S.Fatone, S.A.Gard, D.S.Childress and B.Malas

An Ankle Foot Orthosis (AFO) is an orthosis that constrains ankle motion for the purpose of providing stability and joint control during walking. The purpose of this research study is to increase our understanding of AFO-assisted gait, and to determine if ankle-foot alignment and foot support significantly affects AFO performance in persons with hemiplegia following stroke. Ankle Foot Orthoses (AFOs) are among the most commonly prescribed lower-limb orthoses. However, despite their popularity, many of the theories underlying AFO prescription are unsubstantiated. For example, the influence that controlling ankle-foot alignment within an AFO may have on knee function or the influence on gait of AFO foot-plate length have not been quantified or objectively documented.

Participants in this study undergo three gait analyses, each two weeks apart: the first while walking on a conventionally aligned AFO, the second while walking on a heel-height compensated AFO with full-length foot-plate, and the third while walking with a heel-height-compensated AFO with ¾ length foot-plate. We acquire bilateral kinematic, kinetic, EMG and plantar pressure data, as well as subjective information from the subjects by means of a questionnaire. We are comparing walking speed, step length, stance phase duration, vertical ground reaction forces, ankle and knee kinematics and kinetics, muscle activation, roll-over shape, and pressure over the navicular.

We believe that the results from this study will give us a better understanding of the effect of ankle-foot alignment and foot support on hemiplegic gait, and may enable us to recommend more appropriate AFO designs. This is a VA-sponsored study and to date, nine subjects have been enrolled in this study. Recruitment of additional subjects is ongoing.

"Analysis of Able-Bodied Spinal Motion During Walking"
Investigators: R.Konz, S.Fatone, S.A.Gard, R. Stine, D.S.Childress, S.Ondra, and A.Ganju

The spine plays a significant role in maintaining an appropriate upright posture and balance. Trunk imbalance occurs when deformities such as scoliosis hamper the spine's ability to compensate for changes in posture and balance. When this occurs, additional mechanisms are required to ensure balance and an upright posture. Most walking studies focus only on motion of the lower legs. If the spine is included, it is usually regarded as a single rigid structure – the 'trunk'. Data on the motion of the different spinal segments, such as the neck, thorax, and lumbar regions, associated with walking are scarce. Furthermore, if a person's deformity exceeds the spine's compensatory abilities, medical intervention may be necessary. Stabilization may be achieved with orthoses or surgical intervention and fusion. This investigation addresses the role of the spine during walking both with and without restriction from a spinal orthosis. We have collected spinal range of motion (ROM) and walking data in conjunction with segmental spinal motion from 10 able-bodied subjects. Additionally, the subjects were fitted with a cus-

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tomized fiberglass body jacket similar to a TLSO (Thoraco-Lumbo-Sacral Orthosis) to restrict the spine's motion. We also collected additional static ROM and walking trials in conjunction with spinal motion to determine the effect of such interventions.

We are comparing kinematic and kinetic parameters between the subjects' unrestricted walking and the TLSO walking to determine how the restricted spinal motion affects gait patterns. This project forms part of Ms. Regina Konz's PhD dissertation and is funded in part through the Department of Neurosurgery at Northwestern Memorial Hospital.

"Pilot Investigation of the Functional Benefits of Stance Control Orthotic Knee Joints"

Investigators: A.M.Boynton, S.Fatone, S.A.Gard, D.S.Childress, M.Kacen

Traditional orthotic knee joints utilized in the design of Knee-Ankle-Foot Orthoses (KAFOs) are either invariably locked or unlocked during gait. Recently, a number of new orthotic knee joint designs have become commercially available which allow stance phase control: providing stance phase stability while allowing knee flexion during swing. These orthotic knee joint options offer great possibilities for energy conservation and/or shock absorption to individuals who wear them. However, to date these benefits have not been objectively documented or quantified.

We are currently working with two of the commercially available joints, the Horton Stance Control Orthotic Knee Joint (SCOKJ) and the Fillauer SPL Orthotic Knee Joint. We are in the process of fitting these joints to a gentleman with post-polio syndrome who currently wears a conventional KAFO with a locked knee joint. We intend to compare kinematic and kinetic parameters for locked knee gait to the gait of persons using the SCOKJ in order to quantify what benefits the new joints may have for people with unilateral quadriceps paresis/paralysis due to conditions such as poliomyelitis. We are grateful to Horton's Orthotic Lab. Inc. for their generous loan of a set of SCOKJs and Fillauer for their generous loan and fabrication of a KAFO with SPL joints. The NIDRR Research Scholar program supported this project.

Research in Upper Limb Prostheses Focuses on Control and Function

Neuro-Fuzzy Logic as a Control Algorithm for Multi-Functional Myoelectic Hands

By Abidemi Bolu Ajiboye, MS

We are developing a controller for a multifunctional hand prosthesis with multiple surface electromyograms (sEMG) using fuzzy logic technology. The sEMG signal is successfully used as a means of control in current myoelectric prostheses. However, these are either single degree-of-freedom (DOF) devices or sequential controlled devices with locking mechanisms to switch between DOFs. There have been several proposed control algorithms extended to multiple DOF prostheses. Early myoelectric prostheses, such as the Sven Hand [1] and the Philadelphia Arm [2], involved the use of electrode arrays and used adaptive weighted filters to process the signals. More recently, Hudgins et. al [3] proposed extracting several parameters out of the first 200 ms of EMG activity to obtain more information from fewer inputs. These have met with varying degrees of success, but have for the most part been limited to laboratory success, and to our knowledge, have not been demonstrated as clinically practical solutions to the multifunctional control problem.

We propose an algorithm based upon neuro-fuzzy technology. Because of the inherent "fuzziness" of human activity, a control algorithm based on fuzzy logic may have advantages for multifunctional prosthesis control. We seek an acceptable compromise between the number of electrode sites used and processing complexity, thereby desiring not more than three to four control sites to control three to four DOF. This approach delivers more information to the system and, by using fuzzy logic, reduces the processing complexity.

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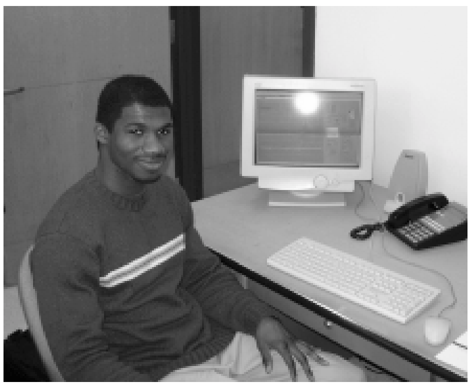
Modifying the width of the medium membership function (MBF) in the three MBF system and its effects in the overall system classification accuracy were investigated. Overall, the four subjects showed highest accuracy with a width of two standard deviations of the input data. The most accurate system was then trained and compared to a four MBF based system, also trained using neuro-fuzzy techniques. As expected for most of the subjects, the neuro-fuzzy trained four MBF based systems resulted in the highest levels of classification, ranging from 95% to 97% accuracy for the subjects with limb deficiencies, and from 96% to 98% for the normal-limbed subjects.



Abidemi Bolu Ajiboye

Comparing the fuzzy control accuracies to currently implemented algorithms in standard commercially available prostheses, it was found that the fuzzy systems performed better than the crisp threshold algorithm (extended to four-site control), quite favorably to the "most on" algorithm for normal limbed subjects and usually better for the subjects with limb deficiencies, and better than the lockout algorithm with hysteresis offset/onset of 3 SD/6 SD above the quiescent.

The high accuracy of classification for the normal-limbed subjects is encouraging in terms of possibly using this algorithm in a clinical prosthesis. There were several trials of motions where the neuro-fuzzy system achieved excellent classification for the entire duration of the motion. This implies that it is possible for the classifier to be effectively trained and thus extremely accurate – the only requirement would be that the user would need to learn to repeatedly perform the desired motion in the same manner.

Acknowledgements

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The Effects of Non-Linearities on E.P.P. Control of an Externally Powered Prosthesis

By Todd Farrell, MS

Proprioception utilizes the physiological components of the nervous and musculoskeletal systems to allow individuals to sense the position of their limbs subconsciously. By providing a rigid connection to an object this proprioceptive ability can be extended to that object and allow the user to sense the spatial location and orientation of the object with respect to his or her body. This concept of "extended physiological proprioception" (EPP) describes how a person can use a tennis racquet to hit a tennis ball without having to observe the position of the racquet during the swing.

Body-powered prostheses take advantage of this proprioceptive ability by relating the motion and position of the prosthesis to the motion and position of an intact joint of the amputee via the control cable. However, most externally powered prostheses do not have any mechanism with which to provide feedback regarding the state of the prosthesis to the proprioceptive system of the amputee.

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Simpson suggested that the concept of EPP could be applied to externally powered prostheses [1]. He stated that, by mechanically linking the movements of an externally powered prosthetic joint (e.g., an elbow) directly to the movements of a physiological joint (e.g., the shoulder), the amputee could 'feel' the position of the prosthetic joint by using the proprioception inherent in the anatomical joint. Much as with a body-powered prosthesis, the linkage between the two joints is able to provide feedback about the position and velocity of the prosthetic joint as well as loads that are applied to the prosthesis.

Todd Farrell modifies an externally powered elbow to improve EPP control of the device.

While the concept of EPP control seems credible and was demonstrated by Simpson [2, 3], implementation of such devices has been problematic. Our laboratory has developed three EPP controllers [4-6], one of which has been clinically fitted to amputees. In certain circumstances the EPP controlled powered elbows exhibit smooth operation in flexion but a 'jerky' behavior in extension. The goal of this study was to attempt to identify the factors that are causing the undesired behavior and compensate for these factors in order to better understand EPP control and improve the performance of prostheses using EPP-type controllers.

To investigate EPP control, a controller simulator has been developed [7] to analyze several control strategies. It was found that backlash (play) and friction in the system had adverse effects on the control of the device. The EPP system that was developed for this study is a force-actuated position-servomechanism, meaning that the tension that exists in the control cable of the prosthesis is used by the controller as a measure of the error that exists between the actual and desired positions of the elbow. The controller then changes the position of the elbow based upon this error signal. It was found that the backlash and friction caused the tension that was measured to not reliably indicate the error that existed between the desired position of the elbow and actual position of the elbow motor. When these two non-linearities were removed from the system the control of the elbow was significantly improved.

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Development of a New Mechanical Humeral Rotator

By Lissette M. Ruberte

Currently, the majority of trans-humeral or above-the-elbow prosthetic components are concerned with mechanisms for bending the elbow and opening and closing of the prehension device to provide lifting and grasping actions. Few components have been designed that allow the user to rotate the forearm along the axis of the humeral section (see Figure 1). Studies performed on persons with intact arms have shown that humeral rotation is essential to correctly position the forearm and hand to perform basic activities of daily living[1,2]. In an attempt to provide the prosthesis user with humeral rotation, most commercially available elbow units incorporate a friction turntable above the elbow unit that can be manually rotated by the user by pushing or

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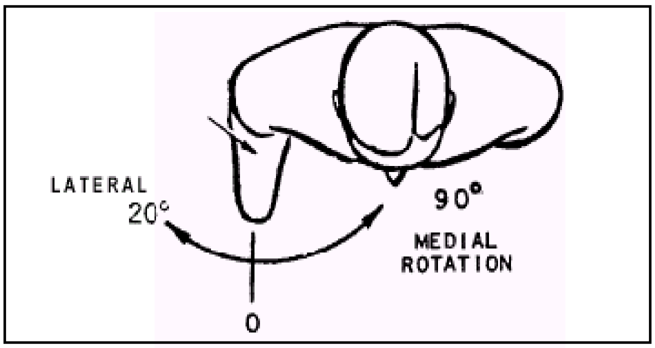
pulling it with the opposite intact hand or against a fixed object in the environment. Only two prosthetic components have been designed to provide humeral rotation. However, both of these devices have a limited number of positive locking positions which some users indicate are insufficient to properly position the forearm for certain tasks. Given the importance of humeral rotation, our goal is to design a lightweight prosthetic rotator that can be positioned easily in a high number of positions and locked in place during activities.

Figure 1. Normal ranges of motion of humeral internal/ external rotation[4].



In 1996 Robin McCall, a master's student in Mechanical Engineering at Northwestern University, designed a mechanical humeral rotator that consisted of a multiple disk brake system with a reciprocal actuator. One pull of the control cable locked the rotator and another pull of the cable unlocked the device. The resulting prototype was capable of resisting torques about the humeral axis of approximately 78 lbf-in when locked. To operate the device an actuating force and excursion of 6.8 lbf and of 0.43 inches respectively, was needed [3]. Although this system met most of the design objectives it can be improved further by reducing its weight, height, and actuating force. Also its inner diameter can be increased to allow a 0.675" inch connector to pass through it, for the use with electric powered elbows or hybrid systems.

As a smaller and lighter weight alternative to the multidisk rotator, we have designed a locking mechanism comprised of a system of gears with reciprocal actuation. The mechanism is locked and unlocked by axially moving an internal gear ring along a shaft so that its teeth mesh with a second gear. The second gear is attached to the bottom housing of the unit and is free to rotate with the forearm when disengaged. The internal gear ring, is keyed to the inside of the upper housing and fixed in relation to the prosthesis socket. Movement of the internal gear ring is effected by means of a cam arrangement. As viewed in Figure 2(a), the device is unlocked when the cam teeth are at the lowest point in the cam profile. In this position the second gear is disengaged and hence free to rotate. Figure 2(b) shows the device in the locked position. In this configuration the cam teeth are at the highest point in the cam profile and the second gear is constrained against rotation by engagement of the teeth on the internal gear ring. Proper rotation of the cam system in equal angular increments is achieved by a cable and ratchet mechanism.

The new unit is expected to reduce the actuating force to half the value obtained for the multidisk rotator. Also we estimate a decrease in weight and height of 0.25 lbs and 0.5 inches respectively, compared to the multidisk rotator. Although the new design does not have an infinite number of locking positions, it can be locked in 180 different positions spaced 2° apart. Despite the limited number of locking positions of our system, it offers ten times as many positions over the locking humeral rotators from Rimjet Corporation and Hugh Steeper, Ltd, which lock at discrete intervals of 22.5° and 18° respectively. We are in the process of developing a prototype model of our design.

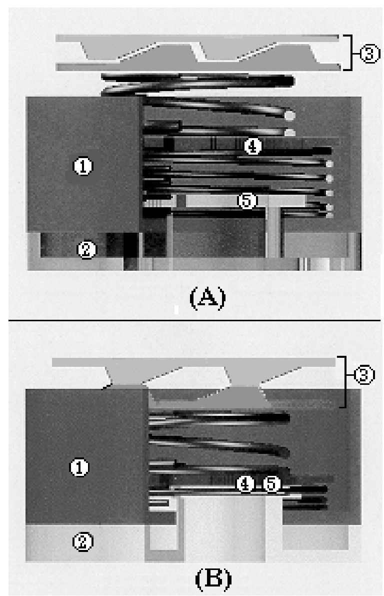


Figure 2. New humeral rotator mechanism (1) Upper housing, (2) Bottom housing (3) Cam system, (4) Internal gear (5) Gear

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Clinical Collaboration to Improve Upper-limb Prostheses

By Craig H. Heckathorne

Research directed toward improving upper-limb prosthetic systems has long been one of the core areas of our laboratory. Our early work focussed on developing new components, including socket designs, motorized prehension devices, and control electronics. While we continue to be active in the development of new upper-limb components, as evidenced by the preceding sections, we have expanded our interest over the last fifteen years to include research on human factors relevant to the use of upper-limb prostheses and modeling of human-prosthesis-environment interaction.

All of this work has required the direct involvement of users of upper-limb prostheses, as well as the participation of physicians, prosthetists (especially those on our staff) and therapists. Before 1988, this involvement was generally on a project-by-project basis, in which all parties worked toward the goal of a specific funded project. However, in 1988, our laboratory and the Prosthetic/Orthotic Clinical Services department of the Rehabilitation Institute of Chicago (RIC) agreed to establish a broader collaborative effort to further the advancement of arm prostheses and the methods of implementing them. Since 1993, the participation of our laboratory in this effort has been supported by the National Institute on Disability and Rehabilitation Research (NIDRR) as part of our Rehabilitation Engineering Research Center in Prosthetics and Orthotics.

A research laboratory such as ours can complement the work of a clinical program in several ways. One way is through our engineering-based understanding of materials, structures, mechanisms, and controls, our staff can adapt and customize existing components to improve the overall function of a prosthesis. Being able to customize prosthetic components can also help in the evaluation of new ideas that might lead to further development and possible commercialization or routine clinical implementation.

A second way is through our possession or access to tools generally not available to clinical programs. Such tools include material testing equipment, computerized data acquisition systems, and motion analysis equipment. These types of tools can be used to analyze the structural integrity of prosthetic components, the operation of prosthetic systems, and the interactions between users of prostheses and their prosthetic systems.

A third way our laboratory can complement a clinical program is through the development of a body of documentation having both quantitative (anthropomorphic measurements and measurements of component and system characteristics) and qualitative (such as photography and video) information that can be used in retrospective analysis. By providing an in depth record of the rationale, choices, and methods for each prosthetic fitting, detailed documentation can potentially lead to improvements in how prostheses are configured and implemented. Developing and maintaining this level of documentation is costly in terms of both time and instrumentation and is generally not reimbursable as clinical care. It is difficult for a clinical program to justify this cost and, therefore, only the minimum record keeping, required by institutional procedures is the general practice.

The benefits are not all one way. Our laboratory staff gains from the knowledge and experience of the prosthetists and technicians in the clinical program. They have day-to-day exposure to the components, devices, materials, and working methods required in constructing and implementing upper-limb prostheses. As a result, they have a broad base of knowledge from which to assess the relative merits of different devices and methods.

The clinical association also puts our laboratory staff and students in direct and routine contact with the immediate needs of persons with arm amputations. This contact helps us to maintain relevancy in our work and helps us to identify problems suitable for our research and development program.

The following is a partial list of developments that have directly grown out of our collaborative work with the RIC's Prosthetic/Orthotic Clinical Services department:

- *an improved frame-type laminated shoulder disarticulation socket that provides cooling through large cutouts and greater rotational stability*
- *an improved version of the Robin Aids four-function forearm setup which uses a single control cable to position a mechanical elbow, wrist rotation unit, wrist flexion unit, and a voluntary-opening split hook prehensor [Childress et al. 1989, Uellendahl and Heckathorne 1993, Uellendahl and Heckathorne 1997, Heckathorne et al. 1998]*
- *hybrid bilateral shoulder disarticulation prosthetic systems that combine somewhat standardized configurations of a body-powered, cable-actuated prosthesis and an electric-powered prosthesis [Childress et al. 1989, Uellendahl and Heckathorne 1992, Meredith et al. 1993, Heckathorne et al. 2001]*

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• *a forearm setup that incorporates a proximally-placed electric rotation unit and a distal mechanical wrist flexion unit [Uellendahl et al. 1990, Heckathorne et al. 1993]*

• *a frame-type laminated shoulder disarticulation socket that permits elevation of the shoulder through the socket for control actuation [Heckathorne and Uellendahl 1990]*

• *strategies for multicomponent control [Heckathorne et al 1993, Uellendahl and Heckathorne 1994]*

• *evaluation, implementation and adaptation of new commercial prosthetic components, including locking shoulder joints and locking humeral rotation joints [Uellendahl and Heckathorne 1999]*

Our clinical collaboration continues to be a source for project development. The E.P.P. control project described by Todd Farrell and the mechanical humeral rotator project described by Lissette Ruberte both came about as a direct result of clinical experiences.

Especially important to us is the promotion of successful ideas to the larger clinical community through our papers, presentations, and personal contacts. Of particular note has been the acceptance by the Hanger Prosthetics and Orthotics Upper Extremity Prosthetic Program (UEPP) of the hybrid approach to fitting persons with high-level bilateral arm amputations [Farnsworth et al. 2003]. The Hanger UEPP is a progressive program providing nationwide service to persons with arm amputations. Through the Hangar UEPP and other clinical programs, concepts which we have been promoting since 1989 will benefit far more individuals than those with whom we come into direct contact.

Our results over the last fifteen years have demonstrated the value of an engineering-based research and development laboratory working in close collaboration with a strong clinical prosthetics program. This collaboration has directly benefitted those persons with whom we have directly come into contact as well as benefitting many more through the transfer of concepts and procedures into the field.

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Listing of Papers and Presentations Resulting from the Preceeding Research Projects

Gard, S.A., and Childress, D.S. "What Determines Vertical Motion of the Human Body During Normal Gait?", Fifth Annual Meeting of the Gait and Clinical Movement Analysis Society (GCMAS), Rochester, MN, April 12-15, 2000.

Hansen, A.H., Childress, D.S., and Knox, E. "Prosthetic Foot Roll-over Shapes with Implications for Alignment of Trans-Tibial Prostheses", Prosthetics and Orthotics Internationa*l, Vol. 24, No. 3, pp. 205-215, December 2000.*

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Continued on page 21

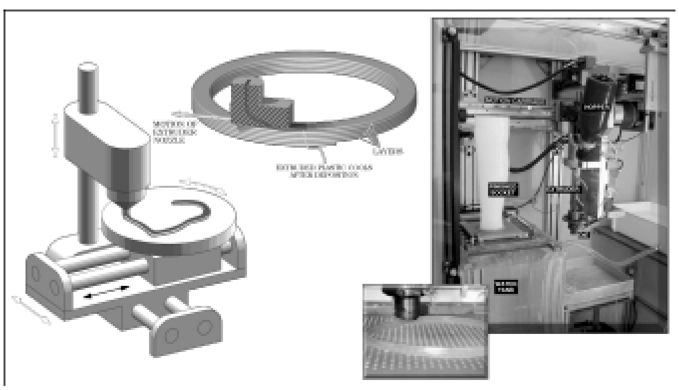
Computer-Aided Engineering

Squirt Shape Enters New Phase of Development

By Joshua Rolock, PhD & Kerice Tucker

An increasing number of prosthetists are now using computer-based techniques in the planning and fabrication of prosthetic sockets. For these clinical professionals, computer-aided design and computer-aided manufacture [CAD/CAM] provides an alternative to hand fabrication for the production of artificial limbs, and results in greater control and productivity in the limb fitting process.

We have developed a device for the computer-aided manufacture of sockets which we call Squirt Shape. Squirt Shape is a fully-automated system for the production of sockets using computer-based shape information. The Squirt Shape approach eliminates the need for the physical socket model that is required when molding sockets manually or when using commercial equipment for computer manufacturing of sockets. Consequently, socket production can be achieved more accurately and at lower cost than when using the other methods.



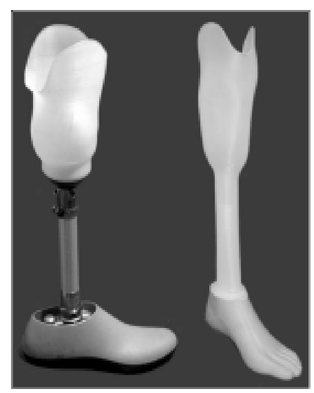
The Squirt Shape method of socket production. *Thin layers of melted plastic are deposited using a motion-guided extruder. Layers are stacked one upon another and thermally bond together to create the prosthetic socket.*

Briefly, the Squirt Shape technique uses a motion-guided extrusion device to deposit thin layers of plastic in precisely shaped cross-sectional profiles. The result is a three-dimensional object (the socket) that is composed of hundreds of plastic layers that are stacked upon one another and thermally bonded together (see figure). The socket is produced in about one hour, by an unattended machine, using less than a dollars worth of raw material. The sockets are typically fabricated with the inclusion of a standard shape at the end which facilitates assembly with the other limb components using off-the-shelf hardware.

In a new phase of development, sponsored by the Department of Veterans Affairs, we are investigating alternatives to traditional methods of assembling artificial limbs. Our approach will capitalize on the features of Squirt Shape to enable us to reduce or eliminate the need for fasteners such as screws, nuts and washers. Furthermore, we anticipate a reduction in the number of components needed to produce a limb, and consequently a reduction in the weight of the limb.

Our first effort in this new phase of development is the integration of the socket and pylon into a single-unit structure. Software was written to add the pylon to the socket shape data, and allows for alterations in the position and orientation of the "virtual" pylon, prior to fabrication, to enable alignment changes to be made. The resultant limb can then be fabricated in standard Squirt Shape fashion. One such integrated limb is shown in the accompanying figure in comparison with a standard type of limb assembly. In this instance, the composite weight was reduced from 1.44 lbs to 0.7 lbs. The strength of the integrated limb was tested in a materials test machine and had a strength of 308 ft-lbs at the ankle level. Fabrication time for the integrated limb was 1-3/4 hours which, while longer than the fabrication time for the socket alone, benefits from reduced assembly time, and reduced cost from the elimination of connector hardware.

The Integrated Limb. *On the left, a prosthetic limb assembled in the conventional way (socket alone produced with Squirt Shape). On the right, the integrated limb; connecting hardware and pylon are replaced by an integrated limb that is fabricated in a single piece using Squirt Shape.*



Further goals of this project include the incorporation of the prosthetic foot, or portions of the foot, into the integrated limb, and the development of specialized attachment hardware for use with Squirt Shape. These improvements will increase the utility of CAD/CAM methods in prosthetics by further increasing productivity, accuracy, and reproducibility as compared to other production methods.

NORTHWESTERN UNIVERSITY

Northwestern University PRL&RERP&NUPOC NEWS

NOTE: The Capabilities date designation has been changed from "January, April, July and October" to "Winter, Spring, Summer and Autumn" to more accurately reflect our quarterly nature. Volume and number designations remain the same.

Childress Presents Keynote Address at the AAOP Annual Meeting

Dudley S. Childress, PhD, presented the keynote address at the annual meeting of the American Academy of Orthotist and Prosthetists (AAOP) held in San Diego, California, March 19 - 22. Andrew H. Hansen, PhD, presented a paper at the meeting titled "Computerized System for the Alignment of Different Kinds of Prosthetic Feet Using Roll-over Shape Principles" at the meeting.

Laura Miller Receives PhD

Laura A. Miller has earned the Doctoral Degree in Biomedical Engineering from Northwestern University. Her doctoral dissertation is titled, "Theories of Human Ambulation with Applications to Swing-through Crutch Gait". Dr. Miller is also a Certified Prosthetist.

Patent Issued for Powered Hand Prosthesis

Notification was received that a patent has been issued for an upper limb development in the NUPRL. The patent is: Weir, R. F. ff., and Grahn, E. G., (2002): A New Externally-Powered Hand Prosthesis Suitable for the Restoration of Prehension of Persons with Amputations at or more Proximal to the level of the Meta-carpophalangeal Joint. United States Provisional Patent, Number: 60/432,676, Filed December 12th, 2002.

Weir is Plenary Speaker

Richard F. *ff*. Weir, PhD, was the Plenary Speaker for Rehabilitation Engineering Track, 29th Annual Northeast Bioengineering Conference, New Jersey Institute of Technology, New Jersey, March 22nd - 23rd, 2003. The title of the presentation was Weir, R. F. ff., (2003): The Great Divide – The Human-Machine Interface: Issues in the Control of Prostheses, Manipulators, and other Human Machine Systems.

Weir also joined Glenn Hedman, MS, as judges for the Student Design Competition of RESNA, the professional society for practitioners of assistive technology in North America. Hedmann, who now heads assistive technology services at the University of Illinois Chicago, was formerly on staff at the Rehabilitation Institute of Chicago and Northwestern University.

Ajiboue and Farrell Earn MS Degrees

Bolu Ajiboyue earned his Master of Science Degree in Biomedical Engineering, Northwestern University, with research in the area of neuro- fuzzy logic asa control algorithm for multi-functional myoelectric hands. His work is discussed on page 13. Todd Farrell has earned his Masters'of ScienceDegree in Biomedical Engineering, Northwestern University, with research in the effects of non-linearities on E.P.P. control of an externally powered prosthesis. His work is discussed on page 14.

Kellie Lim Joins Lab Staff

Kellie Lim, who was the NIDRR Scholar in 2000, has joined the staff of the NUPRL & RERP research programs. Kellie, who received her Bachelor of Arts degree Biological Scioences and Asian Studies from Northwestern University, is a Research Technologist and working with various projects.

Heinemann Presents Ethics Seminar

Allen Heinemann, PhD. presented a Disability Ethics Seminar January 21. His topic was "Patient Satisfaction with Medical Rehabilitation: An Important Quality of Life Indicator". Heinemann, who is the Director of the Rehabilitation Services Evaluation Unit at the Rehabilitation Institute of Chicago, is chief investigator for the Center for Rehabilitation Outcomes Research (CROR). The Center, funded by NIDRR, coordinates closely with NUPRL & RERP. For more on Dr. Heinemann's work, see page 5, *Capabilities* for Autumn 2002.

Papers and Presentations Resulting from the Preceeding Research Projects

Continued from page 18

Gard, S.A. and Childress, D.S. "What Determines the Vertical Displacement of the Body During Normal Walking?"Published in the Journal of Prosthetics and Orthotics (JPO)*, 12 (3), pp. 64-67, September 2001. 27th Annual meeting of the AAOP, March 7 – 10, 2001 in Dallas, TX.*

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Heckathorne, C.W., Hungspreugs, P. and Childress, D.S. "Current Work on the Prosthetic Arm Design and Simulation System", 27th Annual meeting of the AAOP, March 7 – 10, 2001 in Dallas, TX.

Miff, S.C., Childress, D.S., and Gard, S.A."Vertical Excursion of the Trunk During Gait is Determined by Step Length", 6th Annual Gait and Clinical Movement Analysis Society at the Shriners Hospital for Children, Sacramento CA, April 25-28, 2001

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Al-angari, H.M., Weir, R.F.*ff*, Heckathorne, C.W., & Childress, D.S.,"A Two Degree-of-Freedom Hand Microprocessor Based Extended Physiological Proprioception (EPP) Controller for Upper Limb Prostheses", *Robotica*, February 2002.

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Continued on page 23

News from the Department of Veterans Affairs

Department of Veterans Affairs Office ofResearch and Development is Conducting Over 14,000 Research Projects

Nelda P. Wray, M.D., M.P.H.
Chief Research and Development Officer

Coordinated by Robert M. Baum
Prosthetic Program Manager, P&SAS SHG,
VA Central Office, Washington D.C.

The Office of Research and Development (ORD) over sees a program funded by more than $1.2 billion from VA and other sources. Investigators at more than 110 VA medical centers are conducting more than 14,000 active research projects designed to enhance the health care VHA provides for veterans. Our four services—Medical Research, Health Services Research and Development, Rehabilitation Research and Development and the Cooperative Studies Program—expand our knowledge through studies in basic biomedicine, the organization and delivery of health care, optimal care for veterans with disabilities, and clinical trials. That solid foundation, however, only serves as the starting point toward even greater contributions to VHA by ORD.

ORD has created a new vision statement—Today's VA Research Leading Tomorrow's Health Care—to succinctly and eloquently guide its efforts to improve health care for the nation's veterans. At first glance, the vision statement may seem obvious—of course a research organization's role is to improve health care. It can take years, however, before research results are translated into practical clinical tools that directly improve the quality of health care. We in ORD believe that is too long.

In response, ORD developed its bold vision as a means to transform VA's research program into a leading model for the country—just imagine a world in which a research result discovered today is practiced clinically tomorrow! Using the vision statement as its guide, ORD is expanding its research in the three following areas:

Clinical research – ORD is widening its clinical research portfolio to include issues that directly affect clinical practice, with an emphasis on research that provides knowledge for the practice of evidence-based medicine. In addition to increasing funding for clinical research studies, ORD will develop a new initiative to dramatically increase its clinical research capacity.

Translation research – The development of information through research does not necessarily mean that such information is applied at the bedside. Therefore, ORD will expand research designed to identify the barriers to the rapid translation of research and will study new organizational structures with the potential to remove those barriers. Additionally, ORD will develop new programs in translation research to train new investigators in the scientific disciplines necessary to advance the field and will provide opportunities for managers to develop an understanding of those concepts.

Quality measurement – Finally, once the clinical and translation research portfolios have been expanded, ORD must make certain that the quality of health care is improving. Therefore, to ensure that VA's research program is directly affecting the quality of health care and to monitor the differences its efforts are making, ORD will expand its health services quality measurement portfolio.

As powerful as this vision may be, it can be translated into action only by an integrated research organization. A cornerstone of this effort will be development of our research organization into a vigorous, vibrant and highly coordinated effort. ORD is developing a comprehensive program to ensure that both new and veteran associate chiefs for staff for research and administrative officers receive the education, training and support they need to do their jobs effectively. At the same time, a committee of VISN and medical center leaders will advise ORD on how to achieve its vision.

This is a very dynamic, exciting time for VA Research. With its compelling vision statement as its guide, ORD is ensuring that the VA Research community never loses sight of its ultimate goal—to turn research results into improved health care for the nation's veterans—and it is paving the way for today's VA Research to lead tomorrow's health care.❖

Please send us your articles, success stories, comments or suggestions for future issues in the VA Presents.
E-mail: *Robert.Baum@hq.med.va.gov* ***Address: PSAS SHG (113), 810 Vermont Ave., NW, Washington, DC 20420. Phone (202) 273-8515. Fax: (202) 273-9110.***

Papers and Presentations Resulting from the Preceeding Research Projects

Continued from page 21

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- ❒ Pediatric Prosthetics
- ❒ Prosthetic Feet
- ❒ Prosthetics & Orthotics: General
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Other Sources for Prosthetic & Orthotic Information:

Consumer Information:
National Limb Loss Information Center
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Prosthetic-Orthotic Education:
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