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Capabilities

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Remaking the Mauch Hydraulic Ankle

Felix Starker

with Andrew Hansen, PhD and R. J. Garrick, PhD

I am working under the supervision of **Urs Schneider, MD (Fraunhofer IPA Institute, Stuttgart, Germany)** and **Andrew Hansen, PhD (Northwestern University Rehabilitation Engineering Research Center)** to re-design a Mauch prosthetic ankle component for my master's degree project. Working in the field of prosthetic ankles is like trying to make the impossible possible. Very high torques, in combination with limited building space and complex mechanics, make the mechanical replication of the human ankle nearly unattainable. However, recent developments in microelectronics and new materials may open the door for important future improvements.

Mauch's Revolutionary Ankle

In the late 1950s, Hans Mauch, a German engineer who worked in Ohio from 1946 until his death in 1984 (See *Capabilities*, 16(3):3, 2008; and 10(4):7, 2001), developed a prosthetic ankle that could adapt passively to different terrain by using hydraulics. The basic feature of Mauch's hydraulic design consists of a small ball that rolls along a track in the base of a concave housing and, when the pylon reaches vertical orientation, the ball stops the flow of hydraulic fluid between two chambers. When walking with this device, the mechanical approach allows the prosthetic foot to "find" the walking surface under lightly damped ankle motion and "locks" the ankle at mid-stance. This feature allows the ankle to adapt to different terrain on each and every step without the need for batteries or motors.



Andrew Hansen, PhD (left), and Felix Starker (right) are working to improve the Mauch Hydraulic Ankle.

Other features are less well-known, such as methods that allow the ankle to return to a neutral or dorsiflexed position in early swing phase. For example, the Mauch ankle uses a bypass channel that allows fluid to flow when weight is not on the ankle. When weight is applied to the ankle, this bypass channel closes, shutting off fluid flow from the rear to the front chambers. Mauch built other functions into his ankle design, including medial-lateral and torsional flexibility. Mauch often wrote that the ankle should be allowed

to invert more easily than to evert, making it less likely for the person to fall laterally over the prosthetic foot.

Proponents described the Mauch ankle as revolutionary. Prosthetists who fit the ankle relayed patients' comments that the ankle "leveled the world" for them. The Mauch ankle adapted to uneven terrain by allowing 20 degrees of inclination, 10 degrees of declination, and 10 degrees of inversion, while restricting eversion to zero for stability. Mauch often wrote that the ankle would provide benefits to patients that were equal to or greater than the benefits seen from the Mauch knee components. Sadly, the ankle invention never succeeded commercially due to problems of hydraulic fluid leakage.

Engineering Genius

We can better understand Mauch's ideas by reading the reports he published in the Veterans Affairs Reports from 1967 to 1972; however, until recently we had only a two dimensional schematic from that era showing a very

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simple model of the prototype. We did not know the design of the final prototype.

Thanks to the assistance of Mr. **Jon Bork** and the generous donation of a late Mauch ankle from Mr. **Richard Rosenberg**, CPO, LPO, we have been able to see the interior workings of Mauch's original device.



Disassembling the Mauch Hydraulic Ankle: The left photo shows the Housing (left) with the Piston Rod within the Shank Tube (right) removed. Visible in the base of the concave-shaped Housing is the gravity-activated Ball that closes the Control Port and prevents the flow of hydraulic fluid when the Shank is at vertical during mid-stance. The right photo shows the layered Chamber Sealings at the base of the Piston Rod. Fluid from the Back Chamber opens the Flap Valve at the site of the bore in the center.

Looking inside the Mauch ankle gives us a view of engineering genius. When we disassembled the Mauch hydraulic ankle component, we were once more surprised by the rich details Mauch integrated into the device. Mauch reduced the complex patent drawings to the design of the prototype. I was most impressed by its simplicity.

Functional Details of the Mauch Ankle

The greatest benefit of the Mauch Ankle is its passive adaption to uneven terrain. To achieve such an adaption, the ankle consists of one hydraulic chamber separated by a rotational piston that pivots over a concave-shaped surface. A control channel inside the piston connects these two separated chambers. At heel strike, the flow of hydraulic fluid decelerates between the two chambers and prevents the foot from lowering too fast and too hard onto the ground.

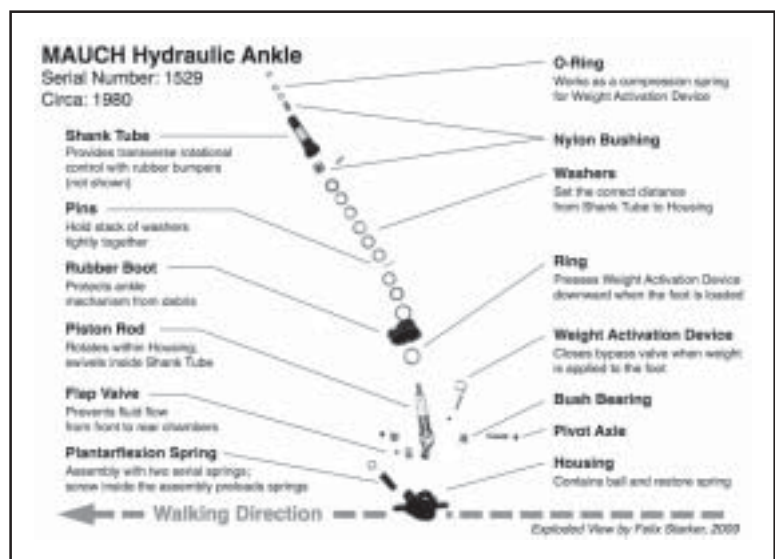
A passively controlled valve is integrated by a ball that rolls along a track in the concave-shaped surface within the hydraulic chamber. Because of gravity, the ball always seeks the lowest point on the concavely curved surface for any angle of the foot and shank. Therefore, in mid-stance when the

shank is in vertical position, the ball blocks the control port because it touches the piston. When the control port is blocked, as the foot rolls over the foot plate, the pressure rises within the rear chamber.

After the foot lifts off the ground in swing phase, due to pressure remaining in the rear chamber, the ball remains in its position and continues to block fluid flow from the rear to the front chamber. Hence, an integrated bypass channel connects the two chambers. This bypass channel is controlled by the weight of the amputee. Therefore, when weight is loaded on the foot, the bypass channel is closed; but when the load is removed, the bypass channel opens and the pressure equalizes between the two chambers. The two neutralizing springs return the foot to a neutral position before the foot again touches the ground.

Prospects for Modification

Now, more than 50 years later, we recognize the far-reaching impact of Mauch's design. An ankle component that adapts passively to different terrain is a big improvement for a person with lower limb amputation. Such a device allows the ambulating person to rely on the prosthesis for accommodation to surface variations, such as a doorsill or a slope in the sidewalk. The possibility of falling and injury is reduced when the person with amputation can rely on the prosthesis to adjust



Exploded View: This schematic drawing by Felix Starker shows the interior parts of the Mauch Hydraulic Ankle. (The authors appreciate the assistance of Craig Heckathorne, MSc, in finalizing this graphic.)

Felix Starker: Visiting Scholar at NURERC

My name is **Felix Starker**. I am a Visiting Scholar from the **Fraunhofer IPA Institute** and a graduate student at the **University of Stuttgart** (Germany). My hometown is Auenstein, located near Stuttgart in southwest Germany. While working as a rescue worker during my National Service duty, I developed some medical knowledge and clinical skills. Based on those experiences, I decided to study mechanical engineering with a focus on biomedical engineering.

I have nearly completed my *diplom ingenieur*, a German degree that is approximately comparable to a master's degree in engineering. From September through February 2010, in collaboration with the biomedical institute at the University of Stuttgart, the Fraunhofer IPA Institute, and the **Northwestern University**



Felix Starker is a Visiting Scholar at NURERC where he is working to modify the Mauch Hydraulic Ankle.

Rehabilitation Engineering Research Center, I am modifying Mauch's hydraulic ankle prosthesis that adapts automatically but absolutely passively to different terrain. I am still considering whether or not I will pursue a doctoral degree. My plans for the future are to work further in the field of biomedical engineering.

Although studying consumes much of my time, I still find time to train for one marathon per year. My other major interest is music. Of course, I love listening to CDs as well as attending live concerts; but the biggest joy for me is standing on stage and performing all night long in a pub somewhere in the middle of nowhere. I play the guitar and bass in nearly every possible style. I play with the band, "Sunpath." We have just released our second album called *Night Dream Call*.

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to differences in terrain, rather than having to pay acute attention to stepping on every surface variation.

The design and function of this hydraulic ankle show that Mauch was a great engineer with a keen eye for detail. As we explored the device, we identified some details that may have led to seal failures and hydraulic leakage. Therefore, we now are developing a Mauch Ankle II that will work with all the benefits of the original design and without hydraulic leakage.

Hans A. Mauch and His Work

For more information about Mauch's hydraulic ankle, see Hans A. Mauch. "The Development of Artificial Limbs for Lower Limbs" (1974) at: www.rehab.research.va.gov/jour/74/11/2/158.pdf

To learn more about Hans Mauch and his work, see *Memorial Tributes: National Academy of Engineering, Volume 3* (1989:258-264) at: http://books.nap.edu/openbook.php?record_id=1384&page=266

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Director Emeritus: Dudley S. Childress, PhD
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NURERC Bids Reluctant Farewell to Andrew Hansen, PhD

R. J. Garrick, PhD

From December 2009, **Andrew Hansen**, PhD, transferred to a full time position at the Minneapolis VA Medical Center (MVAMC) where he will focus on lower limb prosthetics and branch into other areas of rehabilitation research. Dr. Hansen will continue his affiliation with NURERC for Prosthetics and Orthotics as Adjunct Research Associate Professor.

Respected by his friends and colleagues as a productive and innovative researcher, Dr. Hansen came to the Prosthetics Research Laboratory in 1995 from the University of Iowa where he graduated with Honors and Highest Distinction in biomedical engineering. At Northwestern University under the tutelage of Dudley S. Childress, PhD, he completed his Master's of Science degree in biomedical engineering with the thesis, *Influence of Prosthetic Foot Mechanics on Alignment of Trans-tibial Protheses* (1998); and his doctorate with the dissertation *Roll-over Characteristics of Human Walking with Applications for Artificial Limbs* (2002). Subsequently, he completed a Postdoctoral Fellowship (2002-2003). Dr. Hansen was Research Assistant Professor from 2003 until earlier this year when he was promoted to Research Associate Professor. From 2006 through November 2009, he held a concurrent appointment as Research Health Scientist at **Jesse Brown VA Medical Center**, Chicago.

On November 20, **Elizabeth Schreiber Rowe** and the members of the laboratory hosted a send-off event for Dr. Hansen where many friends and colleagues assembled to wish him well. On behalf of the NUPRL and colleagues past and present, **Steven A. Gard**, PhD, Director of NURERC, reviewed Dr.



Andrew Hansen, PhD, cutting a cake decorated with messages of "Happiness, Success, and Good Luck" surrounding a laser image of the Rollover Shape.

Hansen's contributions to the lab product and detailed some of his attributes.

"I couldn't help but think of characteristics that uniquely define him. As an analogy, I used to work for a land surveyor. The position of a "corner" or a marker placed in the ground was defined by referencing it to the positions of three or more surrounding static structures, thus defining its uniqueness. I've prepared a list of attributes about Andy and what makes him unique to me.

I know Andy to be uniquely defined as a farm boy, an Iowa Hawkeye, a drummer, singer and guitar player. He is an accomplished programmer, a Matlab guru, an inventor with patent applications, a motivator and encourager. He sets a good example as a prolific grant proposal and manuscript author and researcher. His mantra is

'Write, write, write!'

"We know that Andy places the highest priority on his family, particularly his wife and kids. For years, Andy and his wife, Lori, have been eager to move closer to their extended families. As Dudley Childress always said 'Family comes first.' Andy, you will be missed. We all wish you, Lori, Cody, and Olivia the very best of luck."

On behalf of many friends and colleagues, **Sara Koehler**, MS, and **Kiki Zissimopoulos**, MS, presented Dr. Hansen with a Fender electric guitar and a poster-sized card that was signed by his friends and colleagues. Visiting Scholar **Felix Starker** provided invaluable consultation in the selection of this instrument. Representing many contributors, **R. J. Garrick**, PhD, presented Dr. Hansen with a Visa gift card that was inserted in the vertical cuts of a



Andrew Hansen, PhD (left) with Steven A. Gard, PhD, Director of NURERC (right).



Dudley S. Childress, PhD (left), mentor and colleague of Andrew Hansen, PhD (right).

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Shape&Roll Prosthetic Foot. **Dudley S. Childress**, PhD, Director Emeritus of NURERC, authored a poem with sentiments that were shared by others in the lab, "My heart is full, Yet my words are few...Thank you for the joy of doing research together!" The festivity concluded with Dr. Hansen cutting and serving a cake decorated with a laser graphic image of the effective Rollover Shape that he had focused on in his doctoral dissertation.

Colleagues expressed reluctance to bid farewell to the capable, congenial, and productive Dr. Hansen; however, everyone wished him every success and supported his decision to move to an area closer to his and his wife's extended families. Many who signed his card expressed a similar combination of reluctant parting coupled with best wishes for his future. Typically,



Dr. Hansen registers surprise, "This isn't what I think it is, is it? Wow! It is!"

always have fond memories of this place and I plan to drop in when I am in the Chicago area. I learned a lot from all of you and will miss you all very much."

We will miss you so much more! Andy, best wishes from all of us at NURERC!

well-wishers expressed thoughts such as: "I will miss your cheerful irreverence and open mindedness. Thank you for always making your knowledge accessible and for considering new ideas. You have contributed to my understanding of this lab's work and product. I have really enjoyed working with you. I wish you and your family much happiness and success in your new home!"

Dr. Hansen later thanked everyone "for the wonderful party and all of the wonderful gifts. I will

NURERC NEWS

Presentations

Three NURERC researchers presented their research results at the **Midwest Chapter American Academy of Orthotists and Prosthetists (AAOP) 2009 Annual Fall Session**, Hickory Hills, IL, on November 7. **Stefania Fatone**, PhD, BPO(Hons) and **Ryan Caldwell**, CP, presented "Gait Kinematics and Kinetics in Sub-Ischial Sockets with Assisted-Vacuum Suspension: Case Studies of Persons with Transfemoral Amputation." **Lexyne Jackson**, MS, presented "The Influence of Sagittal Plane Prosthetic Ankle Motion in Persons with Bilateral Transfemoral Amputations." **Sara Koehler**, MS, presented "An Investigation of Shock-Absorbing Components in Persons with Unilateral Transfemoral Amputation."

Lexyne Jackson, MS, spoke to **UnLIMBited Potential**, an amputee support group at the Rehabilitation Institute of Chicago. She discussed her research in standing balance in persons with lower limb amputations on November 6. **R. J. Garrick**, PhD, introduced opportunities for voluntary participation in NURERC research projects and educational tours of the NURERC laboratory.

Stefania Fatone, PhD, BPO(Hons) was invited to present "Review of the Evidence for Sub-Atmospheric

Suspension Systems" at the **American Academy of Orthotists & Prosthetists One-Day Certificate Program**, held October 10 in Chicago, IL.

Stefania Fatone, PhD, BPO(Hons), was an Invited Speaker at the **ISPO Canada 2010 Symposium**, "Prosthetics and Orthotics Care for People with Diabetes," held October 22 through 24 in Toronto, Ontario, Canada. Dr. Fatone presented "The Biomechanics of Neuropathic Gait and Partial Foot Amputation" and "Functional Evaluation of Ankle Foot Orthoses in Adults with Post-Stroke Hemiplegia."

Kathryn Waldera, MS, and **Craig Heckathorne**, MSc, attended the **Farm Progress Show**, held September 1 through 3 in Decatur, IL, where they disseminated information to farmers and ranchers about NURERC's ongoing collaborative project with **AgrAbility** from a booth in the Health and Safety tent. On October 5 through 8, they presented "Assessing and Responding to the Prosthetic Needs of Farmers and Ranchers" at the **AgrAbility National Training Workshop** in Grand Rapids, MI.

Craig Heckathorne, MSc, was an Invited Participant in the **Orthocare Innovations Foundation Symposium** "Prosthetics 2020: The Future of Physical Restoration,"

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High School Seniors Visit NURERC

R. J. Garrick, PhD

Crystal Lake South High School seniors who study Physiology and Anatomy with Ms. **René Kasischke** visited NURERC on December 1. NURERC Director, **Steven A. Gard**, PhD, welcomed the group with an overview about rehabilitation engineering research for Prosthetics and Orthotics.

While visiting work stations throughout the laboratory, students enthusiastically learned about P&O clinical applications and research. **Chris Robinson**, MBA, CPO, ATC, spoke about educational requirements and careers for Prosthetists and Orthotists. **Craig Heckathorne**, MSc, discussed upper limb prostheses with respect to control, function, and cosmesis. **Kerice Tucker**, Research Engineer, explained the Shape&Roll Prosthetic Foot, its economical fabrication, and use in developing countries. **Eric Nickel**, graduate student, introduced his work to develop a mechanical ankle that adapts to surface variation. He demonstrated ambulation while wearing a reflective marker system; and **Rebecca Stine**, MS, explained the function of force plates and the motion capture system for gait and motion analysis. **Stefania Fatone**, PhD, BPO(Hons) explained the Pedar System. **Joshua Rolock**, PhD, discussed CAD-CAM principles for measuring and fabricating prosthetic sockets and orthoses. He demonstrated a B-K Scanner (with VA Cyberware; prototype December 2002) that uses a laser to scan 3-dimensional shapes, transfer the image data to



A CLSHS science student positions her arm in the B-K Scanner, which converts 3-dimensional laser measurements of exterior objects to digital files for fabrication.

computer, and provide output that can reduce time-labor in the manufacture of prosthetic sockets. He also explained the Squirt Shape machine that builds accurate prosthetic sockets.

Students reflected about what they learned. About the Shape&Roll Prosthetic Foot, a student observed, *"I learned that you can teach people in other countries how to make a foot that works. And it only costs 10 dollars."* Other students expressed amazement about upper limb research. *"The cosmetically designed hand-arm was more real-looking than I thought possible"* and *"I was encouraged to see how science was focused on helping others."* Students recognized that some research principles that had been introduced in their recent class work. *"The cool thing was learning about muscle depolarization in class and then seeing the electric hand move."* After participating as a voluntary model demonstrator of the B-K Scanner, a student observed, *"It was cool to*

have my arm scanned and then see the thinnest pieces of plastic put in place by a computer."

Ms. Kasischke expressed appreciation for the P&O research products that she and her class observed during their visit. *"We feel inspired by your work. Your researchers communicate with our students at just the right level: not too technical, yet never over-simplified. I am certain that our students will reflect on this experience for many years to come."*

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held October 28 through 30 in Oklahoma City, OK.

Committee Service

On November 19 and 20, **Stefania Fatone**, PhD, BPO(Hons), served on the **NSF Research to Aid Persons with Disabilities (RAPD) Unsolicited Proposal Panel** in Arlington, VA.

In September, Dr. Fatone accepted an invitation to join the **Advisory Board of the Rehabilitation Institute of Chicago's Battery of Rehabilitation Assessments and Interventions in Neurorehabilitation (BRAIN)**.

Karolewski Honored as Educator



Thomas Karolewski

Thomas Karolewski, CP, FAAOP, **Director of Prosthetics Education**, Northwestern University Prosthetics-Orthotics Center (NUPOC) was honored at the **Illinois Association of Health, Physical Education, Recreation and Dance** state convention in St. Charles, IL, on November 19. Mr. Karolewski was honored for his twenty-five years of service and commitment to education.

NUPOC Group Visits Guatemala

Founded in 2005 by NUPOC graduate **David Krupa**, CP, and **Eric Neufeld**, CPO, the **Range of Motion Project (ROMP)** provides prostheses and orthoses to Guatemalans who do not have access to these resources. Mr. Krupa maintains that “*Guatemalans are not hampered by amputations, but by the lack of prostheses.*” ROMP is developing new services to meet client needs. Contributions to ROMP from private donors and P&O entrepreneurs enabled the opening of a prosthetic clinic that is serviced by teams of volunteers. Additional contributions have enabled ROMP to acquire upper limb components that are essential to Guatemalans who have survived machete attacks, electrical burns, or other traumatic amputations.

The first cohort of recent NUPOC graduates participated in what is hoped will become an annual collaborative effort between NUPOC and ROMP. From October 23 to 31, NUPOC graduates gained supervised clinical and technical experience while improving Guatemalans’ access to prosthetic and orthotic care. During their 9-day stay at the **ROMP**



Among those pictured are David Krupa, Daniella Duran, Jeff Henderson, Mike Cavanaugh, Holly Tuscherer, Katie Antle, MS, Anna Gray, Audrey Beatty, and Chris Robinson.

Loren J. Mallon Centro de Rehabilitacion (Zacapa, Guatemala), the team fabricated 6 KAFOs, 4 AFOs, 1 FO, 1 UCB, as well as a fracture brace and some arm orthoses. As the NUPOC volunteers practiced their skills, they provided essential services and empowered many Guatemalan clients.

Participants in this NUPOC trip were **Chris Robinson**, MBA, CPO, ATC, NUPOC instructor; **David Krupa**, CP (NUPOC Prosthetics

2003); **Daniella Duran** (NUPOC Orthotics 2008); **Audrey Beatty**, **Jeff Henderson**, and **Mike Cavanaugh** (NUPOC Orthotics 2009); **Holly Tuscherer**, CO (NUPOC Orthotics 2007 and Prosthetics 2009); **Katie Antle**, MS (NUPOC Prosthetics 2009 and Orthotics 2010), and **Anna Gray** (NUPOC Prosthetics 2009). Mr. Robinson observed that NUPOC’s collaboration with ROMP will “*continue to offer the combination of unique clinical experience with the opportunity to genuinely help those in need.*”

Learn more about this Chicago-based nonprofit organization at: www.rompglobal.org.

NURERC in the NEWS

Research supported by the **National Institute on Disability and Rehabilitation Research’s (NIDRR) Rehabilitation Engineering Research Center (RERC) for Prosthetics and Orthotics** is mentioned in the summer 2009 issue, *CROR Outcomes*.

NURERC and CROR are collaborating on “Enhancing Quality of Prosthetic and Orthotic Services with Process and Outcome Information,” a project that focuses on patients with lower-limb prosthetics. Read about this project at: <http://www.ric.org/cror>

News You Can Use

The **American Academy of Orthotists and Prosthetists (AAOP)** will hold its 36th Academy Annual Meeting and Scientific Symposium in Chicago on February 24 to 27, 2010. NURERC researchers will contribute to the scientific program. **Stefania Fatone**, PhD, BPO(Hons), and **John Michael**, CPO, will receive awards from the Academy in recognition of their professional contributions to P&O.

During this time, **NUPOC** will hold an event to raise funds for its planned 2010 merger with NURERC. Plan to attend!

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NUPOC Adds Key Staff

R. J. Garrick, PhD

John W. Michael, MEd, CPO/L, FAAOP, FISPO, **Associate Director of NUPOC**, is a prominent P&O professional who brings an infusion of energy, diplomacy, focus, and a lifetime of achievements in P&O. A NUPOC graduate, Mr. Michael will oversee the 2010 merger of NUPOC and NURERC into a single entity. The two programs have existed in tandem, but independently for the past 50 years and both groups welcome their unification as a long-anticipated, collaborative development. Mr. Michael also will supervise the establishment of the NUPOC master's curriculum and degree program mandated for 2013.

Throughout his career Mr. Michael has contributed to P&O as a clinical practitioner, educator, administrator, committee member/officer, and researcher. Mr. Michael also has a BS in Psychology from the University of Michigan and a Master's of Education from the University of Illinois. He has taught on Prosthetics and Orthotics topics at Northwestern University and at Duke University Medical Center, University of Washington, California State University, Century College, and St. Petersburg College; and Applied Physiology at Georgia Institute of Technology, where he remains adjunct faculty in the Department of Physiology. His awards include 2007 Outstanding Researcher Award from the American Academy of Orthotists and Prosthetists.

A forthright, diplomatic, and effective communicator, Mr. Michael's skills as liaison may derive partially from his Canadian-US heritage or from his parents' respective

degrees in law and sociology. Drawing from his multi-disciplinary background in P&O, pre-med, psychiatric casework, and entrepreneurship, he demonstrates deep commitment to the P&O profession. An eclectic devotee of Chicago blues and classic Studebakers, particularly the Avanti, Mr. Michael communicates comfortably with groups and individuals at all levels, including clinical practitioners, academicians, administrators, students, and clients.

Vigorous and congenial, Mr. Michael enjoys the balance of working creatively with both his intellect and his hands. In addition to conducting research and authoring significant publications, he constantly contributes to professional committees and outreach service forged by what he calls "*an inability to say no.*" Acknowledging that commuting represents his leisure time, he admits, "*I love this profession.*"

A persuasive proponent of evidence-based practice and improved professional standards in the field of P&O, he is now the "go-to guy" in the NUPOC-NURERC unification. Eager to meet new challenges, Mr. Michael sees the merger of these two fraternal programs as a golden opportunity to amplify their effectiveness by combining their historic strengths. His vision is to unite NUPOC-NURERC into a cohesive program and to build a successful P&O master's degree program.

NUPOC and NURERC welcome John Michael and look forward to supporting his efforts.



John W. Michael,
MEd, CPO/L, FAAOP