2017

Rush Orthopedics Journal

RUSH

A world of difference. Orthopedic surgeons at Rush cross time zones and oceans to provide musculoskeletal care in underserved communities. Read about the many challenges and rewards of their humanitarian efforts on pages 13-26 and 62-72.

Articles

The online version of the 2017 *Rush Orthopedics Journal,* plus past issues of the journal, can be accessed via the Department of Orthopedic Surgery home page. These versions contain all cited references and applicable financial disclosures; as well as a list of orthopedic faculty publications for the prior year. Go to **www.rush.edu/orthopedicsjournal** to view or download the pdf.

Chairman's Letter

According to the World Health Organization, musculoskeletal disorders and diseases are major public health concerns: They are the leading causes of disability in the US and the most common causes of severe long-term pain and physical disability worldwide.

One of the key contributing factors is that musculoskeletal problems often go untreated both in impoverished communities in the US and in developing countries, where devastating poverty and lack of access to basic health care force millions of adults and children to live with debilitating injuries that otherwise would be highly treatable.

Helping people overcome financial and access-related barriers to care is a pillar of the Rush mission. Members of the Department of Orthopedic Surgery are among those at Rush stepping up to address unmet health care needs both locally and worldwide. A number of our physicians, trainees, students, and staff participate in international humanitarian missions, work with local nonprofit organizations, and train surgeons from other countries to improve the care they provide back home. Our physicians have also contributed—and continue to develop—novel prevention and treatment strategies to help relieve the global burden of musculoskeletal diseases and disorders. This includes studying a range of innovative technologies, from three-dimensional printing (see page 27) to traction frames made out of PVC pipe (see page 23).

You can read about the extraordinary experiences of several of our attending physicians and trainees in this year's journal (pages 12-26 and 62-72). Other orthopedic faculty at Rush have also donated their time and expertise to projects that include the following:

- Hand, wrist, and elbow surgeon **John Fernandez, MD,** traveled to Nairobi, Kenya, for an orthopedic surgery mission in 1995; and was part of Rush Global Health's medical mission to Haiti in February 2010 to provide orthopedic care after the earthquake.
- Adult reconstructive surgeon **Scott Sporer, MD, MS,** has worked with Operation Walk for the last 5 years, performing surgeries in the US. He was also part of a group that recently traveled to Hospital San Juan de Dios in Santa Cruz, Bolivia; there, Sporer and 5 other surgeons worked 12-hour days and completed 66 joint replacements in just 1 week.
- Foot and ankle surgeons **Simon Lee, MD,** and **Johnny Lin, MD,** visit homeless shelters throughout Chicago to provide free foot exams for shelter residents; patients can then receive follow-up care at Rush for any issues identified during the exams.

The scope of humanitarian outreach efforts at Rush goes beyond our faculty and trainees to include our family members and support staff. Here are just a few examples of this important work.

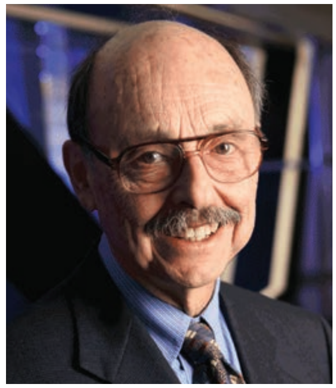
- **The Midwest Orthopaedics at Rush Significant Others (MORSO)**—led by Kari Levine, wife of adult reconstructive surgeon Brett Levine, MD, MS, and my wife, Faye Jacobs—donates its time and raises money for Deborah's Place. This charity provides comprehensive services for families affected by domestic violence.
- **Helen Vera,** a former administrative assistant with Midwest Orthopaedics at Rush, has gone on several missions to Ecuador to provide much-needed supplies and support for local families.

I encourage you to peruse the articles and interview features in this year's *Rush Orthopedics Journal*. I'm sure you'll be as inspired as I was by the stories of how our department is helping to bridge the ever-increasing gap between the need for and the availability of musculoskeletal care.

Joshua J. Jacobs, MD
The William A. Hark, MD/Susanne G. Swift Professor of Orthopedic Surgery
Chairman, Department of Orthopedic Surgery
Rush University Medical Center

Jorge O. Galante, MD, DMSc (1934-2017)

In Memoriam



By Aaron G. Rosenberg, MD

Jorge O. Galante, MD, DMSc, died on February 9, 2017, in the home he loved on Florida's Sanibel Island. He was 82. He was a true Renaissance man, and those of us fortunate enough to call him friend also knew him as a great humanitarian with incredible reserves of commitment and compassion. It is not his pioneering work as surgeon, scientist, and scholar, or his myriad achievements for which he will be most dearly remembered; it is his unique ability to elevate the visions and achievements of everyone with whom he worked.

Educated through medical school in his hometown of Buenos Aires, Argentina, Jorge emigrated to Chicago in 1958 and completed his orthopedic residency at the University of Illinois Hospital in 1964. After receiving his doctorate from the University of Göteborg in Sweden in 1967, he returned to the University of Illinois Hospital. Then, in 1972, he was recruited by Rush Medical College to serve as chairperson of its new Department of Orthopedic Surgery, where he began to forge one of the finest orthopedics programs in the world.

Jorge was, above all else, an astute clinician and an exceptionally talented surgeon. But as he said in 2014, "While participating in patient care, I soon realized there were too many questions for which there were no good answers. There were serious problems affecting millions of people and few valuable solutions. From my viewpoint, the allure of tackling unresolved issues of that magnitude was irresistible."

His collaboration with scientists, surgeons, engineers, and industry leaders in the 1980s led to the creation of the most widely used joint replacement systems in history. His groundbreaking implant designs resulted in replaced joints that worked better, lasted longer, diminished pain, and helped patients recover more rapidly, directly affecting millions of patients worldwide.

Jorge's pioneering contributions to orthopedics began with a method of fixing implants to bone using titanium mesh. The key feature of this—and all of his subsequent development work—was not only his insistence on doing the research needed to ensure clinical viability but also his emphasis on patient safety. He was committed to upholding the ancient physician's dictum, "Primum non nocere."

His extraordinary career was complemented by his zest for living. In this way as well, Jorge was larger than life: multilingual, widely travelled, and a connoisseur of literature, art, music, food, and wine. He was well known for fully immersing himself in his extracurricular interests, rarely finding himself at anything less than the pinnacle of his chosen endeavors. Through all this he was a devoted and loving husband to Sofija, a dedicated dad to his son, Charles, and a grandfather who cherished every moment with his grandchildren.

Jorge's ability to recognize and nurture the talent of others is reflected in the accomplished careers of the hundreds of scientists and clinicians who came to work with, and learn from, the master. While he retired as chairperson in 1994, his students continued to guide the growth and development of the department while he served as a Rush trustee and the Grainger Director Emeritus of the Rush Arthritis and Orthopedic Institute. His leadership fueled the amazing success of the department he had nurtured from its infancy, and his passion for orthopedics stayed with him until just days before his passing, as he remained involved in the design of a new knee implant.

Jorge lived a life truly blessed, and he, in turn, generously blessed everyone fortunate enough to have known him.

See additional remembrances of Jorge Galante on page 53

Orthopedic Faculty and Fellows

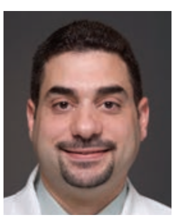
ADULT RECONSTRUCTIVE SURGERY

Craig J. Della Valle, MD
The Aaron G. Rosenberg, MD Endowed Professor of Orthopaedic Surgery
Director, Division of Adult Reconstructive Surgery
Director, Section of Research
Professor, Department of Orthopedic Surgery
Associate director, Orthopedic Surgery Residency Program

Richard A. Berger, MD
Director, Section of Minimally Invasive Surgery
Assistant Professor, Department of Orthopedic Surgery

Tad L. Gerlinger, MD
Associate Professor, Department of Orthopedic Surgery

Joshua J. Jacobs, MD
The William A. Hark, MD/Susanne G. Swift Professor of Orthopedic Surgery
Chairman, Department of Orthopedic Surgery



Brett Levine, MD, MS
Associate Professor, Department of Orthopedic Surgery

Denis Nam, MD
Assistant Professor, Department of Orthopedic Surgery

Wayne G. Paprosky, MD
Professor, Department of Orthopedic Surgery

Aaron Rosenberg, MD
Professor, Department of Orthopedic Surgery
Director, Adult Reconstructive Orthopedic Surgery Fellowship Program

Scott M. Sporer, MD, MS
Director, Section of Quality and Outcomes
Associate Professor, Department of Orthopedic Surgery

Nicholas T. Ting, MD
Assistant Professor, Department of Orthopedic Surgery

FELLOWS

Andrew J. Bryan, MD
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Nikkole M. Haines, MD
Residency – Carolinas Medical Center, Charlotte

Vasili Karas, MD, MS
Residency – Duke University Medical Center

Daniel R. Mesko, DO
Residency – The Cleveland Clinic Foundation

Sara J. Shippee, MD, MPH
Residency – University of Washington, Seattle

Linda I. Suleiman, MD
Residency – Northwestern University McGaw Medical Center

ELBOW, WRIST, AND HAND SURGERY

Mark S. Cohen, MD
Director, Section of Hand and Elbow Surgery
Professor, Department of Orthopedic Surgery

Robert W. Wysocki, MD
Assistant Professor, Department of Orthopedic Surgery

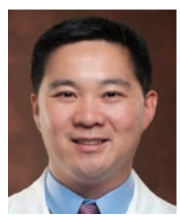
John J. Fernandez, MD
Assistant Professor, Department of Orthopedic Surgery

HAND, UPPER EXTREMITY, AND MICROVASCULAR FELLOW

Andrew G. Tsai, MD
Residency – University Hospitals – Case Medical Center

FOOT AND ANKLE SURGERY

George Holmes Jr, MD
Director, Section of Foot and Ankle Surgery
Associate Professor, Department of Orthopedic Surgery



Simon Lee, MD
Assistant Professor, Department of Orthopedic Surgery

Kamran S. Hamid, MD, MPH
Assistant Professor, Department of Orthopedic Surgery

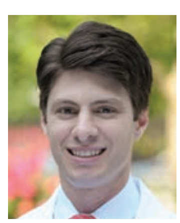
Johnny L. Lin, MD
Assistant Professor, Department of Orthopedic Surgery

FELLOW

Katherine Gavin, MD
Residency – University of New Mexico

ONCOLOGY

Steven Gitelis, MD
Director, Section of Orthopedic Oncology
Rush University Professor of Orthopedic Oncology
Professor, Department of Orthopedic Surgery



Alan T. Blank, MD, MS
Assistant Professor, Department of Orthopedic Surgery

ONCOLOGY AND SPINE SURGERY

Matthew W. Colman, MD

Assistant Professor, Department of Orthopedic Surgery

PEDIATRIC ORTHOPEDIC SURGERY

Monica Kogan, MD

Director, Section of Pediatric Orthopedic Surgery

Assistant Professor, Department of Orthopedic Surgery

Director, Orthopedic Surgery Residency Program

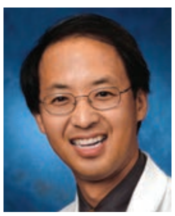
SPINE SURGERY

Frank M. Phillips, MD

Director, Division of Spine Surgery

Director, Section of Minimally Invasive Spine Surgery

Professor, Department of Orthopedic Surgery

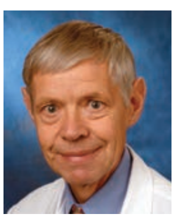


Howard S. An, MD

The Morton International Chair of Orthopedic Surgery

Professor, Department of Orthopedic Surgery

Director, Spine Surgery Fellowship Program



Gunnar B. J. Andersson, MD, PhD

The Ronald L. DeWald, MD, Endowed Chair in Spinal Deformities

Professor and Chairman Emeritus, Department of Orthopedic Surgery

Christopher DeWald, MD

Assistant Professor, Department of Orthopedic Surgery

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Assistant Professor, Department of Orthopedic Surgery

Edward J. Goldberg, MD

Assistant Professor, Department of Orthopedic Surgery

Kim W. Hammerberg, MD

Assistant Professor, Department of Orthopedic Surgery

Gregory Lopez, MD

Assistant Professor, Department of Orthopedic Surgery

Kern Singh, MD

Professor, Department of Orthopedic Surgery

Co-Director, Minimally Invasive Spine Institute

FELLOWS

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Sravisht Iyer, MD
Residency – Hospital for Special Surgery

Peter Derman, MD
Residency – Hospital for Special Surgery

SPORTS MEDICINE, SURGERY

Nikhil N. Verma, MD

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Director, Section of Clinical Research

Professor, Department of Orthopedic Surgery

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Professor, Department of Orthopedic Surgery

Charles A. Bush-Joseph, MD

Professor, Department of Orthopedic Surgery

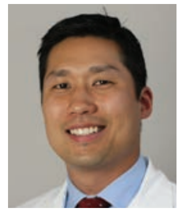
Brian J. Cole, MD, MBA

Director, Rush Cartilage Restoration Center

Associate Chairman for Academic Affairs and Professor, Department of Orthopedic Surgery

Brian Forsythe, MD

Assistant Professor, Department of Orthopedic Surgery



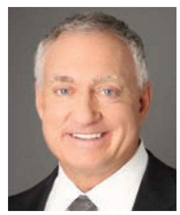
Shane J. Nho, MD, MS

Director, Section of Young Adult Hip Surgery

Assistant Professor, Department of Orthopedic Surgery

Gregory Nicholson, MD

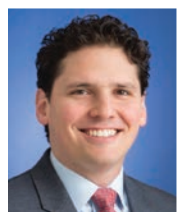
Associate Professor, Department of Orthopedic Surgery



Anthony A. Romeo, MD

Director, Section of Shoulder and Elbow Surgery

Professor, Department of Orthopedic Surgery



Adam Yanke, MD

Assistant Professor, Department of Orthopedic Surgery

FELLOWS

Gregory Cvetanovich, MD

Residency – Rush University Medical Center

Grant Garcia, MD

Residency – Hospital for Special Surgery

Natalie Leong, MD

Residency – University of California Los Angeles

Joseph Liu, MD

Residency – Hospital for Special Surgery

Austin Stone, MD

Residency – Wake Forest School of Medicine/North Carolina Baptist Hospital

SHOULDER SURGERY FELLOW

Michael D. Charles, MD

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ORTHOPEDIC TRAUMATOLOGY

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Assistant Professor, Department of Orthopedic Surgery

SPORTS MEDICINE, PRIMARY CARE

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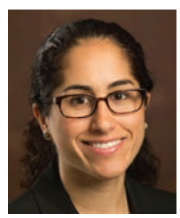
Assistant Professor, Department of Orthopedic Surgery

Nicole Boniquit, MD
Assistant Professor, Department of Orthopedic Surgery

Jeremy Alland, MD
Assistant Professor, Department of Orthopedic Surgery and Department of Family Medicine

Julia Bruene, MD
Assistant Professor, Department of Orthopedic Surgery and Department of Family Medicine

Joshua Blomgren, DO
Assistant Professor, Department of Orthopedic Surgery and Department of Family Medicine



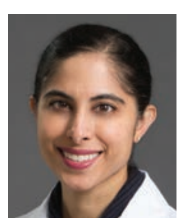
Leda A. Ghannad, MD
Assistant Professor, Department of Orthopedic Surgery and Department of Physical Medicine and Rehabilitation

FELLOW

Nina Yaftali, DO
Residency – White Memorial Medical Center, Los Angeles

ORTHOPEDIC PHYSICAL MEDICINE AND REHABILITATION

David S. Cheng, MD
Assistant Professor, Department of Orthopedic Surgery and Department of Physical Medicine and Rehabilitation



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April M. Fetzer, DO
Assistant Professor, Department of Orthopedic Surgery and Department of Physical Medicine and Rehabilitation

Research Faculty

THE ROBBINS AND JACOBS FAMILY BIOCOMPATIBILITY AND IMPLANT PATHOLOGY LABORATORY

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Director, the Robbins and Jacobs Family Biocompatibility and Implant Pathology Laboratory

Associate Professor, Department of Orthopedic Surgery

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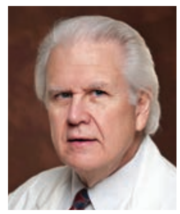
Deborah J. Hall

Assistant Professor, Department of Orthopedic Surgery



Thomas M. Turner, DVM

Associate Professor, Department of Orthopedic Surgery

BIOMATERIALS LABORATORY

Nadim J. Hallab, PhD

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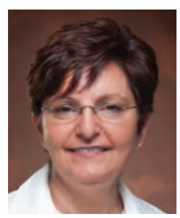
Professor, Department of Orthopedic Surgery



Anastasia Skipor, MS

Instructor, Department of Orthopedic Surgery

Director, Metal Ion Laboratory

SECTION OF MOLECULAR MEDICINE

Di Chen, PhD

Director, Section of Molecular Medicine

Professor, Department of Orthopedic Surgery

Tibor T. Glant, MD, PhD

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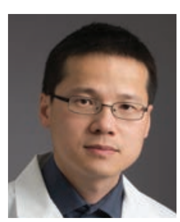
Program Director, Biotechnology

Professor, Department of Orthopedic Surgery and Department of Biochemistery



Jian Huang, PhD

Assistant Professor, Department of Orthopedic Surgery

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Katalin Mikecz, MD, PhD

Professor, Department of Orthopedic Surgery

Chundo Oh

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Senior Director, Comparative Research Center

Assistant Professor, Department of Orthopedic Surgery

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Assistant Professor, Department of Orthopedic Surgery

John Sandy, PhD

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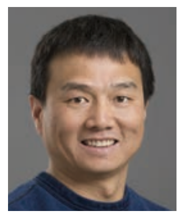
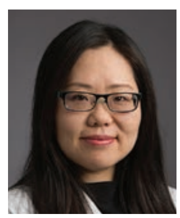
Guozhi Xiao, MD, PhD

Professor, Department of Orthopedic Surgery



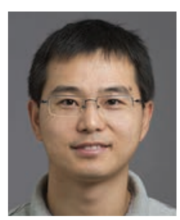
Rong Xie, PhD

Assistant Professor, Department of Orthopedic Surgery



Lan Zhao, PhD

Assistant Professor, Department of Orthopedic Surgery



Ke Zhu, PhD

Instructor, Department of Orthopedic Surgery

Not pictured:
Adrienn Markovics, MD, PhD, Assistant Professor, Department of Orthopedic Surgery

THE JOAN AND PAUL RUBSCHLAGER MOTION ANALYSIS LABORATORY

Markus A. Wimmer, PhD

The Grainger Director of the Rush Arthritis and Orthopedics Institute

Director, the Joan and Paul Rubschlager Motion Analysis Laboratory

Director, the Joan and Paul Rubschlager Tribology Laboratory

Associate Chairman for Research and Professor, Department of Orthopedic Surgery

Antonia Zaferiou, PhD

Director of Sports Medicine Motion Analysis

Instructor, Department of Orthopedic Surgery

Not pictured:
Jeffrey Hausdorf, PhD, Visiting Professor, Department of Orthopedic Surgery

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Professor, Department of Orthopedic Surgery

Alejandro A. Espinoza Orías, PhD

Assistant Professor, Department of Orthopedic Surgery

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Professor, Department of Orthopedic Surgery

Dino Samartzis, PhD

Associate Professor, Department of Orthopedic Surgery

THE JOAN AND PAUL RUBSCHLAGER TRIBOLOGY LABORATORY

Markus A. Wimmer, PhD

The Grainger Director of the Rush Arthritis and Orthopedics Institute

Director, the Joan and Paul Rubschlager Tribology Laboratory

Director, the Joan and Paul Rubschlager Motion Analysis Laboratory

Associate Chairman for Research and Professor, Department of Orthopedic Surgery

Hannah J. Lundberg, PhD

Assistant Professor, Department of Orthopedic Surgery

Alfons Fischer, PhD

Visiting Professor, Department of Orthopedic Surgery

Mathew T. Mathew, PhD

Visiting Professor, Department of Orthopedic Surgery

Not pictured:
Joachim Kunze, PhD, Visiting Instructor, Department of Orthopedic Surgery
Michel Laurent, PhD, Scientist, Department of Orthopedic Surgery

Department of Orthopedic Surgery Residents

CLASS OF 2017

Gregory L. Cvetanovich, MD
Medical school – Harvard Medical School

Brandon J. Erickson, MD
Medical school – Tufts University School of Medicine

Yale A. Fillingham, MD
Medical school – Rush Medical College

David M. Levy, MD
Medical school – Columbia University College of Physicians and Surgeons

Nathan G. Wetters, MD
Medical school – University of Illinois College of Medicine at Rockford

CLASS OF 2018

Bonnie P. Gregory, MD
Medical school – University of Louisville School of Medicine

Molly C. Meadows, MD
Medical school – Columbia University College of Physicians and Surgeons

Bryan M. Saltzman, MD
Medical school – Rush Medical College

Robert A. Sershon, MD
Medical school – Rush Medical College

Matthew W. Tetreault, MD
Medical school – University of Pittsburgh School of Medicine

CLASS OF 2019

Joshua Bell, MD
Medical school – Medical College of Georgia at Georgia Regents University

Kevin Campbell, MD
Medical school – University of Wisconsin School of Medicine and Public Health

Philip Louie, MD
Medical school – University of Washington School of Medicine

Timothy Luchetti, MD
Medical school – Columbia University College of Physicians and Surgeons

Allison Rao, MD
Medical school – Stanford University School of Medicine

CLASS OF 2020

Brian A. Basques, MD
Medical school – Yale University School of Medicine

Daniel D. Bohl, MD, MPH
Medical school – Yale University School of Medicine

Islam Elboghdady, MD
Medical school – Rush Medical College

Charles Hannon, MD
Medical school – Georgetown University School of Medicine

Mick Kelly, MD
Medical school – University of Wisconsin School of Medicine and Public Health

CLASS OF 2021

Junyoung Ahn, MD
Medical school – University of Texas Southwestern Medical School

Nitin Goyal, MD
Medical school – Northwestern University Feinberg School of Medicine

Ian MacLean, MD
Medical school – University of Virginia School of Medicine

Arash Sayari, MD
Medical school – University of Miami Leonard M. Miller School of Medicine

David Zhu, MD
Medical school – Yale School of Medicine

CLASS OF 2022

Matthew R. Cohn, MD
Medical school – Weill Cornell School of Medicine

William M. Cregar, MD
Medical school – Virginia Commonwealth University School of Medicine

Joshua A. Greenspoon, MD
Medical school – University of Miami Leonard M. Miller School of Medicine

Timothy C. Keating, MD
Medical school – Virginia Commonwealth University School of Medicine

Michael T. Nolte, MD
Medical school – University of Michigan Medical School

"Education-centered missions can strengthen the medical infrastructure of developing nations, teach advanced procedures…, and establish a collaborative network…"

Introducing Arthroscopic Techniques in Kenya

An Intermediate-term Follow-up

KEVIN WANG, BS / ANNABELLE DAVEY, BS / ERIC COTTER, BS
KYLE PILZ, MMS, PA-C / FRANCIS MBUGUA, MBCHB / BRIAN J. COLE, MD, MBA

AUTHOR AFFILIATIONS

Department of Orthopedic Surgery (Messrs Wang, Cotter; Ms Davey), Rush University Medical Center; and Midwest Orthopaedics at Rush (Dr Cole; Mr Pilz), Chicago, Illinois; and Department of Orthopedic Surgery (Dr Mbugua), Africa Inland Church–CURE International Hospital, Kijabe, Kenya.

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MEDICAL VOLUNTEERISM

As the Internet has become globally accessible, the exchange of ideas and knowledge has fostered a global health movement aimed at improving the training of physicians in resource-limited settings.[1-3] However, not all aspects of the health care education model are adapted easily to the virtual world; physicians traditionally train through direct interaction with patients under the close supervision of experienced practitioners. In an effort to obtain more advanced training and increase their earning potential, physicians from countries with less well-developed home programs often migrate to foreign countries.[4-7] This medical brain drain weakens developing health care systems and decreases their attractiveness to homegrown talent.[8] Access to more advanced techniques and training is a driving factor behind physician migration,[6,7,9] and one potential avenue to address this problem is targeting the skills gap in advanced surgical techniques between developed and developing health care systems. One way to target this skills gap is surgical volunteerism—specifically, education-oriented mission efforts that include experienced surgeons—but the sustainability of these practices is unclear.[10-12] When appropriately implemented, these missions can strengthen the medical infrastructure of developing nations, teach advanced procedures to otherwise accomplished surgeons, and establish a collaborative network that allows the developing country to continue an exchange of ideas and decision making long after the traveling providers have left.

THE IMPORTANCE OF SURGERY

Estimates suggest that between 11% and 32% of the overall global burden of disease is treatable by means of surgery,[13-15] but an estimated 2 billion people lack access to basic surgical care.[16] To address the mismatch between supply and demand for surgical care, numerous organizations such as Orthopaedics Overseas, Operation Rainbow, and the Mercy Ships work to facilitate the delivery of surgical services in low- and middle-income countries (LMICs).[17] From 2007 to 2013, the contributions from these organizations

Figure 1. Patient recruitment flyer for CURE International Hospital.

Figure 2. Kenyan partner Francis Mbugua, MD, (left) with senior author Brian J. Cole, MD, MBA (right).

accounted for an estimated $3.1 billion in overseas-directed health care spending.[18] These efforts continue to grow and have had a tremendous effect on health care quality and access by providing more than half of all surgical care in some LMICs.[19,20] Although many have focused on the short-term effect of mission trips,[21,22] the growing effect of surgical volunteerism necessitates consideration of the long-term effects on the local health care systems within LMICs. In recent studies, the authors have investigated the sustainability of these improvements, which is essential to consider when analyzing the long-term effects of these mission trips.[23-25]

ORTHOPEDICS WITHIN SURGICAL VOLUNTEERISM

Much of the orthopedic-related literature discussing volunteerism in LMICs focuses on trauma care.[26-28] Although trauma remains an important problem in LMICs,[29] there is growing interest in the application of modern orthopedic surgery techniques, such as arthroscopy, in other disciplines of orthopedic surgery, such as sports medicine. Recently, Tibor and Hoenecke[12] explored the ethical and economic implications of introducing arthroscopic techniques to developing nations, including questions of appropriate resource allocation, sustainability, and follow-up care. Although these considerations are important, it is also important to consider the educational desires of trainees within LMICs.

Much as the approach to medical care has become a more patient-centered, collaborative model, the approach to global medical education can be tailored to a learner-centric, collaborative model. Results of a recent investigation demonstrated that surgeons in some LMICs express low self-confidence with arthroscopic techniques and desire to improve their ability to manage articular disease.[30] In addition, some surgeons in LMICs express concern about the difficulty in finding the resources to develop the foundation for modern orthopedic techniques, such as arthroscopy, because of the large burden of trauma cases.[31] Although the importance of trauma care should not be overlooked in these nations, it is evident that the development of arthroscopic techniques has fallen behind. In developed nations, such as the United States, arthroscopic surgeries are among the most commonly performed orthopedic procedures.[32] The advancement of arthroscopy, a cornerstone of modern surgery, appears to be neglected in LMICs because relatively few investigators have reported on the matter other than Tibor and Hoenecke.[12] The apparent lack of arthroscopy training in developing countries may drive promising young surgical trainees who desire these skills to migrate to other countries for their training, contributing to the aforementioned medical brain drain in their home countries.[12]

CURRENT STATE OF ORTHOPEDICS IN KENYA

The University of Nairobi School of Medicine established the first department of orthopedic surgery in Kenya in 1972.[33] Before the development of formal training programs within the country, the first orthopedic surgeons in Kenya were foreign-born, foreign-trained physicians who served in the country on mission trips without establishing formal, domestic training programs.[33] Because of the lack of domestic training programs, the first African-born orthopedic surgeons in Kenya were trained overseas.[33] Since its inception in 1972, orthopedic surgery in Kenya has grown steadily. In 2007, there were 31 orthopedic surgeons registered with the Kenya Medical Practitioners and Dentists Board; that number grew to 69 by 2015. Generally, these surgeons are African born and have trained primarily in Kenya, with at least an additional year of training in either the United Kingdom or South Africa.[33,34] An orthopedic surgery residency in Kenya is a 5-year program that mainly focuses on the diagnosis and treatment of trauma. In Kijabe, residents are afforded an introduction to specialty training in sports medicine, spine, pediatrics, and joints, but there are only a handful of surgeons who treat these subspecialty cases, and there is no definitive case log requirement.

There is a paucity of data regarding the outcomes of common orthopedic sports medicine procedures performed in Kenya.

We found only 2 studies to date in which the authors reported the outcomes of arthroscopic sports medicine procedures in Kenya.[35,36] Gakuu[35] reported on 35 patients with anterior cruciate ligament (ACL) tears treated with bone–patellar tendon–bone autografts. Similarly, Byakika[36] conducted 20 arthroscopic ACL reconstructions (ACL-Rs) by using hamstring autografts and demonstrated satisfactory outcomes in all 20 patients. Although limited, these case series demonstrate that there is patient demand for arthroscopically assisted sports surgery but that there are few practitioners who regularly perform these procedures.

In this article, we will present the midterm outcomes of a short-term educational mission trip to Kenya. The delivery of surgery overseas generally is achieved by means of 1 of 2 methods: the use of temporary surgical platforms or the development of specialty surgical hospitals.[24] In the temporary platforms model, surgeons and supporting staff travel overseas for a short term to conduct a restricted set of surgeries, often relying on local physicians for follow-up. In the specialty hospitals model, organizations establish physical entities within LMICs that specialize in treating specific conditions. Although both models are beneficial, specialized surgical hospitals have more cost-effective, sustainable results.[24,37] In this article, we present a case example that is a hybrid of the 2 models—a short-term mission trip focused on education in the context of a previously established specialty surgical hospital.

THE KENYA EXPERIENCE

CURE International Partnership

CURE International, a nongovernmental organization founded in 1996 and based in New Cumberland, Pennsylvania, partnered with the Africa Inland Church (AIC) to create the AIC-CURE International Children's Hospital, Kijabe (AIC-CURE IHK) in 1998 with a focus on pediatric orthopedic conditions.[38] Subsequently, AIC-CURE IHK partnered with the larger AIC Kijabe Hospital in training its physicians. Both hospitals are licensed training hospitals for orthopedic surgery residents.[39] Results of previous investigations suggest that established, local hospitals are essential for the sustainability of international missions,[24] and the CURE partnership with the local AIC-CURE IHK provided a stable context for the mission trip.

The weeklong mission trip occurred in the summer of 2013. During the mission, the senior author (B.C.) partnered with a licensed Kenyan orthopedic surgeon (F.M.) interested in establishing a sports medicine practice at AIC-CURE IHK (Figure 1). F.M. is the first domestically trained Kenyan orthopedic surgeon and was the first orthopedic resident to train with CURE Kenya. F.M. finished his 5-year residency training in 2011 and was treating primarily trauma and pediatric cases before the mission trip—approximately 12 per week—but he had noticed a gap in sports medicine care in Kenya and was interested in establishing an orthopedic sports medicine practice. Before the mission, F.M. was training to conduct sports surgeries under an American-born and -trained orthopedic surgeon who moved to Kenya as a missionary surgeon. In total, there were 4 permanent consultant orthopedic surgeons (2 from Uganda and 2 Kenyan trained) at AIC-CURE IHK at the time of the mission, including F.M.

The Mission

The goals of the mission were to donate fully functional arthroscopy equipment to the orthopedic surgeons at AIC-CURE IHK and to teach 1 of the partner surgeons (F.M.) how to perform modern knee and shoulder arthroscopic techniques (Figure 2). The team, consisting of K.P., F.M., B.J.C., and a traveling anesthesiologist, spent the first day evaluating prescreened patients in the clinic to identify appropriate surgical candidates (Figure 3), and the remaining 4 days were devoted to the operating room (OR). More than 500 pounds of equipment, including a full arthroscopy tower (Figure 4) and all associated consumables to perform ACL-R, meniscus repair, arthroscopic labral repair, and rotator cuff repair, were donated by private companies—including Arthrex and Smith & Nephew—before the trip and set up in the preexisting ORs at AIC-CURE IHK, facilitated by the senior author's physician assistant (K.P.).

Figure 3. Dr Cole demonstrates a knee examination at CURE International Hospital.

The mission team (K.P., B.J.C.) provided a comprehensive clinical skills tutorial to the Kenyan physicians at AIC-CURE IHK. On day 1, teaching was delivered by 3 means. First, there was a morning didactic session focusing on patient evaluation and basic arthroscopic techniques. Second, during the outpatient clinic, the mission team instructed 2 Kenyan consultant physicians (F.M. and another physician) on physical examination techniques and clinical approaches to many common sports injuries of the knee and shoulder. Third, the mission team also instructed the OR staff on the appropriate methods for sterilizing the instrumentation, stocking the surgical trays, and preparing the rooms and arthroscopy equipment for the upcoming surgical days.

Most of the teaching during the trip centered on surgical techniques within the OR. The senior surgeon (B.J.C.) initially served as the primary surgeon and was assisted by his Kenyan colleague (F.M.). During these surgeries, B.J.C. demonstrated advanced arthroscopy techniques (Figure 5). After performing multiple full surgeries together, the roles were reversed, with F.M. acting as the primary surgeon assisted by B.J.C. Finally, F.M. was observed teaching orthopedic residents on the same procedures.

F.M. and B.J.C. operated on 11 patients (12 joints) with an average age of 30.33 years (range, 21-56 years), including 7 male athletes and 1 female athlete (Table). After the trip, F.M. followed up these patients for a median follow-up of 14 weeks (range, 2-39 weeks) and described the outcome as good in 10 (91%) of 11 cases on a scale of good, fair, or poor. Return to sport was reported in 6 (75%) of 8 athletes, but 2 of 3 basketball players did not return to sport. One patient had a fair subjective outcome requiring subsequent anterior interval release and lateral femoral condyle microfracture surgery on the index joint and did not return to basketball. He is still followed up by F.M. for knee pain. The other patient did not return to basketball for nonmedical reasons.

Figure 4. The arthroscopy tower setup at Africa Inland Church–CURE International Hospital, Kijabe, Kenya.

DEVELOPMENTS SINCE THE MISSION TRIP

Before the mission, F.M. did not have an independent sports medicine clinic. Since the mission, F.M. has developed a robust sports medicine clinic held 1 day per week, and he sees 25 to 30 patients each clinic day. The average time from injury to surgery for the patients seen in the clinic has improved from an estimated several months to several weeks. From his biennial case review, in the 2 years before the mission, F.M. treated 98 arthroscopy cases (88 knee and 10 shoulder) for an average of 49 cases per year (Figure 6). An annual breakdown of this case log was not available for analysis. His estimated case log before the mission consisted of primarily arthroscopic debridements and partial meniscectomies. He performed an estimated 12 ACL-Rs (exclusively hamstring autograft) annually and had never performed a Bankart repair.

Since the mission, F.M. has treated an average of 75 arthroscopy cases per year (64 knee and 11 shoulder), with an average of 2.7 Bankart repairs and 24.3 ACL-Rs, including patellar tendon autograft (Figure 7). F.M. is now comfortable performing multiple arthroscopic surgeries, including patellar tendon ACL-R, all-inside meniscal repair, knee microfracture surgery, synovial debridement, and arthroscopic Bankart repair. He continues to have a trauma and pediatric practice of a similar size as he did before the mission trip, and now he treats approximately 4 additional sports medicine surgical cases per week. He currently is teaching 3 trainee surgeons these procedures. In all, F.M. has demonstrated these procedures to 18 surgical residents, none of whom had any previous firsthand

Figure 5. Dr Mbugua and Dr Cole discuss arthroscopic findings.

Table. Kenya Trip Case Log and Outcomes

Sex	Age	Weight (kg)	Sport	Laterality	Diagnosis	Procedure	Follow-up (mo)	Subjective Outcome	Reoperation on Index Joint
M	29	69	Basketball	R	Chronic patellar tendon rupture	Patellar tendon repair	3	Good	No
M	21	94.5	Rugby	L	Recurrent shoulder dislocation	Bankart repair	1.5	Good	No
M	56	79	N/A	R	GHJ arthritis	Anterior and posterior capsulotomy	0.5	Good	No
M	28	86	Rugby	R	SLAP tear	SLAP repair	0.5	Good	No
M	26	90	Rugby	R	ACL tear	ACL-R (BTB)	1.5	Good	No
M	26	118	Rugby	L	ACL tear	ACL-R (BTB)	39	Good	No
M	30	85	Basketball	R	ACL tear, lat meniscus tear	ACL-R (BTB), partial lat mx	39	Fair	Yes
F	29	58	Basketball	L	ACL tear	ACL-R (hamstring)	4	Good	No
M	22	90	Rugby	Bilateral	R osteochondral lesion (MFC), L lat meniscus tear	R knee MFC mfx, L lat meniscus repair	39	Good	No
M	28	95	N/A	R	ACL tear, med meniscus tear	ACL-R (BTB), med meniscus repair	1.5	Good	No
M	43	102	N/A	R	Med and lat meniscus tear, osteochondral lesion (MFC)	Partial med and lat mx, MFC mfx	4	Good	No
M	26	75	N/A	L	Recurrent shoulder dislocation	Bankart repair	39	Good	No

Abbreviations: ACL, anterior cruciate ligament; ACL-R, ACL reconstruction; BTB, bone–patellar tendon–bone; F, female; GHJ, glenohumeral joint; L, left; lat, lateral; M, male; med, medial; MFC, medial femoral condyle; mfx, microfracture; mx, meniscectomy; N/A, not applicable; R, right; SLAP, superior labrum anterior to posterior.

experience with arthroscopy. In addition, he has instructed another consultant surgeon in arthroscopic techniques. Subjectively, the training from the mission has increased both F.M.'s and his patients' confidence in his training and abilities.

F.M. has become a key player in the Kenyan orthopedic sports medicine community, serving as a team physician with the Kenya Rugby Union and as the official tournament doctor at 4 rugby events in 2016. Through his experiences, F.M. has identified a relative lack of sports medicine–trained physicians and rehabilitation personnel, and he ultimately hopes to establish a sports medicine fellowship training program to improve the level of care throughout Kenya. Finally, F.M. visited Midwest Orthopaedics at Rush University Medical Center in October 2013 and in March 2015 to gain a better understanding of B.J.C.'s practice. In addition, F.M. visited the American Academy of Orthopaedic Surgeons Orthopaedic Learning Center and attended the Arthroscopy Association of North America course in October 2013 for additional training experience.

CHALLENGES AND FUTURE GOALS

The current challenges in Kenya are largely secondary to resource limitations. Durable equipment—such as the arthroscopy tower, cameras, shaver box, and associated power cords—from the mission is still functional, but the single-use equipment—such as all-inside meniscal suture kits, suture anchors, and shoulder cannulas—has been depleted. There are financial barriers to acquiring equipment, and the cost of surgery can be prohibitive for many patients. The average cost for uninsured patients to undergo diagnostic knee arthroscopy is approximately $2000. It costs approximately $2500 for ACL-R and $2500 for shoulder arthroscopy. These costs frequently are subsidized by donations of equipment from charitable foundations. Today, approximately 60% of F.M.'s patients have insurance (either private or governmental) compared with approximately 25% when B.J.C. visited, and those with governmental insurance are beginning to have sports-related surgeries covered. Patient payments are sufficient to fund day-to-day operations at the hospital, but AIC-CURE IHK relies on monetary and equipment donations to mitigate costs to patients and fund capital improvements.

Another challenge is that AIC-CURE IHK uses paper record keeping, which limits the ability to assess outcomes, perform research, and improve the quality of care. F.M. and

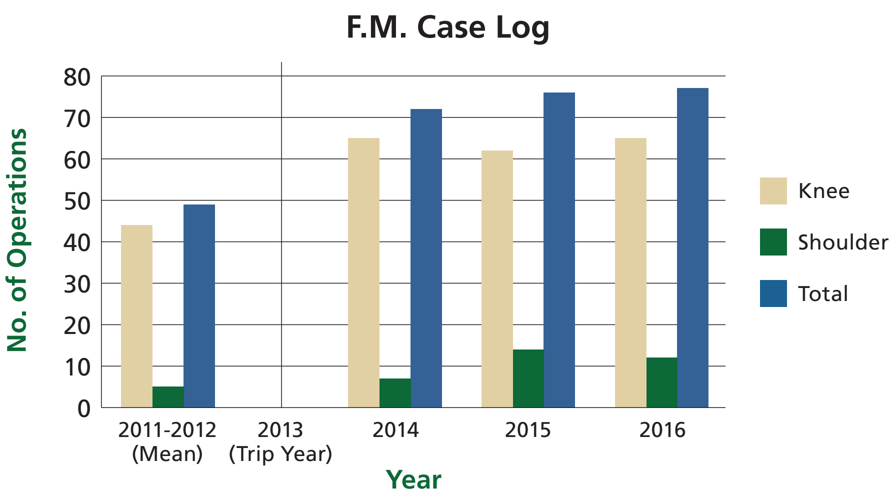

Figure 6. F.M. case log summary before and after the trip. We determined the mean number of operations from 2011 to 2012 by averaging 2-year case review data from those years because annual case review data were not available. We excluded data from the year of the trip, 2013.

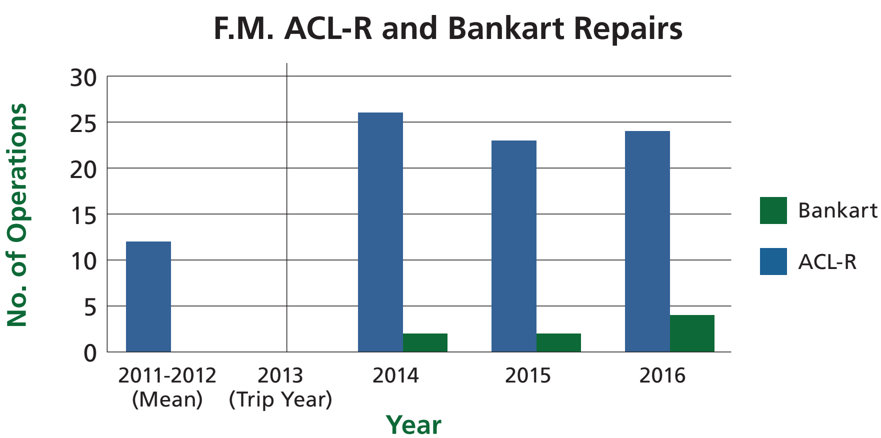

Figure 7. F.M. case log breakdown for anterior cruciate ligament reconstruction (ACL-R) and Bankart repairs. We determined the mean number of operations from 2011 to 2012 by averaging 2-year case review data from those years because annual case review data were not available. We excluded data from the year of the trip, 2013.

his colleagues hope to implement an electronic health record, but they do not have the experience to accomplish the transition alone and actively are seeking outside expertise. Ultimately, although trips such as the 1 described are important to introduce advanced techniques and provide valuable equipment, development of the health care system relies on continued investments in medical infrastructure and the efforts of local health care providers.

There is a recent development that has the potential to reshape the health care landscape in Kenya. Since early December 2016, the physicians in Kenya's public hospitals have been on strike because of deteriorating conditions, government corruption disrupting funding, low salaries, and a lack of foreseeable improvement in staffing and infrastructure. As a result, the public hospitals—which care for approximately 90% of Kenyans—have been shut down almost completely.

Faith-based and private hospitals, such as AIC-CURE IHK, have been burdened with high patient volumes, and there has been a loss of health care coverage in many rural settings that has caused many deaths.

CONCLUSIONS

There is no substitute for hands-on instruction in surgical training. However, knowledgeable experts are scarce in low-resource settings, and trainees from LMICs looking to expand their skill sets and earning potential traditionally have traveled internationally to more medically developed areas. However, this migration of promising trainees outside of their countries can stunt developing health care systems. International volunteerism offers an opportunity to introduce advanced techniques to surgeons within their home countries to enable them to expand their own practices and to educate the next generation of surgeons.

Education-centered missions can strengthen the medical infrastructure of developing nations, teach advanced procedures to otherwise accomplished surgeons, and establish a collaborative network that allows the developing country to continue an exchange of ideas and decision making long after the traveling providers have left. By providing these established, motivated individuals with high-level surgical training and critical equipment and establishing an ongoing dialogue, it is possible to instigate grass-roots level development of previously neglected areas within existing health care systems. ✣

References and financial disclosures are available online at www.rush.edu/orthopedicsjournal.

"This trip has become a highlight for the residents, and the effect of these outreach efforts on both the community and the physicians is considerable."

Rush Orthopedic Surgery Outreach to the Dominican Republic

ROBERT A. SERSHON, MD / MICK P. KELLY, MD / MONICA KOGAN, MD

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INTRODUCTION

In 2005, a group of volunteers in various clinical specialties at Rush University Medical Center formed a partnership with the community of Peralta, Azua Province, Dominican Republic. In 2010, the group formed a similar relationship with several communities in urban and suburban Port-au-Prince, Haiti. The intent was to provide personnel, supplies, medications, training, and encouragement to help these communities become empowered and positioned to offer independent and sustainable care.

Currently, groups from Rush make 8 to 10 trips a year, providing services in primary care; general surgery; urology; urogynecology; otorhinolaryngology and plastics. Teams comprise attending staff, residents, medical students, pharmacists, physical therapists, nurse practitioners, physician's assistants, psychotherapists, nurses, and support staff.

In addition to clinical work, volunteers from Rush have been involved in the development of water purification and distribution in Peralta, revenue from which supports operations in our partner clinic.

The program has grown over the past 8 years to include more than 100 participants annually. A volunteer board governs the program, with funding primarily through outside philanthropic support, including an annual art benefit. Rush's Office of Global Health, which was formed in 2014, assists with administration and development and provides formal institutional support and structure around global health education and research. Community Empowerment, a US-based nonprofit organization, supports the relationship between the Rush volunteers and the local communities through infrastructure logistics and program development. This organization provides valuable insight into the cultural aspects and relationship development that are critical to the success of the program.

THE ORTHOPEDICS OUTREACH PROGRAM

Until 2014, the Office of Global Health did not have an orthopedic surgery mission trip. Although there was a tremendous need for orthopedic surgeons, the challenge had been the lack of implants at local hospitals. In 2012, as a third-year resident, William Slikker, MD, paired with the Office of Global Health and began organizing a trip for orthopedic surgery. In 2014, fifth-year residents Slikker and David Walton, MD, second-year resident Robert A. Sershon, MD, and an attending physician went on the first orthopedic trip to Peralta. Currently, the trip is part of the orthopedics residency program, and Monica Kogan, MD, who serves as program director, recruits 5-6 residents for each annual trip in January.

That first year, the orthopedics team traveled to Peralta with a urology team and completed only surgeries requiring minimal implants due to extremely limited resources. However, the group operated on more than 20 patients and helped start the orthopedic presence in this underserved area. In 2016, Kogan and 5 residents returned on the first solo orthopedic trip. They performed surgeries at Taiwan Hospital in the city of Azua.

LOCAL CONCERNS

Taiwan Hospital was built in 2005 with cooperation from the Taiwanese government. There are 2 private orthopedic surgeons, Dr Roa, chief of orthopedic surgery; and Dr Beltran. However, the local surgeons are unable to treat patients who cannot afford to pay for the services and implants. The presence of these surgeons led the Office of Global Health to believe that Taiwan

Figure 1. Cleaned orthopedic surgical instruments prior to sterilization.

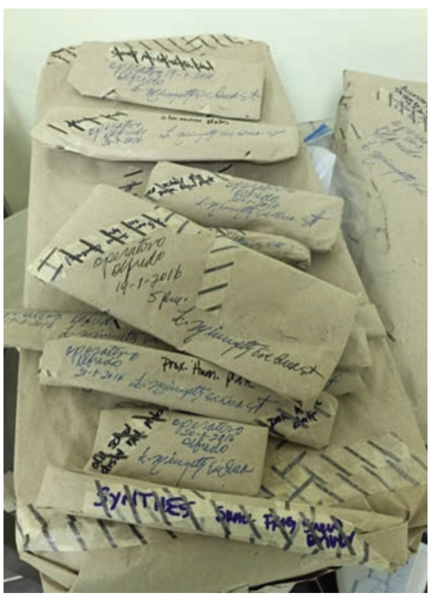

Figure 2. Orthopedic surgical instrument set packs are labeled, then sterilized.

Figure 3. The central supplies area, including sterilized orthopedic surgical instruments.

Hospital had good resources to accommodate orthopedic surgeries.

Community Empowerment's translator helped with the language challenges, but on the 2016 trip, internist Stephanie Crane, MD, the orthopedic attending physician, and one resident spoke Spanish fluently.

Due to the unrest in the Dominican Republic, the safety and security of the team also presented concerns. During one of the trips prior to 2014, a medical team with the Office of Global Health had to be evacuated emergently from the Dominican Republic, and the Rush team had a security guard with them at all times.

SUPPLIES AND RESOURCES

The orthopedic team brought all supplies (sutures, gowns, gloves, dressings, implants, scalpels, Esmarch bandages, iodine surgical solution, hand sanitizer), as well as anything that was going to be discarded from the Rush surgical suites (unused towels, unused gowns, drapes, gloves, surgical sponges, laparotomy sponges). They used everything.

The team had applied for grants from major implant companies; however, none were able to provide any implants or supplies. Synthes, however, donated a small fragment set to an attending physician who had made the trip previously. This was stored at the hospital.

There were no orthopedic surgical instrument sets, and the team spent a day creating a system to make efficient use of what they had. At the end of each day, they grouped the instruments needed for the first procedure of the next day in an orthopedic surgical pack.

The team sterilized instruments twice a day, which required an hour. They cleaned and grouped the instruments (Figure 1), wrapped them in 4 layers of paper, and then put them in the sterilizer. All the packs came out wet, and the paper was often ripped. Once the instruments had been sterilized, the team marked them with black lines (Figure 2) and put them in the central supplies area (Figure 3). Because the team could not sterilize the Esmarch bandages, they soaked them in chlorhexidine gluconate solution.

When in surgery, the team used Esmarch bandages as tourniquets, there was no electrocautery and no way to obtain intra-operative imaging. The hospital lacked air conditioning. The team also served as housekeeping staff (Figure 4). There was no overhead lighting, so the team used standard floor lamps (Figure 5). Drills and retractors were very difficult to find. The local orthopedic surgeons loaned the team very old power drills, which were plugged into wall outlets with extension cords.

All patients admitted to the Taiwan Hospital in Azua needed to bring their own sheets, food, and medications, unless they were able to pay cash. Family members slept next to them on the floor and provided postoperative care. Postoperative pain medication was limited to acetaminophen or ibuprofen, regardless of the extent of the procedure, and the patients never complained. The Office of Global Health provided the acetaminophen and ibuprofen to give to the patients treated on the trip.

Each hospital room has 10 beds with 1 bathroom. Nurses were scarce. Dr Crane, who runs the Office of Global Health, addressed common postoperative medical issues (pain control, nausea and vomiting from pain medication, etc). She, along with the partners of Community Empowerment, also dealt with many of the social issues patients faced, including transportation back to villages, and how to earn an income while physically restricted due to injury.

Figure 5. Operating room. Residents Robert A. Sershon, MD, (left) and Michael Hellman, MD, (right) operate using a standard floor lamp as the primary source of light.

PATIENTS AND SURGERIES

On arriving, the team was met by 120 patients who had been waiting with the hope of being treated. Many of the patients had fracture malunions. Others had years-old indolent chronic infections from previously treated fractures with nonunions (Figure 6). There was no shortage of cases, but because of the lack of resources, the team was not able to treat patients whom they easily could have treated in the United States. It was very difficult for the surgeons to tell a person that the team could not operate because of the lack of resources.

Figure 4. Michael Hellman, MD, cleans up after an operation. There was no housekeeping or air conditioning.

Local anesthesiologists preferred to administer regional blocks, and the team performed surgeries under these conditions. If the regional block ran out, the anesthesiologists resorted to general anesthesia.

The team performed the following surgeries: both bone forearm fracture malunions (n = 6); tibial fracture malunion (n = 3); tibial plateau fracture (n = 1); midshaft humeral amputation (n = 1); toe amputation (n = 1); removal of infected hardware (n = 4); femoral neck fracture (n = 1); femoral fracture malunion (n = 2); humeral shaft fracture malunion (n = 1); and irrigation, debridement, and removal of hardware (n = 4). This past year the team performed 31 procedures, often observed by the local orthopedic surgeons (Figure 7).

Another orthopedic surgeon who travels to Azua with the Office of Global Health follows up the patients on whom the Rush team operated. The Rush team, in turn, will follow up on his patients when we come back to Azua.

FUNDING

The Office of Global Health funds all of the team's expenses while in the Dominican Republic. The residents are typically responsible for only the cost of airfare. In 2017, thanks to the incredible generosity of many attending physicians at Midwest Orthopaedics at Rush, the residents had no costs associated with the trip.

After returning from the trip in 2016, the team submitted grants for implants and secured a large fragment set from Synthes for the 2017 trip through the Surgical Implants Generation Network (SIGN). This international nongovernmental organization provides orthopedics implants to hospital systems in developing countries, provided that the receiving institution set up a reporting system and an oversight board. In addition to the implants, the group also secured some older power drills that were not being used anymore.

CONCLUSIONS

There are many mission organizations, but working with the Office of Global Health has allowed continuity of care. Although the conditions may be less ideal than in some other medical mission programs and hospitals, the team feels that each year it will continue to increase the ability to treat patients.

This trip has become a highlight for the residents, and the effect of these outreach efforts on both the community and the physicians is considerable. Most important, the group provides high-quality orthopedic care to an underserved population. The benefits the team receives are equal to or greater than those the patients and their families receive. The work reminds the Rush team how fortunate they are to be medical professionals and provide care for these people. And, finally, the experience strengthens the camaraderie between residents and builds lifelong friendships and memories. The group eagerly looks forward to expanding this program.

In an interview on page 69, Robert A. Sershon, MD, and Mick P. Kelly, MD, share their personal experiences, and discuss the challenges and rewards of the department's orthopedic mission trips. ✣

There are no references for this article. The authors' personal disclosure information can be accessed through the AAOS Orthopedic Disclosure Program at www.aaos.org.

Figure 6. Radiograph of a patient's left tibia illustrates the result of delay of care: a chronic infected nonunion of the tibia with severe bone loss.

Figure 7. Local surgeon observing operation. Michael Hellman, MD, (left), Robert A. Sershon, MD, (center), Dr Roa (right).

"The polyvinyl chloride (PVC) traction frame provides a safe, locally sourced, cost-effective measure to bridge the gap between injury and surgical fixation."

A Novel Traction Frame for Femur Fracture Management in Developing Countries

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INTRODUCTION

Fractures of the femur—most frequently caused by road traffic accidents—have long been a major cause of morbidity and mortality in developing countries. In World War I, mortality from femur fractures was improved with the Thomas traction splint, originally designed by Welsh orthopedist Hugh Owen Thomas for treatment of tuberculosis affecting the knee. This setup consisted of metal rings around the groin and ankle connected by metal rods, and traction was applied through tensioning leather strips that supported the leg over a crossbar.[1] In World War II, German orthopedist Gerhard Küntscher treated fractures sustained by German soldiers and captured pilots by using intramedullary nailing.[2] After multiple refinements of the original implants and technique, intramedullary nail fixation has become the standard of care for diaphyseal fractures of the femur. However, modern techniques require proper implants, access to imaging, and accessible operating room facilities, all of which are of limited availability in the developing world.[3] Improved technology, such as the Surgical Implant Generation Network nail, has been developed to address orthopedic trauma in nations with limited funds or access to radiography. However, obstacles such as inadequate sterility, lack of skilled operating room personnel, and lack of electricity continue to limit access to definitive fixation.[4]

Delayed care of femur fractures results in malunion, stiffness, wound complications, and infection risk[5]; however, these complications can be minimized with effective and immediate traction. Furthermore, timely traction application facilitates intraoperative reduction in the setting of delayed surgical care. Although effective, overhead traction apparatuses require equipment that is challenging to transport, is expensive, and is made of relatively inaccessible materials.[1]

Over the past 40 years, the senior author (D.J.G.) has provided orthopedic care under circumstances that called for innovation. In the 1970s in Vietnam, the only means of traction available were applied straight over the foot of the bed, leading to inadequate fracture reduction. In conjunction with the organization CARE Medico (now Orthopaedics Overseas) in Uganda and Bangladesh, his team created balanced traction suspension from overhead frames. Stimulated by necessity, he incorporated homemade hinges into cast braces as part of Neufeld traction. This method consists of traction applied through a hinged cast brace by using a single rope suspended from a roller on an overhead beam. This roller traction technique was used extensively in the Dominican Republic, permitting early mobilization and excellent results.[6]

As intramedullary nailing gained popularity, the availability of overhead traction beds diminished in orthopedic wards throughout the world. However, developing nations were unable to augment operating facilities to compensate for the scarcity of formal traction equipment. Thus, the senior author devised a traction frame for management of femur fractures that is made locally from polyvinyl chloride (PVC). A modification of the Bohler-Braun frame,[7] this apparatus permits traction for femur fractures for long intervals. As reported here, the senior author has used the PVC frame in the Dominican Republic and Haiti, and it has applicability elsewhere in the developing world.

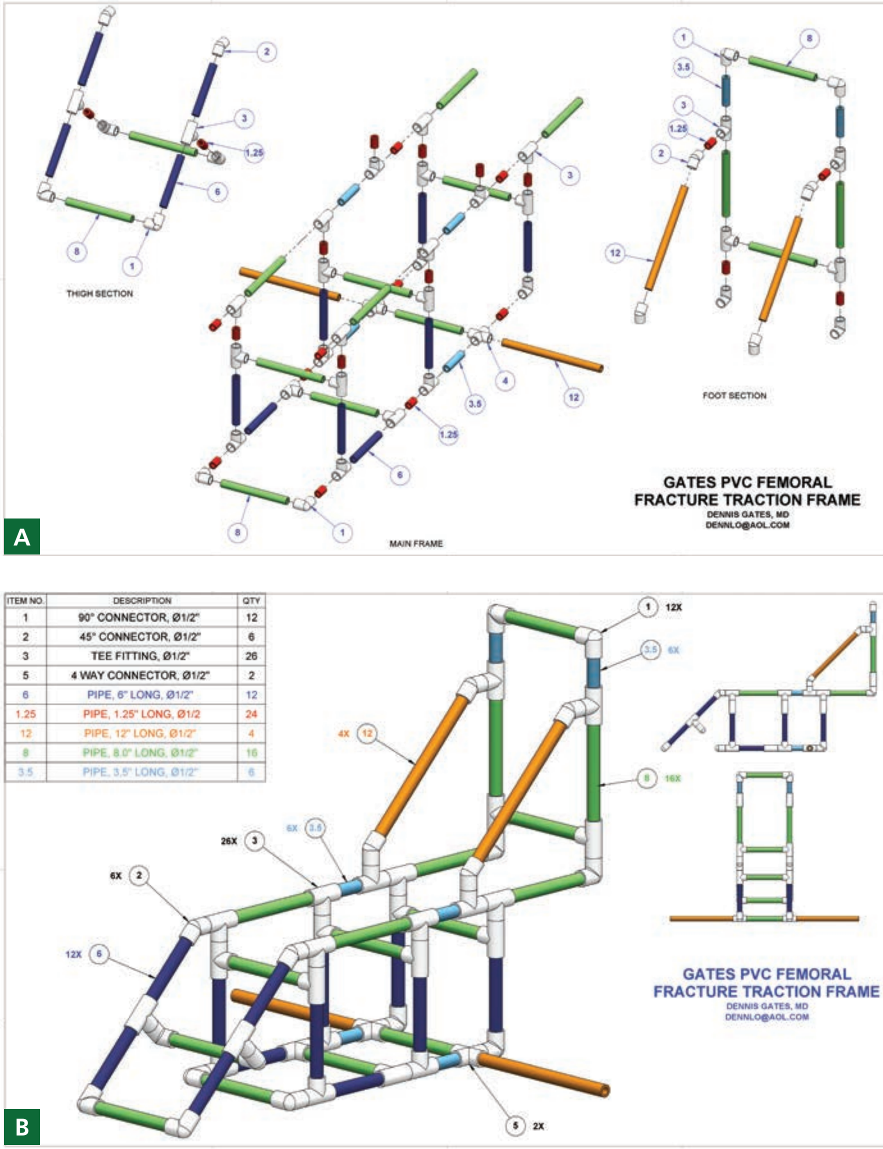

Figure 1. Frame Setup.

Table 1. Materials Required for Frame Setup

Items for Purchase	Quantity
PVC pipe (1/2 inch), cut at the following lengths: 3.5 inches—6 pieces; 6 inches—10 pieces; 8 inches—12 pieces; 12 inches—4 pieces; 1.25 inch—24 pieces	30 feet*
T-angled connectors	26
90° connectors	12
45° angled connectors	6
4-way angled connectors	2
1/2-inch self-tapping sheet metal screws or duct tape	120
1/8-inch smooth nylon rope	6 feet
4-inch elastic bandage	3
Weights (3-gallon water bottles or other weights)	NA
Additional Equipment	
PVC pipe cutter or saw; pliers; hammer; ruler; marking pen	

*PVC is sold in 10-foot lengths; based on the quantity required to build the frame, there will be leftover pipe.

MATERIALS AND METHODS

The PVC femoral fracture traction frame is a simple traction frame made of PVC piping to elevate, align, maintain length, and provide friction-free traction. PVC is an inexpensive material locally available in all developing countries. This frame is easy to assemble and can be made by residents or any available carpenter or craftsman. The parts must be fixed at each joint with a small screw, duct tape, or glue.

Materials required for the frame include 30 feet of half-inch PVC pipe; smooth angled connectors; screws, tape, or cement; rope; and weights for traction (Table 1). The typical cost of the materials is approximately $35. In addition, pliers, a hammer, and a PVC pipe cutter or saw are necessary to create appropriately sized pieces. Once the PVC pipe is cut in appropriate lengths, it is important to label the lengths of each piece or color-code the pieces with marker. The frame is assembled in 3 parts: thigh support, base frame, and foot support tower (Figure 1). After each section is assembled, they are joined together to complete the frame (Figure 2A). The connection must be secured with PVC glue, screws or duct tape. PVC cement is not recommended because it hardens quickly and has a high rate of fixation failure. The traction rope is centered over the foot tower by using 2 screws or a pulley.

For support, an elastic compression bandage is wrapped circumferentially around the thigh support and main portion of the frame. Traction is applied through a tibial pin by using 20 to 30 pounds for length (Figures 2B and 2C). Water bottles may be used as weights, with 1 gallon of water providing approximately 8 pounds of traction. The leg should be checked for proper alignment and length at least daily by comparison of the position of the patella with that of the contralateral leg. Traction must be in line with the femur and should be maintained during transfer to the operating room.

Figure 2. Traction Frame. **A,** Traction frame before wrapping. **B,** Traction frame wrapped with elastic bandage for leg support. **C,** Traction frame with a patient (left) and Dennis J. Gates, MD (right).

DISCUSSION

Orthopedic injuries account for a growing proportion of global morbidity and mortality, particularly in developing countries.[3] The incidence of musculoskeletal injury in low-income nations has been estimated at 1000 to 2600 per 100 000 persons from 1990 to 2010,[8] with femur fractures constituting 17% of these injuries.[9] Untreated femur fractures lead to a high degree of patient morbidity, carrying a disability weight higher than that of malaria or tuberculosis.[10] Although intramedullary nailing is the standard for treating diaphyseal femur fractures, both cost and patient-related barriers may limit access to timely surgical intervention in developing nations. Thus, strategies to maintain effective traction are paramount to facilitate fracture reduction at the time of eventual surgery or to ensure proper alignment in cases of nonoperative management.[10] The PVC traction frame is a simple, cost-effective system that allows for adequate traction in settings with limited resources.

In 1985, Gates and colleagues[6] reported outcomes in 11 patients with femur fractures treated with the previously described Neufeld traction method of a hinged cast and roller traction. In their series, all but 1 fracture united in appropriate alignment without complication. However, this method requires a bed setup and resources that are difficult to obtain. Although the Surgical Implant Generation Network nail has improved overall access to surgical fixation in the developing world,[11,12] prolonged surgical delays remain a challenge. As a result, this frame was developed as an affordable, accessible, and reliable method that requires minimal setup and training.

Achieving acceptable outcomes in low-resource settings is challenging regardless of treatment; however, the literature demonstrates a particularly high complication rate associated with prolonged, inadequate traction. In their systematic review of femoral shaft fractures treated with traction, Kramer and colleagues[10] described the results of 9 studies with a total of 455 patients in a variety of clinical settings. The mean time spent in traction was 52.8 days, with a mean time to partial weight bearing of 52.2 days. Overall, they reported 221 complications in 455 patients, with 25 nonunions (5%), 91 malunions (20%), 60 infections (13%), and 45 other complications (10%). Although the authors did not specify the techniques of skeletal traction in each study, it is likely that many of the included patients were subjected to ineffective traction setups. Not surprisingly, results of studies of outcomes of femur fractures treated with intramedullary nailing in low-income countries demonstrate lower complication rates, indicating that surgical fixation remains preferable to prolonged traction in developing nations.[11,13] However, despite these data, a lack of funding and implant availability limit access to surgical fixation in low-resource nations. Practically speaking, a patient is given a prescription to purchase an intramedullary rod or a plate and screws, and until the patient can raise the necessary funds, he or she may lie in bed for weeks or months. Thus, it is important to emphasize safe and effective traction to manage delays in surgical care.

The PVC traction frame provides a safe, locally sourced, cost-effective measure to bridge the gap between injury and surgical fixation. Furthermore, the frame can serve as a definitive management strategy when access to surgical care is not feasible. The frame has been used with success in the Dominican Republic and Haiti and would be effective in developing nations worldwide. With increasing awareness about global health issues, particularly in the field of orthopedic trauma, further innovations in low-cost technology will improve delivery and outcomes of orthopedic care in developing nations.

CONCLUSIONS

The complications of delayed surgery for femur fractures in developing countries can be overcome by using a modern modification of an old technique. The PVC femoral fracture traction frame is a modification of the old Bohler-Braun frame. PVC piping and connectors are available at low cost in every developing country in the world. An orthopedic surgeon or craftsman can construct the PVC traction frame easily by using the simple drawings contained in this article. (More detailed instructions are available without cost by contacting the author or online at www.rush.edu/orthopedicsjournal.)

In a feature on page 66, Dennis J. Gates shares memories from more than 5 decades of international medical missions, as well as his experiences as a civilian physician providing care for troops during the Vietnam War. ✣

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"The advantages of 3D printing lie not only in enabling the surgical team to conduct thorough preoperative analysis and planning but also in the teaching and training aspects of surgical practice."

Use of a 3-Dimensionally Printed Anatomic Model for Surgical Correction of a Supracondylar Humerus Fracture Malunion

A Case Report

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INTRODUCTION

Three-dimensional (3D) printing, an emerging technology with applications in all industrial sectors, has experienced tremendous growth in the past decade.[1] In clinical medicine, there are 3 main areas in which it can provide enormous advantages to users: producing medical models for teaching, training, and surgical planning; making surgical tools such as guides; and printing subject-specific implants and prostheses. The latter is a federally regulated activity that belongs to the realm of established medical implant manufacturers,[2] so at Rush University Medical Center, we are introducing the capability to work on the first 2 areas.

Three-dimensional printing is becoming more popular in the medical field for creating anatomical models to assist in complex surgical procedures. The medical field first began to use 3D printing at the turn of the 21st century.[3-12] However, the high cost of owning and running a 3D printer constituted an insurmountable barrier to its daily use in a clinical setting. Therefore, instead of being a readily accessible tool, it typically was seen as an oddity. In the past 5 years, key developments in the software necessary to process the raw image data sourced from clinical computed tomography or magnetic resonance imaging, as well as innovations in the printing technology itself, have lowered these once onerous costs and made 3D printing more accessible to the general population. A sizable movement currently seeks to disseminate and promote this technology, with the goals of increasing its popularity and use, improving patients' lives, and giving clinicians a new tool to make better treatment decisions and plans.[13-32] In this case study, we present early in-house experiences with this innovative technology.

CLINICAL BACKGROUND

Supracondylar humerus fractures most commonly occur in the pediatric population and account for approximately 15% of all pediatric fractures.[33] The mechanism of injury often involves a fall on an outstretched arm, which places a hyperextension load on the arm and typically causes posterior displacement of the distal fragment. Supracondylar fractures are classified according to the Gartland classification into types I, II, and III, on the basis of the original description, with some authors adding a type IV.[34] In most cases, doctors treat displaced fractures with closed reduction and percutaneous fixation with pins. Even with attempts at reduction and internal fixation, the potential exists for malunion, ranging from minor cosmetic abnormalities to major deformities with loss of functional use of the arm.

In this case, the patient was 14 years old at the time of injury and sustained a high-energy type III supracondylar fracture. He underwent immediate open reduction and internal pin fixation, followed by removal of the hardware 6 months after surgical treatment. He developed a malunion in the coronal, sagittal, and axial planes with

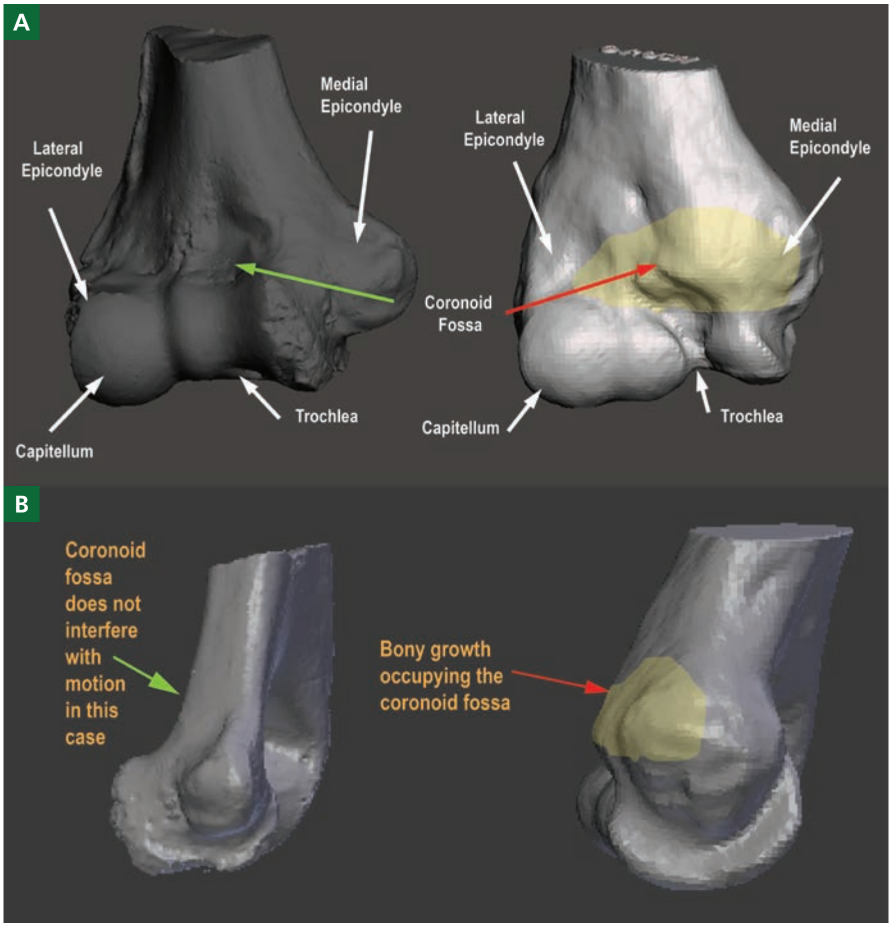

Figure 1. Anterior Distal Humerus Anatomy. Side-by-side comparison of normal (left) and present-case (right) anatomy. **A,** Coronal images showing differences in the medial epicondyle and the capitellum-trochlea regions of the distal humerus. Most important to regaining range of motion were changes in the coronoid fossa, indicated by the red and green arrows. **B,** Sagittal images. Shaded region shows the protrusion where the coronoid fossa should have been located.

articular involvement (Figure 1). During the adolescent growth spurt, the malunion caused a bony growth deformity in the medial epicondyle and the capitellum-trochlea region of the distal humerus. The deformity worsened, resulting in profoundly limited elbow mobility, with range of motion limited to 5° to 95°. Because of the loss of elbow flexion, the patient was unable to use his arm for self-care, feeding, and daily activities.

The patient presented to our clinic 2 years after injury with hopes of regaining elbow flexion and functional use of his dominant arm. The patient's articular segment was posterior to its normal axis. In this configuration, impingement between the coronoid and the displaced anterior humeral cortex blocked flexion (Figure 1). The initial procedure we recommended was a correctional 3D osteotomy of the humerus, with the goal of realigning the resultant articular surface with the distal humeral shaft. This procedure would have required lengthy surgery, with double plate fixation and possibly an autograft. The procedure presented the possibility of considerable morbidity and inherent risks. With all these clinical considerations in mind, we decided to use 3D-printed, patient-specific anatomical models to aid in preoperative planning and help illustrate the surgical procedure for the patient's family.

MATERIALS AND METHODS

To aid in preoperative planning, we obtained a CT scan of the patient's elbow (Figure 2A) and used the raw data to create 3D printed models of the humerus, ulna, and radius (Figure 2B). We segmented the clinical CT images by using Mimics Innovation Suite19 (Materialise, Leuven, Belgium), a commercially available segmentation software, and used it to convert the resulting 3D models to .STL format. Then we further refined the models in Meshmixer 3.0 (Autodesk, San Rafael, California), enabling us to emboss patient case numbers and smooth the outside surfaces. We then printed the parts at a 1:1 scale in a stereolithography 3D printer (Full Spectrum Laser, Pegasus Touch, Las Vegas, Nevada) by using proprietary gray photocurable resin (Full Spectrum Laser) at an isotropic resolution of 50 µ with no hollow cavity. We chose solid parts because they allowed us to prepare cuts and simulate placement of any orthopedic screws and plates on the anatomical model before the actual surgery.

The 3D models were essential in understanding the highly complex rotational and angular deformity of the elbow. By using these, we determined the difficulty in completing the original surgical plan. In closely studying the models, we learned that we could restore elbow motion simply by sculpting out the bony overgrowth and prominence of the distal humerus above the articular surface to restore the coronoid fossa. To evaluate this option, we used a high-speed surgical burr to create a concavity on the model, which helped us confirm our theory, thereby simplifying the entire operative procedure.

The model allowed the surgeon (M.S.C.) to replicate the sculpting of the patient's actual humerus (Figure 3). We could measure the amount of expected elbow motion accurately. Because it was not a planar image, the 3D model allowed us to manipulate, visualize, and implement properly the changes required to improve elbow motion.

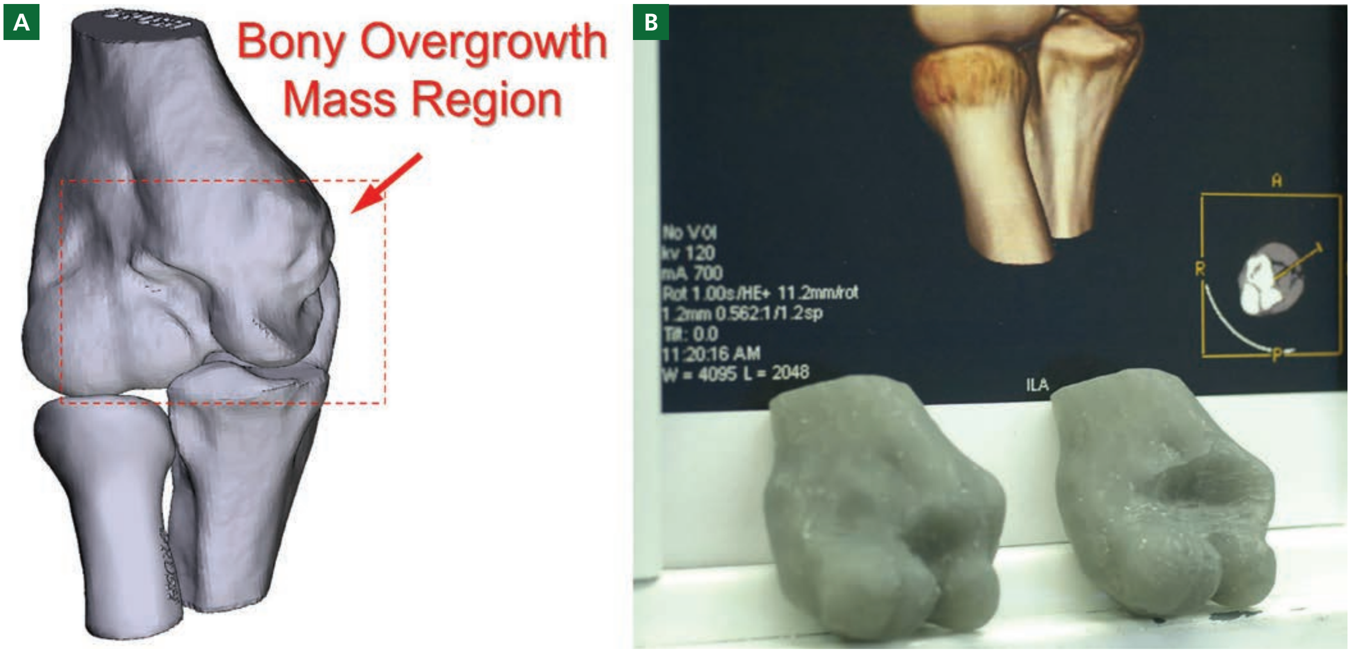

Figure 2. **A,** Three-dimensional (3D) assembly view of the segmented model. **B,** The control (left) and practice (right) models in the operating room in front the 3D rendering, for reference during the procedure.

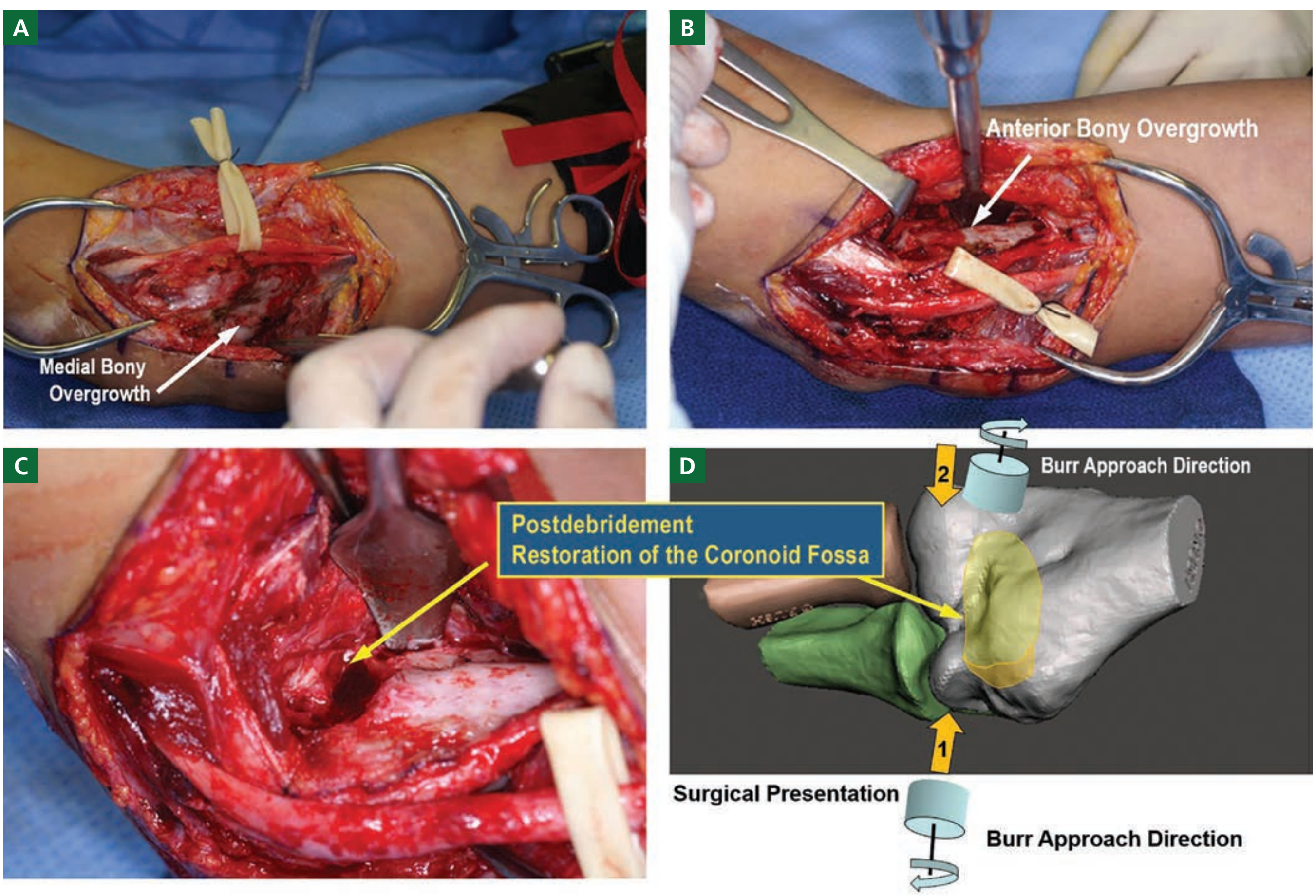

Figure 3. Surgical Approach. Visualization of the bony overgrowth from **A,** the medial aspect and **B,** the anterior aspect. **C,** Intraoperative image showing the debrided location representing the restoration of the coronoid fossa. **D,** Schematic showing the position of the burr to restore the coronoid fossa.

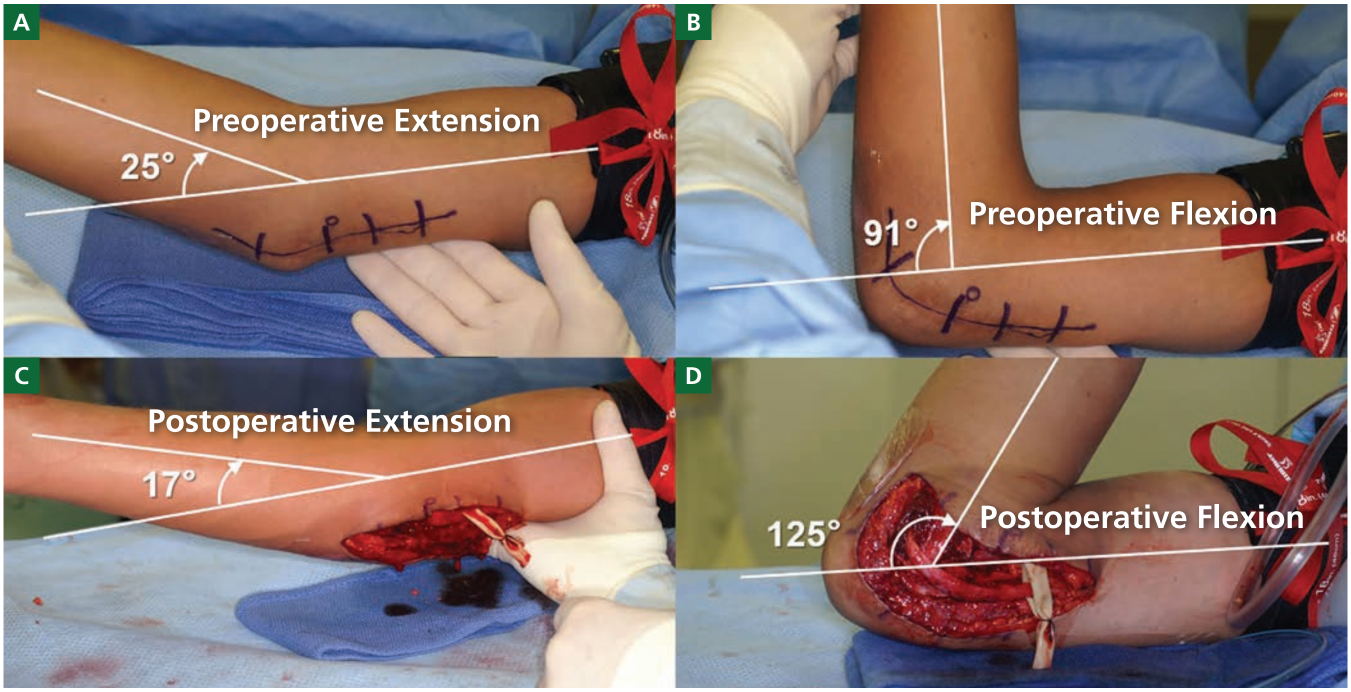

Figure 4. Surgical Outcome. This preoperative (**A, B**) vs postoperative (**C, D**) intraoperative comparison of the patient's elbow shows marked improvement in the range of motion provided by the surgical intervention. The total arc of motion went from 66° preoperatively to 108° postoperatively.

Figure 2B shows the 2 printed models side by side, evidencing the large size variation at the malunion site. After we completed sculpting the model, we used an optical laser scanner (2020i; NextEngine, Santa Monica, California) to compute the volume of bony overgrowth. By performing a Boolean subtraction of the practice model from the intact model, we determined that the debrided bone constituted a volume of 6.6 cm^3. Figure 4 shows that the intraoperative range of motion had returned to almost normal.

SURGICAL PRESENTATION AND APPROACH

As noted, our use of the 3D model clarified that a complex 3D osteotomy was not necessary, so we performed a simple elbow release and debridement by using a medial approach to the elbow. We dissected out and protected the ulnar nerve and reflected anteriorly the anterior aspect of the flexor-pronator origin to expose the anterior joint cartilage and the bony deformity. We then used a conical burr to sculpt out a fossa to accept the coronoid process and the radial head during flexion. We sequentially removed bone on the table as motion improved until we achieved what the model had predicted. This approach resulted in an operative time less than 2 hours and permitted unprotected rehabilitation. The models were essential intraoperatively, helping guide the surgeons in determining the area and amount of bone that needed to be removed to recover elbow mobility.

At the time of surgery, the patient achieved the degree of flexion the 3D model predicted. Based on the model, the elbow would flex to approximately 125°; intraoperatively, we gained approximately 125° to 130° of flexion. The patient participated in 4 months of postoperative rehabilitation, including use of a continuous passive motion machine, static progressive splint for flexion, and occupational therapy. At 5 months postoperatively, the patient's range of motion spanned from 10° to 125°.

DISCUSSION

Examining the 3D printed model of this patient's elbow changed the recommended surgical procedure from one that would take a full day of surgery and up to a year of recovery to a 2-hour procedure with 4 months of rehabilitation. The model was essential in establishing the most appropriate procedure for this patient. Cases like this illustrate that 3D printing not only can be used efficiently during the surgical planning stage and intraoperative process but also can offer insights that save both time and resources by providing patients with better options for quicker times for recovery and return to function.

CONCLUSIONS

The advantages of 3D printing lie not only in enabling the surgical team to conduct thorough preoperative analysis and planning but also in the teaching and training aspects of surgical practice. When teaching hospitals accrue data and create 3D models of complex and rare cases such as this one, future surgeons and clinicians gain exposure to these situations and can receive hands-on training, rather than just reading about these oddities in a journal article. In summary, 3D printing is a new technology with enormous potential to improve care and help with case management decisions and is part of the future of orthopedics. ✣

References and financial disclosures are available online at www.rush.edu/orthopedicsjournal.

"When used as a coagulation and cutting tool, cold plasma is particularly useful for large open operations that are associated with clinically significant blood loss."

New Technology in Orthopedic Oncology

Preliminary Experience With a Hybrid Cold Plasma Surgical Tool

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INTRODUCTION

Surgeons have been using intraoperative coagulation devices to control bleeding for many years. William T. Bovie, PhD, invented electrocautery, and it remains a viable method. A Bovie can cut and coagulate but does so at a very high temperature—more than 200°F. As a result, it causes substantial tissue necrosis that may be responsible for postoperative complications. In addition, it also poses a minimal fire risk in the operating room because of the use of alcohol-based skin preparations. Plasma, the fourth state of matter, is naturally occurring and seen throughout nature. High-temperature plasma is used for industrial applications, such as welding and metallic surface modifications, but operates at an extremely high temperature.

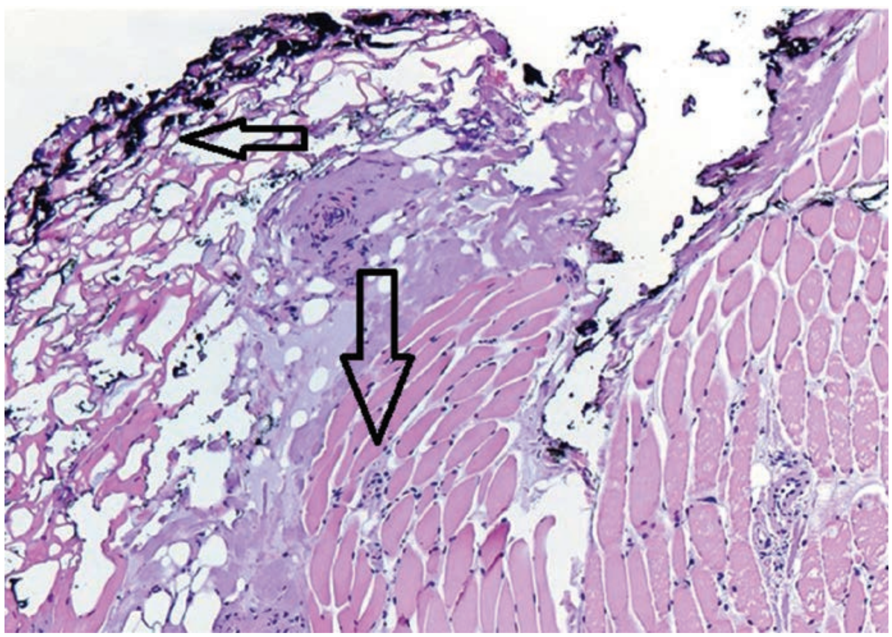

Figure 1. Histological effect of plasma on tumor and underlying muscle (hematoxylin-eosin, original magnification 100×). The upper left arrow indicates the surface effect of the plasma on the necrotic tumor (osteosarcoma after chemotherapy). Note the lack of muscle damage (bottom arrow).

Cold plasma has been developed and now is a useful surgical tool.[1,2] Cold plasma is created by a pressurized inert gas, either argon or helium that is electrified, and it releases ions at high speed but at low temperature. Argon plasma, for instance, operates at body temperature, or 98°F. Helium plasma operates at an even cooler 60°F. These cold-temperature hybrid plasma surgical instruments cut and coagulate simultaneously with limited tissue necrosis (Figure 1). There is also increasing evidence that cold plasma technology will ablate cancer cells at the tumor margin.

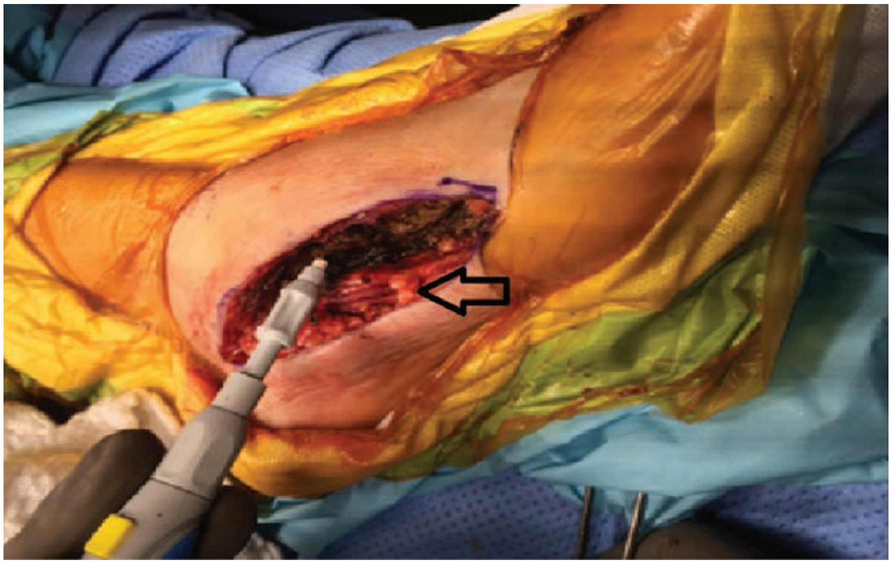

Figure 2. Plasma ablation of the surgical margin of a synovial sarcoma of the foot after tumor resection. Note the proximity of the neurovascular bundle (arrow).

Currently, cold plasma is being used for pancreatic and liver cancer, but there is great interest in using it to ablate sarcoma cells. Residual sarcoma cells can remain at the margin of resection and are responsible for relapse. Clinicians can use cold plasma to ablate these cells at the margin to decrease the risk of local recurrence. The cancer kill is at the surface of the tumor bed but spares the deeper tissues. When used as a coagulation and cutting tool, cold plasma is particularly useful for large open operations that are associated with clinically significant blood loss.[3] Because it simultaneously cuts and coagulates, it saves time switching from a coagulation instrument to a cutting instrument.

In a level 3 clinical trial in which they compared the Hybrid Plasma Scalpel (Canady; US Medical Innovations, Takoma Park, Maryland) to the Aquamantys (Medtronic, Fridley, Minnesota) device, Guild et al[4] reported the blood loss and operative time to be significantly reduced with the cold plasma device. This finding was from a study of direct anterior total hip arthroplasty procedures. Clinicians also can use it in spinal surgery, which tends to be hemorrhagic, with clinically significant blood loss. Those spinal procedures require extensive stripping of muscle off the spine, and clinicians can manage them with the Hybrid Plasma Scalpel to control blood loss effectively.

The Hybrid Plasma Scalpel is particularly useful in orthopedic oncology. Given the large exposures frequently required in this field, this device may assist in minimizing blood loss. Because the scalpel operates at body temperature, the clinician can perform the critical neurovascular dissection needed to remove long segments of bone and soft tissue safely. The plasma can operate in proximity to the neurovascular bundle without harm (Figure 2). In addition, it is effective in killing sarcoma cells (Figures 3A and 3B). When they used it for osteosarcoma of the upper tibia, investigators measured tumor kill in dozens of cell layers and approximately 0.5 mm in thickness. Thus, it may be a useful tool in eradicating microscopic disease at the edges of the tumor dissection that could lead to local recurrence. Animal modeling with a rat chondrosarcoma is currently under way to prove eradication of microscopic disease in the reactive zone around the sarcoma.[5]

CONCLUSIONS

The hybrid cold plasma surgical instrument is a very useful tool in open procedures and is particularly useful for cancer operations. It operates at low temperature and, thus, minimizes the risk of tissue necrosis. It can operate safely around the neurovascular bundle. It simultaneously cuts and coagulates, controlling blood loss and decreasing operative time. Finally, there is increasing evidence that it will be a useful oncological tool to extend margins and minimize the risk of recurrence when treating a sarcoma. ✣

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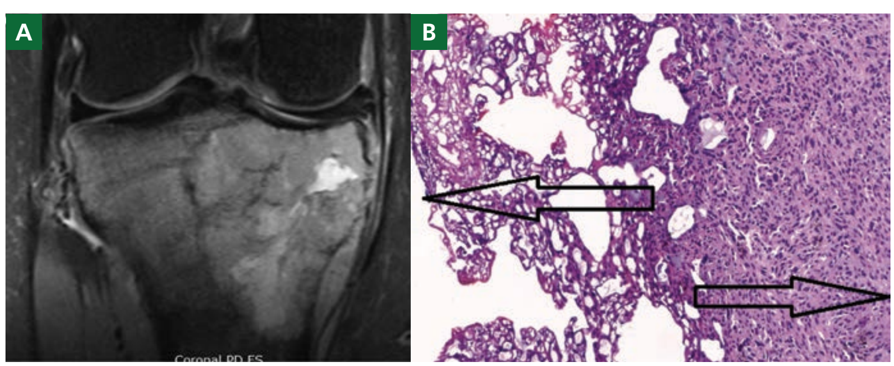

Figure 3. A, Coronal T2-weighted magnetic resonance image shows osteosarcoma of the tibia treated in vitro with argon plasma. **B,** Tibial osteosarcoma surgical specimen (hematoxylin-eosin, original magnification 100×). The depth of cancer kill (left arrow) is approximately 0.5 mm. The right arrow indicates viable tumor after chemotherapy.

"The most isometric region on the lateral femoral condyle does not completely encompass the natural insertion site of the anterior cruciate ligament."

Dynamic 3-Dimensional Mapping of Isometric Anterior Cruciate Ligament Attachment Sites on the Tibia and Femur

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INTRODUCTION

Physicians perform anterior cruciate ligament (ACL) reconstructions with an incidence of 68.6 per 100,000 people per year.[1] Despite the profound knowledge and advancements in reconstruction techniques, the ACL failure rate is as high as 27.3%.[2] Investigators have attributed the cause of ACL failure to a variety of factors, but technical error is a substantial contributor to surgical failure, with the rate of tunnel malposition estimated to be between 22% and 79%.[3] Of these surgical factors, malposition of the femoral tunnel is a common error.[4]

A primary goal of surgical reconstruction is to replicate the native kinematics of the intact ACL as closely as possible. Throughout knee range of motion, the bundles and fibers of the ACL are subject to varying forces.[5] In addition, the intra-articular distances from the medial wall of the lateral femoral condyle (MWLFC) to the tibial plateau vary with knee flexion.[6] A graft placed in a position with significant length changes will be subject to increased forces, which can lead to graft stretching and increase the risk of failure.[7] To decrease the stress on the ACL graft, clinicians should place tunnels in a position with the least amount of length change throughout range of motion.[8] Femoral tunnels placed in the anatomic position more closely restore knee kinematics than do nonanatomically placed tunnels, but anatomic tunnels demonstrate nonisometric properties.[9,10]

Investigators have characterized the load-bearing properties and isometry of the direct and indirect fibers of the ACL. The direct fibers of the ACL, located more anteriorly (higher) within the ACL footprint, bear more force and are more isometric during flexion than are the posterior (lower) indirect fibers.[11] With variable length changes throughout the native ACL footprint, one cannot create a truly anatomic and isometric tunnel position; however, a strategic femoral tunnel position that is the most isometric and the most anatomic should exist.

The objectives of this study were to map the length changes of the whole MWLFC with respect to various points about the tibial ACL footprint and to compare the length changes of 4 areas on the MWLFC throughout the full range of motion by using 3-dimensional (3D) computed tomography (CT) modeling. We hypothesized that an isometric region would be present within the native footprint of the ACL and that 1 of the 4 regions would demonstrate favorable isometry. In addition, we hypothesized that changes in both of the tibial tunnel positions would affect the intra-articular isometry significantly.

MATERIALS AND METHODS

3D CT Knee Models at Various Flexion Angles

We used 6 fresh-frozen cadaveric human knees in this study, obtained from patients with no prior history of arthritis, cancer, surgery, or any ligamentous knee injury. The mean age of the donors for the collected knees was 47 years (range, 26-59). We preserved each knee at −20°C and thawed each for 24 hours before imaging. We obtained CT images (BrightSpeed, GE Healthcare, Chicago) of each knee at various flexion angles in the coronal, axial,

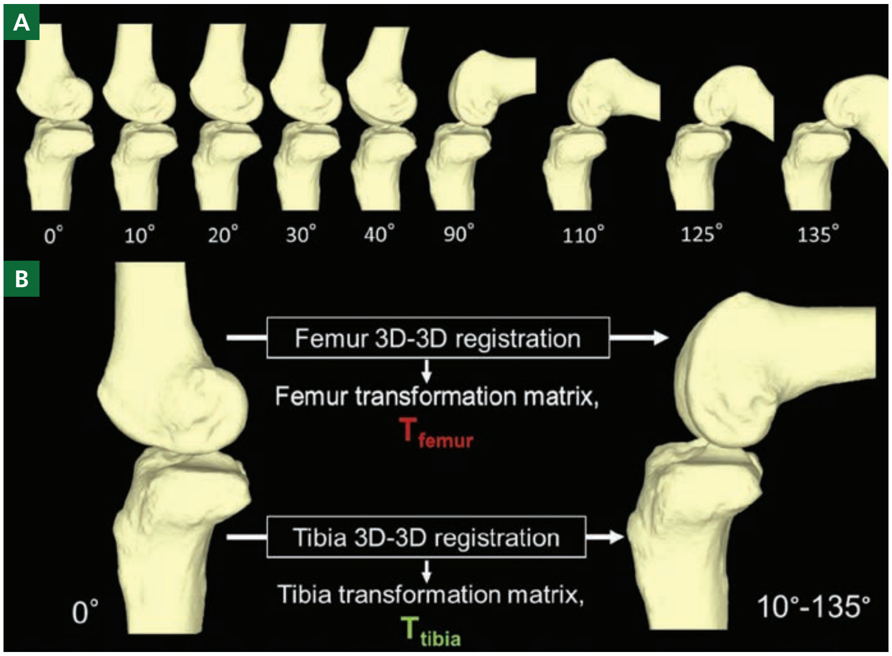

Figure 1. A, Three-dimensional (3D) computed tomography (CT) models in the tested flexion angles. **B,** A representative 3D CT model outlining the 3D-3D registration in preparation for subsequent point matrix incorporation on the femur and tibia.

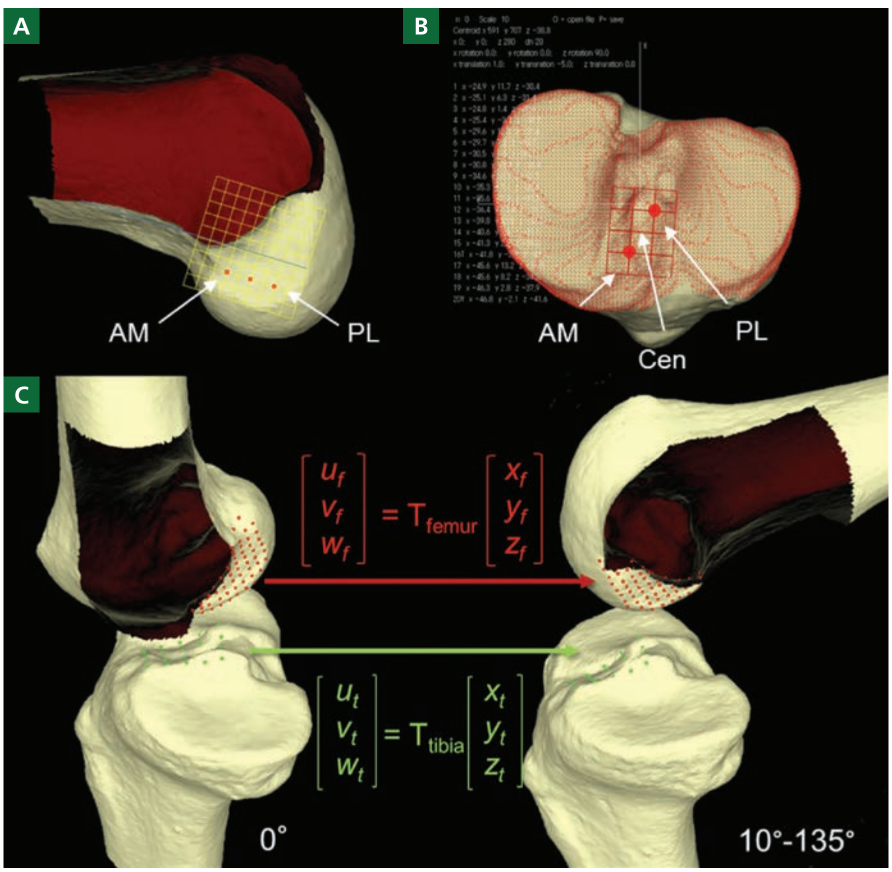

Figure 2. A, Grid placement on the medial wall of the lateral femoral condyle with the anteromedial (AM) bundle center point and posterolateral (PL) bundle center point indicated by dots and arrows. **B,** Tibial grid placement about the AM and PL bundle center points. *Cen* indicates center of tibial footprint. **C,** Matrix transformations on the femur and tibia at 2 flexion angles demonstrate the permanence of the points. u_f, v_f, w_f, refer to femur matrix at 0° flexion. x_f, y_f, z_f, refer to femur matrix at given flexion angle. The points are maintained at these sites on the specimen throughout the range of motion, allowing length calculations for the same sites at all flexion angles.

and sagittal planes by using 0.625-mm contiguous sections, a 20-cm field of view, and a 512 × 512 matrix. Using an external fixation device to ensure consistent flexion, we scanned the knees at 0°, 10°, 20°, 30°, 40°, 90°, 110°, 125°, and 135° of flexion. We took additional care to avoid any rotational torque on the specimens during fixation. We imported the CT images into Digital Imaging and Communications in Medicine format and segmented the images by using 3D reconstruction software (Mimics, Materialise) to generate the 3D knee models (Figure 1). We then converted the 3D CT models to point-cloud models to allow for intra-articular measurements (Figure 2).

Determination of Tibial ACL Insertion Sites

We determined a total of 21 virtual tibial insertion sites on the tibial plateau model at 0° of flexion. We also identified the tibial spine and the medial and lateral intercondylar tubercles, and we used them to determine the locations of the anteromedial (AM) and posterolateral (PL) tibial tunnels according to a double-bundle reconstruction Forsythe et al[12] described. We sized and carefully placed a planar 20-point grid to align the 2 bundle locations with the coordinates of the grid. We set an additional point (tibial center, not shown) at the midpoint of the AM and the PL points (Figure 2). We then sized the grid and oriented it so the tunnel locations corresponded to the same relative coordinates for each sample. We projected the grid on the 3D tibia plateau model, obtaining the 3D coordinates of each insertion point (Figure 2). Using the grids and the 3D-3D registration technique, we calculated transformation matrices from the tibial model at 0° to the tibial models in flexion, and we transformed the ACL insertion points at 0° of flexion to those in the flexed tibial models (Figure 2). This procedure allowed us to create the tibial insertion points in various flexion angles identical to those in 0° of flexion.

Determination of Femoral ACL Insertion Sites

Similar to the way in which we determined the tibial ACL insertion sites, we virtually placed a 100-point grid on the MWLFC in femoral model at 0° of flexion by referring to the lateral intercondylar ridge and the bifurcate ridge. After the surgeon (B.F.) identified these landmarks, we determined the center point of the AM bundle femoral footprint and PL bundle femoral footprint. We then aligned the 100-point grid parallel to the lateral intercondylar ridge, making sure to encompass the center point of the AM and PL bundles (Figure 2). We projected the grid on the 3D lateral femoral condylar model, determining the ACL femoral insertion sites at the grid points on the MWLFC. We set an additional point at the center of the AM and the PL points. We determined a total of 60 to 64 femoral insertion points and obtained the 3D coordinates of each insertion point (Figure 2). As described earlier, we calculated the insertion points in the flexed conditions.

ACL Length Calculation

We calculated the ACL length, L_{ijk}, between the tibial insertion point j and the femoral insertion point k at the femoral flexion angle i as a 3D distance between these 2 points by using the following equation:

$$L_{ijk} = \sqrt{(x_{tij} - x_{fik})^2 + (y_{tij} - y_{fik})^2 + (z_{tij} - z_{fik})^2},$$

where $(x_{tij}, y_{tij}, z_{tij})$ are coordinates of the tibial insertion point j at the femoral flexion angle i and $(x_{fik}, y_{fik}, z_{fik})$ are coordinates of the femoral insertion point k at the flexion angle i (Figure 2). We evaluated isometry at the femoral flexion angle i between the tibial insertion point j and the femoral insertion point k by an increment of the change in length, Δ, in reference to the length at flexion angle 0°, calculated by using the following: $\Delta = L_{ijk} - L_{0jk}$. The 0 value of Δ indicates isometry, the positive value indicates elongation of the ACL, and the negative value indicates shortening of the ACL during femoral flexion.

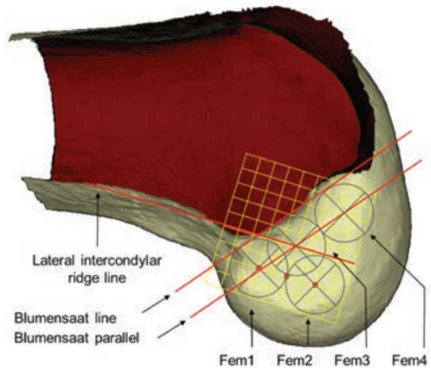

Figure 3. Representation of the Systematically Placed Circles on the Femur. Fem1 is centered about the anteromedial (AM) bundle insertion; Fem2, about the posterolateral (PL) bundle insertion; Fem3, on the intercondylar ridge centered between Fem1 and Fem2; and Fem4, tangential to Fem3 and parallel to the Blumensaat line. We used the points encompassed in these groupings for subsequent analysis.

Femoral Insertion Site Grouping Analysis

For isometry analysis, we used 4 groupings of points (Fem1, Fem2, Fem3, and Fem4) that encompassed various regions of the MWLFC (Figure 3). We determined these groupings by systematically placing 4 circles on the femoral grids relative to the AM and PL bundle center points. We first placed 2 circles about the center points of the AM and PL bundles by using a radius of half the distance between the 2 center points. Fem1 represents the AM bundle, and Fem2 represents the PL bundle. Next, we drew a line over the lateral intercondylar ridge. Along this line, we marked the point perpendicular to half the distance between the center of the AM and PL bundles. We identified the Blumensaat line and, finally, drew a line parallel to the Blumensaat line through the point on the line encompassing the lateral intercondylar ridge. We placed the third circle, Fem3, by using the same radius as for Fem1 and Fem2, over the intersection of the lateral intercondylar ridge. We placed the last circle, Fem4, on the line parallel to the Blumensaat line and externally tangential to Fem3.

We used the calculated distances between the points encompassed by the circles, representing the 4 different tunnel apertures on the femur and the 3 tunnel locations on the tibia (AM center point, PL center point, and midway point) for further analysis. We calculated mean distances for each potential combination of femoral grouping and tibial tunnel locations (12 total per knee) and at each angle of knee flexion. Next, we defined the maximum ligament length through the knee range of motion for each tunnel combination. We then normalized ligament lengths at each flexion angle to this maximum length to allow for more direct comparisons between specimens. We determined the percentage change in ligament length over the range of motion for each tunnel combination. In addition, we calculated the mean length across the range of motion for each tunnel.

Statistical Analysis

We performed statistical analyses with Excel (Microsoft Corporation) and Stata 14 (StataCorp). We compared the mean ligament length across flexion angles for all potential tunnel combinations by using analysis of variance with a Bonferroni correction. First, we tested the variation in the femoral tunnel position while holding the tibial tunnel constant. Next, we tested changes in the tibial tunnel position for each of the femoral tunnels. We defined significance for these tests as $P < .05$.

RESULTS

Mapping of Intra-articular Length Changes

Using all 21 coordinates on the tibia, we measured the intra-articular distances to each of the points on the MWLFC. We calculated the length changes in millimeters from 0° to 10°, 20°, 30°, and 40° of flexion. Using 0° as reference, we displayed these changes on a representative scale of lengthening, minimal change, and shortening. Figure 4 shows each of the MWLFC length change maps, representing the change in length from 0° to 40° of flexion. We arranged the images with

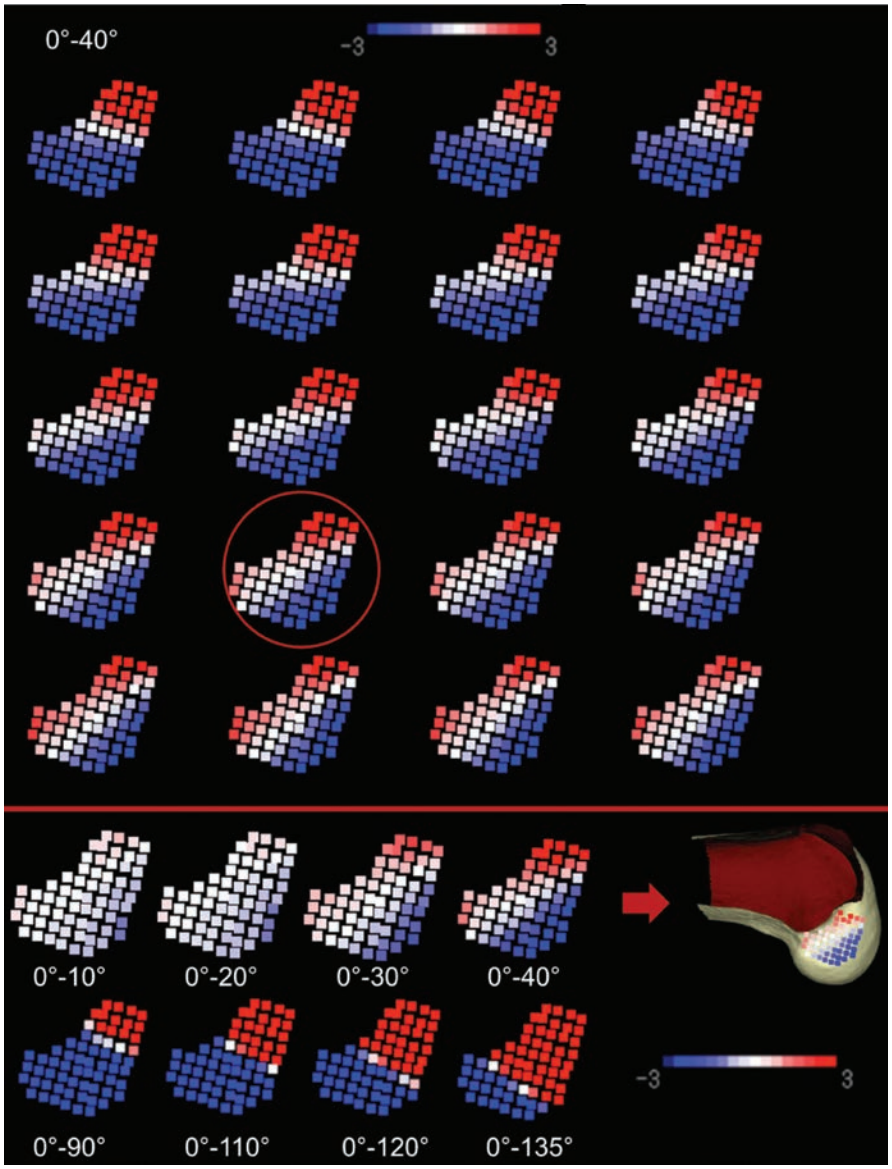

Figure 4. Length Change Maps From 0° to 40° for Each Tibial Site. Length change maps at all flexion angles for the anteromedial (AM) tibial point are shown with the corresponding orientation on the femur. Using 0° as reference, we displayed these changes on a representative scale of red indicating lengthening, white indicating minimal change, and blue indicating shortening. The circled tibia location represents the AM bundle tibial insertion.

Table 1. Range of Normalized Lengths (%)

Tibial Point	Fem1 (AM)	Fem2 (PL)	Fem3	Fem4
AM	18	21	9	30
Center	21	27	15	32
PL	30	24	10	34

Abbreviations: AM, anteromedial; Fem1, femoral position 1 is centered about the AM bundle insertion; Fem2, femoral position 2 is centered about the PL bundle insertion; Fem3, femoral position 3 is on the intercondylar ridge centered between Fem1 and Fem2; Fem4, femoral position 4 is tangential to Fem3 in and parallel to the Blumensaat line; PL, posterolateral.

respect to each of the 20 locations on the tibia. The results for 1 representative specimen depicts the length changes from the AM point on the tibia as flexion increases to 135° (Figure 4). The area of least change decreases as flexion increases.

Intra-articular Length Change

We displayed the intra-articular length changes as a range of normalized length (Figure 5). We identified the minimum and maximum lengths throughout the knee range of motion. Femoral position 1 (Fem1) is centered about the AM bundle insertion; femoral position 2 (Fem2), about the PL bundle insertion; femoral position 3 (Fem3), on the intercondylar ridge centered between Fem1 and Fem2; and femoral position 4 (Fem4), tangential to Fem3 in and parallel to the Blumensaat line. Fem3 demonstrated the smallest normalized range at each position on the tibia (Table 1). Each group on the MWLFC exhibited minimal change in low flexion angles. We observed the greatest changes in length across the full range of motion with Fem4, with mean changes of 30% to 34% in ligament length. For Fem1, Fem2, and Fem3, we observed the longest ligament lengths in 0° to 40° of knee flexion. At Fem4, the ligament was shortest in 0° to 40° of flexion, with progressive lengthening as the knee flexed from 90° to 135°. From 0° to 40°, the length change for all sites was lesser compared with the length changes from 40° to 135° of flexion. Moreover, the anterior site (Fem4), as opposed to the posterior sites (Fem1, Fem2, and Fem3), increased in length with greater flexion angles.

At each of the 3 tibial positions, the ligament length from Fem4 was significantly shorter than the length from the other 3 femoral positions ($P < .001$ compared with all) (Table 2). When the femoral tunnel was held constant, there was less variability in length changes among the 3 tibial positions (Table 2). We observed no significant differences between any of the tibial tunnel positions for each femoral tunnel.

We identified the minimum length and the maximum length throughout the range of

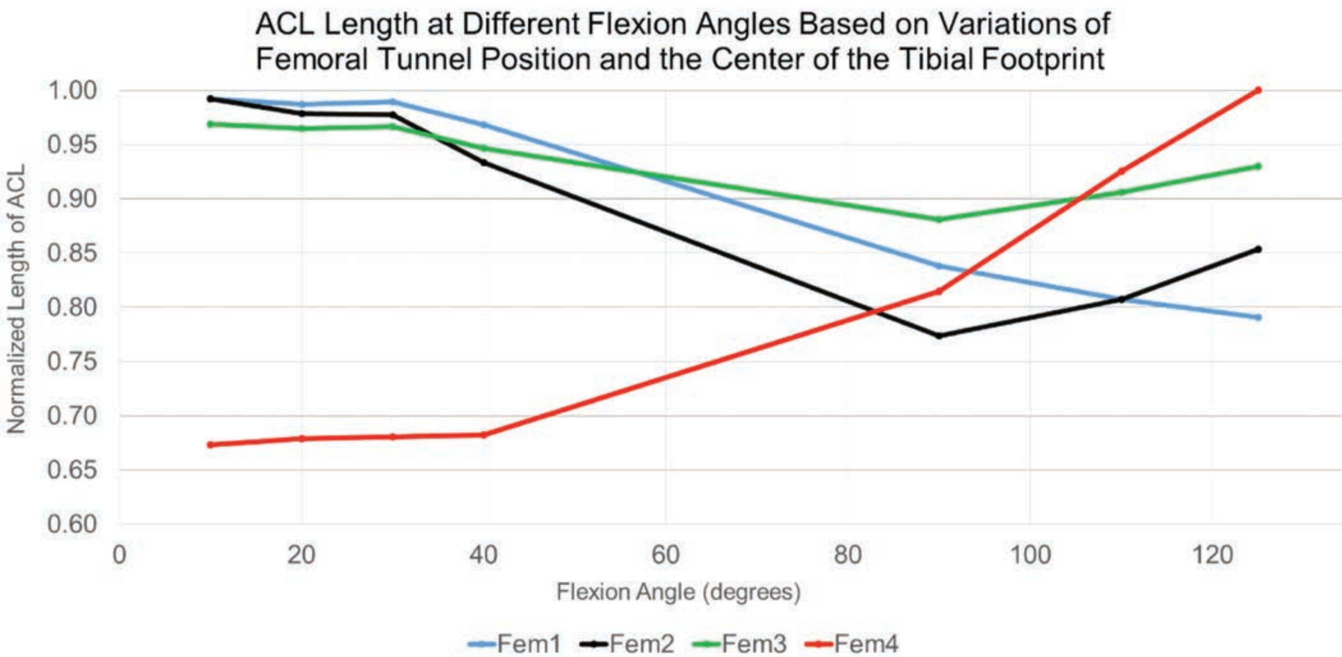

Figure 5. Intra-articular Normalized Length Change. Graph shows anterior cruciate ligament (ACL) length at different flexion angles on the basis of variations of femoral tunnel position and the center of the tibial footprint.

Abbreviations: Cen, center; Fem1, femoral position 1 is centered about the anteromedial bundle insertion; Fem2, femoral position 2 is centered about the posterolateral bundle insertion; Fem3, femoral position 3 is on the intercondylar ridge centered between Fem1 and Fem2; Fem4, femoral position 4 is tangential to Fem3 in and parallel to the Blumensaat line.

motion and used them to normalize the depicted range of length change. Fem1 represents the femoral footprint of the AM bundle, Fem2 represents the femoral footprint of the PL bundle, Fem3 represents the area anterior or high point of the AM and PL areas, and Fem4 represents the area high in the intercondylar notch.

DISCUSSION

In this study, we demonstrated that the most isometric region on the lateral condyle does not completely encompass the natural insertion site of the AM or PL bundle. From 0° to 40° of flexion, the most isometric region expands over the anterior portion of the AM bundle footprint and extends anteriorly (or high) outside of the native footprint. However, throughout the full range of motion, all femoral insertion sites demonstrated length changes, albeit of varying magnitude. Therefore, no true isometric region existed over the full range of motion from any combination of femoral and tibial insertion sites. Furthermore, the length changes related to the tibial tunnel insertion sites had less effect on the isometry than did the femoral insertion sites.

In a cadaveric study, Nawabi et al[11] investigated the load-bearing properties and isometry of the direct and indirect fibers of the ACL. They determined the load sharing of the ACL fibers by an anterior load at 30° and 90° of flexion and a combined valgus and internal rotation torque at 15°. In all settings, they subjected the direct fibers (located anteriorly in the femoral footprint) to significantly more force than they did the indirect fibers, which are located more posteriorly in the footprint. They found that the most isometric region of the footprint was in the anterior portion of the AM footprint. Our study results help confirm this finding, but they also demonstrate that the more isometric region expands outside of the anatomic femoral footprint.

By assessing isometry through the full range of motion in this study, we characterized the length change relationships beyond 90°. Beyond 40°, the insertion sites posterior on the MWLFC all showed relative shortening. The insertion sites anteriorly (Fem4) lengthened with the increase in flexion. Shortening of the PL bundle was more prominent than that of the AM bundle, although we did not observe a significant difference. Although the physiological meaning of the changes in the length of the natural ACL have yet to be clarified, we demonstrated in the present study that the isometric zone exists with the flexion angle up to 40°, which is important in considering the femoral tunnel position for ACL reconstruction.

This study has limitations. Although we recognized trends and absolute lengths demonstrating consistent patterns of length change, we did not recognize a statistical difference between the more posterior insertion site groupings (Fem1, Fem2, and Fem3). Because we did not perform a power analysis, the small sample size could have underpowered the study. In addition, the placement of grids on specimens introduces some variability; however, we think that using osseous landmarks and systematically grouping the insertion sites have minimized some of the variability inherent to this study design.

CONCLUSIONS

In conclusion, from 0° to 40° of flexion, length changes are minimal compared with those at 40° to full flexion. Insertion sites in the anterior portion of the MWLFC increase in length with greater flexion compared with those in the posterior portion. The femoral tunnel position affects isometry to a greater extent than does the insertion site on the tibial footprint, and the most isometric region appears to encompass the anterior portion of the AM bundle footprint, in addition to some of the area just anterior to this region. Clinically, from these data, practitioners should not drill the femoral tunnel too posteriorly or distally on the MWLFC, and tunnels too anterior will be subject to greater length changes at higher flexion angles. In addition, with longer intra-articular length, the tensioning of the graft should occur with the knee between 10° and 20° of flexion. ✣

References and financial disclosures are available online at www.rush.edu/orthopedicsjournal.

Table 2. Comparison of Mean Normalized Length at Each Tibial Position by Femoral Position

Variable	Mean	SD	*P* Value
Tibia 1			
Fem1	0.92146	0.09650	
Fem2	0.90297	0.09830	
Fem3	0.94970	0.05725	.431 for Fem2 vs Fem3
Fem4	0.79332	0.15565	< .001 for Fem4 vs Fem1, Fem2, Fem3
Tibia 2			
Fem1	0.87160	0.13859	
Fem2	0.87733	0.11525	.038 for Fem1 vs Fem4
Fem3	0.91556	0.08020	.022 for Fem2 vs Fem4
Fem4	0.78396	0.17670	< .001 for Fem3 vs Fem4
Tibia 3			
Fem1	0.90684	0.11837	
Fem2	0.89968	0.10945	
Fem3	0.93496	0.06782	< .001 for Fem4 vs Fem1, Fem2, Fem3
Fem4	0.77247	0.16836	> .999 for all others
Fem1			
Tib1	0.92146	0.09650	.248 for Tib1 vs Tib2
Tib2	0.87160	0.13859	> .999 for Tib1 vs Tib3
Tib3	0.90684	0.11837	.656 for Tib2 vs Tib3
Fem2			
Tib1	0.90297	0.09830	
Tib2	0.87733	0.11525	.968 for Tib1 vs Tib2
Tib3	0.89968	0.10945	> .999 for Tib1 vs Tib3, Tib2 vs Tib3
Fem3			
Tib1	0.94974	0.05725	.123 for Tib1 vs Tib2
Tib2	0.91556	0.08020	> .999 for Tib1 vs Tib3
Tib3	0.93496	0.06782	.728 for Tib2 vs Tib3
Fem4			
Tib1	0.79332	0.15565	
Tib2	0.78396	0.17670	
Tib3	0.77247	0.16836	> .999 for all

Abbreviations: Fem1, femoral position 1 is centered about the AM bundle insertion; Fem2, femoral position 2 is centered about the PL bundle insertion; Fem3, femoral position 3 is on the intercondylar ridge centered between Fem1 and Fem2; Fem4, femoral position 4 is tangential to Fem3 in and parallel to the Blumensaat line; Tib1, tibia position 1, anteromedial bundle footprint on tibia; Tib2, tibia position 2, center of anteromedial and posterolateral bundle footprints; Tib3, tibia position 3, posterolateral bundle footprint on tibia.

“Perioperative pain management for hip arthroscopy can be challenging given the anatomy of the hip.”

Efficacy of Intra-Articular Injections for Pain Control After Hip Arthroscopy for Femoroacetabular Impingement

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INTRODUCTION

Hip arthroscopy has become a prominent surgical technique in the field of orthopedic sports medicine. As its popularity expands, so does the need to achieve better pain management in the early postoperative period. Surgeons use different modalities, ranging from local to systemic treatments, to control pain.

Narcotic pain medications are the mainstay of pain management in surgery. However, they are not without adverse effects, including nausea, vomiting, sedation, dysphoria, respiratory depression, and constipation.

The regional management of perioperative hip pain is more difficult than that of the knee and shoulder for multiple reasons. Pain generators for the hip include not only the muscle and soft tissues surrounding the hip joint but also, and most notably, the hip capsule, which derives innervation from multiple nerves, including the obturator nerve, sciatic nerve, femoral nerve, nerve to the quadratus femoris, and superior gluteal nerve.[1] Therefore, unlike those in the shoulder and knee, regional blocks in the hip can be challenging because of the multiple nerves that innervate the hip. Along with this, treating these nerves also results in a motor deficit, which limits immediate postoperative mobility and rehabilitation potential.

Local injections to the hip and surrounding area may be a reasonable option for pain relief. Surgeons often use local anesthetics such as bupivacaine hydrochloride and epinephrine injection because this drug combination has a low potential for side effects and provides hours of pain relief. Doctors often inject the knee and shoulder joints with local anesthetic to help manage pain in the perioperative area; however, given that they inject the hip joint less consistently, the literature minimally addresses pain management in this joint. Therefore, we proposed that an intra-articular injection of local anesthetic at the end of the surgical procedure will provide the patient with pain relief in the immediate postoperative period.

MATERIALS AND METHODS

Before commencing the study, we received institutional review board approval. The patient population consisted of those who had undergone hip arthroscopy with the senior author (S.J.N.) during the period from January 2014 to June 2016. During that period, patients received 1 of 2 different treatments for intraoperative pain management. Patients undergoing surgery from January to July 2014 received no intra-articular bupivacaine hydrochloride (NIABH) injection, and those undergoing surgery during the period from January 2015 to June 2016 received an intra-articular bupivacaine hydrochloride and epinephrine (IABH) injection at the conclusion of the surgery, before closure of the portal incisions. Inclusion criteria included any patient undergoing hip arthroscopy for a diagnosis of femoroacetabular impingement. The exclusion criterion was BMI (body mass index) greater than 43. We matched the cohorts so they were similar in sex distribution.

We performed all arthroscopic procedures with the patient under general anesthesia in the supine position on a standard traction table, a technique that has been described previously.[2-4] Briefly, the surgeon accessed the central compartment via the

Table 1. Patient Demographic Characteristics

Characteristic	NIABH (n = 50)	IABH (n = 50)	*P* Value
Sex, no. (%)			NA
Male Female	20 (40) 30 (60)	20 (40) 30 (60)	
Age, y	31.0	28.4	.284
BMI	25.6	25.7	.952

Abbreviations: BMI, body mass index; IABH, intra-articular bupivacaine hydrochloride and epinephrine; NA, not applicable; NIABH, no intra-articular bupivacaine hydrochloride and epinephrine.

Table 2. Medications Administered

	NIABH	IABH
Cyclobenzaprine	0	44
Acetaminophen	14	44
Scopolamine	25	23
No preoperative medication	15	4

Table 3. Intraoperative Data

Variable	NIABH (n = 50)	IABH (n = 50)	*P* Value
Mean ASA/PS score	1.52	1.35	.148
General anesthesia, no. (%)	50 (100)	50 (100)	NA
Mean surgery time, min	87.3	104.5	<.01
Mean traction time, min	35.5	32.2	.031

Abbreviations: ASA/PS, American Society of Anesthesiologists/physical status; IABH, intra-articular bupivacaine hydrochloride and epinephrine; NA, not applicable; NIABH, no intra-articular bupivacaine hydrochloride and epinephrine.

anterolateral and midanterior portals and performed procedures that included, but were not limited to, acetabular rim trimming of pincer deformities, labral refixation or selective labral debridement, removal of loose bodies, and os acetabuli excision. After completing work in the central compartment, we released traction and accessed the peripheral compartment. We performed T-capsulotomy in all patients through the distal anterolateral accessory portal to assist with arthroscopic visualization in the peripheral compartment. We performed comprehensive femoral osteochondroplasty in the peripheral compartment to address cam deformity, and finally we conducted a dynamic examination to confirm that there was no evidence of impingement. At the conclusion of the procedure, we performed a capsular closure to ensure proper soft-tissue tension.

For patients receiving IABH before cannula removal, we injected 30 mL of 0.5% bupivacaine hydrochloride and epinephrine into the hip joint through the cannula to ensure that the local anesthetic reached the correct location at the joint capsule. Then we removed the cannula and completed routine closure of the portal incisions.

The anesthesia team directed pain management preoperatively and immediately postoperatively in the recovery room. Once patients were in the recovery room, the team administered pain medications as determined according to the patients' pain ratings.

RESULTS

As shown in Table 1, we included 100 patients in the study, with 50 patients in the NIABH group and 50 in the IABH group. Each group contained 20 male patients and 30 female patients. We noted no differences between the 2 groups in age (31.0 years in NIABH versus 28.4 years in IABH; $P = .284$) or BMI (25.7 in NIABH versus 25.6 in IABH; IABH $P = .952$.

Preoperatively, we administered cyclobenzaprine, acetaminophen, and scopolamine at the discretion and preference of the anesthesia team. As shown in Table 2, patients in the NIABH group received medications as follows: no patients received cyclobenzaprine, 14 received scopolamine, 25 received acetaminophen, and 15 received no preoperative medication. In the IABH group, 23 patients received scopolamine, 44 received acetaminophen, 44 received cyclobenzaprine, 4 patients received no preoperative medications.

As shown in Table 3, all patients received general anesthesia with complete muscle relaxation for the duration of the surgery. Intraoperatively, most patients in each cohort received fentanyl. Surgical time did differ between the groups, with 87.3 minutes in the NIABH group versus 104.5 minutes in the IABH group ($P < .01$). The traction time had no significant differences (35.5 minutes in the NIABH group versus 32.2 minutes in the IABH group).

Visual analog scale (VAS) pain scores at successive time intervals did not differ between the 2 groups, with the exception of the VAS at 1 week follow-up, in which patients who had received bupivacaine hydrochloride and epinephrine had less pain (Table 4). The average postoperative stay in the postanesthesia care unit was longer in the NIABH cohort by 14 minutes (161 minutes for NIABH versus 147 minutes for IABH, $P < .03$). We noted no complications in either group, and all patients were discharged home the day of surgery.

DISCUSSION

Perioperative pain management for hip arthroscopy can be challenging because of the anatomy of the hip and because many hip operations, although done through minimally invasive approaches, are extensive procedures. It is common to use regional anesthesia, either nerve block or localized injection, with hip arthroscopy, although its use is neither uniform nor optimized. Nerve block locations include the femoral nerve, lumbar plexus, fascia iliaca, and lumbar paravertebral. Femoral nerve blocks have helped to decrease pain[5] and increase satisfaction in pain control.[6] However, femoral nerve blocks increase the fall risk because of both sensory and motor blockade.[7] Doctors also have used lumbar plexus blocks during hip arthroscopy, with outcomes showing decreased pain in the immediate postoperative period.[8,9] Fascia iliaca and lumbar paravertebral blocks, although not commonly used,[10-12] may be another option in regional anesthesia.

It is unclear whether intra-articular versus portal site local anesthetic injections are more helpful for pain management. In a study in which the researchers compared intra-articular versus portal site bupivacaine injection, the researchers randomly assigned patients to receive intra-articular bupivacaine at the completion of surgery. These patients required more rescue analgesia immediately after surgery. However, in the first 2 hours after surgery, there were no differences in VAS pain scores. Patients who received an injection around the portal sites had statistically significantly lower VAS scores 6 hours after surgery. The authors suggested that the intra-articular injection helps immediately after surgery because of the iatrogenic capsular injury but also propose that patients receive a combination of both intra-articular and portal site local anesthetic to optimize pain management.[13]

In a randomized controlled trial, Shlaifer et al[14] compared the efficacy of intra-articular and periacetabular injections for postoperative pain control. The authors found that the periacetabular injection of 0.5% bupivacaine after hip arthroscopy at 30 minutes and 18 hours postoperatively produced greater pain reduction than did intra-articular injection. After the first postoperative day, there were no significant differences in VAS scores or in narcotic analgesic consumption during the next 14 days.

Although local anesthetics such as lidocaine or bupivacaine hydrochloride and epinephrine are common for intra-articular injections, doctors have used other drugs as well. Cogan et al[15] evaluated the efficacy of intra-articular morphine in combination with clonidine on postoperative pain and narcotic consumption after hip arthroscopy surgery for femoroacetabular impingement. Patients who received an intraoperative intra-articular injection of morphine and clonidine had a significantly reduced narcotic requirement during the postsurgical recovery period.

Pain reduction in the immediate postoperative period with the use of regional anesthesia offers many benefits. The reduction in postoperative opioids may decrease adverse effects related to the narcotic medication, improve overall pain management, and lead to better quality of recovery and improved patient satisfaction. Hip arthroscopy rehabilitation includes early range-of-motion exercise, and failure to control pain early on can result in setbacks in the rehabilitation schedule.

There are several limitations to this study, including the study design. This is not a randomized or prospective trial, which introduces several sources of bias. Similarly, the length of procedures in the IABH group was shorter than that in the NIABH group, which may have affected the results. We will need to use power analysis to determine whether we can study more appropriately with increased enrollment the values that approached significance.

Table 4. Postoperative Pain Scores

Variable	NIABH, Mean (SD)	IABH, Mean (SD)	*P* Value
VAS time			
Immediately postoperatively	2.7 (3.8)	3.5 (3.7)	.311
At 10 min	3.6 (4.0)	4.7 (3.4)	.198
At 20 min	5.3 (3.4)	4.6 (3.1)	.317
At 30 min	5.3 (2.9)	4.4 (2.9)	.129
At discharge	3.0 (1.4)	2.6 (2.3)	.226
At follow-up	3.9 (2.1)	2.5 (2.2)	.004*
PACU time, min	**161.0 (54.7)**	**147.0 (42.0)**	**<.03**
ΔVAS			
Immediately postoperatively	0.0 (3.9)	0.8 (4.3)	.344
At 10 min	1.0 (4.3)	2.0 (4.2)	.248
At 20 min	2.6 (3.7)	1.9 (4.3)	.379
At 30 min	2.6 (3.4)	1.7 (3.9)	.238
At discharge	0.3 (2.6)	–0.1 (3.5)	.579
At follow-up	1.2 (2.8)	–0.2 (3.2)	.054

Abbreviations: IABH, intra-articular bupivacaine hydrochloride and epinephrine; NIABH, no intra-articular bupivacaine hydrochloride and epinephrine; PACU, postanesthesia care unit; SD, standard deviations; VAS, visual analog scale.
*Significant at $P = .05$.

CONCLUSIONS

Although there was no statistically significant difference in the VAS pain scores in the patients receiving an intra-articular injection of bupivacaine hydrochloride and epinephrine postoperatively, at 20 minutes postoperatively and beyond, the VAS scores tended to improve, as compared with those in patients who did not receive an injection. On the basis of the results from this study and others, further work needs to be done to determine the best modality of immediate postoperative pain control after hip arthroscopy. Going forward, it would be advantageous to evaluate further the effectiveness of various injection locations, formulas, and time frames to optimize results. ✣

References and financial disclosures are available online at www.rush.edu/orthopedicsjournal.

"PEEK's biologically inert characteristics coupled with a modulus of elasticity close to that of bone have driven consideration of its use as an orthopedic implant."

Carbon-Fiber-Reinforced Polyetheretherketone

How a Novel Material Is Challenging Historical Thinking

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INTRODUCTION

As we push the bounds of medicine, physicians must continually invent and cautiously venture toward the unknown. Innovative techniques and technological advances make incremental progress possible; however, paradigm shifts in orthopedic surgery potentially may come from translation of new materials used in nonmedical industries.

Polyetheretherketone (PEEK) is a thermoplastic polymer used extensively in aerospace and automotive engineering because of its unique mechanical and chemical properties. PEEK's biologically inert characteristics coupled with a modulus of elasticity close to that of bone have driven consideration of its use as an orthopedic implant.[1] Although PEEK's potential in medicine has been recognized since the late 1980s, harnessing this material's properties in a manner conducive to musculoskeletal therapy has reached fruition only recently—major applications have been in the form of spinal instrumentation and as bony anchors.[2,3]

MATERIAL PROPERTIES

A composite material with carbon fiber reinforcement (CFR) of PEEK appears to be an option in orthopedic trauma (Figure 1).[4] Carbon fiber is resistant to corrosion and provides high strength with low weight for use in conjunction with PEEK, allowing the composite to possess exceptional fatigue strength. The isotropic properties of materials such as stainless steel and

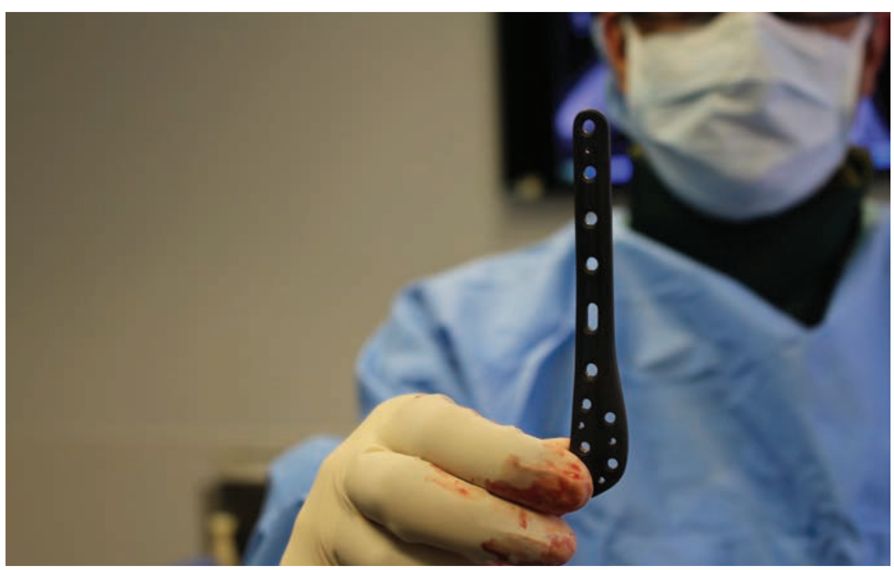

Figure 1. Carbon-fiber-reinforced polyetheretherketone anatomic distal fibula plate is shown prior to implantation.

titanium can limit their application because of excessive rigidity. However, carbon fibers can provide directional properties, allowing for bending in one degree of freedom (eg, twisting) while providing rigidity in another (eg, flexion-extension). In addition, metals transfer heat at a rate different from that of human tissue, resulting in pain during cold weather. CFR-PEEK does not conduct heat to the same degree and is theorized to cause less pain than metal in similar cold conditions.[4]

Investigators have not demonstrated concerns regarding the wear, breakage, and reactivity of these materials. Modern iterations of CFR-PEEK implants include fiber directionality and new adhesive and modern lamination processes in their production.[5] Furthermore, the robust fatigue properties of contemporary designs prevent fiber breakage and splintering. Results of biomechanical studies have demonstrated wear particles from the titanium-CFR-PEEK interface to be less than that of screws with a standard alloy plate.[5,6] Although PEEK is a bioinert substance, there is a case report of synovitis secondary to a first-generation CFR-PEEK distal radius plate, so further investigation into reactivity with modern designs is warranted.[7]

To date, the primary orthopedic application of CFR-PEEK has been in the realm of spinal surgery in the form of cages and rods.[2,3] Investigators recently have reported use of these implants for upper extremity fracture management.[8-11] In addition to the aforementioned properties, CFR-PEEK implants are radiolucent and allow for enhanced intraoperative fracture reduction visualization, postoperative fracture evaluation, and superior advanced imaging (eg, computed tomography and magnetic resonance imaging) without artifact distortion. The latter is theorized to be of great value in orthopedic oncology for assessment of residual tumor burden after resection and reconstruction.[1]

APPLICATION FOR FRACTURE MANAGEMENT

The usefulness of these implants in standard fracture care challenges prior thought processes governed by the dicta of the Arbeitsgemeinschaft für Osteosynthesefragen. Physicians historically have fixed ankle fractures with a lag screw and neutralization plate, along with 6 to 12 weeks of immobilization. CFR-PEEK has challenged the conventional wisdom of anatomic reduction via compression and rigid fixation in favor of functional reduction with a modicum of motion governed by a near-physiologic modulus of elasticity. In our practice, this flexibility has allowed for fixation using locking screws without rigidity. The locking screw head threads cut

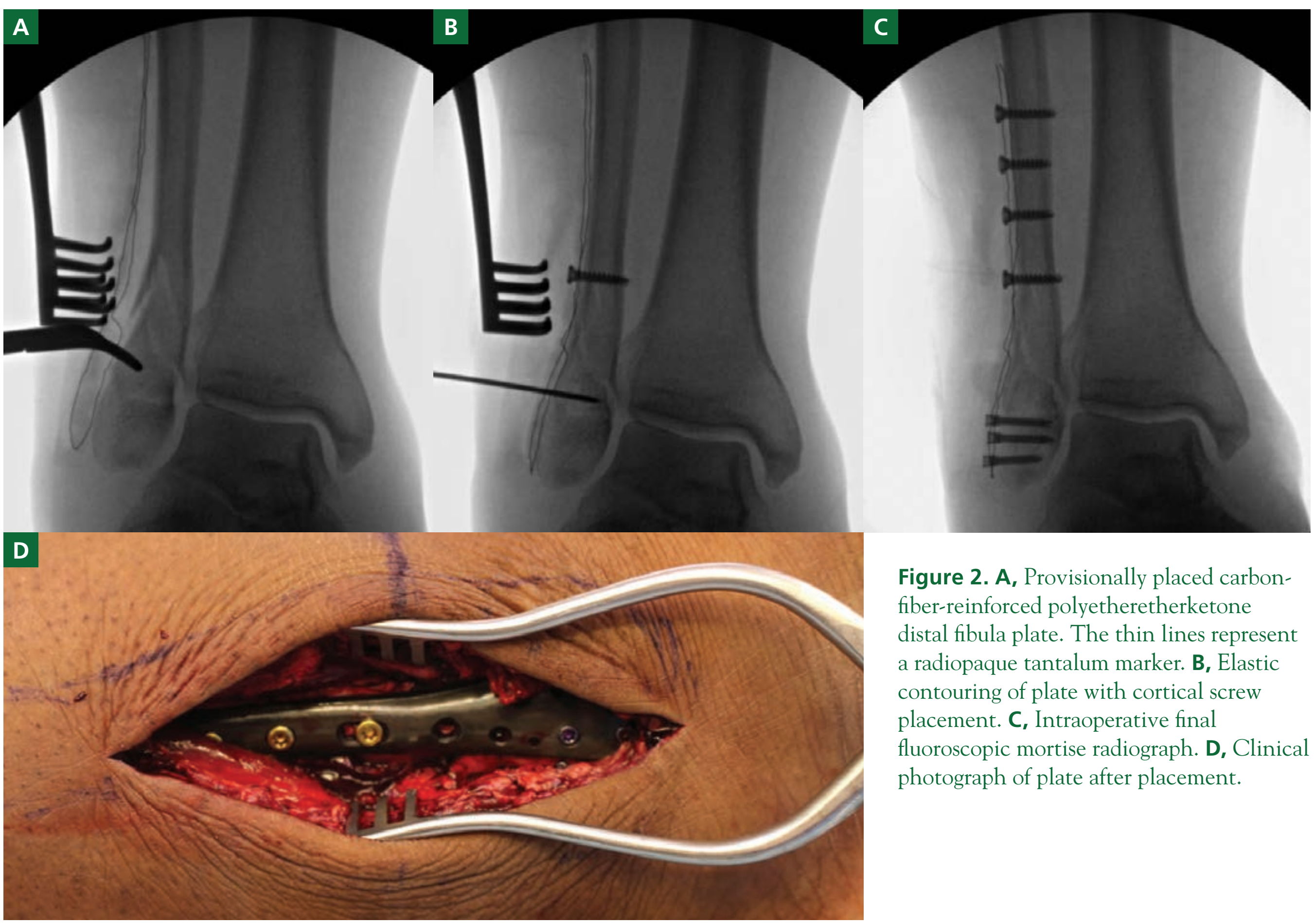

Figure 2. A, Provisionally placed carbon-fiber-reinforced polyetheretherketone distal fibula plate. The thin lines represent a radiopaque tantalum marker. **B,** Elastic contouring of plate with cortical screw placement. **C,** Intraoperative final fluoroscopic mortise radiograph. **D,** Clinical photograph of plate after placement.

Figure 3. Six-week postoperative (**A**) mortise and (**B**) lateral radiographs demonstrating majority resolution of fracture line after 4 weeks of weight bearing. The patient's visual analog scale score for pain was 0 of 10 for walking in shoes.

into the plate, so we can place screws at variable angles and compress the plate to the bone. Although the distal fibula plates are contoured anatomically, they can conform elastically to bone without requiring prebending to deform the plate plastically, as is standard practice with metal (Figure 2).

We have adopted early weight bearing 2 to 3 weeks postoperatively and currently are assessing clinical outcomes (Figure 3). In a recent study, Matson et al[12] identified mean time to clinical and radiographic union in an ankle fracture cohort as being 15.9 weeks after surgery. Advances in techniques and materials may enable us to decrease this time and lead to improvements in radiographic healing, clinical pain, and patient morbidity. Further investigation of CFR-PEEK is warranted. ✣

References and financial disclosures are available online at www.rush.edu/orthopedicsjournal.

"In this prospective, randomized study, we used subjective and objective criteria to compare outcomes from arthroscopic subpectoral vs. open subpectoral biceps tenodesis using interference screw fixation."

Randomized Prospective Analysis of Arthroscopic Suprapectoral and Open Subpectoral Biceps Tenodesis

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INTRODUCTION

Although controversy exists regarding the function of the long head of the biceps tendon (LHBT), it is clear that disease affecting the LHBT can cause clinically significant pain.[1-3] LHBT disease is common, and there are several nonoperative treatment options available, including rest, activity modification, physical therapy, nonsteroidal anti-inflammatory drugs, and corticosteroid injections.[4-6] However, in the event of nonoperative treatment failure, several effective surgical options exist to treat LHBT disease.[7] Surgeons commonly perform biceps tenodesis in young, active patients and those concerned about cosmetic deformity and muscle cramping[8,9]; a tenodesis also has the advantage of maintaining the length-tension relationship of the biceps muscle, which may reduce spasms.[10-12]

Indications for tenodesis include biceps instability, tendinopathy, partial biceps tears, superior labrum anterior-posterior lesions, and biceps pulley lesions.[13] There are myriad options for biceps tenodesis with regard to surgical approach, location of tenodesis, and method of fixation. Surgeons have used both open and arthroscopic approaches successfully, and tenodesis locations have included osseous sites at the entrance of the bicipital groove proximally, the suprapectoral and subpectoral regions, or in soft-tissue sites such as the conjoint tendon.[13] Methods of fixation include interference screw, suture anchor, keyhole technique,[14] or other bone tunnel techniques.[7]

Arthroscopic suprapectoral biceps tenodesis (ASPBT) and open subpectoral biceps tenodesis (OSPBT) are 2 commonly used tenodesis procedures to address LHBT disease.[3,11,13] Investigators in a small number of cadaveric and biomechanical studies compare these 2 techniques.[15-17] In addition, some clinical study investigators demonstrate the effectiveness of both ASPBT and OSPBT.[12] However, few clinical study investigators have compared ASPBT and OSPBT directly, and those who have done so have conducted retrospective studies.[13,18] In this prospective, randomized study, we used subjective and objective criteria to compare outcomes from arthroscopic subpectoral vs. open subpectoral biceps tenodesis using interference screw fixation. To our knowledge, this is the first such study to be reported. Our hypothesis is that there will be no clinical difference in shoulder scores, biceps function, pain relief, and complications with use of the ASPBT and OSPBT techniques.

MATERIALS AND METHODS

In this prospective randomized clinical trial, we compared the clinical outcomes of 2 LHBT tenodesis techniques, OSPBT and ASPBT, for treatment of biceps disease.

Patient Eligibility

To determine patient eligibility, the lead surgeon and 2 of the other authors (B.F., W.Z., B.G.) reviewed medical records for all incoming surgical patients scheduled to undergo tenodesis for the LHBT. We excluded patients if they previously had undergone superior labrum anterior-posterior tear repair, had evidence of a

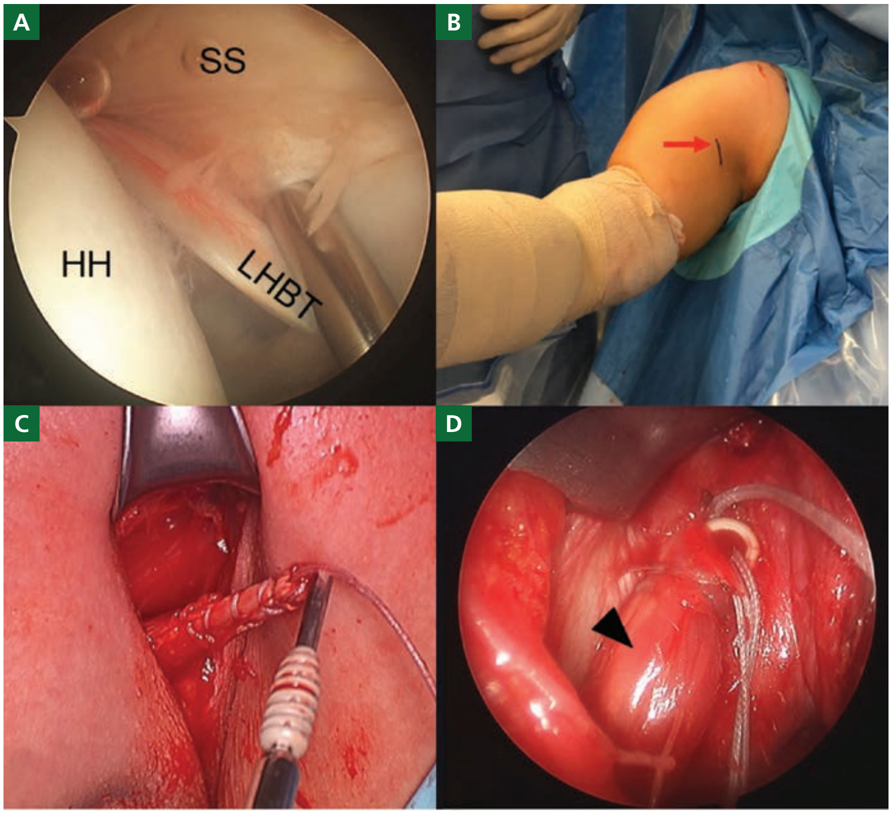

Figure 1. Open Subpectoral Biceps Tenodesis. **A,** View of an inflamed long head of the biceps tendon (LHBT) from the posterior portal. Abbreviations: HH, humeral head; SS, supraspinatus. **B,** The arrow indicates the mark for incision, just lateral to the inferior border of the pectoralis major tendon. **C,** Whipstitched tendon with tenodesis screw. **D,** Tendon and tenodesis screw inserted and suture tails tied. The arrowhead indicates the biceps tendon.

subscapularis tear, had undergone a prior biceps procedure, had a prior shoulder infection, or were unwilling to comply with postoperative follow-up. We then offered enrollment to patients who were older than 18 years, had anterior shoulder pain or pain in the bicipital groove, and had provided written informed consent for a tenodesis procedure. After we ensured informed consent was obtained and answered the patients' questions, the patients' enrollment then depended on the intraoperative findings and decision to perform biceps tenodesis.

Operative Technique

Two of 4 (B.F., A.A.R.) fellowship-trained orthopedic surgeons performed all procedures. All patients received an interscalene nerve block from a trained anesthetist before undergoing general anesthesia. We used the standard beach chair position for all patients, and we used anterior, posterior, and accessory superolateral portals for all patients. After diagnostic arthroscopy, if the LHBT was torn completely or if the subscapularis was torn, we excluded the patient from the study. Furthermore, if we did not perform biceps tenodesis intraoperatively, we also excluded the patient. Before the surgeon incised the LHBT with arthroscopic scissors, the team opened a randomization envelope in the operating room. We made the randomization envelopes by using a random number generator (Excel; Microsoft, Seattle, Washington) to fill the envelopes randomly for technique identification. A member of the research team not directly involved in the operation completed the randomization. Results of a 2-tailed power analysis showed that a minimum of 15 patients per group was required to detect the minimal clinically important difference of 15 points for the American Shoulder and Elbow Surgeons (ASES) score[19] at a significance level (α) of .05.

OSPBT Technique

The surgeon positions the arm in about 45° abduction, forward flexion, and slight external rotation to approximately 10° to 20°. Flexion of the elbow between 10° and 20° prevents overtensioning of the biceps muscle tendon unit during fixation. The surgeon palpates the inferior border of the pectoralis major tendon and makes a 3-cm longitudinal incision just lateral to the axillary fold (Figure 1). Blunt dissection proceeds to the humerus, affording extra attention to nearby neurovascular structures such as the musculocutaneous nerve, radial nerve, and deep brachial artery.[20] The surgeon follows the inferior border of the pectoralis major tendon manually to the intertubercular groove. The surgeon then manually retrieves the LHBT from the groove and pulls it out of the incision.

We standardized the remainder of the technique, with the exception of tenodesis screw size and number of whipstitches placed in the LHBT. With careful assessment of the tendon length and the tenodesis location, the surgeon then places 5 to 7 Krackow whipstitches in the LHBT (No. 2 FiberWire; Arthrex, Naples, Florida). The surgeon removes the remaining tendon and passes a suture tail through a tenodesis screw (Polyetheretherketone Vented; Arthrex), holding the tendon close to the tip of the screw (Figure 1). The surgeon then drills a guidewire in line with the intertubercular groove just beneath the inferior border of the pectoralis major tendon. Depending on screw size, the surgeon drills a 6.5-, 7-, or 8-mm-diameter tunnel through the cortex to accommodate the tendon and screw. The surgeon then inserts the tendon into the drill hole and fixates it with the tenodesis screw. The surgeon ties the suture tails to one another to provide additional fixation strength (Figure 1). By creating a closed loop through the cannulated tenodesis screw, the surgeon prevents tendon slippage past the screw.

ASPBT Technique

We standardized the following technique for all patients. With the arthroscope positioned in the lateral portal to view distally down the humerus, the surgeon gently debrides the area around the superior border of the pectoralis major tendon and the distal portion of the intertubercular groove with a radiofrequency device beginning along the lateral aspect of the groove. The surgeon then mobilizes the LHBT by release of any adhesions and, if necessary, the transverse humeral ligament. The surgeon localizes an accessory anterosuperolateral portal with a spinal needle positioned perpendicular to the groove, 1.5 cm proximal to the superior border of the pectoralis major tendon (Figure 2). The surgeon removes the LHBT from the subdeltoid space through the portal and prepares it in a fashion similar to that used in the OSPBT technique. Particularly in larger shoulders, the LHBT cannot be retracted sufficiently to allow whipstitch placement. In these cases, passing the open body of an army-navy retractor over the tendon can depress soft tissues adequately to facilitate proper whipstitching and fastening to the tenodesis screw. Once the LHBT is associated firmly with the tip of the tenodesis screw, the surgeon places a guidewire approximately 1.5 cm superior to the superior border of the pectoralis major tendon perpendicular to the intertubercular groove. The surgeon then inserts the tendon with the tenodesis screw. The surgeon ties the suture tails in a manner similar to that used in the OSPBT technique, with 5 alternating half hitches made using an arthroscopic knot pusher.

Postoperative Care

We standardized postoperative care of all patients for the concomitant procedures regardless of tenodesis procedure technique.

Surgical Data

We recorded surgical data in the operating room. We timed each biceps procedure beginning at the incision for OSPBT and at the time of arthroscopic dissection for ASPBT until the confirmation of the secured interference screw. The attending surgeon assessed the degree of tenosynovitis and tendinosis at the time of diagnostic arthroscopy. For ASPBT, we recorded the distance proximal to the pectoralis major tendon. We recorded the amount of resected tendon for both techniques.

Outcome Measures

We assessed patients preoperatively and at 3 months and 6 months with a series of biceps-specific questions, and we performed strength testing. We assessed the ASES score and the Single Assessment Numeric Evaluation (SANE) score before the procedure, at 6 months, and at 1 year. Specifically, we asked the patients about anterior shoulder pain, biceps spasms, biceps fatigue, and biceps cosmesis. We measured biceps flexion strength by using a dynamometer (Commander PowerTrack II; JTech Medical, Midvale, Utah) with the arm at 90° against the body without elbow support. We measured the length of the biceps from the inferior border of the pectoralis major tendon to the apex of the muscle belly, which we then compared with that of the contralateral arm. We also performed the Speed, Yergason, and O'Brien tests. We recorded revisions and complications throughout the study.

Statistics

We used descriptive statistics to report patient demographic characteristics and intraoperative data. We performed statistical analysis with software (Excel; Microsoft). We used a χ^2 test to compare

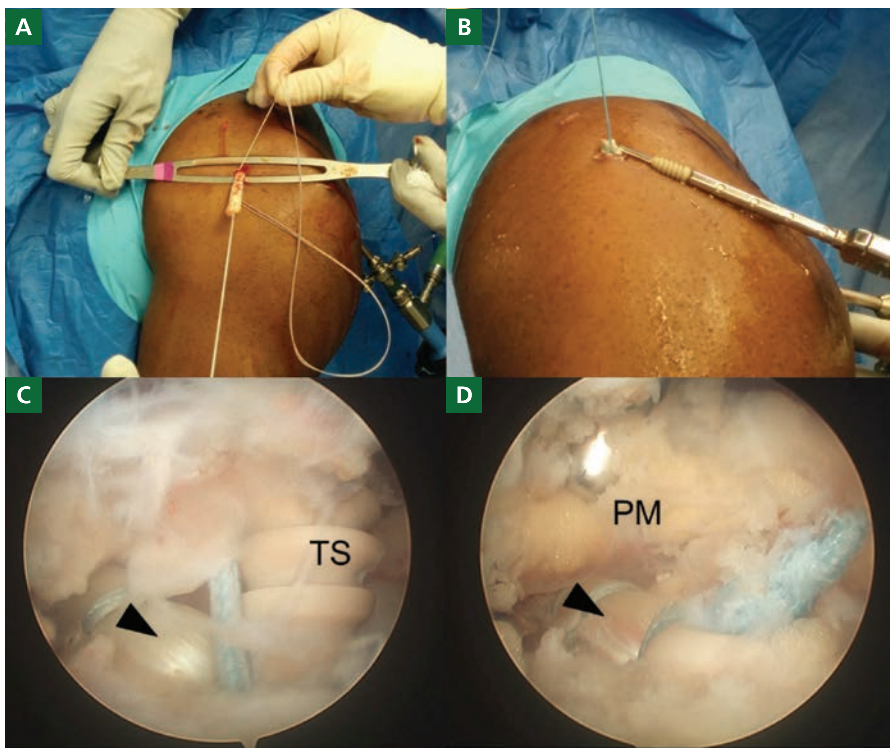

Figure 2. Arthroscopic Suprapectoral Biceps Tenodesis. **A,** Biceps tendon whipstitched and army-navy retractor depressing soft tissue for maximal extraction. **B,** Accessory anterosuperolateral portal with biceps tendon and tenodesis screw. **C,** Tendon implanted and secured with tenodesis screw (TS). The arrowhead indicates the biceps tendon. **D,** Final fixation superior to the pectoralis major (PM) tendon. The arrowhead indicates the biceps tendon.

Table 1. Patient Demographic and Other Characteristics

Characteristic	ASPBT (n = 16)	OSPBT (n = 20)	*P* Value
Age (SD)	46.6 (9.8)	45.4 (9.3)	.41
Sex, no. (%)			
Male	11 (68.8)	15 (75.0)	.68
Female	5 (31.2)	5 (25.0)	.68
BMI (SD)	30.4 (5.8)	29.1 (5.2)	.56
Surgical procedure			
Rotator cuff repair	6 (37.5)	12 (60.0)	.19
Glenohumeral joint debridement	4 (25.0)	8 (40.0)	.35
SLAP debridement	6 (37.5)	11 (55.0)	.30
Distal clavicle excision	2 (12.5)	4 (20.0)	.55
Subacromial decompression	16 (100)	20 (100)	NA

Abbreviations: ASPBT, arthroscopic suprapectoral biceps tenodesis; BMI, body mass index; NA, not applicable; OSPBT, open subpectoral biceps tenodesis; SLAP, superior labrum anterior-posterior.

Table 2. Intraoperative Findings

Finding	ASPBT (n = 16)	OSPBT (n = 20)
Mean (SD) surgical time, min[a]	20.0 (11.3)	11.5 (4.6)
Tenosynovitis severity, no. (%)		
Mild	10 (62.5)	11 (55.0)
Moderate	4 (25.0)	8 (40.0)
Severe	0 (0)	1 (5.0)
Tendon inflammation severity, no. (%)		
Mild	3 (18.8)	2 (10.0)
Moderate	9 (56.2)	15 (75.0)
Severe	3 (18.8)	1 (5.0)
Fixation screw, mm/tunnel size, mm[b], no. (%)		
6.25/6.5	7 (43.8)	18 (90.0)
7/7	9 (56.2)	2 (10.0)
8/8	0 (0.0)	1 (5.0)
Number of tendon passes, no. (%)		
5 passes	16 (100)	19 (95.0)
7 passes	0 (0.0)	1 (5.0)
Mean (SD) amount of resected tendon, cm[a]	2.1 (0.9)	6.4 (2.2)

Abbreviations: ASPBT, arthroscopic suprapectoral biceps tenodesis; OSPBT, open subpectoral biceps tenodesis.
[a]Statistically significant difference ($P < .05$).
[b]Polyetheretherketone vented tenodesis screw (Arthrex).

patient demographic characteristics and concomitant procedures between ASPBT and OSPBT groups. We used the *t* test to compare ASPBT and OSPBT outcomes and surgical data. We set statistical significance at $P < .05$. To determine the minimal number of patients per group, we executed an a priori power analysis (G*Power 3; Heinrich-Heine-Universität Düsseldorf; http://www.gpower.hhu.de/en.html). We used a minimal clinically important difference of 12 for the ASES score as the group difference,[19] and considering the range of ASES score deviations,[9,18,21] we assumed an SD of 9. A minimum of 16 patients per group provides 95% power to detect the minimal clinically important difference at a significance level of .05.

RESULTS

We enrolled 38 patients in the study, with the senior author (B.F.) completing 37 procedures and another author (A.A.R.) completing 1 procedure. One patient refused to complete the ASES and SANE scores or answer any questionnaires after the procedure, and another patient required conversion to OSPBT because of severely attenuated and torn tendon tissue. Thus, we included 36 patients in this analysis. Mean (SD) follow-up for patient-reported outcomes and physical examination results was 11.0 (2.3) months (range, 7-14 months). ASES and SANE scores significantly increased at final follow-up compared with those at preoperative assessment ($P < .01$). Patient demographic characteristics and concomitant procedures for each group were not significantly different ($P > .05$) (Table 1).

Intraoperative findings were similar between the 2 groups, including the severity of tenosynovitis and tendinosis (Table 2). We used the same fixation device throughout the study with slight variation in the size of the tenodesis screw (Table 2). The amount of tendon resected was significantly different, with more tendon resected for the OSPBT group than for the ASPBT group ($P < .01$). With an identical method of fastening the tenodesis screw to the tendon, the number of suture passes through the tendon was not significantly different. The mean (SD) surgical time for ASPBT (20.0 [11.3] minutes) was significantly greater than that for OSPBT (11.5 [4.6] minutes; $P = .01$). We performed a subgroup analysis to compare body mass index (BMI) with surgical time for ASPBT. When BMI was greater than 34, the surgical time for ASPBT was significantly greater than that in the patients with a BMI less than 34 ($P = .04$). However, this difference was not significant when comparing the OSPBT groups ($P = .17$).

Preoperative evaluation results demonstrated no difference in shoulder examination outcomes between the 2 groups. At 3 months and at 6 months, we found no significant difference between the 2 groups in anterior shoulder pain, flexion strength, biceps length, or biceps fatigue (Table 3). In addition, the ASES and SANE scores at baseline, 6 months, and 1 year were not statistically different between the ASPBT and OSPBT groups ($P = .18$, .58, and .24, respectively, for ASES scores and $P = .72$, .91, and .07, respectively, for SANE scores) (Figure 3).

Complications

There were no complications during this study. However, 1 patient randomly assigned to the ASPBT group had surgery converted to OSPBT. This patient had severe tendinosis and attenuation of the LHBT. The attenuated tendon tissue partially tore as the surgeon pulled it through the incision for tenodesis screw preparation. After assessing the remaining intact tendon, the surgeon determined it to be insufficient to restore the length-tension relationship, so the surgeon performed OSPBT. We excluded this patient from analysis because the original randomized biceps technique (ASPBT) could not be completed.

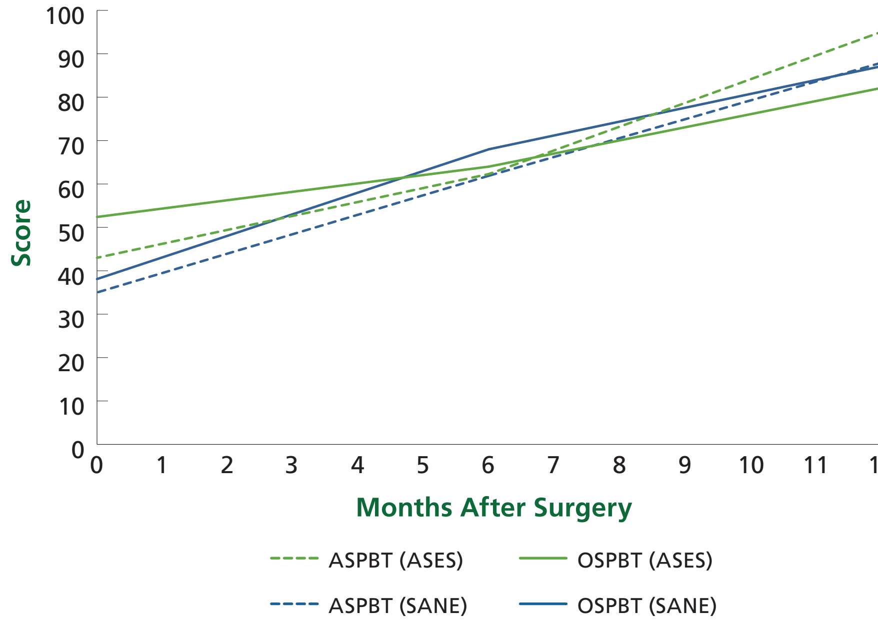

Figure 3. Prospective Comparison of Arthroscopic Suprapectoral and Open Subpectoral ASES and SANE Scores. Mean (SD) ASES scores for ASPBT at baseline, 6 months, and 12 months were 43.0 (16.7), 62.3 (20.7), and 95.0 (8.3), respectively. Mean (SD) ASES scores for OSPBT at baseline, 6 months, and 12 months were 52.4 (21.1), 64.0 (19.0), and 82.1 (21.6), respectively. Mean (SD) SANE scores for ASPBT at baseline, 6 months, and 12 months were 35.0 (21.9), 61.9 (26.2), and 87.9 (11.8), respectively. Mean (SD) SANE scores for OSPBT at baseline, 6 months, and 12 months were 38.1 (26.5), 68.0 (23.0), and 87.1 (13.1), respectively. Abbreviations: ASES, American Shoulder and Elbow Surgeons; ASPBT, arthroscopic suprapectoral biceps tenodesis; OSPBT, open subpectoral biceps tenodesis; SANE, Single Assessment Numeric Evaluation.

DISCUSSION

To our knowledge, this is the first prospective randomized study in which investigators directly compared the clinical outcomes of the ASPBT and OSPBT techniques. Both techniques resulted in favorable outcomes. Furthermore, we saw no significant difference in anterior shoulder pain, strength, and patient-reported outcome measures. However, the surgical time for ASPBT was significantly greater than that for OSPBT, and 1 case necessitated conversion of ASPBT to OPSBT secondary to severe tendinosis and attenuated tissue quality.

In a biomechanical cadaveric study, Werner et al[17] compared ASPBT and OSPBT techniques. They randomly assigned 18 cadavers to either ASPBT or OSPBT groups (9 per group) and performed load-to-failure testing. They found that the ASPBT group had a significantly decreased load to failure than did the OSPBT group and that the ASPBT technique tended to overtension the biceps tendon. However, given that they performed this study ex vivo in cadaver specimens, the clinical implications are unclear. There is a relative paucity of clinical data comparing ASPBT and OSPBT techniques, despite their being the 2 most commonly used biceps tenodesis techniques.[13] Most study investigators reporting clinical outcomes after ASPBT and OSPBT do not compare the 2 groups of patients directly. However, investigators in a few studies, like our study, directly compared clinical outcomes after ASPBT and OSPBT.[13,18]

Werner et al[13] published results similar to ours in a retrospective study of clinical outcomes after ASPBT and OSPBT performed using an interference screw. Their study included 32 patients in the ASPBT group and 50 patients in the OSPBT group, with a minimum 2-year follow-up. However, they excluded patients with concomitant rotator cuff repair. They found no significant differences in several shoulder scores (Constant-Murley, ASES, SANE, Simple Shoulder Test, long head of the biceps, and Veterans RAND 36-Item Health Survey scores) between groups. They also found no range-of-motion or strength deficits in either group after 2 years of follow-up. In addition, the only

Table 3. Biceps-Specific Examination 2-Tail Significance Values Between Arthroscopic Suprapectoral and Open Subpectoral Groups

	P Value		
Finding	**Baseline**	**3 Months**	**6 Months**
Anterior shoulder pain	.06	.06	.72
Biceps length			
Surgical	.97	.77	.49
Nonsurgical	.88	.52	.97
Elbow flexion strength	.28	.42	.31
Biceps fatigue	.98	.12	.68

postoperative complication noted was postoperative stiffness, which affected 9.4% of the ASPBT group and 6.0% of the OSPBT group. However, each of these patients had regained full range of motion by the final follow-up visit with the use of intra-articular corticosteroid injections or physical therapy.

In the present study, we found no differences in complications between the ASPBT and OSPBT groups. Nho et al[22] found a low incidence of postoperative complications after OSPBT with interference screw fixation (7 [2%] of 353 patients). One concern that has been raised about arthroscopic biceps tenodesis techniques is that patients may have persistent bicipital groove pain and tendinopathy if a proximal tenodesis site leaves a portion of the tendon within the bicipital groove.[15,23,24] Intra-articular findings of biceps tenosynovitis continuing distally into the bicipital groove suggest an inflammatory component within the groove and support this hypothesis.[25] We performed the arthroscopic technique used in this study with a suprapectoral tenodesis site distal to the bicipital groove, and we found no difference in bicipital groove pain between the 2 techniques. We suspect that the results between the 2 groups were similar because of the standard tendon fixation technique of whipstitching and use of a tenodesis screw.

This study has several limitations. We enrolled patients undergoing a concomitant rotator cuff procedure in the study, which may have affected the course of their treatment, rehabilitation, and recovery time. Unlike in previous literature, we included patients with rotator cuff repairs because of a lack of patients presenting with only LHBT disease. However, statistical analysis results demonstrated that there was no significant difference between concomitant procedures performed among the ASPBT and OSPBT groups. Moreover, evaluating the biceps tenodesis in a general population that often presents with concomitant shoulder diseases strengthens the external validity of this study. Another limitation of this study relates to the currently available patient-reported outcome because no outcome measure has been validated for a biceps procedure.

CONCLUSIONS

In this study, we found no difference in patient-reported and functional outcomes after ASPBT compared with those after OSPBT in which we used the same tendon fixation technique. The surgical time for ASPBT was significantly greater than that for OSPBT, and a BMI greater than 34 was associated with greater surgical times in the ASPBT group as well. Surgeons can perform both procedures effectively and safely. ✣

References and financial disclosures are available online at www.rush.edu/orthopedicsjournal.

"Periacetabular osteotomy surgery can improve the longevity of the joint and reduce pain in patients whose hip dysplasia is diagnosed before extensive injury to the hip cartilage."

Hip Preservation and Periacetabular Osteotomy

Clinical Update and Case Presentation

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INTRODUCTION

The hip is an incredibly complicated area of the body. When functioning correctly, the hip joint silently facilitates standing, walking, running, and sports. When the hip is not functioning correctly, it can be a debilitating source of pain that prevents individuals from living an active, pain-free lifestyle.

Hip preservation is a rapidly growing area of orthopedic surgery focused on treatments to maintain the native hip joint and postpone or avoid arthroplasty. The field has roots in sports medicine, joint reconstruction, pediatrics, and trauma. The hip preservation team at Midwest Orthopaedics at Rush leads a multidisciplinary approach to treating all conditions related to the hip. These conditions can occur in patients of any age, including children, adolescents, adults, and seniors. Our goal is to reduce hip pain, increase function, and preserve quality of life without a hip replacement. Common conditions treated by the hip preservation team include femoroacetabular impingement (FAI), labral tear, hip dysplasia, acetabular retroversion, slipped capital femoral epiphysis (SCFE), Perthes disease, and avascular necrosis (AVN).

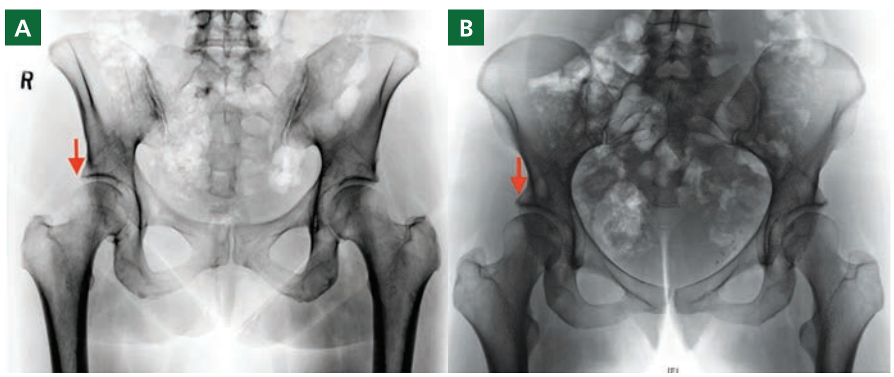

Figure 1. Anteroposterior radiographs of pelvis showing **A,** normal lateral joint coverage (see arrow) and **B,** dysplastic, decreased lateral joint coverage (see arrow).

HIP DYSPLASIA

Hip dysplasia (ie, congenital development of the hip or developmental dysplasia of the hip) is a shallow or deficient hip socket (Figures 1A and 1B). This abnormality can develop in utero, in childhood, or in adolescence. Symptoms sometimes occur at a young age, but often signs or symptoms are not detected until late adolescence or early adulthood. Left untreated, dysplasia can lead to accelerated cartilage wear and early-onset arthritis. Once arthritis occurs, the only treatment is a hip replacement. If diagnosed and treated before the arthritis process occurs, a hip replacement can be avoided or postponed.

During the physical examination, we gather information about gait and leg length inequality. Next, we examine hip

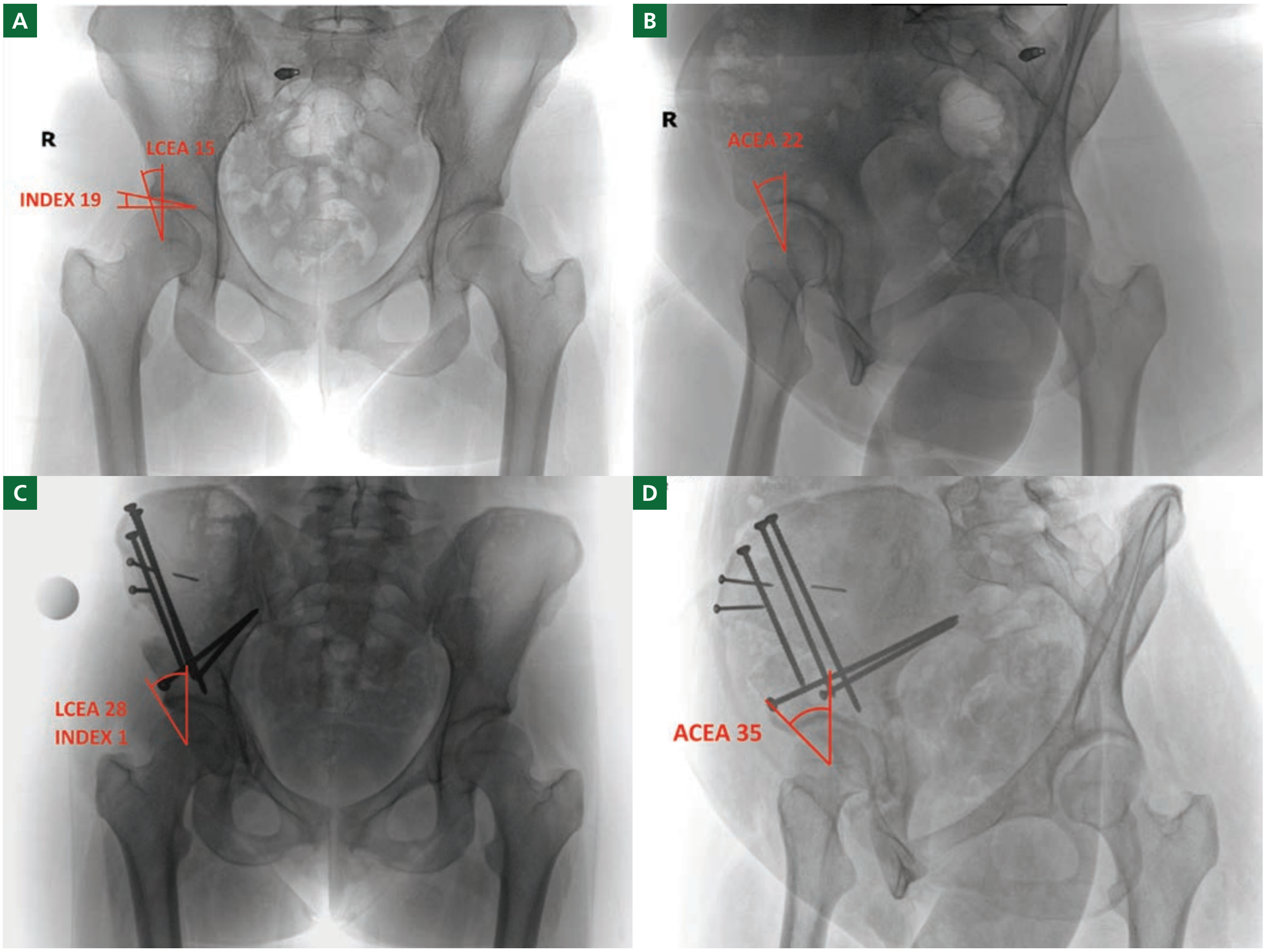

Figure 2. Pre- and Postoperative Radiographs of Pelvis in a 20-year-old Woman With Hip Dysplasia. Preoperative: **A,** anteroposterior with lateral center edge angle (LCEA) of 15° and acetabular index (INDEX) of 19° and **B,** false-profile with anterior center edge angle (ACEA) of 22°. Postoperative with improved parameters: **C,** anteroposterior with LCEA of 28° and index of 1° and **D,** false-profile with ACEA of 35°.

range of motion and muscle strength, comparing the hips with each other. In addition, we perform specialized maneuvers to help with the diagnosis. Clicking, popping, or limping occasionally may assist in the diagnosis of hip dysplasia.

Plain radiography is the primary imaging modality used to diagnose hip dysplasia. It is economical, fast, and widely available. Plain radiographs also allow recognition of a wide variety of other underlying hip disorders (eg, femoroacetabular impingement, Perthes disease, slipped capital femoral epiphysis, and so on) and can help exclude the presence of osteoarthritis. To interpret plain radiographs correctly, standardized acquisition techniques must be applied because plain films are 2-dimensional images of a 3-dimensional structure. Important parameters include the distance between the beam and the film and the distance between the patient and the film. To avoid positional artifacts, the beam and patient also need to be perfectly centered and not rotated.

Radiography can help determine the severity of dysplasia. There are several ways to measure the amount of dysplasia on radiographs. A common measurement for the depth of the socket is the lateral center edge angle (LCEA; Figure 2A). The normal LCEA angle is between 25° and 45°. Radiographs also can show whether the femoral head is centered within the acetabular socket (normal) or whether there is lateral extrusion or cranial migration. Hips that are displaced laterally or upward usually wear out faster than hips that are centered. Other radiographic parameters include the acetabular index (Figure 2A) and anterior center edge angle (ACEA; Figure 2B).

We evaluate femoral version with CT or MRI torsional studies. We try to dispel over-emphasis on labral tears, which may be significant but should not diminish the long-term importance of underlying bone abnormalities.

Non-operative measures, for those with minimal symptoms or those with disease too advanced for osteotomy, are appropriate to reduce pain include weight loss, avoidance of high-impact activities in favor of low-impact exercise, anti-inflammatory medicines, joint injections, and physical therapy.

PERIACETABULAR OSTEOTOMY (PAO)

We employ PAO, a surgical procedure, to re-orient the acetabular socket to improve coverage of the femoral head. The surgeon makes a series of cuts that render the acetabular segment fully mobile, then fixes the re-positioned acetabulum with screws. Sometimes, in conjunction with PAO, the surgeon performs a femoral osteotomy to realign the femur in the coronal pain or rotation. Realignments may reduce pain, restore function, prevent further deterioration of the hip joint, preserve the life of the hip joint and postpone hip replacement.

The ages of those eligible for these procedures range from 11 to 40. Younger patients recover more rapidly, but adults still benefit if the hip joint cartilage is not severely damaged. Current data suggest that more than 60% of patients have a good outcome at 20-year follow-up.[1] Preoperative predictors of a poor outcome include advanced age, poor hip function, limp, and advanced arthritis.

The 20 year-old woman depicted in Figure 2 had progressive right hip pain and was unable to work. Hip arthroscopy had relieved her symptoms for 2 years, but for the past 2 years the pain had recurred. Preoperative anteroposterior and false-profile pelvis radiographs (Figures 2A, 2B) show hip dysplasia with the LCEA of 15°, acetabular index of 19°, and ACEA of 22°. Postoperatively (Figure 2C, 2D), radiographic parameters improved to an LCEA of 28°, acetabular index of 1°, and ACEA of 35°. Her pain was improved.

References and financial disclosures are available online at www.rush.edu/orthopedicsjournal.

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By Gunnar B. J. Andersson, MD, PhD

Jorge Galante was a warm, friendly, generous person, and a brilliant orthopedic surgeon and scientist. He changed my life, convincing me to move to the United States, and his encouragement and mentorship shaped my career.

On a personal level, Jorge was my brother. We shared many interests and passions. Our children were born at the same Swedish hospital, and our families became close. I will always remember wonderful food and spectacular wines, which I enjoyed immensely and he carefully sampled. His home and office doors were always open.

I miss you, Jorge. The world will never be the same.

Sofija and Jorge Galante, Faye and Joshua Jacobs, and Kerstin and Gunnar Andersson.

By Joshua J. Jacobs, MD

Jorge Galante was among the most influential orthopedic surgeons in the 20th century, thanks to his pioneering work in total joint replacement.

He also had a profound impact on orthopedics at Rush University Medical Center. He was a founding member of what is now Midwest Orthopaedics at Rush, and the first chairman of the Department of Orthopedic Surgery. Through these leadership roles, Jorge instilled in our faculty and trainees the core principle that continues to inspire and guide us: clinical excellence based on rigorous scientific investigation. That is perhaps his greatest legacy.

As the current department chairman, I feel so fortunate to stand on the shoulders of two great men—my immediate predecessor, Gunnar Andersson, and our founding father, Jorge Galante, a truly transformative, innovative orthopedic surgeon.

By Ronald DeWald, MD

Jorge Galante's memorial service was held June 29, 2017, at Rush University Medical Center. There were more than 150 people at the ceremony, including colleagues, friends, nurses, physical therapists, residents, fellows, and researchers. The speakers all expressed Jorge's unique ability to be all things to all people. He was kind, thoughtful, demanding, polite, endearing, inspirational, and motivational besides being a comforting, skillful surgeon and a world-class orthopedic and basic science researcher.

Jorge and I were both born in 1934. We were raised during the Great Depression and then World War II. He was raised in Argentina, and I was raised in the US. Those world events may have shaped the courses of our lives.

Jorge and I were residents at the University of Illinois starting in 1960; we were together 1960, 1961, and 1962. In those years, Presbyterian-St. Luke's hospital was part of the U of I residency program.

Jorge introduced me to Sofija one night at the Greeks. The Greeks was really the University Inn, which was located across from the old Cook County Hospital. It was a bar, grocery store, lounge, and hangout for all the interns, residents, nurses, etc. from County and Presbyterian-St. Luke's hospitals. Sofija was a very attractive lady. I knew that Jorge and Sofija would soon be newlyweds.

We worked together on a resident's presentation. The title was "Scoliosis, Quo Vadis?" We borrowed that title from a recent *Journal of Bone and Joint Surgery* article. He did the literature review, and I reviewed the cases from the university hospital. Yes, Jorge was interested in spine.

Ronald DeWald and Jorge Galante.

"I'll miss him; we all will miss him."

I was caught in the "doctors draft" when the Berlin Wall was built and President Kennedy called up the reserves. I had enough training for an orthopedic MOS number and spent 2 years at the Valley Forge Hospital in Pennsylvania. I returned in 1964 to finish my residency, and Jorge was off to Sweden.

When he returned to the U of I in 1968, I was on the clinical faculty and he was on the academic faculty. Together, we published papers in the JBJS (1970 and 1973) on orthotics for the spine.

I was also on the Presbyterian-St. Luke's staff. Rush was restarting its medical school, and my task was to write the orthopedic curriculum for the school. Jorge became the inaugural chairman of the Department of Orthopedic Surgery at Rush.

At the same time, I was offered the position of chairman of orthopedic surgery at Loyola in Maywood. I spoke with Jorge about this opportunity, and he encouraged me. He also suggested that I not resign from Rush, but take a leave of absence in case I didn't like the culture in Maywood. Of course, he was correct, and I returned to Rush a year later and helped Jorge build the department. Jorge asked me to run the Resident Selection Committee and to organize and run our weekly grand rounds, which I did for almost 15 years. Our selections of residents early on proved fruitful, as some stayed on and became stars of our staff. Two spoke at the ceremony—Aaron Rosenberg and Steve Gitelis.

Jorge always called me "Ronnie." When he hosted his fabulous parties, he would walk around the tables with a bottle of wine in each hand. When he came to me he would say, "Ronnie, take this bottle; the other one is for the residents." Jorge knew his wines.

Jorge and I were both admitted to the American Orthopaedic Association (AOA) in 1976. We were 41 years old. The AOA was prestigious and by invitation only. Two from the same institution was unusual.

We were awarded endowed chairs in our names in the 1990s. We were chairs 72 and 73. They were conferred on the same day.

Jorge's infectious enthusiasm established an *esprit de corps* for the department. Orthopedics has been the joy of my life, and Jorge made it that way. His *joie de vivre* touched everyone around him.

I'll miss him; we all will miss him. ✣

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REACHING OUT

The unmet need for orthopedic care is within arm's reach at Rush—in the underserved communities of Chicago. It is also worldwide—in developing countries like Haiti and the Dominican Republic, where unrelenting poverty and natural disasters have left millions without access to even basic health services.

Community service is an integral part of the Rush mission, and members of the Department of Orthopedic Surgery are among those volunteering their time and expertise to the places and people who need it most (see chairman's letter on p 2).

In addition to local outreach, the department sponsors the involvement of its faculty, students, and residents in international missions to provide orthopedic care, teach local physicians, and establish training programs. Several articles in this issue of the *Rush Orthopedics Journal* highlight these efforts:

- Under the direction of Brian J. Cole, MD, MBA, the scope of orthopedic care in Kenya has been expanded to include self-sustaining orthopedic education (p 12).
- Monica Kogan, MD, and residents Robert A. Sershon, MD, and Mick P. Kelly, MD, discuss the annual department-led orthopedic mission trips to the Dominican Republic (p 18).
- Dennis Gates, MD, demonstrates how the necessities of developing countries stimulate orthopedic innovation (p 22).

In the pages that follow, you will read more from Drs Gates, Sershon, and Kelly about their experiences providing orthopedic care in developing countries. Dr Gates, a longtime medical missionary and faculty member at Rush, describes the adventures and rewards of the service-focused career path he has chosen. Drs Kelly and Sershon sit down together for an interview to recount their memorable mission trips to the Dominican Republic under Dr Kogan's leadership, which helped them grow as surgeons, doctors, and people.

We begin with COL (Retired) Tad Gerlinger, MD, who returned to a civilian orthopedic practice at Rush after his military service concluded. Dr Gerlinger writes of the harrowing, poignant, and compelling military experiences he routinely shares in presentations and conversations with colleagues and students at Rush—including the many ways the US military medical service provides volunteer outreach services to sick and injured civilians. ✣

Call of Duty

Providing surgical care for soldiers and civilians in combat zones

BY TAD GERLINGER, MD
ADULT RECONSTRUCTIVE SURGEON

Distinguished service record. My first deployment was to Kosovo with Task Force Falcon, Operation Joint Guardian, in 2001. Three weeks after 9/11, I was deployed from Fort Bragg with the 274th Forward Surgical Team (Airborne)—the first FST sent into Afghanistan—for Operation Enduring Freedom. Two years later, I was part of the Joint Special Operations Task Force in the initial actions of Operation Iraqi Freedom. And I returned to Afghanistan in 2011 with the 936th Forward Surgical Team and served with the Norwegian Provincial Reconstruction Team. That was my last deployment.

Targeting civilians. In armed conflict, the vast majority of casualties and injuries are the locals—the civilian population. That was true for the conflicts in Afghanistan and Iraq back when I served, and it's true today in countries like Syria. What's happening in Syria with ISIS, where they're using human shields, was very common for Al Qaeda, too.

In 2011, our special mission unit went in to get a high value target in northern Afghanistan. After our soldiers surrounded the compound, they asked the enemy to send out all of the noncombatants. As soon as all of the women and children had come out into the courtyard and our soldiers had gone out to secure them to safety, the enemy threw grenades at the entire group. So the majority of the casualties from that mission were women and children—and, of course, our soldiers were injured trying to protect the families of the men who threw the grenades.

I don't think most people in the US can truly appreciate that kind of utter disregard for human life and sanctity of family. Nobody is a noncombatant to Al Qaeda or ISIS. They have no problem feeding their own families to the fire.

Treating the aftermath. You never forget seeing children and women blown apart. In 2011, I was stationed at Forward Operating Base Meymaneh with a small surgical team. The morning of our first day, we were supposed to begin training with the Norwegians who were running the local hospital; we were going to run through trauma scenarios. Just as we were having coffee and talking through the scenarios, there was a suicide bombing in the local village, and we had 15 to 20 casualties right away. One infant died with shrapnel wounds to his head, and multiple children were injured. These innocent people had been gathered in the town center going about their business, and then someone walked into the village with a bomb strapped to his chest.

During my deployments, I've treated everything from blasts to penetrating wounds to blunt traumas, and also more typical orthopedic injuries: We saw a lot of broken bones and dislocations from falls or from hard landings while troops were parachuting in.

The one thing that's very different than in the US is the blast injuries. I can remember seeing my first landmine casualty, what that injury looks like. I remember there was a Canadian reporter who was riding downtown in Kabul, and a terrorist dropped a hand grenade in her lap through the car window, and the grenade blew up. That was a catastrophic injury. There was also a Norwegian soldier who was disarming a landmine and had his face shield up, and the landmine blew up in front of his face. I can still remember what that looked like.

Survival skills. It's extremely hard to bear witness to the atrocities of war. But I think as a surgeon, it provides a very unique perspective to taking care of people here in the US. When it comes to doing an elective procedure—a hip or knee replacement—I don't think much gets me rattled in the operating room. Nobody is shooting at me, or at the building in which I'm operating, and I'm not treating the types of catastrophic injuries you see in combat.

Medical personnel in general are probably the best equipped of anyone in the military to deal with these injuries, because we treated traumatic injuries before our deployments. We're used to taking care of people who are severely injured. What I saw in Iraq and Afghanistan was at a completely different level, but as a surgeon, I appreciate those experiences because I had a role in helping improve the situation, whether it was an individual's medical condition or the condition of the country.

Critical conditions. The facilities in which we had to provide care ran full spectrum, both in terms of proximity to combat and the facilities themselves.

The first level or area in which you can provide surgical care—the first place where surgeons are on hand—is a forward surgical team. That's typically 20 people: 4 surgeons, 3 registered nurses, 2 certified registered nurse anesthetists, an administrative officer, a detachment sergeant, 3 licensed practical nurses, 3 surgical techs, and 3 medics.

The FST is very far forward; it's situated pretty close to the front lines, where the combat is. You want to be a very short helicopter or vehicle ride away from where people are being injured, because that's where that golden hour comes into effect and our ability to save lives.

Teaching an Afghani surgeon placement of a lower extremity external fixator on his patient, who was struck by a motor scooter and had an open tibia fracture.

When we first arrived in Afghanistan in 2001, we were set up in a MiG hangar in Uzbekistan. It was an old concrete structure, and it was filthy, so we put up our tent inside the building in an effort to control the environment to some degree. We moved very shortly into Afghanistan proper, where we were set up in an old air traffic control tower built by the Soviets at Bagram Airfield. It had been bombed and was blown out, so we patched it up as best we could and tried to generate some heat because it was chilly. But we were basically treating patients—including performing surgery—in a bombed-out building.

I've also operated in tents, and in the back of airplanes and helicopters. So it can be that rustic, that challenging an environment. Or it can be like in 2011, where we had really nice facilities. It was like MASH, basically. The Norwegians had built a little combat support hospital with a 1-room trauma bay and a 1-room OR that accommodated 2 beds. It was solid like a bunker, with thick concrete walls and a protected overhead to shield us from mortars. It was also warm and well-lit, and had modern surgical equipment.

Off limits. We're used to such a high level of care in the US, with access to all of the latest modern equipment. But you just don't have the ability to perform these tremendous tertiary care procedures in Iraq or Afghanistan. There are limitations based on equipment and materials, but also, what's a sustainable technology for the patient.

For instance, if a patient needs an above-knee amputation, they're never going to be able to get a prosthesis due to both availability and cost. And what if they're eligible for a limb salvage procedure: Do you have the ability to do bone transport and some of the other interventions that could save the leg? Chances are, you don't have all the necessary technologies at your fingertips, as you would in the US.

I once tried to perform limb salvage on an Afghani man who got shot through his leg. Between his knee and ankle, he had about 4 inches of destroyed tibia and fibula. I did a spanning external fixator and tried to

Medevac flight in the mountains of northern Afghanistan, 2011.

clean up the wound as best I could, but he was going to need some significant bone grafting. We didn't even have a dermatome on hand, which is pretty basic for limb salvage procedures. I did some tissue transfers, and then our nurse actually flew to Germany, signed out a dermatome from the operating room of a hospital in Landstuhl, and flew back into Afghanistan so I could perform the grafting. We did ultimately save his leg. So sometimes you get lucky, but it's often a huge, heroic task just to get the materials you need.

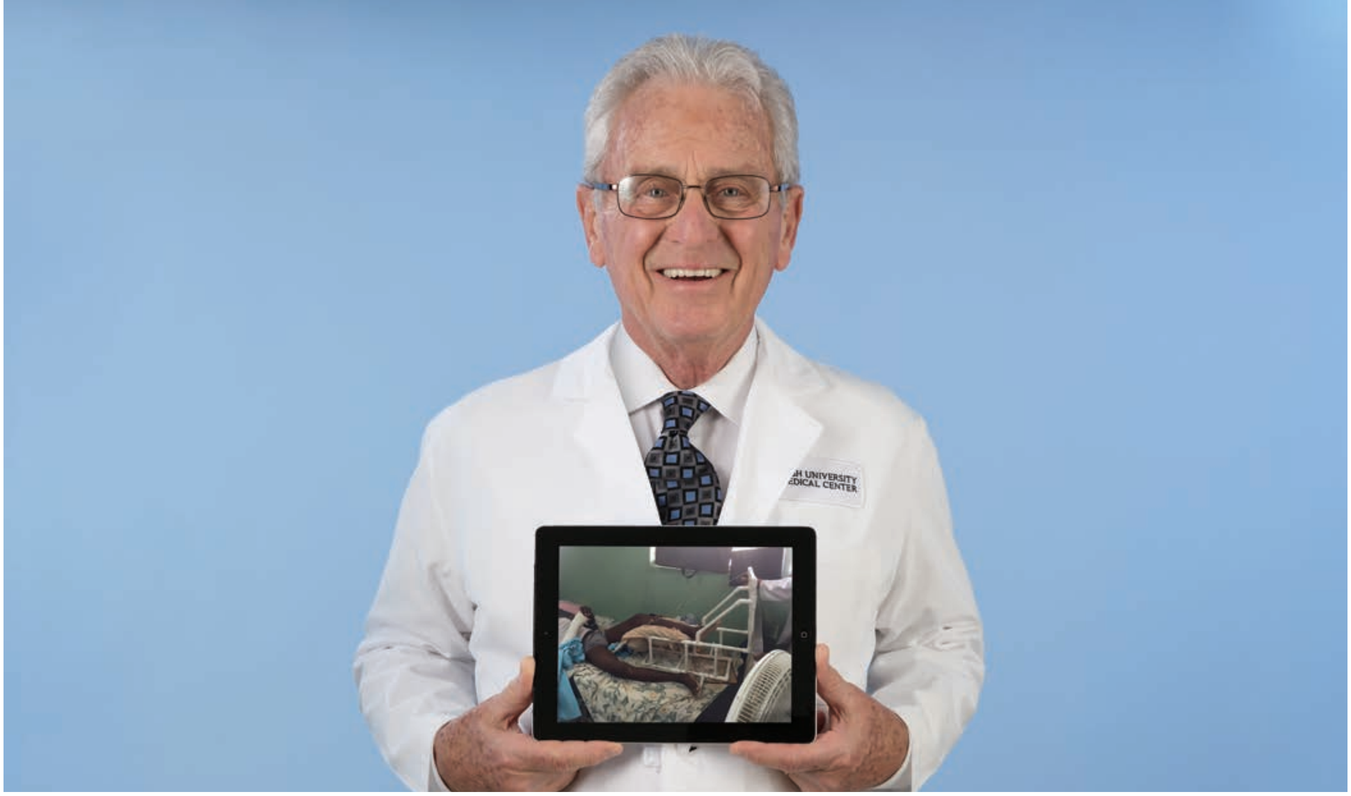
Another limiting factor is infection. You can't close wounds in combat zones or they will become infected, and then you have to deal with infection through debridement and surgical care. We simply didn't do procedures that were prone to infections—putting in implants, for instance. I was able to do some intramedullary nails and fracture fixation during my last deployment in 2011 because we had a sterile OR and could safely put in implants. But in most forward areas, there is no way you can safely do those types of things. There are data on disaster care from China after one of the earthquakes: They saw a tremendously high 50% complication rate when they used hardware.

Issues with tissues. During my deployments, I learned a lot about soft tissue care and healing, and I think that has made me a better surgeon. In orthopedic surgery, we tend to focus on implants and putting those in correctly, but sometimes taking care of soft tissue, getting it to heal, can be the biggest challenge. I have great respect for soft tissue injuries, both those people come in with and those we create when we perform surgery.

Passing the torch. Even though I'm no longer in the military, I remain involved with the Society of Military Orthopedic Surgeons (SOMOS). While I was still in uniform, I helped establish a disaster response course for the American Academy of Orthopaedic Surgeons (AAOS) that was designed to prepare civilian surgeons to travel overseas. SOMOS already had a predeployment course for its military surgeons; surgeons take the course to help them prepare to transition from very modern, safe facilities to damage-control orthopedics in military combat zones. After the earthquake in Haiti, AAOS approached SOMOS about adapting our course for civilian surgeons who volunteer to provide care in disaster-ravaged areas, such as Haiti. I'm no longer directing the course, but AAOS still uses it to train American surgeons, and that's really gratifying.

To serve and protect. Few people realize that the US military is the largest humanitarian organization in the world, between disaster relief efforts and helping take care of the local populations in conflict zones. I was in Kabul in December 2001 when girls were able to attend school for the first time since the Taliban had taken over (after the Soviets left in 1989). I actually got to watch those girls walk to school. It was a truly remarkable thing, and it made you realize that you could make a difference.

Of course, I also witnessed a lot of tragedy. Not a day goes by that I don't think about something I saw or did, someone I worked with, or someone who was injured or killed. Every time I hear the National Anthem play, I think of the guys I served with who aren't going to see their families, who aren't watching the World Series, who aren't able to see their kids grow up because they were trying to do something good and help others. I'll carry those memories with me for the rest of my life. ✣



Man on a Mission

Chronicling more than 5 decades of international humanitarian trips

BY DENNIS J. GATES, MD
EMERITUS PROFESSOR OF ORTHOPEDIC SURGERY

A history of humanitarianism. I have been doing medical missions for more than 50 years. My first trip was as a medical student at Loyola, when I worked as a laboratory technician for a couple of doctors in Brazil. That experience enlightened me to a far greater need for orthopedic and medical care in Brazil than in the US. A child in America with a club foot is going to get treatment somehow, whereas in Brazil, that's not the case. There aren't adequate medical facilities, and patients can't afford treatment or simply don't have access to care. Then, 2 years in the Peace Corps as a family doctor in Nigeria and Ghana reinforced in me the incredible medical needs of developing countries.

Once in orthopedic practice, some colleagues and I started making regular mission trips to Brazil. We'd go down to a little clinic on the Amazon River, called Esperanca, to perform many surgeries and train orthopedic residents. When we started in the mid-1970s, there was only 1 local orthopod; by the time we stopped doing the trips 30 years later, there were 7 well-trained orthopedic surgeons in town. That was pretty satisfying.

Taking the training wheels off. A lot of Americans don't realize it, but during the Vietnam War, the American Medical Association—through the Volunteer Physicians for Vietnam—sent more than 800 American civilian physicians to take care of wounded, ill Vietnamese civilians. In 1971, I was a senior resident at Northwestern, and they allowed me to go to Vietnam with the AMA-VPV in place of my rehabilitation rotation.

As a resident, I was supposed to be supervised by an attending. But when I arrived in Can Tho, Vietnam, I walked into this little French Quonset hut filled with patients and asked one of the nurses, "Where's the supervising orthopedic surgeon?" The nurse looked at me and said, "You are." And I said, "No, no, I mean the *other* doctor." She said, "There *is* no other doctor."

We treated the same things we're treating today in Haiti and the Dominican Republic—malunions and open fractures mostly—but in Vietnam the injuries were all caused by gunshot, bomb, and grenade wounds. What's amazing is that when we'd run out of supplies, we would motor scooter across town to the US Army hospital, and they would give us whatever we wanted: blood, rods—"Oh, you need screws; here's some extra screws." The military surgeons were tough as nails and also very compassionate. They took care of all the American troops, but when time allowed, they would take care of anyone who needed care.

Gaining traction. It was there in Vietnam in 1971 when I really began to understand the serious and too frequent problem of the fractured femur—and resultant disabilities—in developing countries.

At that time, the usual treatment was inadequate straight traction over the foot of a bed, followed by a spica cast. When the US Army hospital gave us extra rods, we did some intramedullary (IM) nailings, but because there were delays in treatment, the results were not the best. As a young attending, I did volunteer work with Care Medico in Bangladesh and Uganda, and the treatment there was balanced traction—suspension with an elaborate British frame mounted on the bed. It was highly effective, but the patient then had to wear a hip spica plaster cast. Results were good for union, but pretty miserable for patients.

In Uganda, with Orthopedics Overseas, we introduced the plaster cast brace with homemade hinges in place of the spica, and patients enjoyed this immensely. They would clamor for the cast brace over the spica. This concept was accepted, and eventually we introduced the Neufield traction and cast brace, called roller traction, in the Dominican Republic in the 1980s, again working with Care Medico. Patients were out of bed in 4 days. The results, which were excellent, were published in the *British Journal of Bone and Joint Surgery*.

In the next decade, the IM rod became commonplace in the US, and continued improvements in technology and technique made this the gold standard of care. Today of course, IM rodding is done with minimal incisions and within 24 hours of injury. But this great care is not available worldwide, because the rods themselves are not available to the average poor patient; or, if they are available, surgeons cannot insert them. The reasons for nonavailability are mainly cost—the patient must buy the implant before surgery—lack of imaging, poor hospital conditions, and surgical delays ad nauseum.

In the 1990s, Lew Zirkle—a dynamic orthopedic surgeon from Spokane, WA, and one of my heroes—developed and self manufactured an inexpensive IM rod that could be inserted without X-ray, and he started a foundation to go with it called SIGN Fracture Care. Their motto is, "Equality of fracture care around the world." He gives the implants, with instruments, to hundreds of hospitals around the world, which has helped thousands of patients.

Re-framing the problem. Even with Lew's admirable efforts, however, 2 problems persisted. Some hospitals don't have any type of fixation. And for many, many patients, surgery is delayed by days, weeks, or months, which is extremely frustrating for the patients, the surgeons, the nurses, and the families. After a few weeks, the fractures begin to heal themselves, leading to malunions, malformations, and other complications. That's why most people in developing countries with untreated fractures end up with some degree of disability. Patients are admitted to the public hospital, but then they lie in bed and wait and wait while their fractures consolidate in poor positions.

It was clear we needed a basic traction frame that could be built inexpensively, with local parts, and required very little training. So we modified a very old British frame—the Böhler-Braun frame—that keeps the leg out to length and aligned, and fashioned a new model out of PVC pipe, of all things. We discovered that PVC is a universal construction material, available worldwide.

It took a year to make dozens of models that would fit a variety of patients, but now the Gates frame is being used routinely in the Dominican Republic and Haiti. The frame is applied immediately when the patient comes in, while they lie in bed waiting for surgery. If they lie there long enough in the frame, they may end up not even needing surgery, just like decades ago when all fractured femurs were treated with traction.

Modern missions. These days, I make regular trips to both the Dominican Republic and Haiti. Since the Haitian earthquake in 2010, I have traveled to Haiti, the Dominican Republic, and other countries 3-4 times a year. Medically, things are so difficult in all these countries that we never accomplish as much as we intend. It can be discouraging, but it's still imperative to go and try to help as much as possible, because there's such a tremendous need.

Some of these trips have been with the Rush Global Health Program and the Department of Orthopedic Surgery. Stephanie Crane, MD, an internist, runs a wonderful program both in Haiti and the Dominican Republic, and works closely with our department.

After the hurricane. Last November, just after Hurricane Matthew hit in Haiti, I received an email: A humanitarian team from a Lutheran church was leaving the day after Thanksgiving for Jeremie, Haiti, to restart their clinic. They needed a doctor. They've been running the clinic in Jeremie for 24 years, and the building was virtually wiped out by 130-MPH winds (and the very poor quality cement block). I signed on.

The conditions were devastating, the worst I've ever seen. There was literally no food.

A patient in Port-au-Prince, Haiti, with a fractured femur, awaiting surgery in PVC frame.

The hurricane blew through the southern tip, and all the crops and veggie fields were destroyed. All the cows and chickens were dead. The people were starving. It was beyond our team's comprehension. Usually, there's food available. And there weren't many humanitarian groups providing support. Following the earthquake in 2010, there were a lot of missions. Following the hurricane, ours was one of the few groups present.

We encountered many patients with fractured bones who were receiving no treatment whatsoever. When we arrived, the road to Port-au-Prince had just reopened, and our team arranged for transport to get some patients to the public hospital in Port-au-Prince. But we soon learned the entire hospital was on strike.

Through series of friends and contacts, we located doctors in Port-au-Prince who agreed to see the patients. We had to fashion splints out of wood—as crude as you can imagine—just to stabilize the limbs during transport.

A tale of two countries. In January 2017, I traveled to the Dominican Republic with a group from Creighton University for 10 days. It's strange and sad, because so many tourists go there for the beautiful beaches and hotels. But the hidden poverty is just staggering. The medical care is almost as difficult as in Haiti; there is no health insurance, and there is no money.

Building a traction frame with an orthopedic resident at Cabral hospital in Santiago, Dominican Republic.

I've been seeing patients at Cabral Hospital in Santo Domingo for 35 years, and conditions were acceptable back in the 1980s. Femurs were treated with balanced cast bracing. It's hard to comprehend how poor conditions are now—both socially and medically. The hospital stopped serving food to the patients; the families have to bring it in. The residents used to have a cafeteria, but they stopped feeding the residents as well.

We performed a lot of surgery on that trip. When we walked into the emergency ward our first day there, we counted 35 patients with fractures lying either on carts or on the floor because there were no available beds. It was mind-boggling. We had 5 of the PVC traction frames on hand for patients who needed traction until receiving surgery, but there were far more patients than frames.

All in the family. My entire family has been going on these mission trips with me. My wife, Lois, is a nurse and the assistant executive director of Misericordia Home for the disabled in Chicago. She first accompanied me to Zaire and cared for young children in a leprosorium while I did orthopedics. On many trips to Brazil she assisted in surgery and the recovery room, and took care of disabled young people in a local facility. She seemed to find her special young people everywhere we traveled. It's shocking to realize that all over the world, you don't have any of the support services that we have in the US for intellectually and developmentally challenged children. All of the support in other countries is provided by the families, and it's too much for them to handle alone.

My children have also accompanied me on missions. It's been a good experience for them to see their parents helping others, as well as to help out themselves. And they went right to work. My eldest son is quite handy, so one time in Brazil when I needed a set of hinges for a cast brace, I said, "John, get these made." He was 18 years old, and he figured it out, finding a local shop to make the hinges. David, our youngest, started traveling when he was 6 years old and recently worked as a translator on a Loyola Medical School trip to Guatemala. And after the Haiti earthquake in 2010, my adult daughters, Ginne and Alba, along with my wife and David, came with and worked in an orphanage in Port-au-Prince. Son Peter, living in Spain has twice joined me in Haiti. The mission trips have been part of our family's culture, something meaningful that we could do together. It is a way of giving back, and, of course, it is in giving that we receive.

The gift of giving. Providing care in developing countries has always given me feeling of peaceful satisfaction. As an orthopedic surgeon, you frequently do get that feeling in your regular practice, but it's not the same because you know that if you don't take care of a patient in the US, someone else will. Patients are always going to get care here. In places like Brazil, Haiti, or the Dominican Republic, if you aren't able to do a case, that patient may not receive treatment at all. It's also gratifying to have a family say thank you for enabling them to work again, and give you a chicken or a bag of fruit. Or to walk through town and everybody knows who we are and calls out to us, "Doctor, doctor, muchas gracias!"

I think it's important for every physician to go on at least 1 medical mission early in their career. Then, as you get older, you may be able to do it more often because you have more time. I'm a seasoned doctor now, but every time I make one of these trips, I am inspired, invigorated and grateful. My favorite high school professor introduced me to John Donne, and I still reflect on one of Donne's poems today: *"No man is an island … Every man is a piece of the continent, a part of the main … Any man's death diminishes me, because I am involved in mankind, And therefore never send to know for whom the bell tolls; it tolls for thee."*

Teachable Moments

Bringing life-changing orthopedic care to the Dominican Republic

AN INTERVIEW WITH ORTHOPEDIC SURGERY RESIDENTS
ROBERT A. SERSHON, MD (CLASS OF 2018), AND MICK P. KELLY, MD (CLASS OF 2020)

Q: How many medical missions have you taken?

Sershon: I've gone on 2 trips to Peralta, Azua Province, Dominican Republic—in November 2014 and January 2016. The 2014 trip included a urology team and 4 of us from orthopedic surgery (3 residents, 1 attending). The 2016 trip was Rush's first orthopedic surgery-only mission. For both trips, we worked out of Taiwan Hospital in Azua, Dominican Republic, which was built about 10 years ago through charitable donations.

Kelly: I also went on the January 2016 trip. That was my first medical mission with Rush.

Q: Mick, what were your expectations as a first-timer?

Kelly: From what I'd heard about the previous mission, they operated a lot and were really busy, and all the residents had amazing experiences. I spent about a year living in South America between undergrad and medical school and had the opportunity to work with similar surgical projects, so I know you can always run into logistical problems with ORs, anesthesia, and equipment. I was expecting a lot of obstacles in the Dominican Republic, but although we had our fair share, I was impressed by how much work we were able to get done in just a short time.

Q: How many procedures did you perform?

Sershon: Both trips have been heavily focused on orthopedic trauma, and between them we've done approximately 50 major orthopedic surgeries for a variety of acute fractures, malunions, nonunions, and posttraumatic deformities. Our patients were all local Dominicans who lack both access to care and the ability to pay, and as a result, many of them had been living with tremendous pain and debility for months, years, even decades.

Kelly: The majority of injuries were motorcycle crashes and machete injuries. One patient was attacked, when he was 10 years old, by his drunk uncle with a machete. After several decades without treatment, his arm was catastrophically deformed; it was painful, nonfunctional, and prohibited him from working because it was hanging at an awkward angle and kept getting in the way. There was no way we could save his arm. We had to perform an above elbow amputation, and even though elective amputations are culturally taboo in the Dominican Republic, the patient was incredibly grateful that he was no longer in pain and could function better.

It's frustrating to know that often, a simple treatment exists that isn't available to patients based on their economic status. This is especially true when it comes to treating fractures. The patients have to pay for the equipment themselves; for people

A local Dominican man presented to our clinic with significant deformity of the left upper extremity related to a machete injury many years prior.

living in poverty, it's unrealistic to be able to purchase a tibial nail, for example. So an injury that could have been easily treated becomes a debilitating factor in their life; to treat it down the line become much more complex—and possibly expensive.

Q: How much planning goes into these trips, and how does it help once you arrive?

Kelly: A great deal has to be done ahead of time. With orthopedic surgery we have unique challenges for international projects because equipment is a necessary part of what we do. It takes a lot more planning to get everything in place so we can even perform the surgeries.

I think we were able to be so successful, and do so many surgeries, because of all the advance work by our Orthopedic Surgery Residency Program director Monica Kogan—the Dominican Republic trip is now part of the residency program—and Stephanie Crane, who heads up the Rush Office of Global Health. When we arrived, we had hundreds of patients waiting to see us, and we could have stayed and operated for many more weeks and still had enough patients.

Sershon: I'm glad you mentioned the Global Health program. Thanks largely to Dr Crane's heroic efforts, Rush has been sending volunteer clinical teams to Peralta and to Port-au-Prince, Haiti, since 2005 and 2010, respectively. The Office of Global Health was created in 2014 to provide more formal developmental and administrative support for the mission work, and it currently facilitates 8 to 10 trips each year to provide medical care, supplies, medications, and training for local clinicians in those 2 areas. These are multispecialty teams, and a few of the attending physicians from our department have gone over the years, including John Fernandez, a hand, wrist, and elbow surgeon.

Rush Global Health really laid the groundwork for our orthopedic missions by cultivating partnerships with the community of Peralta. It can't just be a team of foreigners coming in for 1 week; you need local leadership and cooperation. We've been fortunate to establish great relationships with the local general orthopedic surgeons in Peralta, Dr Roa and Dr Beltran. We've also partnered with another orthopedic surgeon who travels to Azua with Rush Global Health; he follows our patients after we leave, and we follow his patients when we return.

Kelly: Those relationships are crucial. The only way we can feel confident that we're doing more good than harm when we come for just a week and operate is knowing that we have postoperative care set up for the patients.

Q: What are some of the biggest challenges you faced treating patients in the Dominican Republic?

Sershon: There are so many things we take for granted here that are simply not possible or available over there.

For instance, here at Rush, you might see 20 patients on a clinic day. In the Dominican Republic, you have 1 clinic day to see about 100 new Spanish-speaking patients. Most have waited months to see you and have driven hours to seek care. Very few have adequate films or studies; most have just an AP (anteroposterior) or lateral film from the time of the injury. Even if you send them for new films—which they have to pay for out of pocket, so most can't afford it—you are not guaranteed to get a worthwhile study.

Given how many patients there are, we unfortunately aren't able to treat everyone with the time and resources available, which means we then have to triage the surgical patients we can realistically help. And that just scratches the surface of the challenges of clinic.

Q: How about preoperatively and during surgery?

Sershon: Honestly, it's tough. Supplies are extremely limited. We have to bring everything with us from the US—even basics like sterile gloves, gowns, and drapes, as well as the trays and power tools. For our first mission in 2014, we only had 1 power drill. If you've ever tried fixing a femoral shaft fracture with a hand-crank drill, you know it's not fun.

We had to take daily inventory of everything and make our own trays and sets for each case, which included everything from pick-ups, scissors, and retractors to the implants. If you forgot something, you probably weren't able to get it during the case. There was also only 1 small frag and 1 large frag set, so we had to divvy up which implants and screws we needed for each case and keep those sets together.

To complicate matters, we also had to plan the case order to allow sufficient time to resterilize certain supplies for a case later in the day. For example, if we had only 1 traveling traction set, we would have to perform the tibial plateau open reduction internal fixation first, and do the tibial shaft later in the day to allow for sterilization of the set. Not planning for this could result in a 3-hour delay and lost spot for a patient. There were multiple times that we did not have enough supplies and had to turn away patients we could have otherwise fixed, which was probably the most difficult thing to do.

Kelly: There's also no intraoperative fluoroscopy or X-ray. So for some fractures, maybe the standard of care is using an IM nail, but we ended up having to plate. Plating is still an adequate way to treat the fracture, but it made it a bit more challenging.

Sershon: The amazing thing is that in spite of all that, we were still able to perform so many major surgeries.

Q: What was it like having 5 residents traveling to the Dominican Republic together?

Kelly: That was one of the best aspects of the trip, in my opinion. As a group, we got really close over the week, and it's unusual in a training program to spend time operating with fellow residents. That's especially true for the seniors; they will rarely operate side-by-side with their co-residents. So for them, the Dominican Republic was a unique opportunity. We had 2 ORs going at the same time, with a senior resident in each room assisted by the junior residents, and Dr Kogan would run back and forth and help out wherever we needed help.

Sershon: It's worth mentioning that for the department to send 5 of us required a team effort from the residents back at Rush, who had to take on a lot more responsibility and cover a lot more patients in our absence. I don't think many other programs would allow about 20 percent of their residents to be gone at one time for a whole week.

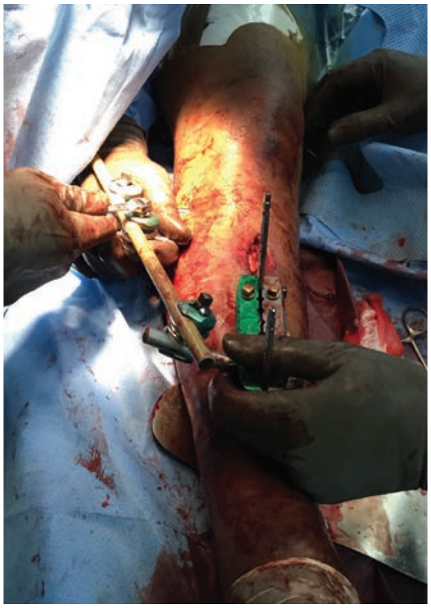
And I have to give props to Dr Kogan, because she was willing to do most of the logistical work and let us do the bulk of the clinical care. She was the one organizing all of the equipment, as well as troubleshooting in the OR or clinic. It's hard work supervising 5 residents at once, but she was very focused and energized and did a great job.

Q: What motivates you to do medical missions?

Sershon: Before our first trip in 2014, I had actually not given much thought to doing volunteer medical work outside of the US. I was fairly involved in Rush's local community outreach efforts during medical school and was of the opinion that there were plenty of underserved people in our own backyard. Why think about efforts elsewhere? When the opportunity to help out in the Dominican Republic presented itself, I thought I might as well give mission work a try before writing it off. I cannot tell you how happy I am that I made that decision.

The rate and degree of poverty, orthopedic pathology, and lack of access to care present in the Dominican Republic is far beyond anything I have witnessed in the US, where we have county systems, charity care, and other potential venues for people with serious orthopedic conditions to seek care. For many Dominicans, we are the only chance they may have for regaining a level of function that allows them to work and provide for their families. Our Dominican Republic patients are not concerned with aesthetics; they want functionality. In many ways, they are perfect patients. They have

The Rush team bringing supplies to Taiwan Hospital in Azua, Dominican Republic, in 2014.



Placement of a lower extremity external fixator for temporary fracture stabilization.

no secondary motives, are appreciative of our care, and will do whatever it takes to get back to being a productive member of society. Having the opportunity to help them do that is what motivates me to go on these trips.

Kelly: I agree. To be able to use your skills to treat people who otherwise probably wouldn't be able to receive care, and to know that you're making a tremendous difference in their lives is both gratifying and humbling. The people of Peralta were so grateful for the care we provided, and we feel fortunate to have the opportunity to help them.

Q: Do you feel your experiences on these trips have made you a better surgeon?

Sershon: There's no question. The amount of preoperative planning and intraoperative problem solving that takes place on this trip is impressive. It's during trips like this that you truly grasp the importance of a preoperative plan, AO principles for fracture reduction and fixation, extended exposures, and knowing multiple ways to approach and fix a problem. It has changed the way I prepare for cases at home, and has made me better appreciate the resources we have here.

Q: What was your most memorable case?

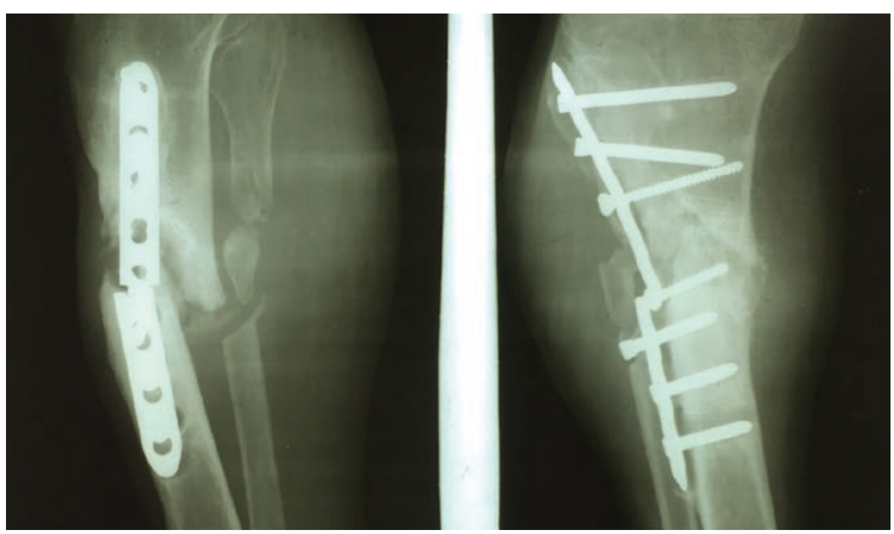
Kelly: In addition to the man I mentioned earlier who was attacked with a machete as a boy, there was one case that really highlights the challenges of not having proper equipment. We had to remove a femoral plate, and we had an extremely difficult time getting the screws out without the imaging and screw removal sets we'd normally be using. It took 3 residents and Dr Kogan about 7 hours—sweating the entire time—to remove the plate.

Sershon: One story is particularly memorable for me: the last surgery we performed during our 2014 trip. It was a patient with an impressive tibial malunion. He had previously undergone an intramedullary nailing for a midshaft fracture, and then fractured through the IM nail, resulting in a 90° malunion at the mid-shaft. Looking at him, you would think he had 2 knees. Unfortunately, this otherwise healthy man in his 30s was unable to perform any sort of manual labor.

As you mentioned earlier, Mick, in the Dominican Republic elective amputations are taboo, no matter how much impairment the limb may be causing. Although we offered to do a below knee amputation, the patient wanted us to attempt a corrective osteotomy with subsequent IM nailing using a Kuntscher nail. We explained the associated risks and difficulty of the procedure, but the patient trusted that we could pull it off.

All of the lower extremity surgeries are performed with spinal anesthesia, which gives us roughly 3 hours to complete any given procedure. As predicted, the osteotomy was extremely difficult, and at the 3-hour mark we were nowhere near completion. Around 3.5 hours, the patient's spinal had completely worn off. Then something unbelievable happened: The patient insisted that we continue. He lay perfectly still, and we were able to finish the surgery. For an entire hour, including the insertion of the tibial IM nail, the patient felt everything we did and continuously demanded that we keep going. I have never seen such toughness.

On our return trip in January 2016, Alfredo (our local host/guide) drove us past the place where this gentleman was now employed. I saw him walking around, working and laughing with his co-workers. Alfredo said the patient thanks him every time he sees him, and that he wishes nothing but the best for the doctors who gave him his life back. Now *that's* pretty cool.



Failed infected nonunion of a tibial plateau with broken hardware.

Kern Singh, MD, spine surgeon; Craig J. Della Valle, MD, hip and knee reconstruction and replacement surgeon; and Brian J. Cole, MD, MBA, sports medicine surgeon

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- Our faculty are innovators, conducting cutting-edge translational research on new treatments for musculoskeletal conditions.
- Our surgeons hold leadership positions in many nationally and internationally recognized orthopedic societies.
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