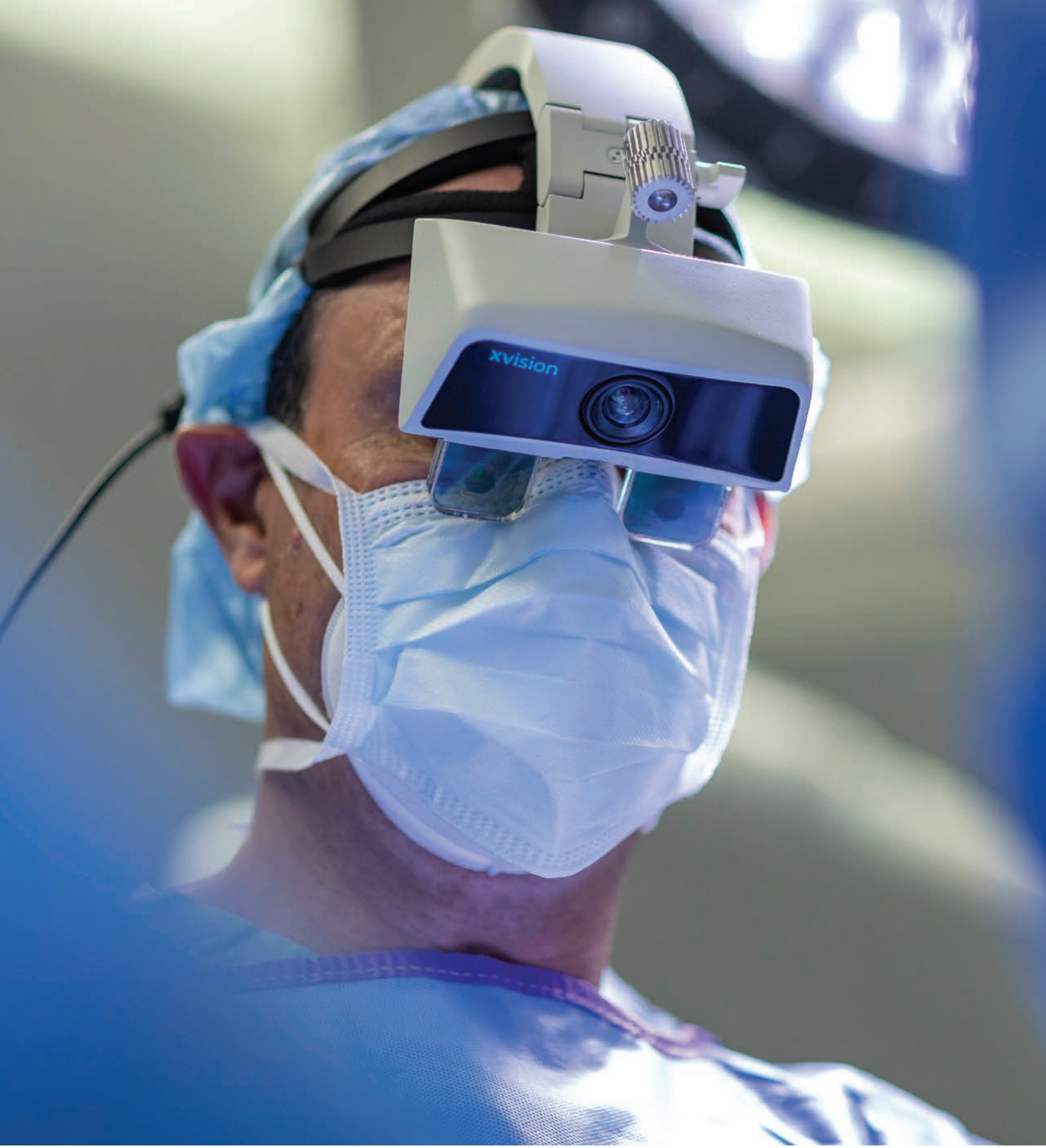
2020

Rush Orthopedics Journal

RUSH



VIRTUAL VIRTUOSO: Frank M. Phillips, MD, and his Rush colleagues are using augmented reality and 3D technology, along with big data to take spine surgery to the next level. Learn more on page 38.

Faculty Editors

Articles

To view the 2020 *Rush Orthopedics Journal* online or to view past issues of the journal, please visit www.rushu.rush.edu/orthojournal.

Chairman's Letter

It's not overstating to say that 2020 has been a year like no other, as our country has faced unprecedented adversity. It is telling that Rush University Medical Center making the *U.S. News & World Report* Honor Roll for the first time in its history and being named as one of the top 25 hospitals in the US by *Newsweek* was not the biggest story of the year for Rush.

I'm referring not only to the COVID-19 pandemic, but to the ongoing fight for racial justice, sparked by repeated incidences of violence against Black Americans. As I reflect on the impact of these crises, I'm extremely proud of how Rush University Medical Center has stepped up to address them—a response that is both saving lives and promoting racial justice.

The Medical Center was uniquely prepared to address COVID-19 long before the virus arrived in the US. When the Rush Tower opened in 2012, it became the first Chicago-area hospital specifically designed to provide treatment for a mass outbreak. With a large number of negative pressure rooms and multiple spaces that can be converted into high-volume screening spaces or isolation units, the Medical Center has been able to accommodate the surge of COVID-19 patients while keeping our non-COVID populations safe. And as a tertiary care center, the Medical Center has been able to care for the most critically ill COVID-19 patients, including those transferred from other hospitals.

As the community spread of COVID-19 took hold, Rush also fully leveraged and expanded its existing virtual care platform programs to drive patients to telehealth options. This included our orthopedic faculty. We were able to convert our entire department over to virtual visits within a matter of days, and our physicians continue to offer video visits as an option even though we are now seeing patients in our clinical spaces. Building on the success of these initial responses, both the Medical Center and our department have been well prepared to handle the recent rise in COVID-19 cases. In the months ahead, we will continue adapting as needed to keep our patients safe while they receive care from our providers.

And while Rush University Medical Center has always had a robust research entity, research has never been more important than during this pandemic. The country, and the world, are depending on the research apparatus to understand the disease, devise diagnostic tests that can be broadly implemented, and develop effective prevention and treatment strategies. In this arena, too, the Medical Center has been a leader nationally, with studies looking at early predictors of severe respiratory failure in COVID-19 patients, remdesivir as a potential treatment, and a COVID-19 vaccine, among others.

It's not lost on Rush leadership that COVID-19 is disproportionately affecting underserved and underresourced patient populations—including our West Side neighbors. As part of its response, the Medical Center created a multidisciplinary Racial Justice Committee to further our efforts to ensure racial justice within and outside of Rush's walls, including identifying new ways that we all can work together to advance health equity. Rush is also part of a collaborative that received a $5 million grant from the Oprah Winfrey Charitable Foundation to accelerate efforts to decrease COVID-19 death rates in Chicago's predominately Black and Latino communities.

The research and accomplishments highlighted in these pages remind us that even amidst a pandemic and protests, we as orthopedic physicians remain committed to serving the needs of our patients—and to finding innovative ways to do it. From augmented reality spine surgery to 3D models for surgical oncology planning, our faculty are doing the sort of groundbreaking work that inspired our No. 5 *U.S. News & World Report* ranking for orthopedics this year. I'm honored to share a sampling of this work with you.

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

Faculty Highlights

New appointments: In 2020, **Brian J. Cole, MD, MBA,** was named the Dr. Ralph and Marian C. Falk Professor of Biochemistry; **Frank M. Phillips MD,** was named the Ronald L. DeWald, MD, Endowed Professor of Spinal Deformities; **Anna Spagnoli, MD,** was named the John W. and Helen H. Watzek Professor of Biochemistry; **Katalin Mikecz, MD, PhD,** was named the Jorge O. Galante, MD, DMSc, Professor of Orthopedic Surgery; and **Nadim J. Hallab, PhD,** was named the Crown Family Professor of Orthopedic Surgery.

Spagnoli, an internationally recognized physician-scientist in the field of regenerative medicine and connective tissue biochemistry for bone and cartilage diseases, returned to Rush in January 2020 (she previously held the Woman's Board Chair of Pediatrics) as a professor in the Department of Orthopedic Surgery and director of the Section of Molecular Medicine.

Adding excellence through recruitment. Nationally recognized concussion expert **Elizabeth Pieroth, PsyD, ABPP,** joined Rush in January 2020 to head up the new multidiscplinary **Rush Concussion Program.** Pieroth, a board certified clinical neuropsychiatrist, has been involved in the assessment of players in the NHL since 1997; is the head injury/concussion specialist for the Chicago Bears, Chicago Blackhawks, Chicago White Sox, Chicago Fire, and National Women's Soccer League; and is co-director of the NFL Neuropsychology Consulting Program. The concussion program focuses on early intervention and active rehabilitation to optimize recovery.

Also joining Rush in 2020: **Vasili Karas, MD,** a hip and knee replacement surgeon who completed his fellowship training at Rush; **Craig Best, DO,** a board-certified physical medicine and rehabilitation/interventional pain medicine specialist who provides comprehensive nonsurgical spine care; and **Michael Kluppel, PhD,** a scientist and laboratory manager who is working with Anna Spagnoli, MD.

STEM success story. **Monica Kogan, MD,** director of the Section of Pediatric Orthopedic Surgery, was chosen to be among the 2020 Notable Women in STEM by *Crain's Chicago Business*. The list recognizes accomplished women who represent different corners of the STEM world and are committed to bringing more women into traditionally male-dominated STEM fields. Kogan is associate chief medical officer for surgical services and associate professor at Rush. In 2018, she was one of two Rush physicians to receive the Carol Emmott Fellowship, which aims to increase the disparities in health care leadership by women.

Excellence in arthritis care. **Craig J. Della Valle, MD,** received the Rowland W. Chang, MD, MPH, Award of Excellence at the Arthritis Foundation's 2019 Freedom of Movement Gala. Della Valle, the Aaron G. Rosenberg, MD, Endowed Professor of Orthopaedic Surgery and chief of the Section of Adult Reconstruction at Rush, was recognized for his years of commitment to the Arthritis Foundation.

Honoring a remarkable research career. Department of Orthopedic Surgery Chairman **Joshua J. Jacobs, MD,** received the 2020 ORS/OREF Distinguished Investigator Award from the Orthopaedic Research Society. The award honors an individual who has compiled a long record of innovative research; demonstrated outstanding mentorship of research trainees and service to the professional community; and exemplified academic collegiality.

Woman of influence. **Kathleen Weber, MD, MS,** director of Primary Care Sports Medicine and Women's Sports Medicine, was named one of 25 "Women of Influence" by the *Chicago Business Journal* and *Bizwomen* for 2019. Weber is the head primary care sports medicine team physician for the Chicago Bulls and White Sox; co-head team physician for the DePaul Blue Demons; and the physician for Hubbard Street Dance and River North Dance. She has also been involved with the MLB Medical Advisory Board and was the first women elected President of the MLB Team Physicians Association.

Forty under 40. **Alan T. Blank, MD, MS,** was named among *Crain's Chicago Business* "40 Under 40" for 2019 and 2020. Blank, an assistant professor at Rush, specializes in malignant and benign primary musculoskeletal growths, metastatic bone disease, and performing limb salvage surgery in adult and pediatric patients. He is leading the nascent field of 3D modeling in orthopedic oncology.

Coordinating COVID-19 antibody testing. In March, Major League Baseball (MLB) participated in a joint epidemiology study to try to identify the prevalence of COVID-19 in the population. An estimated 10,000 employees from 27 MLB teams were tested for COVID-19 antibodies using finger prick tests. **Nikhil N. Verma, MD,** director of the Section of Sports Medicine and head team physician for the White Sox, helped coordinate the testing. "We've been hearing about so many minimally symptomatic or asymptomatic cases," Verma says. "So the question is: How many people really have antibodies or have some history of exposure to this problem?"

Continued on page 30

Orthopedic Excellence

No. 5 in the Nation. The orthopedics program at Rush University Medical Center is ranked No. 5 in the nation and best in Illinois by *U.S. News & World Report* and has been ranked in the top 10 for 8 consecutive years. In addition, the Medical Center was rated high performing for hip replacement and knee replacement.

Chicago's Top Doctors. Four Rush University Medical Center orthopedic physicans were named among the "Top Doctors" in the January 2020 issue of *Chicago* magazine: **Bernard R. Bach, Jr, MD,** and **Charles A. Bush-Joseph, MD** (sports medicine); **Mark S. Cohen, MD** (hand surgery); and **Joshua J. Jacobs, MD** (orthopedic surgery).

Presidential Prestige. Brian J. Cole, MD, MBA, was named president of the Arthroscopy Association of North America for the 2020-21 term. Cole is associate chairperson of the Department of Orthopedic Surgery and director of the Rush Cartilage Restoration Center. **Frank M. Phillips, MD,** was named president of the International Society for the Advancement of Spine Surgery for 2020-21. Phillips is director of the Division of Spine Surgery and the Section of Minimally Invasive Spine Surgery.

PRO FOOTBALL HALL OF FAME
CANTON, OHIO

HALL OF FAME
HEALTH

Hall of Fame Providers: In October, the National Football League's new Hall of Fame Health program selected Midwest Orthopaedics at Rush (MOR) as one of its preferred providers. This new program offers vital services, including health care, insurance plans, and advice to any former NFL player or team employee, and their families. MOR is one of a dozen partner providers nationwide, and the only one in Illinois and Indiana.

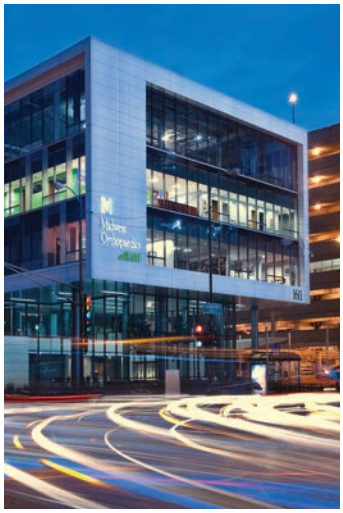
Volume and Quality Data

Attending physicians
51

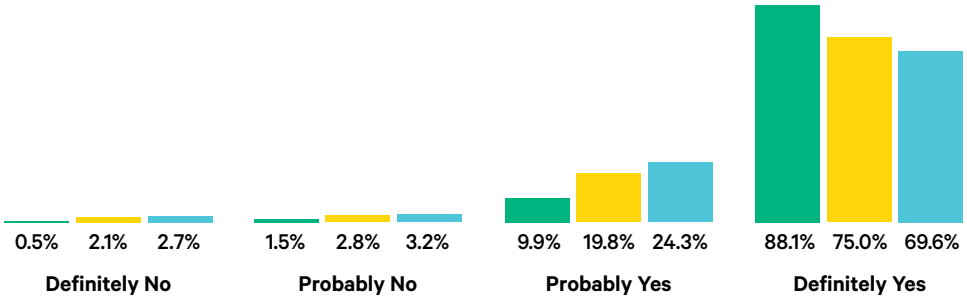
Research faculty
30

Residents and fellows
48

Advanced practice nurses and physician assistants
69



Patient satisfaction (for orthopedics providers surveyed), FY20



Recommend this hospital?

Rush | Vizient peer group (232 hospitals) | All Illinois hospitals (102 hospitals)

Source: Press Ganey

Mean length of stay (days), observed, FY20

14-day readmission rate (%), FY20

Rush | Illinois Vizient hospitals | US Vizient hospitals

For orthopedics cases. Source: Vizient

Mortality rates, FY20

Cases	2,828
Observed Mortality (%)	.07
Expected Mortality (%)	.19
Observed/Expected Ratio	.37

For orthopedics cases. Source: Vizient

Orthopedic Faculty and Fellows

ADULT RECONSTRUCTIVE SURGERY

Craig J. Della Valle, MD – Division Director; Director, Section of Research

Richard A. Berger, MD – Director, Section of Minimally Invasive Surgery

Tad L. Gerlinger, MD – Director, Adult Reconstructive Orthopedic Surgery Fellowship Program

Joshua J. Jacobs, MD – Chairman, Department of Orthopedic Surgery

Vasili Karas, MD, MS

Brett Levine, MD, MS

Denis Nam, MD

Wayne G. Paprosky, MD

Aaron G. Rosenberg, MD

Scott M. Sporer, MD, MS – Director, Section of Quality and Outcomes

Fellows (residency programs)

Kimberly Bartosiak, MD (Washington University St. Louis)

Prashoban Bremjit, MD (University of Washington)

Anthony Boniello, MD (Thomas Jefferson University Hospital)

Darren Plummer, MD (The Ohio State University)

Michael Ransone, MD (Carolinas Medical Center – OrthoCarolina)

Ali Sobh, MD (Beaumont Health System)

ELBOW, WRIST, AND HAND SURGERY

Mark S. Cohen, MD – Section Director

John J. Fernandez, MD

Xavier C. Simcock, MD

Robert W. Wysocki, MD

Hand, Upper Extremity, and Microvascular Fellow (residency program)

Matthew Winterton, MD (Hospital of the University of Pennsylvania)

FOOT AND ANKLE SURGERY

George Holmes Jr, MD – Section Director

Simon Lee, MD

Johnny L. Lin, MD

Fellow (residency program)

Emily Zhao, MD (University of Pittsburgh Medical Center)

NEUROPSYCHOLOGY

Elizabeth Pieroth, PsyD, ABPP – Director, Rush Concussion Program

ONCOLOGY

Steven Gitelis, MD – Section Director

Alan T. Blank, MD, MS

Matthew W. Colman, MD

ORTHOPEDIC TRAUMATOLOGY

Joel Williams, MD

PEDIATRIC ORTHOPEDIC SURGERY

Monica Kogan, MD – Section Director; Director, Orthopedic Surgery Residency Program

SPINE SURGERY

Frank M. Phillips, MD – Division Director; Section Director, Minimally Invasive Spine Surgery

Howard S. An, MD – Director, Spine Surgery Fellowship Program

Gunnar B. J. Andersson, MD, PhD

Matthew W. Colman, MD

Christopher DeWald, MD – Section Director, Spinal Deformity

Edward J. Goldberg, MD

Kim W. Hammerberg, MD

Gregory Lopez, MD

Kern Singh, MD

Fellows (residency programs)

Augustus Rush, MD (Jackson Memorial Hospital, Jackson Health System)

Nicholas Shepard (NYU Langone Orthopedic Hospital)

Thomas B. Sullivan (University of California, San Diego)

SPORTS MEDICINE, SURGERY

Nikhil N. Verma, MD – Division Director; Director, Section of Clinical Research

Bernard R. Bach Jr, MD

Charles A. Bush-Joseph, MD

Jorge Chahla, MD

Brian J. Cole, MD, MBA – Director, Rush Cartilage Restoration Center; Associate Chairman for Academic Affairs

Brian Forsythe, MD

Grant E. Garrigues, MD

Shane J. Nho, MD, MS – Director, Section of Young Adult Hip Surgery

Gregory Nicholson, MD – Director, Section of Shoulder and Elbow Surgery

Adam B. Yanke, MD, PhD – Associate Director, Rush Cartilage Restoration Center

SPORTS MEDICINE, SURGERY, cont.

Fellows (residency programs)

Blake Bodendorfer, MD (Georgetown University Medical Center)

Steven DeFroda, MD (Brown University/Rhode Island Hospital)

Benjamin Kester, MD (New York University Langone Orthopedic Hospital)

Derrick Knapik, MD (University Hospitals)

Nicholas Trasolini, MD (LAC+USC/Keck Medical Center)

Shoulder Fellow

Ryan Quigley, MD (Baylor College of Medicine)

SPORTS MEDICINE, PRIMARY CARE

Kathleen Weber, MD, MS – Director, Primary Care/Sports Medicine Program

Jeremy Alland, MD

Joshua Blomgren, DO

Julie Bruene, MD

Leda A. Ghannad, MD

Nicole Levy, MD

John (Jack) Nickless, MD

Fellow (residency program)

Caitlin Nicholson, MD (Hospital of the University of Pennsylvania)

ORTHOPEDIC PHYSICAL MEDICINE AND REHABILITATION

Divya Agrawal, MD

Craig Best, DO

Madhu K. Singh, MD

Research Faculty

THE ROBBINS AND JACOBS FAMILY BIOCOMPATIBILITY AND IMPLANT PATHOLOGY LABORATORY

Deborah J. Hall – Director, Implant Retrieval Laboratory

Robin Pourzal, PhD – Director, Implant Material Analysis

Thomas M. Turner, DVM

BIOMATERIALS LABORATORY

Nadim J. Hallab, PhD – Director

Anastasia Skipor, MS – Manager, Trace Metal Ion Laboratory

COMPUTATIONAL BIOMECHANICS LABORATORY

Hannah J. Lundberg, PhD – Director

THE JOAN AND PAUL RUBSCHLAGER MOTION ANALYSIS LABORATORY

Markus A. Wimmer, PhD – Director; Associate Chairman for Research

SECTION OF MOLECULAR MEDICINE

Anna Spagnoli, MD – Director; John W. and Helen H. Watzek Professor; Pediatrics, Orthopedic Surgery

Gabrielle Cs-Szabo, PhD

Jian Huang, PhD

Michael Kluppel, PhD

Adrienn Markovics, MD, PhD

Katalin Mikecz, MD, PhD

Chundo Oh, PhD

Jeffrey P. Oswald, DVM, DALCLAM – Section Director, Comparative Research Center

Lan Zhao, PhD

Ke Zhu, PhD

SPINE RESEARCH LABORATORY

Spine biomechanics

Nozomu Inoue, MD, PhD – Director

Anna Chee, PhD

Alejandro A. Espinoza-Orías, PhD

Phil Malloy, PT, PhD

Dino Samartzis, DSc

THE JOAN AND PAUL RUBSCHLAGER TRIBOLOGY LABORATORY

Markus A. Wimmer, PhD – Director; Associate Chairman for Research

Alfons Fischer, PhD

Joachim Kunze, PhD

Thomas M. Schmid, PhD

ASSOCIATED FACULTY AT RUSH UNIVERSITY MEDICAL CENTER

Susan Chubinskaya, PhD – Pediatrics, Orthopedic Surgery, and Medicine

Jun Li, MD – Internal Medicine, Rheumatology

Carl Maki, PhD – Cell & Molecular Medicine

Anna Plaas, PhD – Internal Medicine, Rheumatology

D. Rick Sumner, PhD – Director, Section of Bone & Cartilage Biology

Department of Orthopedic Surgery Residents

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

Class of 2023

Robert Browning, MD
Medical school – Medical University of South Carolina

Robert Burnett, MD
Medical school – University of Iowa Roy J. and Lucille A. Carver College of Medicine

Edward Hur, MD
Medical school – University of Michigan Medical School

Nabil Mehta, MD
Medical school – The Warren Alpert Medical School of Brown University

Elizabeth Terhune, MD
Medical school – Georgetown University School of Medicine

Class of 2024

Michael P. Fice, MD
Medical school – Rush Medical College

Tai Holland, MD
Medical school – University of Iowa

Obianuju Obioha, MD
Medical school – University of Pittsburgh

Joseph Serino, MD
Medical school – Georgetown University

Sarah Tepper, MD
Medical school – Washington University

Class of 2025

Vincent Federico, MD
Medical school – University of Florida College of Medicine

John Higgins, MD
Medical school – The Ohio State University

Johnathon McCormick, MD
Medical school – University of Miami Miller School of Medicine

Vince Morgan, MD
Medical school – University of Chicago, Pritzker School of Medicine

Shelby Smith
Medical school – Sidney Kimmel Medical College at Thomas Jefferson

"Most study results have shown encouraging outcomes after SCR in patients with these complex conditions..."

Update on Superior Capsular Reconstruction

Clinical Outcomes and Analysis of Failures

RON GILAT, MD / ERIC D. HAUNSCHILD, BS / BRADY T. WILLIAMS, MD / NOLAN CONDRON, BS / MICHAEL C. FU, MD
GRANT E. GARRIGUES, MD / ANTHONY ROMEO, MD / NIKHIL N. VERMA, MD / BRIAN J. COLE, MD, MBA

AUTHOR AFFILIATIONS

Department of Orthopedic Surgery (Drs Gilat, Williams, Fu, Garrigues, Romeo, Verma, and Cole and Messrs Haunschild and Condron), Rush University Medical Center; and Midwest Orthopaedics at Rush (Drs Garrigues, Romeo, Verma, and Cole), Chicago, Illinois; and Department of Orthopedic Surgery, Shamir Medical Center and Tel Aviv University, Tel Aviv, Israel (Dr Gilat).

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INTRODUCTION

Management of patients who have symptoms of an irreparable rotator cuff tear for whom conservative treatment has failed remains challenging.[1] Physicians have used many procedures to address rotator cuff deficiency, including partial repair,[2] debridement and subacromial decompression,[3,4] tuberoplasty,[5] reversed subacromial decompression,[6] muscle and tendon transpositions or transfers,[7-11] graft augmentation,[12,13] subacromial spacer implantation,[14] and reverse total shoulder arthroplasty (RTSA).[15] However, to date, no procedure has provided optimal and reliable outcomes in terms of pain relief and restoration of function.[1,16]

Arthroscopic superior capsular reconstruction (SCR) is a relatively new procedure for the treatment of irreparable rotator cuff tears. After Mihata et al[16] introduced SCR, many researchers have described surgical techniques for the procedure.[17-19] Most study results have shown encouraging outcomes after SCR in patients with these complex conditions, and surgeons worldwide increasingly are adopting the procedure.[16,20-26] As with many relatively new procedures, patient selection for SCR has not been defined optimally, and patient factors associated with treatment failure have yet to be studied extensively.

In this study, we aim to identify demographic, clinical, radiographic, and surgical factors associated with failure after SCR. We also will describe the clinical and functional outcomes in this subset of patients.

MATERIALS AND METHODS

Patient Population

After we received approval from Rush University Medical Center's institutional review board, we identified subjects through a database of prospectively collected data in patients who had undergone arthroscopic SCR with a dermal allograft between 2015 and 2018 at Rush. We included patients who had undergone SCR for an irreparable rotator cuff tear with a minimum 1-year follow-up. We excluded patients with anterior, posterior, or inferior instability; patients without 1-year follow-up; and patients with advanced osteoarthritis (Hamada grades 4b and 5[27]).

Data Collection

We recorded demographic characteristics and results of the preoperative physical examination. An orthopedic surgery resident (R.G.), who was blinded for review, performed imaging and measurements by means of a picture archiving and communications system (Opal-RAD PACS; Viztek, Garner, North Carolina). We recorded surgical details, including the presence of a subscapularis tear, technique details, and concomitant procedures. Clinical and functional outcomes included postoperative range of motion (ROM), patient-reported outcomes (PROs), and conversion to RTSA. We set a low threshold to define failure, including 1 or more of the following criteria: conversion to RTSA, a decrease in 1-year postoperative shoulder-specific PROs compared with preoperative scores, or patient

reporting at final follow-up that his or her shoulder was in worse condition than before surgery.

Operative Technique

We positioned patients in the beach chair position, draped the shoulder, and prepared in the usual sterile fashion. We then established posterior, anterior, and lateral portals and performed subacromial decompression and debridement of the superior labrum and the rotator cuff footprint. If necessary, we repaired the infraspinatus, subscapularis, or both before performing the SCR. In most cases, we placed 3 knotless anchors medially on the glenoid and 2 anchors just lateral to the humeral head articular margin at the medial edge of the rotator cuff footprint. We performed measurements and prepared an acellular dermal allograft on the back table (Figure 1). After preparing the graft, we passed it into the joint (Figure 2) and secured it to the anchors by using sutures medially and suture tapes laterally, and then we placed 2 lateral row anchors. We then placed side-to-side sutures to close the interval between the graft and the infraspinatus and subscapularis where possible (Figure 3).

Statistical Analysis

We performed univariate logistic regression analysis (Stata version 13.0; StataCorp, College Station, Texas) to assess the association between the failure criteria and each of the demographic, imaging, and operative variables. We performed additional analysis for statistically significant continuous variables associated with failure by using receiver operating characteristic (ROC) curve analysis and the Youden index to define the optimal cutoff point. We assessed differences between preoperative and postoperative active ROM, American Shoulder and Elbow Surgeons (ASES), Constant, and 12-Item Short Form Health Survey (SF-12) scores by using the paired student *t* test.

Figure 1. Preparation of the Dermal Allograft on the Back Table.

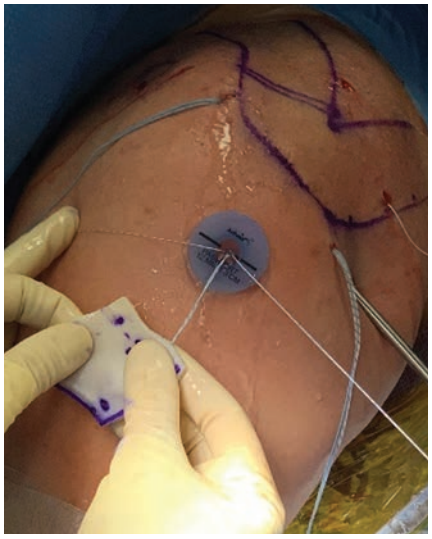

Figure 2. Preparation for Graft Passage Into the Shoulder Joint. Before passing the graft, we cut the cannula with scissors to allow the graft easy passage. We also used a back grasper to facilitate graft passage to the joint and assist in the appropriate positioning of the graft.

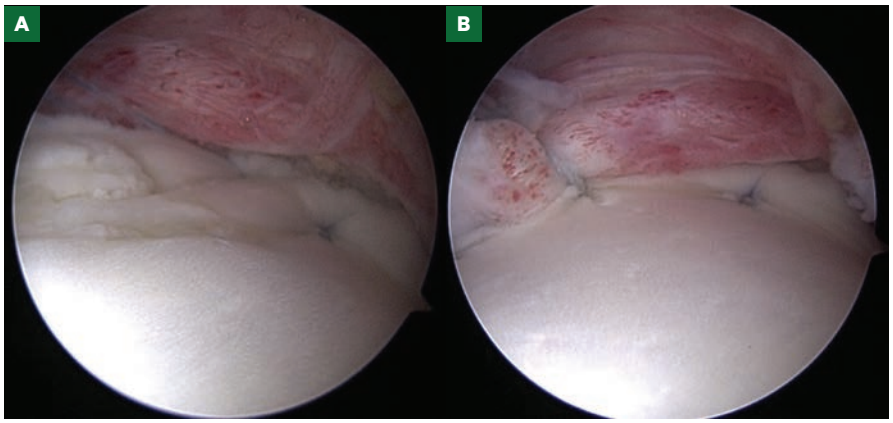

Figure 3. Arthroscopic View. **A,** A completed superior capsular reconstruction with a dermal allograft. **B,** Side-to-side sutures allowing marginal convergence between the remnant rotator cuff tissue and the dermal allograft.

RESULTS

Patient Demographic Characteristics

We included in the study 44 patients (mean [SD] age, 56.7 [5.6] years; range, 46-70 years) who had undergone SCR, with minimum 1-year follow-up. Mean follow-up after surgery was 19 months (range, 12-43 months). There were 13 (29.5%) smokers and 17 (38.6%) patients with a workers' compensation claim. Of the 24 (54.5%) patients who had undergone rotator cuff repair (RCR) that failed, 10 (22.7%) had undergone biceps tenodesis during primary RCR (Table 1).

Table 1. Demographic Characteristics

Characteristic	Patient Data (N = 44)
Age, Mean (SD), y	56.7 (5.6)
Sex, No. (%)	
Female	14 (31.8)
Male	30 (68.2)
Affected Side, No. (%)	
Right	23 (52.3)
Left	21 (47.7)
Dominant hand affected	21 (47.7)
BMI, Mean (SD), kg/m^2	30.7 (5.5)
Workers' Compensation Claim, No. (%)	17 (38.6)
Prior Health Conditions, No. (%)	
Smoking	13 (29.5)
Hypertension	16 (36.4)
Diabetes	6 (13.6)
Prior Surgical Procedure, No. (%)	
None	20 (45.5)
RCR[a,b]	14 (31.8)
RCR+BT[c]	10 (22.7)

Abbreviations: BMI, body mass index; BT, biceps tenodesis; RCR, rotator cuff repair.
[a]One patient had undergone biceps tenotomy, and 1 patient had undergone biceps tenotomy and distal clavicle excision.
[b]At the time of superior capsular reconstruction, 6 (13.6%) patients had an absent biceps tendon, with unknown status of tenodesis, tenotomy, or prior rupture.
[c]One patient had undergone concomitant distal clavicle excision, 1 patient had undergone revision RCR, 1 had undergone 2 revision RCRs, and 1 had undergone manipulation and capsular release.

Imaging Findings, Measurements, and Classifications

The average acromiohumeral distance (AHD) was 5.25 mm. Sixteen (36.4%) patients had signs of acromioclavicular joint arthritis. Radiographic imaging was not available for 1 patient, and of the remaining 43 patients, 8 (18.6%) had signs of some glenohumeral arthritis, with Hamada grade 3 in 7 (16.3%) patients and Hamada grade 4a in 1 (2.3%) patient. Assessment using magnetic resonance imaging (MRI) demonstrated the supraspinatus was torn in all 44 (100%) patients, the infraspinatus was torn in 22 (50%) patients, and the subscapularis was torn in 9 (20.5%) patients (Table 2).

ROM

Mean preoperative active ROM for forward flexion, abduction, and external and internal rotation are detailed in Table 3. There was no statistically significant difference in preoperative vs postoperative ROM, including forward flexion, abduction, and external and internal rotation (P = .53, .87, .75, and .14, respectively).

Outcomes

Thirty-two (73%) patients had a minimum of 1 year of completed PROs for analysis. Mean ASES scores improved from 47.4 preoperatively to 65.5 by 6 months postoperatively (P < .001), with further statistically significant improvement seen from 6 to 12 months (65.5-68.3; P = .01). Mean Constant and SF-12 Physical Health scores also showed significant improvement between preoperative and 6-month scores (12.6-17.1; P = .002, and 32.3-35.4; P = .04, respectively). Although mean scores continued to trend toward further improvement at 12 months, the increase was not statistically significant (P = .24 and .11, respectively) (Table 4).

Factors Associated With Failure

Ten patients (22.7%) met the criteria for clinical failure. Of these, 3 patients had undergone RTSA in the 6 to 12 months after SCR, 1 of whom experienced complications due to subsequent prosthetic dislocation.

We examined 28 factors for their association with failure. Lower preoperative active forward flexion was associated with failure (P = .041). ROC curve analysis revealed an area under the curve of 0.64 (95% CI, 0.396-0.879) (Figure 4). The optimally predictive cutoff point was 110°; patients with less than 110° preoperative forward elevation experienced failure more frequently (sensitivity, 60%; specificity, 81.25%; P = .018).

Of the 44 patients, 9 had a subscapularis tear. Of the 34 patients who had a successful SCR, 5 patients had a

Table 2. Imaging Findings, Measurements, and Classifications

Characteristic	Patient Data (N = 44)
Mean Acromiohumeral Distance, mm	5.25
Acromioclavicular Joint Arthritis, No. (%)	16 (36.4)
Hamada Classification Grade, No. (%)	(n = 43)[a]
1	27 (62.8)
2	8 (18.6)
3	7 (16.3)
4a	1 (2.3)
Tears, No. (%)	
Supraspinatus	44 (100)
Infraspinatus	22 (50)
Subscapularis	10 (24.4)
Goutallier Classification Grade, No. (%) [a,28]	
0	1 (2.4)
1	4 (9.8)
2	12 (29.3)
3	13 (31.7)
4	11 (26.8)
Thomazeau Classification Grade, No. (%)[b,29]	
1	14 (34.1)
2	15 (36.6)
3	12 (29.3)

[a]Radiographic imaging was not available for 1 patient.
[b]We performed Goutallier classification with MRI and not computed tomography, as first described by Goutallier.[28] Three patients did not have imaging uploaded to our servers to allow classification.

Table 3. Preoperative and Postoperative Active ROM

Action	ROM		*P* Value
	Preoperative	**Postoperative**	
Forward Flexion, Mean (SD)	138.2° (41.1)	142° (36.3)	.53
Abduction, Mean (SD)	107.5° (45.8)	102.1° (30.8)	.87
External Rotation, Mean (SD)	48.9° (15.1)	50.5° (14.5)	.75
Internal Rotation, Mean (range)	~L2 (T8-S1)	~L1 (T7-S1)	.14

Abbreviation: ROM, range of motion

Table 4. Preoperative and Postoperative Patient-Reported Outcome Scores

Survey Instrument	Preoperative	6 Months	12 Months
ASES	47.4	65.5[a]	68.3[a]
Constant	12.6	17.1[a]	20.0
SF-12 Physical Health	32.3	35.4[a]	40.3
SF-12 Mental Health	53.3	56.1	52.1

Abbreviations: ASES, American Shoulder and Elbow Surgeons; SF-12, 12-Item Short Form Health Survey.
[a]Statistically significant increase when compared with preoperative or 6-month postoperative scores.

subscapularis tear (14.7%), all of which we repaired. Of the 10 patients whose surgery failed, 4 had a subscapularis tear (40%). Of these tears, we repaired 3. We determined that the presence of a subscapularis tear at preoperative MRI or diagnosed during the procedure was associated with failure (P = .027). All other variables included in the analysis were not associated with failure in a statistically significant way.

DISCUSSION

The main findings of this study are that limited preoperative forward flexion and the presence of a subscapularis tear are associated with failure after arthroscopic SCR. We also report a significant improvement in PROs in this cohort of patients, supporting earlier outcome studies of arthroscopic SCR.

Two recently published systematic reviews evaluated the efficacy and complication rates of SCR for irreparable rotator cuff tears. Catapano et al[20] included 7 published articles and 3 abstracts, reporting on a total of 350 shoulders, with a mean follow-up of 20.6 months. The authors found a significant improvement in PROs in all studies. They also reported a combined radiographic and clinical failure ranging between 3.4% and 36.1%. This study's results also showed a statistically significant improvement in PROs. Although ROM for active forward flexion and external rotation improved after SCR, the difference was not statistically significant. Our clinical failure rate was 22.7% and is well within the range of the studies included in the systematic review by Catapano et al.[20]

Sochacki et al[30] performed a similar systematic review, reporting improvement in PROs and ROM. They reported a 14.2% graft failure at MRI, 3.8% complications, and an 11.7% reoperation rate. However, the results of this systematic review should be appreciated with the understanding that patients included

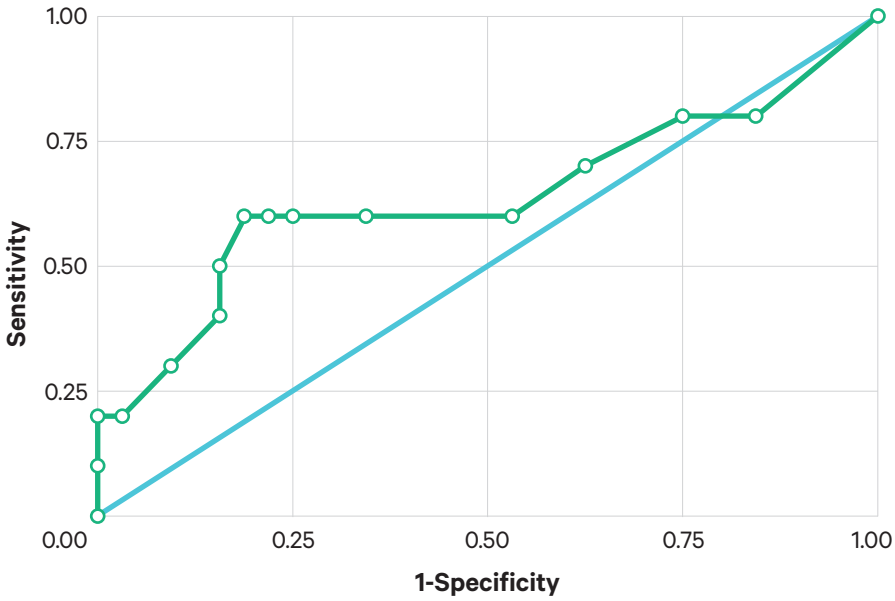

Figure 4. Receiver operating characteristic curve for preoperative active forward elevation association with failure after superior capsular reconstruction.

those undergoing SCR with autologous fascia lata, as well as those receiving an acellular dermal allograft.[31]

Studies in which the authors reported on factors associated with SCR failure are limited. Lee and Min[22] studied the effect of an inadequate increase in AHD after SCR and poor posterior remnant tissue on retear rates. They included 32 patients (36 shoulders) who had undergone arthroscopic SCR by using either fascia lata autograft or dermal allograft. They reported 13 (36%) retears diagnosed by means of ultrasonography and MRI and found retears to be associated with small AHD improvement and poor posterior remnant tissue. Denard et al[21] published preliminary results of a case series of 59 patients undergoing arthroscopic SCR with a dermal allograft. On the basis of postoperative MRI, they found that subscapularis atrophy was lower in the group of patients with a healed graft.

In our study, we focused on patient factors associated with clinical outcomes rather than on radiographic outcomes. We found lower preoperative active forward flexion and the presence of a subscapularis tear to be associated with failure. These results are consistent with those of the study published by Denard et al,[21] which showed that preoperative subscapularis atrophy was associated with a higher rate of graft tearing with postoperative MRI surveillance.

Lastly, this study provides a statistically significant (P = .018) cutoff point of 110° forward flexion, under which patients might be at an increased risk of treatment failure after SCR with a dermal allograft. However, the area under the curve of our ROC analysis was 0.64, which is below the acceptable value of assessing ROC model reliability (0.7).[32] Thus, this cutoff should be regarded as suggestive only.

The main limitation of the current study is the relatively small sample size. However, the number of patients in this study is comparable with that of most studies published on this relatively new surgical procedure. Another limitation is the lack of 1-year PROs for several study patients. However, all patients in the study group had a minimum 1-year follow-up with their physician, reporting on the status of their shoulder. Also, our PRO compliance rate is still relatively high (73%), and that is without including 3 patients who had undergone arthroplasty and were not relevant for 1-year PROs. Although a minimum 1-year follow-up is considered short term, we believe most failures that are not related to progression of arthropathy occur during this period, similar to failures after RCR.

CONCLUSIONS

SCR is a successful procedure in most cases, demonstrating high satisfaction rates and a steady increase in PROs. Limited preoperative forward flexion and the presence of a subscapularis tear are associated with increased risk of failure after SCR. We need further high-quality studies to substantiate these preliminary findings. ✤

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

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"We sought to determine where our single-center, high-volume NCI-designated sarcoma division appropriately complied with NCCN guidelines for bone sarcoma and STS."

Compliance of a Sarcoma Service with National Comprehensive Cancer Network (NCCN) Guidelines

A Retrospective Review

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INTRODUCTION

In the United States there are approximately 10 000 new cases of soft-tissue and bone sarcomas diagnosed and treated annually.[1] Because of the rarity of these malignancies, many health care providers are unfamiliar with the appropriate diagnostic and treatment courses required. However, specialized centers have within their institution a more experienced, multidisciplinary team, which is better able to address the complex needs of patients with these conditions. The National Cancer Institute (NCI) has identified various centers throughout the country as designated cancer institutes based on volume and quality of care. These centers treat high volumes of patients with sarcoma and are therefore proficient in all facets of sarcoma care. The National Comprehensive Cancer Network (NCCN) has produced a series of evidence- and consensus-based guidelines for appropriate workup and treatment for many categories of malignancy, including bone sarcoma and soft-tissue sarcoma (STS).[2,3] These guidelines are also important for high- and low-volume treatment centers (NCI designated or not) to achieve uniform quality of care. In a number of published series, researchers have examined compliance with NCCN guidelines,[4-10] and the results of these studies have shown a positive association between compliance and clinical outcomes.[11-16]

Sarcomas of bone and soft tissue are rare, and our group believes that NCCN guideline compliance is crucial for optimizing workup and treatment of patients with this diagnosis. We sought to determine whether our single-center, high-volume NCI-designated sarcoma division appropriately complies with NCCN guidelines for bone sarcoma and STS. We also sought to uncover errors in compliance, including where the errors occur, and whether improvements to our practice might benefit overall treatment of patients with sarcomas.

MATERIALS AND METHODS

Patients and Methods

We prospectively followed a cohort of patients with sarcoma from August 2016 to February 2017 at Rush University Medical Center, a high-volume, tertiary academic center with extensive sarcoma experience. We collected clinical data, including diagnoses, imaging and procedures performed, adjuvant treatments received, and discussions from a weekly multidisciplinary care conference. After data collection, we reviewed each patient's workup and treatment course to determine whether health care providers performed the

appropriate imaging, procedures, and/or adjuvant treatments per the NCCN guidelines. We also assessed used of a multidisciplinary care conference for discussion of specific diagnoses.

We present data as frequencies and percentages of total diagnoses, staging, treatment guideline protocols used, and treatment recommendations made. We represent compliance as the overall percentages for each respective category, as well as in percentages relative to the overall NCCN treatment guidelines.

Following institutional review board approval, we retrospectively reviewed prospectively collected data from patients seen within the orthopedic oncology outpatient setting. We included patients who presented to our sarcoma clinic without a prior diagnosis of sarcoma and subsequently began their workup and treatment within our clinic. We included diagnoses of bone sarcoma and STS, giant cell tumor (GCT) of bone, and desmoid tumors, choosing these diagnoses because they exist within the published NCCN guideline protocols. We excluded patients from the study if they had received therapy, including neoadjuvant or adjuvant radiation or chemotherapy, or surgical intervention, from an outside facility prior to presentation. We also excluded patients who were not included if they presented to the medical oncology clinic within our NCI center to begin workup, rather than to the orthopedic oncology clinic. Finally, we excluded patients if they were lost to follow-up or decided to seek further care from another provider. We performed descriptive statistics by using software (Stata/IC, version 16.0; StataCorp, College Station, Texas).

Table 1. Characteristics in Study Group

Characteristic	Patients, No. (%) (N = 35)
Diagnosis	
GCT of bone	7 (20)
Undifferentiated pleomorphic sarcoma	4 (11)
Soft-tissue leiomyosarcoma	3 (9)
Liposarcoma	3 (9)
Extremity synovial sarcoma	3 (9)
Chondrosarcoma	3 (9)
Desmoid tumor	3 (9)
High-grade STS	2 (6)
Low-grade STS	2 (6)
Scalp STS	2 (6)
Angiosarcoma	1 (3)
Myxofibrosarcoma	1 (3)
Epithelioid sarcoma	1 (3)
NCCN Guidelines Used	
STS	
Extremity	18 (51)
Head	2 (6)
Desmoid tumor	3 (9)
Trunk	2 (6)
Bone	
GCT of bone	7 (20)
Chondrosarcoma	3 (9)
TNM Staging	
IA	3 (9)
IB	4 (11)
IIA	3 (9)
IIB	5 (14)
III	4 (11)
IV	5 (14)
IVA	1 (3)
No staging necessary	10 (29)

Abbreviations: GCT, giant cell tumor; NCCN, National Comprehensive Cancer Network; STS, soft-tissue sarcoma; TNM, tumor-node-metastasis.

RESULTS

From August 2016 to February 2017, 35 patients met inclusion criteria. Table 1 summarizes clinicopathologic and NCCN guideline. The most common diagnoses were GCT of bone (7 cases, 20%), undifferentiated pleomorphic sarcoma (4 cases, 11%), soft-tissue leiomyosarcoma (3 cases, 9%), liposarcoma (3 cases, 9%), extremity synovial sarcoma (3 cases, 9%), chondrosarcoma (3 cases, 9%), and desmoid tumor (3 cases, 9%). Miscellaneous diagnoses included high- and low-grade STS (4 cases, 12%), angiosarcoma (1 case, 3%), myxofibrosarcoma (1 case, 3%), scalp STS (2 cases, 6%), and epithelioid sarcoma (1 case, 3%). The most commonly used NCCN guideline protocols were STS extremity guidelines

(18 cases, 51%), GCT of bone guidelines (7 cases, 20%), STS desmoid guidelines (3 cases, 9%), and bone chondrosarcoma guidelines (3 cases, 9%). Miscellaneous guidelines included STS head guidelines and STS trunk guidelines. The most common tumor-node-metastasis (TNM) staging at time of diagnosis was IV (5 cases, 14%), IIB (5 cases, 14%), III (4 cases, 11%), and IB (4 cases, 11%). Ten cases (29%) of desmoid tumors and GCTs of bone required no formal malignancy staging. Physicians recommended surgery in 24 (68%) cases, radiation in 11 (32%) cases, and systemic therapy in 10 (29%) cases.

Table 2 shows performance in NCCN compliance categories. Health care providers performed primary site imaging in 35 cases (100%). They performed chest imaging in 34 (97%) cases, and full-body imaging in each of the 5 cases for which it was indicated (100%). Health care providers obtained tissue preoperatively in 34 (97%) cases. They reviewed images at a multidisciplinary treatment planning conference (TPC) in 34 (97%) cases. In TPCs, physicians specifically discussed histopathological findings in 33 (94%) cases and reviewed TNM staging and care plans in 35 (100%) cases. Health care providers appropriately followed NCCN guidelines in 33 (94%) cases, with the 2 exceptions being a delay in performing chest imaging in 1 patient with GCT and a failure to perform pre-resection tissue biopsy in 1 patient with long-standing enchondroma, which developed into chondrosarcoma.

DISCUSSION

The rarity of STS and bone sarcoma emphasizes the importance high-volume sarcoma centers in establishing the correct diagnosis and initiating appropriate treatment. These centers have the experience, infrastructure, and multidisciplinary expertise to appropriately manage bone sarcoma and STS and are a key factor to providing a higher quality of care. However, researchers find that data from international studies that attempt to evaluate the utility of these approaches are inconclusive.[17-23] Obstacles to adequate classification of sarcoma center multidisciplinary experiences include evolving treatment options across time, unclear definitions of what defines the team, and issues in creating a randomized controlled trial to assess its efficacy.[24,25] Regardless, multidisciplinary care has numerous theoretical advantages, including involvement of specialists in every facet of care while facilitating provider input from a variety of pertinent specialties.

From these and other studies in which investigators describe the efficacy of a multidisciplinary effort in directing patient care, the NCCN has created recommended guidelines for the treatment of various oncologic disorders.[2,3] The specific guidelines for different diagnoses are based on both the available literature in each specialty and the consensus of expert opinions.[26] Health care providers universally accept these guidelines as the standard of care, and international agencies have used the NCCN guidelines as a framework for their own treatment algorithms.[27] When in compliance with NCCN guidelines, a number of other oncologic specialties have shown successful outcomes, both oncologic and functional, as compared to instances of observed deviation from the guidelines.[4,6-10,28,29] Therefore, this study sought to evaluate the consistency of a high-volume sarcoma institution in abiding by these guidelines and identify shortcomings in its successful utilization. Our hope is that these data contribute to the body of evidence in support of NCCN guideline utilization for treatment of sarcoma.

Limitations to this study include the relatively small sample size. Although our sarcoma division is a high-volume center, outside health care providers worked up or treated a large number of presenting patients. We excluded these patients from the study because their workup and treatment courses are often more complex than those of patients who present to the division without prior care. While we obtained most data in a prospective fashion, we collected

Table 2. Clinic Performance in NCCN Compliance Categories

NCCN Guidelines Compliance Category	Compliance (%) (N=35)
Imaging	
Primary site	35 (100)
Chest	34 (97)
Full body	5 (100)[a]
Tissue Obtained Preoperatively	34 (97)
Multidisciplinary TPC Review	
Images	34 (97)
Histopathological findings	33 (94)
TNM stage	35 (100)
Plan of care	35 (100)
Treatment Guidelines Followed	33 (94)

Abbreviations: NCCN, National Comprehensive Cancer Network; TNM, tumor-node-metastasis; TPC, treatment planning conference.
[a]Guidelines indicated full-body imaging in only 5 of the 35 cases.

some data retrospectively, which limits the generalizability of the findings from this study. During retrospective data collection, we identified 1 patient with GCT in whom the appropriate chest imaging strategy was not followed. Quick identification allowed our team to rectify this shortcoming, and the patient subsequently received the appropriate imaging. However, we collected all data either prospectively or retrospectively within a few days, and therefore this study served as a real-time quality assessment tool that allowed the team to deliver care within the NCCN guidelines.

We enrolled 35 total patients, whose most common diagnoses were various forms of STS, GCT of bone, desmoid tumor, and chondrosarcoma. This pattern of diagnoses seems to be consistent with that of our adult orthopedic oncology practice overall. Because most patients had STS, we used the STS extremity guidelines most often, followed by GCT of bone guidelines, desmoid tumor guidelines, and finally chondrosarcoma guidelines. These findings align with the department's approximate understanding of exposure to and treatment of commonly encountered diagnoses. Given the high-volume nature of our service and similarity in infrastructure and multidisciplinary expertise to other institutions, we believe that these observed rates are comparable to those of any adult orthopedic oncology practice with an NCI-designated treatment center.

We performed full-body imaging in 100% of the 5 indicated cases and obtained tissue preoperatively in 34 (97%) cases. The single case that did not include a pre-resection tissue diagnosis involved an elderly patient with a long-standing history of a benign-appearing cartilaginous lesion of his proximal humerus. This patient came to us with images from an outside facility that showed the lesion. However, newer imaging results obtained in our clinic and clinical examination, showed an aggressive chondrosarcoma with a pathologic fracture. Because the diagnosis was quite clear, the multidisciplinary group came to the consensus that limb salvage with wide resection and reconstruction was the appropriate choice.

Physicians reviewed images at multidisciplinary TPC in 34 (97%) of all included cases, and histopathology in 33 (94%) of cases. Furthermore, physicians reviewed TNM staging and plan of care during TPC for all 35 cases (100%). Our multidisciplinary care conference prides itself on encouraging all members of the team to contribute to the conversation. We believe that participation allows the conference to address each patient's care in a more holistic manner. Ultimately, the clinic followed treatment guidelines in 33 (94%) of the 35 cases reviewed. The 2 cases of failed compliance included the aforementioned failure to perform chest imaging as prescribed in the GCT treatment guidelines and the lack of pre-resection tissue diagnosis for the chondrosarcoma of the proximal humerus. Overall, our clinic had a very high rate of compliance. Furthermore, we do not believe that these 2 errors affected the overall care of either patient. For example, the patient with GCT in whom we had omitted chest imaging benefitted from the subsequent identification of this shortcoming. Second, in the patient with longstanding enchondroma, a pre-resection tissue biopsy would not have changed the operative course of treatment for either the pathological fracture or wide margin resection and limb salvage for chondrosarcoma.

CONCLUSIONS

In this study, we evaluated the workup and treatment provided by a single-center, NCI-designated sarcoma service to a series of patients with diseases defined with the NCCN sarcoma treatment guidelines. At our sarcoma service, we saw a diverse range of disease, with GCT of bone and extremity STS being most common. Overall rates of performing appropriate imaging and biopsy were high (34-35 cases, 97%-100%), as was the rate of reviewing all pertinent information in a multidisciplinary TPC (33-34 cases, 94%-100%). Health care providers followed NCCN guidelines appropriately in 33 cases (94%), the exceptions being a delay in performing chest imaging in 1 patient and failure to perform pre-resection tissue biopsy in a case of long-standing enchondroma that progressed to chondrosarcoma. By following these NCCN guidelines, we believe that health care providers can optimize patient care and treat each case in an individually appropriate manner. Given larger patient enrollment and longer follow-up, investigators in future studies can evaluate whether diligently following these sarcoma guidelines leads to improved care. ✤

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

"Potential benefits of these technologies include reducing ionizing radiation exposure for patients and medical staff, reducing complications, and improving surgical outcomes."

The Utility of Virtual Reality and Augmented Reality in Spine Surgery

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INTRODUCTION

Training advances in spine surgery have provided new visual aid technologies such as virtual reality (VR) and augmented reality (AR). Virtual reality was conceived first in the 1960s,[1] with commercial use starting roughly 2 decades later.[2] Augmented reality is a more recent development and has a strong presence in learning and education in numerous professions. With many electronic companies such as Sony, HTC, and Facebook investing heavily in VR and AR technology, we expect AR to evolve rapidly. Cruz-Neira[3] has defined VR as an "immersive, interactive, multi-sensory, viewer-centered, 3D (3-dimensional) computer-generated environment." This synthetic world has demonstrated use in general surgery as a training aid for laparoscopy.[4] In 1995, Milgram et al[5] described AR as an environment that "augment[s] natural feedback to the operator with simulated cues." This mixed reality bridges the VR spectrum by combining technologies from VR and AR. Orienting real-world objects in space and time along with virtual objects distinguishes AR from VR.[6]

Surgeons have implemented simulation technology successfully in spine surgery involving the cervical spine,[7] thoracic spine,[8,9] and lumbar spine.[10] Applications for AR and VR also have provided benefits to specific operative techniques such as kyphoplasty,[11] pedicle screw placement,[9] foraminotomy,[12] and laminectomy.[12] Institutions are using VR more as an educational tool, providing trainees and experienced surgeons the opportunity to practice their technique in a safe environment. Potential benefits of these technologies include reducing ionizing radiation exposure for patients and medical staff, reducing complications, and improving surgical outcomes.

COMPONENTS OF AN AR SYSTEM

Descriptions of AR often entail virtual objects that are superimposed onto real-world objects so that the user can experience and manipulate both concurrently.[13] Synonyms for augmented reality include *computer-mediated reality* and *mixed reality*. In the surgical environment, AR consists of both hardware and software components. In the field of spine surgery, an AR system consists of 3 components: system-control software, a tracking system, and a display (Figures 1-4).[14] The AR tracking system maintains the relative position of anatomical structures and instruments within the operating field. The system then processes these data as an image that the surgeon can view and interact with through a display system (Figure 4).[15]

Augmented reality can be thought of as a tool to enhance the surgeon's experience in the operating room. An AR headset can overlay the surgeon's

visual field with a projection of important surgical information (Figure 1). This system can be compared to the heads-up displays that military pilots use to receive important instrument information without having to look down into the cockpit. In the operating room, however, this capability can project patient data and pre- and intraoperative imaging that allows the surgeon to "see through" the patient before creating any incisions (Figure 4). Pre- or intraoperative imaging can be obtained via computed tomography (CT) and then calibrated with the surgical field.

TRAINING APPLICATIONS

Kyaw et al[16] have defined VR as a technology that uses headsets and computer-generated multimedia to immerse the user in a 3-dimensional (3D) environment. Although physicians used early VR applications in many surgical fields,[17-20] there are limitations to VR advances within spine surgery.[12] Traditional approaches to surgical training involve the use of cadavers, a resource that can be very limited, expensive, and ethically challenging.[21] Although undergraduate anatomical dissections often involve dissecting cadavers in an unaltered state, surgical training typically involves removal, rearrangement, and altering a cadaver with metal pins, rods, or other implants.[22] In addition, surgical training can be associated with industry incentives and donations to supply the increased training demands for cadavers.[23] Virtual reality offers a potential way to circumvent this demand and avoid these concerns.

Figure 1. Pedicle Screw Placement Using Augmented Reality. Reprinted with permission from Augmedics, Arlington Heights, Illinois.

Figure 2. Example of an Augmented Reality Headset. Reprinted with permission from Augmedics, Arlington Heights, Illinois.

Although surgical training frequently has made use of simulators, more readily accessible technology has allowed VR to become increasingly feasible in spine surgery training.[24]

Virtual reality helps circumvent many of the training barriers encountered in more traditional methods. The results of several investigations have demonstrated surgical benefits from VR simulator training, including improved accuracy, speed,[25-27] and patient care.[25-28] Furthermore, surgeons can use established VR systems in a relatively unrestricted manner, offering users multiple opportunities for repetition without any risk to patients.[29,30] Trainers and surgeons also can use VR systems with customized scenarios that are tailored to the user's experience level and desired training goal.[28,31] In addition to using VR for training, institutions can use VR systems as a reproducible simulated evaluation system to measure surgeon competency in standardized scenarios with objective performance variables.[24] For example, the Royal College of Physicians and Surgeons of Canada[32] has used VR technology to compare and certify trainees[33,34] on the basis of distance from an anatomical feature, time durations, and choice of surgical tools.

The results of much of the research focused on VR have provided evidence regarding improvement observed among residents or less-experienced surgeons.[35] However, study results also indicate that VR devices

Figure 3. Features Provided by Commercial Augmented Reality Headset. Reprinted with permission from Augmedics, Arlington Heights, Illinois.

improve active learning and ease of task completion among attending physicians who were experienced in cervical surgery.[36] Virtual reality may have applications in numerous other areas of spine surgery. For example, the evolution of minimally invasive spine surgery (MISS), in particular, makes VR especially attractive for spine surgery training. Virtual reality systems could be an ideal way to overcome challenging MISS learning curves, increase proficiency in a rapidly changing field, and assist with familiarization of multiple anatomical approaches.[19,20]

SURGICAL APPLICATIONS

Researchers have used AR in a variety pedicle screw placement studies.[9-10] Surgeons can use numerous techniques for pedicle screw placement: these may include fluoroscopy-based, anatomically based freehand, and 3D imaging techniques. Each of these methods is thought to have its own advantages and disadvantages. The situational information provided by AR offers a clear edge over freehand surgery, but it comes with the burden of a physical headset, a learning curve, and dependence on an additional technology. Freehand surgery is the gold standard; however, despite the advantage that it requires only a surgeon, with no need for advanced technologies, it requires a patient or cadaver for practice. Virtual reality and augmented reality provide a platform for trainees and experienced surgeons to hone their skills without the need of a physical patient. Although researchers who have performed studies involving freehand techniques have, in some cases, reported encouraging results, many believe these current techniques still can be improved.[37-39] For example, AR surgical navigation systems offer a possible paradigm shift for placing pedicle screws. These systems offer the spine surgeon the ability to plan a path by using specialized cameras to track instrumentation. In 1 study with results demonstrating improved surgical task durations, Elmi-Terander et al[9] observed a mean (SD) navigation time of 90 (53) seconds with use of AR for following the planned pedicle screw placement path. These time durations not only are endorsed in the current literature but also are faster[40] than techniques that rely on conventional fluoroscopy.[41]

These AR systems offer a potential alternative navigation system that could change our most frequently performed procedures. Although MISS techniques have grown in popularity compared with conventional open procedures, a drawback is the requirement for cumbersome intraoperative radiological imaging. Augmented reality has the potential to change radiation exposure levels. For example, in a cadaveric study, Elmi-Terander et al[9] established that, during MISS, AR could be used to facilitate efficient and accurate fixation without the need for radiographic navigation. The same group conducted another study comparing AR-aided navigation to freehand techniques. Using this system—which requires no fluoroscopy—the authors observed that AR pedicle screw placement was superior to freehand techniques in terms of perfect screw placement (51% vs 30%; $P < .05$), breach reductions greater than 4 mm (2% vs 25%; $P < .05$), and overall accuracy (85% vs 64%; $P < .05$).[42] Researchers in other investigations also have endorsed the use of pedicle screw placement with AR-based navigation systems that increase accuracy and limit radiation exposure.[43,44] Gibby et al[10] superimposed CT images on a head-mounted AR image to assist with placement of needles in models of the lumbar spine. When the authors extrapolated needle positions, they noted that 97% would have made contact with the pedicle.

Only recently have advances in mobile graphical processing unit, display, and sensor technologies made the clinical study of AR systems substantially more feasible.[15] Study results have demonstrated that navigation systems using AR, with sensors mounted to a C-arm for thoracic pedicle screw placement, have an accuracy of 97%, without any cases of pedicle breach.[45] Augmented reality computer-assisted spine surgery involves the use of preoperative images to project a 3D model of the patient intraoperatively. A camera and a projector display

relevant patient anatomy, which minimizes the need for imagery generated with radiation exposure.[46] Surgeons have used other AR systems in percutaneous vertebroplasty procedures to enhance their ability to establish an ideal needle insertion point and trajectory.[47] Although surgeons use AR in a number of practical applications of spine surgery, as mentioned earlier, Ponce et al[48] and Luciano et al[49] observed that the use of AR in simulations and training results in substantial increases in surgeon performance.

CONCLUSIONS

Augmented reality and virtual reality systems may offer a wide array of opportunities for surgeons of all experience levels. Whether institutions use them in the operating room or in a training environment, both technologies allow for opportunities in a variety of spine surgery settings, including cervical spine surgery, deformity surgery, elective procedures, and MISS. Although the use of AR and VR could have vast advantages, more high-quality randomized trials would further establish their effect. Even if these technologies are successful in improving surgical outcomes or surgeon proficiency, their cost-effectiveness should be evaluated critically before implementation.[50] Although AR and VR likely will yield numerous benefits in both training and surgery, we need to ensure that this technology benefits patients' future outcomes in an economical manner. ✣

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A Surgeon View on Patient

B Monitor View

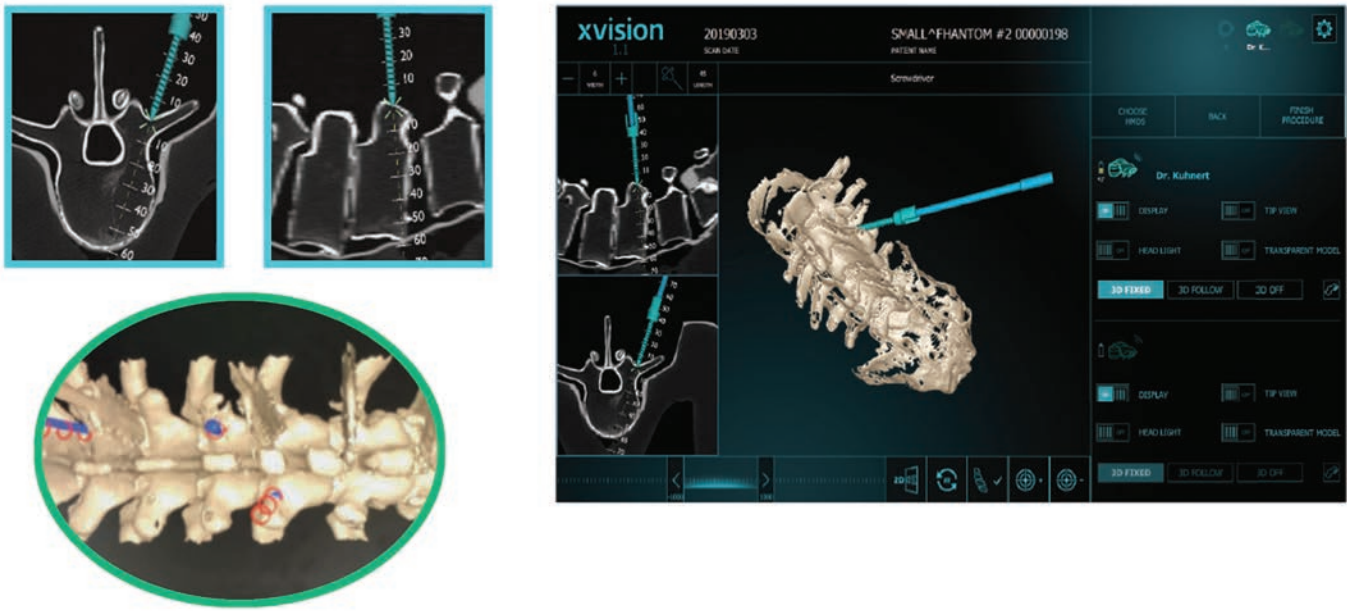

Figure 4. Intraoperative View With Augmented Reality (AR). **A,** Surgeon's view with AR headset, showing axial, transverse, and posterior views of the spine, and **B,** monitor view showing axial and transverse views and 3D rendering of the spine. Reprinted with permission from Augmedics, Arlington Heights, Illinois.

"Study results have shown that when physicians use 3D-printed models for surgical planning, patient outcomes improve."

Three-Dimensional Printing in Orthopedic Oncology

Current Use and a Review of the Literature

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INTRODUCTION

The clinical application of 3-dimensional (3D) printing in medicine has grown quickly over the past few decades, particularly within the field of orthopedics.[1] Physicians have applied 3D printing to many aspects of orthopedic surgery, including surgical planning,[2-4] arthroplasty,[5-7] cutting guides,[8,9] and implant design.[10-12] The 3D printing process begins with segmentation, a phase in which physicians process and compile data from computed tomography (CT) scans or magnetic resonance images to create a 3D anatomical model.[10,13] They then use these virtual 3D models to print a physical 3D model, which then can serve multiple purposes. The subspecialty of orthopedic oncology may benefit substantially from 3D printing technology, as we will review here.

Orthopedic oncologists treat a diverse group of diagnoses ranging from benign tumors to malignant tumors, such as sarcomas, to metastatic bone disease. There are an estimated 15 000 new cases of sarcoma in the United States each year,[14] as well as nearly half a million cases of metastatic bone disease. These conditions often involve delayed diagnosis, and as a result, extensive disease progression. As orthopedic oncologists, we face a number of challenges in treating advanced, destructive bone lesions, including achieving negative margins, selecting reconstructive options, preventing local recurrence, and mitigating surgical complications. Although survival trends vary based on the histological subtype, general trends reveal that axial advanced malignancies lead to worse outcomes than do those identified in the extremities. Sarcomas of the pelvis are associated with local recurrence rates nearing 30% and wound complication rates as high as 40%, as well as numerous other potential surgical complications.[15,16] Moreover, results from a systematic review of surgical outcomes after limb-sparing resection and reconstruction for pelvic sarcomas revealed a pooled non-oncological complication rate of 53% and a pooled non-oncological reoperation rate of 37%, demonstrating the inherent complexity involved.[17] In addition, after sarcoma resection and allograft reconstruction, grafts in some series still have nonunion rates up to 30%.[18] The issues of achieving negative margins, providing reconstructive options, and minimizing surgical and wound complications remain challenging. Three-dimensional printing technology may offer substantial improvements to many of these problems.

3D-PRINTED MODELS

Study results have shown that when physicians use 3D-printed models for surgical planning, patient outcomes may improve. The results of multiple studies have demonstrated that preoperative 3D-printed templating can decrease operative time, reduce intraoperative blood loss, and, in some instances, reduce tumor recurrence rates.[19-21] Shorter, safer procedures

also are associated with reduced perioperative morbidity and more efficient use of hospital resources.[22] Surgeons can use these models intraoperatively to compare actual patient tumor anatomy with the 3D models in situations in which visibility or exposure is limited, such as in pelvic malignancies. However, study limitations include small sample sizes and poor reproducibility across studies, which complicates how the current data are interpreted and applied. In our orthopedic oncology division, we use 3D-printed models for many challenging pelvic and long-bone resection cases (Figures 1 and 2). These models highlight the tumor, as well as the anatomy of both patient and tumor during surgery. The models are also an integral part of the surgical planning process with engineers, wherein the surgeon defines the sites of resection and the reconstructive approach.

3D-PRINTED CUTTING GUIDES AND IMPLANTS

Obtaining negative margins in difficult anatomical locations can present intraoperative challenges. Patient-specific, 3D-printed cutting guides can lead to more accurate tumor resection, improved margins, and more accurate prosthesis or implant positioning and alignment when compared with freehand osteotomies.[2,9,23] In addition, advances in 3D-printed technology have led to the creation of customized implants that can match patient anatomy accurately and promote proper osseointegration with good short-term functional results as outlined with Musculoskeletal Tumor Society 93 scores (Figure 3).[24] Patient-specific 3D-printed cutting guides also promote more accurate bone and soft-tissue resections, which allow the patient to perform more appropriate biomechanical loading and thus increase implant longevity.[25] Surgeons can use these models to educate patients about an upcoming procedure, thereby facilitating greater patient satisfaction and understanding.[26] Additionally, teaching hospitals have used similar models to assist in the

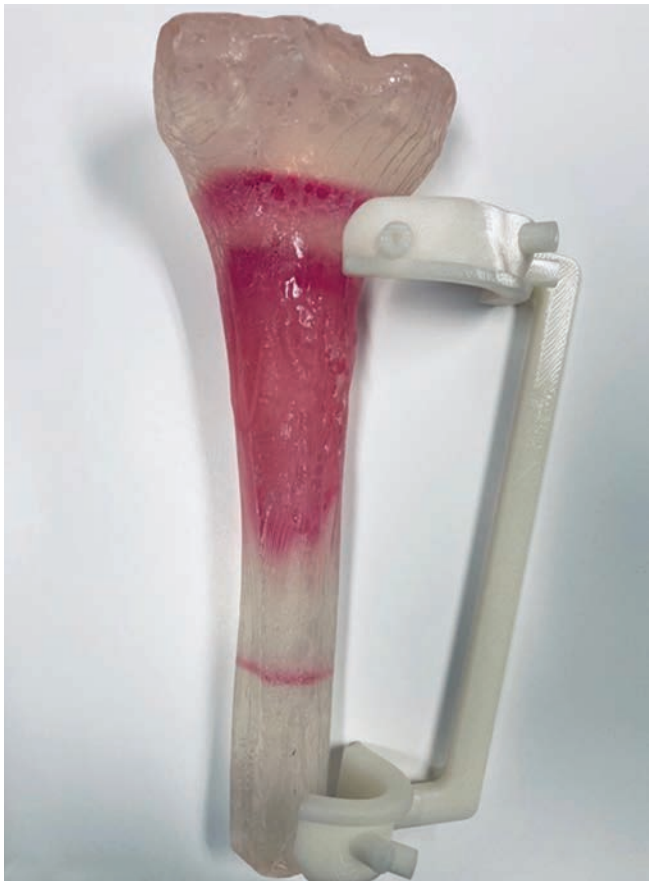

Figure 1. Photograph of a 3-Dimensional–Printed Model of a Diaphyseal Tibial Osteosarcoma. The red central part of the model indicates the sarcoma, and red lines above and below the sarcoma indicate the osteotomy lines. This 26-year-old patient underwent chemotherapy followed by successful resection and intercalary reconstruction with an allograft.

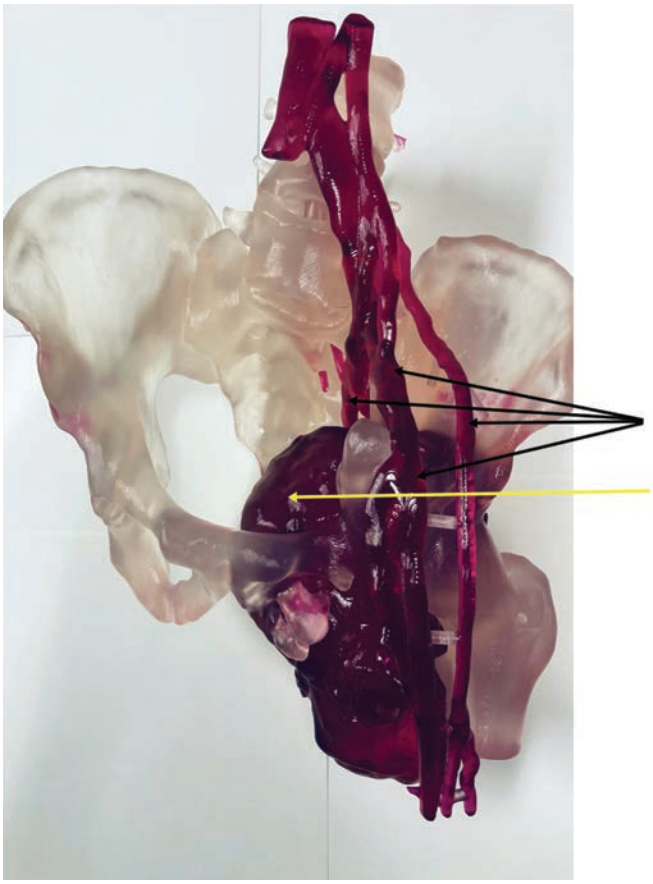

Figure 2. Photograph of a 3-Dimensional–Printed Model of a Large Pelvic Sarcoma. The large red portion of the model (yellow arrow) represents the tumor, and the red linear structures (black arrows) represent nerves, arteries, and veins. This 56-year-old male was treated with chemotherapy and an external hemipelvectomy.

surgical training of medical students and residents[27] Investigators have shown that adding surgical navigation during procedures that use 3D-printing technology increases the accuracy of custom implant placement and improves the rate of negative surgical margins.[28] However, these efforts have a large learning curve and difficult training period, limiting their incorporation and routine use.[19]

Other theoretical advantages of 3D modeling, such as fewer complications due to decreased surgical time, have yet to be investigated fully in the literature. Many complex pelvic resections have an expected major complication rate of 30%, so less surgical time reasonably could lead to improvements. We currently use 3D-printed cutting guides in patients with complex pelvic resections and in select long-bone resections (Figures 3 and 4). Using a duplicate cutting guide on both the patient's diaphyseal lesion and allograft assists with creation of nearly perfect junctional site congruency. We currently reserve the use of 3D-printed implants for complex pelvic reconstruction operations in select patients (Figure 4). In the near future, we will use 3D-printed implants in some proximal femoral and proximal tibial reconstructions because they offer advanced bone and soft-tissue ingrowth surfaces.

LIMITATIONS

Although trends in the current literature suggest that 3D-printed technology supports improved patient outcomes, there are still some limitations associated with its use. Surgical planning supplemented with 3D modeling can provide more information than can traditional CT scans or magnetic resonance images; however, surgeons do not always find the software intuitive to use.[13,25] The amount of time required to design and produce the 3D models often can impede their use in emergent surgical cases or when tumors continue to grow after performing imaging. In addition, pelvic implant loosening is still a concern with the use of customized 3D implants. Some evidence indicates that implant loosening after pelvic reconstructions secondary to tumor resection may be as high as 15%, which leads to questions regarding the efficacy of these procedures.[24,29] Unfortunately, these cases often do not offer multiple implant options for study, which makes direct comparisons very difficult.[19,27] Another technical limitation is intraoperative reproducibility because cutting guides can limit the ability to adapt spontaneously and modify surgical plans.[27] The effect of soft-tissue retraction and interposition between the guide and bone also can modify the alignment of the cutting guides, and physicians suggest that this movement of soft tissues may be a source of complications.[27] Furthermore, patient-specific models often can give the surgeon a false sense of accuracy that is not guaranteed during surgery.[14] Given that these models are specific to the individual patient, the time and financial resources necessary for

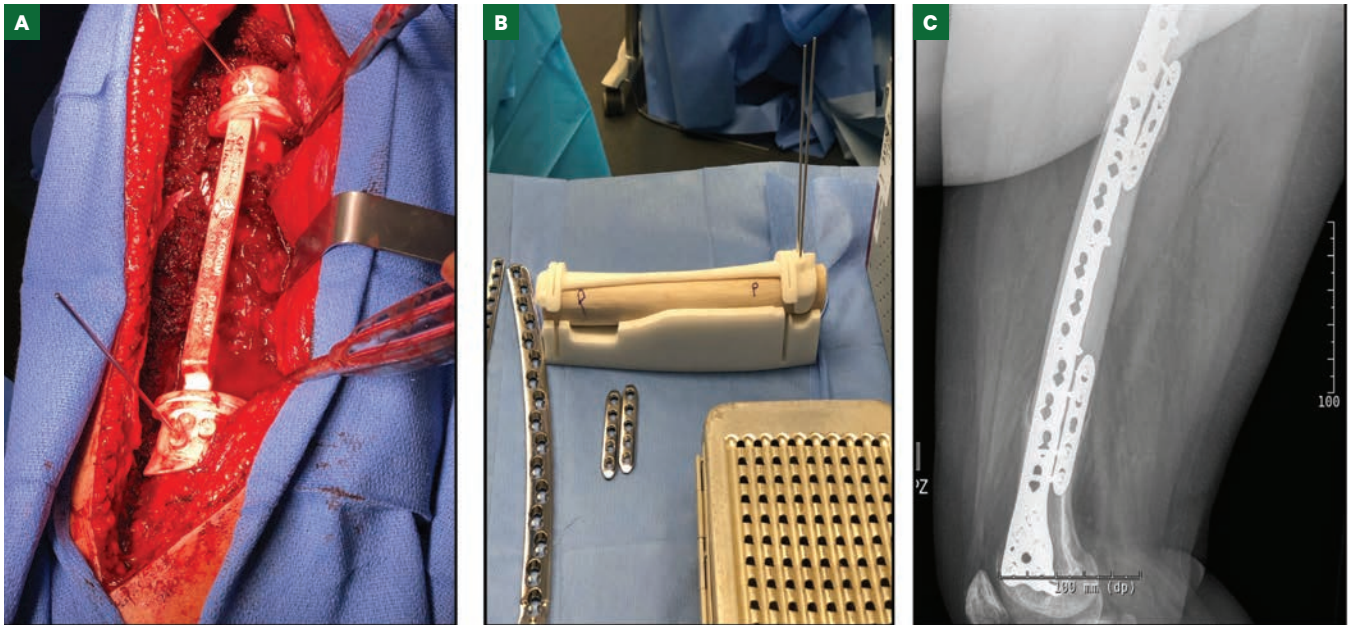

Figure 3. Images from Resection of a Femoral Chondrosarcoma in a 38-Year-Old Female, Using 3-Dimensional (3D)–Printed Cutting Guide. **A,** Intraoperative photograph of the 3D-printed cutting guide used during resection. **B,** Intraoperative photograph of the femoral allograft in the 3D-printed cutting guide used during resection and intercalary allograft reconstruction. **C,** Three-month postoperative radiograph of the femur showing new bone formation at both junctional sites.

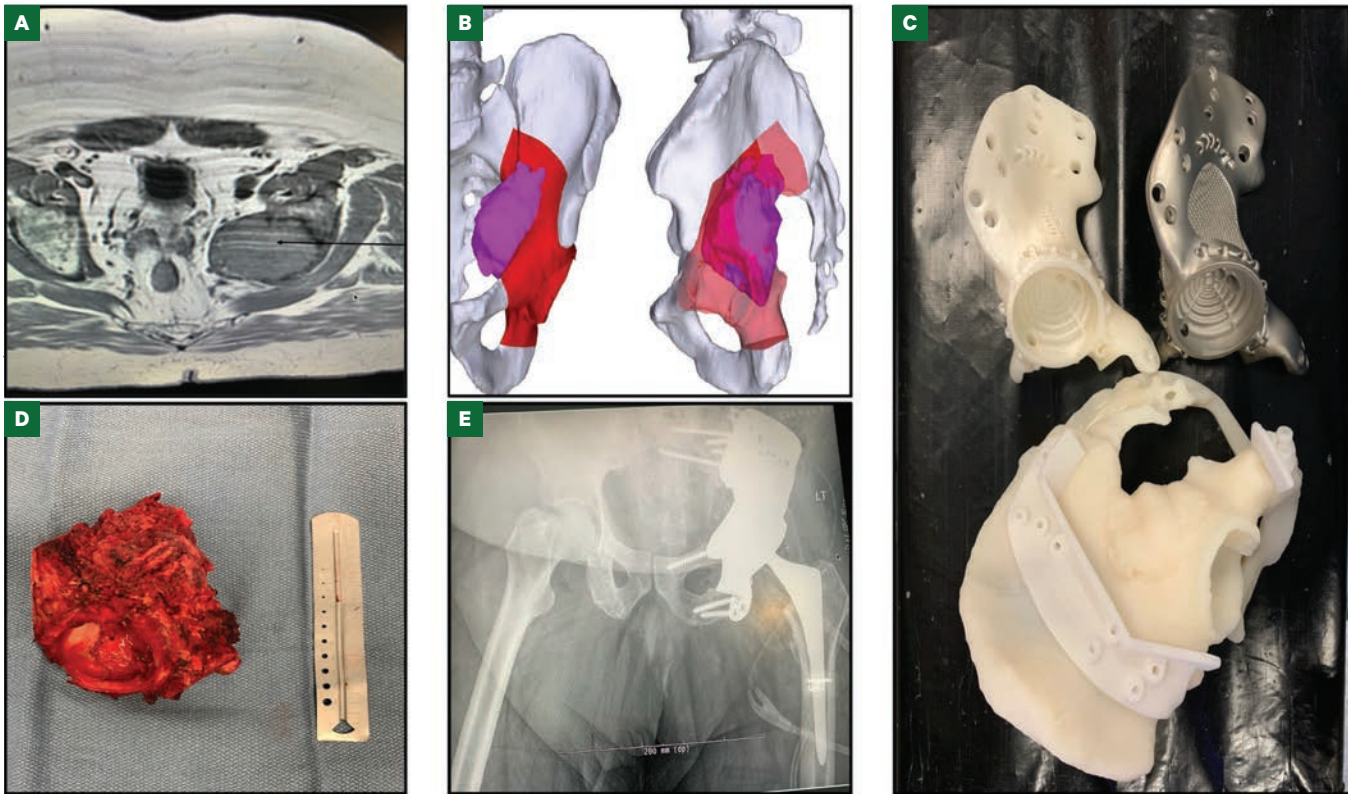

Figure 4. Images from an Internal Hemipelvectomy and Reconstruction of Acetabulum in a 54-Year-Old Male, Using a 3-Dimensional (3D)–Printed Implant. **A,** Axial T1-weighted magnetic resonance image showing a large, left-sided acetabular destructive lesion consistent with a solitary site of renal cell carcinoma (black arrow). **B,** 3D reconstructions of the large pelvic malignancy generated using computed tomography and magnetic resonance imaging from a planning session with computer engineers and surgeon. The teams used these images to define the sites of resection and the reconstructive approach. Purple is the malignancy, and red is the planned resection with negative margin. **C,** Photograph showing the 3D-printed cutting guide and 3D-printed implant used in reconstruction of the acetabulum after removal of the destructive lesion. **D,** Intraoperative photograph of the resected acetabular mass reconstructed with the 3D-printed acetabular implant. **E,** Anteroposterior radiograph of pelvis showing final status.

construction are important limitations as well.[27,30,31] Finally, most uses of 3D-printed models, cutting guides, and implants are not yet approved by the United States Food and Drug Administration (FDA), and physicians must limit their use to a custom or compassionate-use basis. Many companies currently are working through the FDA regulatory process to obtain approval for cancer procedures.

There appears to be a bright future for 3D-printing in the field of orthopedic oncology. Surgical margins, operative time, complication rates, and functional outcomes potentially can improve with the use of 3D-printing technology in difficult bone tumor resections. Study results have demonstrated improvements due to this technology, with some questions still unanswered. A more generalized acceptance of the use of 3D-printing technology will depend on universal FDA approval as well as on efforts to reduce 3D-printing time and cost to make this a more viable option for surgeons and patients in the future.

CONCLUSIONS

Physicians have demonstrated growing interest in the use of 3D technology in orthopedic oncology over the past 15 years. The results of numerous studies demonstrate how physicians can use 3D-printed models to improve preoperative planning, decrease surgical times and total blood loss, and reduce local tumor recurrence. However, the cost, time, and approval issues of custom-designed implants still pose major limitations on full incorporation of 3D technology in orthopedic oncology. In our clinical practice, we have been using 3D-printing technology in select malignant cases for the past few years. We believe that using these models, cutting guides, and implants can facilitate more efficient surgery and possibly improved outcomes. As the cohort for this novel technology grows, we plan to review and publish these data. ✣

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

"…it is imperative to understand the factors that separate higher-quality studies from the overwhelming amount of literature provided by those who simply seek to increase the effect of their work."

The Effect of Open Access in the Orthopedic Sports Medicine Literature

An Analysis of Publication Citation Rates Between 2 Journals

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ADDITIONAL CONTRIBUTION

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INTRODUCTION

Peer-reviewed sports medicine journals provide clinicians and surgeons with contemporary techniques and knowledge regarding outcomes that enhance clinician education and guide treatment approaches. Each of these articles has a citation rate, which represents the total number of times authors reference the article in subsequent studies during a given period of time. This citation rate influences journal impact factors, ranking of academic institutions, recruitment of researchers, and funding decisions.[1,2] Given the widespread dissemination of these studies published via electronic and print mediums, it is imperative to understand the factors that separate higher-quality studies from the overwhelming amount of literature provided by those who simply seek to increase the effect of their work.

In the interest of reaching a broader readership and disseminating scientific knowledge, open access to peer-reviewed manuscripts is becoming increasingly popular.[3,4] The proportion of subscription journals worldwide decreased by approximately 12% between 2012 and 2016, while the proportion of open-access journals increased.[5,6] The proposed benefit of open-access journals is that they are freely accessible online to the public, in contrast to subscription journals, albeit authors publishing in some journals may incur costs exceeding $3000 per open-access article once their manuscript is accepted, following peer review.[7] In a review of more than 4 600 articles, Davis[8] showed that articles published in open-access journals had substantially more full-text downloads and higher numbers of unique visitors than did their subscription-based counterparts. Furthermore, a randomized controlled trial of assignment of articles to either open access or subscription access found open-access articles to be associated with 89% more full-text downloads than were subscription articles within the first 6 months of publication.[9] However, the fact that open-access sports medicine journals are fairly new and may lack the prestige of more established subscription journals could lead to a misperception that the open-access journals do not publish studies of quality comparable to that of established subscription journals, which may influence citation rates.

Although open-access orthopedic sports medicine journals have been in publication for many years, there are few studies of predictors of citation rates between subscription and open-access journals within literature specific to sports medicine. In this study, we aim to investigate differences in 4-year citation rates between a prominent subscription orthopedic sports medicine journal, the *American Journal of Sports Medicine (AJSM),* and its open-access counterpart, the *Orthopedic Journal of Sports Medicine*

(OJSM), and to determine the journal characteristics associated with increased citations. We hypothesized that *AJSM,* the more established publication, would have a statistically significantly higher citation rate than *OJSM* after controlling for publication factors.

METHODS

Study Eligibility and Selection

This study was exempt from institutional review board approval. We queried electronic versions of all articles published in *AJSM* and *OJSM* in 2014. Because *OJSM* came into publication in 2013, we chose to investigate articles from 2014 to collect a full year of data for which 4-year citation rates could be extracted, representing mid-term citation rates. We chose *AJSM* and *OJSM* because they are tightly linked in both subject matter and submission pattern and included the following published article types in the study sample: basic science or modeling, prospective randomized controlled trial, prospective cohort, prospective case series, retrospective cohort or case control, retrospective case series, systematic review or meta-analysis, case study or case report, cross-sectional, and technical notes. We excluded published items classified as expert opinions, commentaries, letters to the editor, and technique tips because they may include data from other published articles in the queried journals.

Data Collection

We determined collected variables for each published article a priori according to methods previously used[10] and included journal name, article title, date of publication, highest degree of first author, number of authors, number of institutions, geographic region of origin, presence of a conflict of interest, study design, subject of study, level of evidence, and sample size (number of participants per study). We determined region of origin on the basis of the location of the first author's institution. We used disclosure statements identified in each published article to determine whether a conflict of interest existed. We selected articles on the following specific subjects: biomechanics or basic science, knee, shoulder, elbow, hip, and foot and ankle. Those original investigations whose subjects we could not best describe using the previous categories we denoted as *other.* These included, for example, additional joints, socioeconomics, and systemic diseases. We determined level of evidence by using the guidelines developed by Sackett et al.[11] Level 1 describes randomized control trials; level 2, cohort studies; level 3, case-control studies; and level 4, case series. We categorized systematic reviews of the above models of investigation within that model's respective level of evidence.

Determination of Citation Rate

We identified citation rates for a 4-year period after the publication date for each included study and extracted them from the Scopus citation database.[12] We used the date of the print version of the study as the publication date and verified that all queried published articles had available records in the database.

Statistical Analysis

We performed statistical analysis by using software (SPSS Statistics, version 22.0; IBM Corporation, Armonk, New York). We used descriptive statistics to summarize the characteristics of published articles. After obtaining these descriptive statistics, we removed all level 5 studies and systematic reviews for further analyses of citation rates between journals because *OJSM* had only 1 level 5 article. We used the Shapiro-Wilk test to determine normality and Levene test to evaluate homogeneity of variance. We used independent sample *t* tests and Pearson χ^2 analysis of association to compare publication characteristics between *AJSM* and *OJSM* for continuous and categorical variables, respectively. To determine predictors for the 4-year citation rate, we performed a multivariate logistic regression by setting whether an article was cited more or less than the mean number of citations as the dependent variable. We defined statistical significance as $P < .05$.

RESULTS

We included 438 articles in the final analysis. Of these articles, 336 appeared in the subscription journal *AJSM,* and 102 appeared in the open-access journal *OJSM*. We present the publication characteristics of all included articles in Table 1.

Comparing the mean number of citations between *AJSM* and *OJSM* at 4 years revealed that research articles in *AJSM* had a significantly greater mean (SD) number of citations than did research articles published in *OJSM* (32.2 [27.6] vs 7.5 [7.8]; $P < .001$). For categorical variables, the Pearson χ^2 analysis revealed that research articles in *AJSM* were associated significantly with the use of more than 20 references by the authors in published studies when compared with that in *OJSM* articles (91.4% vs 76.5%; $P < .001$) and that there were significant associations between journal and study design ($P = .002$). There were no other differences in publication characteristics between the 2 journals.

We used a binary logistic regression model controlling for publication characteristics to isolate the independent association between publishing in *AJSM* vs *OJSM* and the odds of achieving greater than the mean number of citations at 4 years, which was 26.4 citations per article. The results of this analysis revealed that publishing an article in *AJSM* was associated independently with obtaining greater than the mean

Table 1. Publication Characteristics of Included Journals[a]

Characteristic	Journal		*P* Value[b]
	AJSM (n = 336)	*OJSM* (n = 102)	
First author degrees			.69
Other	118 (35.1)	38 (37.3)	
MD/DO	218 (64.9)	64 (62.7)	
Study origin			.052
Other	138 (41.1)	31 (30.4)	
North America	198 (58.9)	71 (69.6)	
Conflict of interest			.54
No	153 (45.5)	50 (49.0)	
Yes	183 (54.5)	52 (51.0)	
Subject of study			.10
Basic science	16 (4.8)	3 (2.9)	
Knee	148 (44.0)	33 (32.4)	
Shoulder	57 (17.0)	17 (16.7)	
Elbow	18 (5.4)	7 (6.9)	
Hip	34 (10.1)	10 (9.8)	
Foot and ankle	16 (4.8)	6 (5.9)	
Other	47 (14.0)	26 (25.5)	
Study design			.002
Basic science or modeling	82 (24.4)	13 (12.7)	
Prospective RCT	12 (3.6)	2 (2.0)	
Prospective cohort	53 (15.8)	14 (13.7)	
Prospective case series	40 (11.9)	12 (11.8)	
Retrospective cohort or case control	65 (19.3)	18 (17.6)	
Retrospective case series	31 (9.2)	11 (10.8)	
Systematic review or meta-analysis	13 (3.9)	9 (8.8)	
Case study or case report	1 (0.3)	1 (1.0)	
Cross-sectional	31 (9.2)	22 (21.6)	
Technical note	8 (2.4)	0 (0.0)	
Sample size			.06
1-30	102 (30.4)	39 (38.2)	
31-100	113 (33.6)	22 (21.6)	
> 100	121 (36.0)	41 (40.2)	
References			.001
1-20	29 (8.6)	24 (23.5)	
> 20	307 (91.4)	78 (76.5)	
Authors			.24
1-5	177 (52.7)	47 (46.1)	
> 5	159 (47.3)	55 (53.9)	
Institutions			.37
1	66 (19.6)	16 (15.7)	
> 1	270 (80.4)	86 (84.3)	
Level of evidence[c]			.12
1 or 2	219 (65.2)	74 (72.5)	
3 or 4	108 (32.1)	27 (26.5)	
Citation rate			< .001
Mean	32.2	7.5	
95% CI	29.2-35.1	6.0-9.1	
Range	1-219	0-45	

Abbreviations: *AJSM, American Journal of Sports Medicine;* DO, doctor of osteopathic medicine; MD, doctor of medicine; *OJSM, Orthopedic Journal of Sports Medicine;* RCT, randomized controlled trial.

[a]Percentages may not total 100% because of rounding. Data are given as No. (%) unless otherwise specified.

[b]Statistical significance at $P < .01$.

[c]We determined level of evidence on the basis of criteria established by Sackett et al.[9]

number of citations for an author's article when compared with publishing in *OJSM* (odds ratio, 32.6; $P < .001$) (Table 2). Furthermore, results from this analysis showed that published articles with a study sample size of more than 100 subjects also was associated independently with achieving greater than the mean number of citations (odds ratio, 2.4; $P = .001$).

DISCUSSION

The results of this study show that research articles of levels 1 through 4 published in *AJSM* had approximately 4 to 5 times more citations than did those published in *OJSM* at 4 years after their print release. Furthermore, when we controlled for publication characteristics previously demonstrated to influence citation rates, publications in *AJSM* had a higher likelihood of being cited at 4 years than did publications in *OJSM*.

We determined that the mean 4-year citation rates for *AJSM* and *OJSM* were 32.2 and 7.5, respectively. Publication characteristics that maximize readership and increase citation potential for a given article have become of interest in the orthopedic sports medicine literature. Movassagi et al[10] showed that predictors of citation rates in the orthopedic sports medicine literature included publications in *AJSM*, those published in North America, and those regarding the hip. This group also quantified the mean 5-year citation rates of other prevalent, subscription-based sports medicine journals—namely, *Knee Surgery, Sports Traumatology, Arthroscopy* and *Journal of Arthroscopic and Related Surgery*—to be 15.2 and 21.7, respectively. Although the current study evaluated the 4-year citation rates of *AJSM* and *OJSM*, the results show that *OJSM* had a lower mean citation rate than did *Knee Surgery, Sports Traumatology, Arthroscopy* and *Journal of Arthroscopic and Related Surgery*. This finding suggests that the purported benefits

Table 2. Logistic Regression Model for the Effect of Article Characteristics on Achieving Greater Than the Mean Citation Rate

Characteristic	Odds Ratio	95% CI	*P* Value[a]
No. of authors			.10
1-5	1 [Reference]		
> 5	1.45	0.93-2.25	
First author degree			.65
Other	1 [Reference]		
MD/DO	1.13	0.65-1.95	
No. of institutions			.62
1	1 [Reference]		
> 1	1.18	0.62-2.22	
Continent of origin			.059
Other	1 [Reference]		
North America	1.70	0.98-2.94	
Sample size			.004
1-30	1 [Reference]		
31-100	1.30	0.75-2.23	.35
> 100	2.41	1.42-4.13	.001
No. of references			.16
1-20	1 [Reference]		
> 20	1.81	0.79-4.16	
Conflict of interest			.78
No	1 [Reference]		
Yes	1.08	0.63-1.86	
Level of evidence			.13
3 or 4	1 [Reference]		
1 or 2	1.59	0.88-2.87	
Journal			< .001
OJSM	1 [Reference]		
AJSM	32.62	9.89-107.63	

Abbreviations: *AJSM, American Journal of Sports Medicine;* DO, doctor of osteopathic medicine; MD, doctor of medicine; *OJSM, Orthopedic Journal of Sports Medicine.*
[a]Statistical significance at $P < .01$.

of open-access journals such as *OJSM*, such as a larger readership and more extensive dissemination of research, may be outweighed by other advantages of more established journals—namely, prestige, name recognition, and inherent trust.

After controlling for multiple publication characteristics previously described, we determined that authors cited research articles published in *OJSM* significantly less than they cited articles published in *AJSM*, despite the potential advantage of being published in an open-access journal. Results from the logistic regression model also indicated that study sample size of more than 100 subjects was associated independently with surpassing the mean number of citations at 4 years after publication, in accordance with findings reported by Okike et al.[13] However, this characteristic differed in a way that was statistically significant when we compared it between the 2 journals. This finding suggests that, despite the known influences of publication characteristics on citation rates, publication in the subscription-based journal, *AJSM*, is an independent predictor of a greater number of citations when compared with the open-access model of *OJSM*.

This finding is in opposition to those of Li et al,[4] who sought to investigate the effect of the CiteScores of open-access journals as a proxy for scientific effect in a large number of journals derived from a database. CiteScore is a composite calculation in which the total number of citations garnered by published documents over a 4-year period—including the year in which the score is being calculated—is divided by the number of documents published in that same time frame.[14] Using difference-in-difference econometric techniques to determine open-access effect, they determined that there was a positive effect in low-ranked journals that were open access and that open-access status increased journal citations. However, these authors analyzed a large variety of publications across various domains, including engineering, medicine, computer science, and social science. The variability in subject matter may explain partially the discrepancy from our findings, which were focused specifically on orthopedic sports medicine literature. This finding may be attributed to *OJSM* being a recently established journal that potentially had not yet reached its peak of influence during the publication dates analyzed.

In 2014, the respective CiteScores and source normalized impacts per article for *OJSM* were 0 and 0.5, whereas those for *AJSM* were 4.9 and 2.4. Furthermore, the scientific journal ranking, a size-independent prestige

indicator that ranks journals by their average prestige per article, for *OJSM* was 0.75, whereas that of *AJSM* was 3.59.[12] As *OJSM* becomes more prestigious over time, being open access may confer significantly higher citation rates for its published articles in the future; however, *OJSM* requires a publication fee to publish, and the effect of this fact on an author's decision to publish in *OJSM* and the subsequent influence on citation rates is currently unknown. Future studies will help determine whether this finding remains consistent among other subscription-based and open-access journal pairings in the orthopedic sports medicine literature and in orthopedics in general.

In this study, we evaluated the 4-year citation rates in the orthopedic sports medicine literature, as opposed to the 5-year citation rate previously reported. Despite the 5-year citation rate being established in the literature, this follow-up was established arbitrarily in previous studies and likely has no implications regarding influencing results in this study. The authors were unable to identify any original investigations that demonstrated citation rates at 5 years are a statistically stronger predictor of mid-term journal impact relative to any other length of time. Furthermore, we decided that we should evaluate 4-year citation rates given that *OJSM* is a recently established journal and that in its first year of inception had a disproportionately smaller number of published articles than did *AJSM*. As mentioned, the recent establishment of *OJSM* may have contributed in part to the discrepancies in 4-year citation rates; however, the large and statistically significant effect of the subscription-based vs open-access journal variable when we controlled for confounding publication characteristics as determined with the logistic regression analysis provides evidence for the benefits of subscription journal models.

CONCLUSIONS

AJSM had a significantly higher 4-year citation rate than did *OJSM*. When we controlled for potentially confounding publication characteristics, publication in *AJSM* was associated independently with achieving greater than the mean number of citations. Researchers may consider submission and resubmission to subscription-based journals to maximize the citations and effect of their work. ✣

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

Continued from page 3

New concussion assessment tool. Rush was the first center in Illinois to start using the EyeBOX, a new eye-tracking technology, to diagnose concussion. The EyeBOX is based on research relating cranial nerve function to eye movements; it can quickly identify ocular changes after a potential concussion or traumatic brain injury and help physicians understand which patients would benefit from earlier treatment. Because the EyeBOX is not dependent on baseline testing, says Concussion Program Director **Elizabeth Pieroth, PsyD, ABPP,** it eliminates both provider subjectivity and a patient's ability to 'game' the evaluation.

Preventing rotator cuff re-tears. Shoulder surgeon **Grant E. Garrigues, MD,** led a review study to determine whether the use of additional material—the patient's own tissue, cadaver tissue, tissue from a different species, or synthetic fabric—during rotator cuff repair improves outcomes vs repair alone. The results, published in the *American Journal of Sports Medicine,* showed that additional materials did not improve outcomes more than repair alone, but found that fewer patients re-tore their rotator cuff when treated with matrix augmentation or interposition graft than those who were not. Patients also reported being able to do more activities of daily life more easily when treated with a patch or bridge than those who were not.

Award, grant from AOSSM. Sports medicine surgeon **Jorge Chahla, MD,** was awarded the Young Investigator Grant by the American Orthopedic Society for Sports Medicine (AOSSM). He is leading an investigation aimed an understanding the regenerative potential of the meniscus, which was previously considered unrepairable, to facilitate better treatment of meniscal tears. **Nikhil N. Verma, MD,** received an AOSSM grant for a randomized controlled trial aimed at improving data collection from patients using electronic and web-based methods. This study will offer a unique perspective on the long-term completion of patient-reported outcomes.

Our Hearts to Your Soles. In December 2019, Rush foot and ankle surgeons, residents, and students provided foot care, boots, and socks to homeless men and women at the Franciscan House of Mary & Joseph, an overnight shelter on Chicago's west side. **Simon Lee, MD,** began the Chicago chapter of the national "Our Hearts to Your Souls" program in 2007; since then, he has been joined by **Johnny L. Lin, MD.** Extreme weather conditions leave Chicago's homeless population in need of medical care; one study reports that only 26% of homeless individuals report ever having a foot exam by a medical provider. ✣

"... the purpose of this study was to compare topographical mismatch and step-off of cartilage and subchondral surfaces between a single, large oblong graft and multiple overlapping grafts."

Overlapping Allografts Provide Superior and More Reliable Surface Topography Matching Than Do Oblong Allografts

A Computer-Simulated Model

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INTRODUCTION

Focal cartilage defects of the knee can result in pain, swelling, and mechanical symptoms, with the potential to cause clinically significant disability.[1] Surgeons generally turn to surgical intervention when conservative measures fail and symptoms persist. Although several surgical options are available, physicians base treatment algorithms primarily on lesion size and location.[2] Surgeons widely use osteochondral allograft (OCA) for symptomatic focal chondral defects of the knee and often select this procedure for patients who are young and athletic. OCA transplant offers immediate structural support and articular surface integrity, restores hyaline cartilage, and may be more suitable for lesions with poor containment or subchondral bone involvement.[3-7]

Study results have shown that OCA transplant has good long-term outcomes, with subjective improvement seen in 75% of patients and an overall 85% graft survival rate 10 years postoperatively.[3,8,9] However, large, irregular, or ovoid cartilage lesions can not only increase operative complexity but also be associated with inferior patient outcomes.[10] Surgeons can manage these large, irregular chondral defects with different grafting techniques, including a single, oblong allograft plug or multiple overlapping cylindrical allografts. Graft mismatch producing even minor areas of articular incongruity (proud or sunken areas) can alter cartilage contact pressures significantly and lead to failure of graft integration.[11] Thus, articular congruity between native and graft cartilage plays an integral role in procedural technique during OCA transplant. A paucity of literature exists in which investigators specifically evaluate which graft method (oblong or overlapping) produces a more native articular environment. Therefore, the purpose of this study was to compare topographical mismatch and step-off of cartilage and subchondral surfaces between a single, large oblong graft and multiple overlapping grafts. We hypothesized that the overlapping graft configuration would produce better subchondral and cartilage surface congruity with surrounding native tissue, as well as less articular step-off when compared with a large oblong graft. We reached this hypothesis because of the theoretical ability for 2 overlapping grafts, compared with a single, large oblong graft, to provide a more similar radius of curvature (ROC) to the recipient.

MATERIALS AND METHODS

A tissue bank (AlloSource, Denver, Colorado) donated 12 cadaveric medial hemicondyle specimens with intact articular cartilage from 12 individual donors, which we used for this study.

We based the sample size on those of previous studies we have published in which we used similar methodology.[12-14] We use the same group of 12 hemicondyles to analyze both types of OCA grafts (overlapping and oblong). All included hemicondyles were free of preexisting osteochondral disease, including osteoarthritis or chondromalacia. An overview of the methodology is as follows: we will obtain computed tomography (CT) scans for the cadaveric specimen and will use them to create 3D models of the articular surface and subchondral bone. We then will create 2 different types of defects and grafts (oblong and overlapping) virtually on these models, and we will perform topography matching analysis for multiple combinations of these defect-graft models. We explain these steps in detail within the following sections.

The institutional review board at the participating institution, Rush University Medical Center, granted this study exemption because of the use of deidentified cadaveric specimens.

Three-dimensional Computed Tomography Computer Model Creation of the Distal Femoral Articular and Subchondral Surfaces

We used a computed tomography (CT) unit (BrightSpeed; GE Healthcare, Wauwatosa, Wisconsin) to scan 0.625-mm, continuous sections of the distal femoral hemicondyles in the coronal, axial, and sagittal planes (120 kV, 100 mA, 1.0-mm/second duration, 20-cm field of view, 512 × 512 matrices). We then created separate, 3-dimensional (3D) CT models of the articular cartilage surface and subchondral surface of each hemicondyle and exported them into polygon and point-cloud models (at a density of 2.3 points/mm^2) by using a 3D-reconstruction software program (Mimics; Materialise Inc., Leuven, Belgium). We used custom-written programs coded in Microsoft Visual C++ with Microsoft Foundation Class programming environment (Microsoft Corp.; Redmond, Washington) to create both oblong and overlapping allograft matching, as described separately in the following sections.

Computer Defect and Graft Model Creation

Oblong Defect and Graft Models

We created oblong articular cartilage defect and graft models with an oval shape (17.0 × 30.0 mm) in the medial distal femoral condyle (Figure 1). We selected this size because it is a common clinically observed defect: a medium-sized defect centering on a primary weight-bearing area. Furthermore, we specifically chose the 17.0 × 30.0-mm size because it corresponds to a commonly used, commercially available template for a medium-sized oblong graft. For each distal femoral condyle, we determined the centroid of the oval shape to be the most distal point of the articular cartilage surface, a primary weight-bearing focus of the condyle, and a common location of an osteochondral defect (Figure 2).[12-14] We then created subchondral bone defect and graft models on the same location as the articular cartilage defect and graft models. When we projected the oval shape of articular cartilage onto the subchondral bone surface, we defined the polygon and point-cloud data within the area as the data set of the defect and graft models.

Overlapping Defect and Graft Models

We harvested 2 circular osteochondral grafts (anterior and posterior, 17.0 mm in diameter) virtually from the medial femoral condyle. We obtained the grafts from any possible location along a center line of the femoral condyle separated by 5.0 mm to avoid convergence of the subchondral plugs at convex areas of the femoral condyle.[14]

We created overlapping defect and graft models at the same location as for the oblong defect. The shape of the overlapping grafts defect was the same at both hemicircular ends of the oblong defect model, having 2 circles 17.0 mm in diameter with 4.0 mm overlap (Figures 1 and 2). The area of the overlapping grafts defect was approximately 5% smaller than that of the oblong defect.

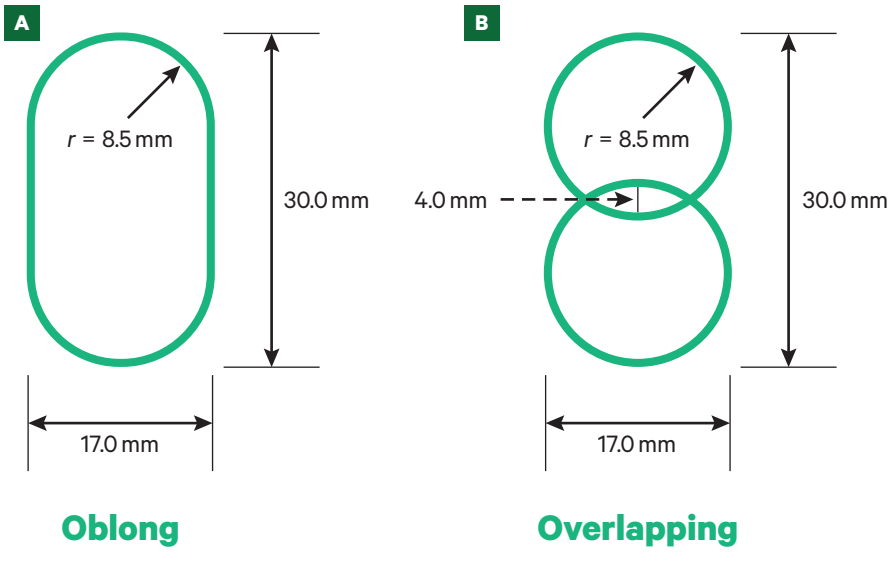


Figure 1. Oblong and Overlapping Defect and Graft Models. We created oblong and overlapping defect and graft models with a radius of 8.5 mm in the medial distal femoral condyle. **A,** For the oblong graft models, we created an oval shape, 17.0 × 30.0 mm. **B,** For the overlapping graft models, we created 2 circles, 17.0 mm in diameter, with 4.0 mm overlapping (dashed arrow).

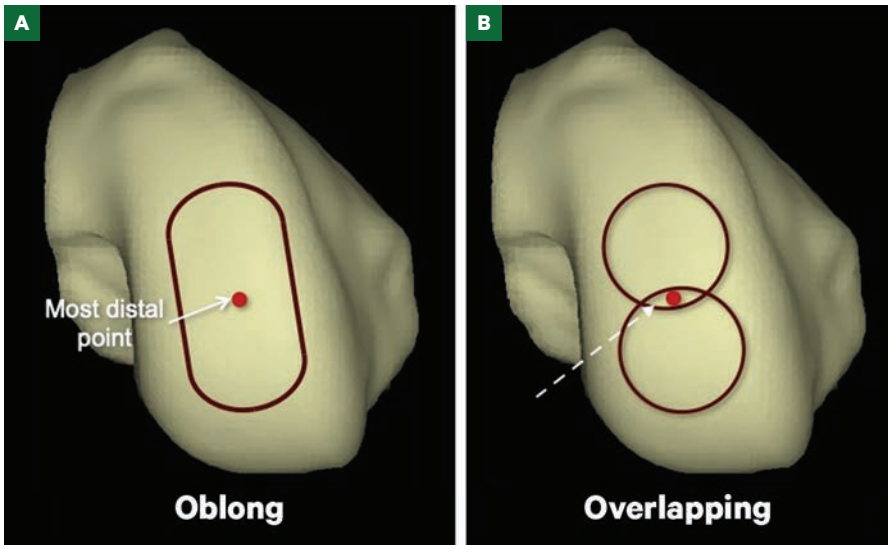


Figure 2. Determination of Centroid and Most Distal Point. **A,** For oblong models, the centroid of the oval shape is the most distal point of the articular cartilage surface in each distal femoral condyle (solid arrow and dot). **B,** For overlapping graft models, we positioned the overlapping circles such that the most distal and centroid point is in the center of the overlapping portion of the circles (dashed arrow and dot).

Three-dimensional Articular and Subchondral Surface Topography Matching

Oblong Defect and Graft Models

We compared the articular cartilage surface of the oblong defect model with the cartilage surface of the oblong graft model in each combination. Including all groups, we simulated 132 recipient-donor combinations: 12 defect models and 11 graft models. We placed the oblong graft model virtually on the oblong defect model and then adjusted orientation of the graft model to match the most anterior and posterior points of the graft model with those of the defect model. We calculated each point-plane distance between the articular cartilage surfaces of the defect and graft models so that we positioned the graft model optimally to minimize surface mismatch with the defect model.[13-15] Then we measured the shortest distance from the point in question on the defect model to the corresponding point in space on the graft model as the mismatch between the 2 models. A perfect congruent match would equal a mismatch of 0 mm for given data points on the simulated articular surface. We calculated a mean value of the mismatch for each combination. We simultaneously calculated articular cartilage step-off as the point-plane distance at the periphery between the defect and graft models. We calculated the shortest point-plane distance between the subchondral bone surfaces of the defect and graft models as the mismatch of the subchondral bone. We performed these calculations on all combinations of simulated graft models and recipient models.

Overlapping Defect and Graft Models

We compared 3D surface topography between the defect and graft articular surfaces for 132 defect-graft comparative combinations: 12 defect models and 11 graft models. We placed the anterior articular surface graft model virtually on the anterior articular cartilage defect surface so that the centroid of both models merged. We then performed defect-graft 3D articular cartilage surface topography matching by using the previously reported procedures.[13-15] We calculated and recorded the distribution of least mean square distances between the defect and graft surfaces. Then we rotated the defect model 360° around the axis perpendicular to the articular cartilage surface in 1° increments and calculated the least distance at each rotating angle. We calculated the least distance at each position and defined the best match as the minimum least distance value. We then applied the same procedure to the posterior graft. We defined a mean value of the anterior and posterior least distances as the best-match value of the cartilage graft model. We repeated these procedures for all graft positions throughout the distal femoral condyle and defined the graft with the minimum value as the best-match graft. We calculated the step-off values at the graft-recipient distal femoral condyle articular cartilage surface junctions. We calculated the subchondral bone surface matching in a similar manner by using the best-matched anterior and posterior grafts.

Statistical Analysis

We performed all quantitative statistical analysis by using software (Stata v13; StataCorp LLC, College Station, Texas; and Excel; Microsoft Corp., Redmond, Washington). We used paired *t* tests to compare mismatch and step-off differences between the oblong and overlapping grafts groups. We used a Fisher exact test to compare the number of minimally clinically adequate allografts (at thresholds of 0.5 and 1.0 mm) between the overlapping and oblong groups.[14,16,17] Finally, we performed an F test to analyze differences in variance between each group. We set significance at $P < .05$.

RESULTS

We included 12 femoral condyles in the final analysis. We tested each donor defect with a graft from each of the remaining condyles, resulting in 132 (12 defect models × 11 graft models) tests for both the oblong and overlapping

grafts groups. Table 1 shows the least mean square distances for cartilage and subchondral topographical mismatch and cartilage step-off for the oblong and overlapping groups. The overlapping group had significantly less cartilage ($P < .001$) and subchondral ($P < .001$) topographical mismatch, as well as articular cartilage step-off ($P < .001$), when compared with the oblong group (Figure 3).

We analyzed the distributions of least mean square distances of cartilage and subchondral topographical mismatch and cartilage step-off. When compared with the oblong group, the overlapping group illustrated significantly less variance in cartilage topography matching ($P < .001$), subchondral topography matching ($P < .001$), and cartilage step-off ($P < .001$) (Figures 4 and 5).

We analyzed overlapping and oblong grafts on the basis of 2 clinically relevant thresholds of mismatch and step-off: least mean squares of 0.5 mm and 1.0 mm. At a threshold of 1.0 mm, overlapping and oblong grafts demonstrated significant differences in the percentage of grafts meeting clinically acceptable step-off ($P < .001$), cartilage topographical matching ($P < .001$), and subchondral topographical matching ($P < .001$) (Table 2). The risk of oblong grafts having a clinically unacceptable difference defined at 1.0 mm in mismatch of cartilage surface incongruity was 10% ($P < .001$). In addition, at a clinically acceptable threshold of less than 0.5-mm mismatch and step-off, overlapping grafts were more likely to be under this threshold for both surface topography matching ($P < .001$) and step-off ($P < .001$) (Table 3). Here, the risk of oblong grafts having a clinically unacceptable difference of cartilage surface mismatch of greater than 0.5 mm was 44% ($P < .001$). All subchondral mismatches were greater than 0.5 mm in both groups. Because no overlapping grafts had a clinically unacceptable cartilage surface topography or step-off exceeding either the 0.5- or 1.0-mm threshold, we could not calculate a risk ratio between oblong and overlapping grafts.

Table 1. Least Mean Square Distances for Cartilage and Subchondral Topographical Mismatch and Cartilage Step-off for Oblong and Overlapping Grafts

Variable	Cartilage Mismatch	Subchondral Bone Mismatch	Cartilage Step-off
Overlapping	0.27 (0.02)	0.80 (0.19)	0.32 (0.04)
Oblong	0.62 (0.43)	1.49 (1.10)	0.77 (0.23)
P Value	< .001	< .001	< .001

Data are presented as mean (SD) and in millimeters.

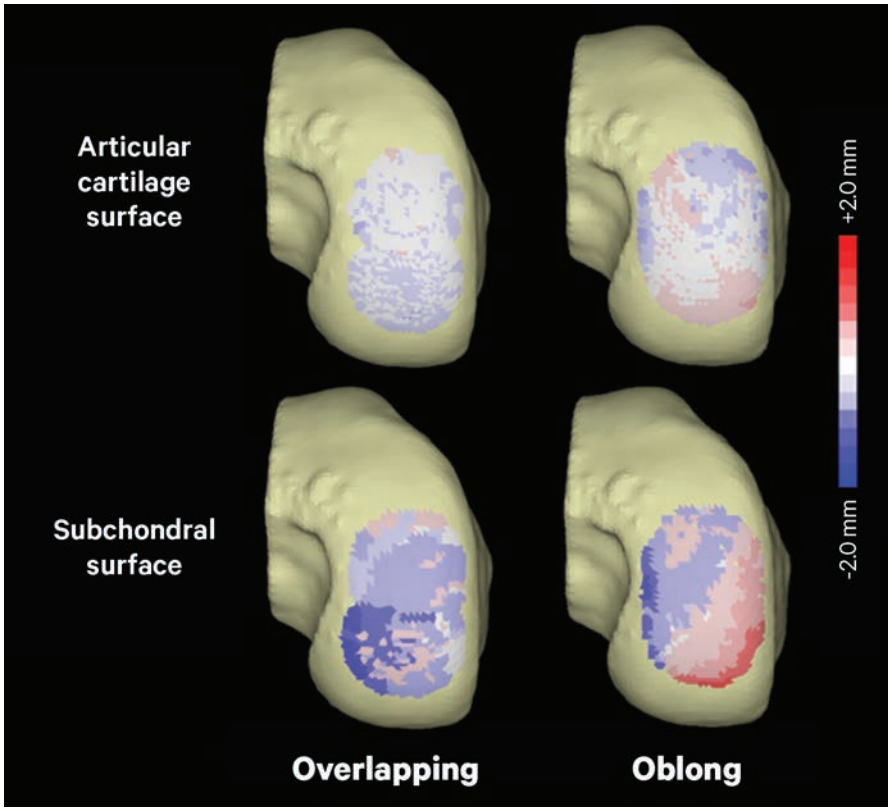


Figure 3. Example of Articular Cartilage and Subchondral Bone Topographic Matching on a Medial Femoral Hemicondyle With Overlapping and Oblong Defect-graft Models. Blue denotes negative mismatch (sunken graft); red denotes positive mismatch (proud graft).

DISCUSSION

In this study, we sought to compare surface topography matching and step-off in a computer-simulated model of matching oblong and overlapping OCA grafts to osteochondral defects of cadaveric medial femoral condyles. We found that overlapping grafts provided surface topography matching statistically significantly superior to that of oblong grafts for both articular cartilage and subchondral bone. In addition, overlapping grafts provided smaller cartilage step-off distances than did oblong grafts. Furthermore, we found that overlapping grafts provided more consistent and clinically reliable results, whereas oblong grafts demonstrated greater variance between surface topography matching and articular step-off data.

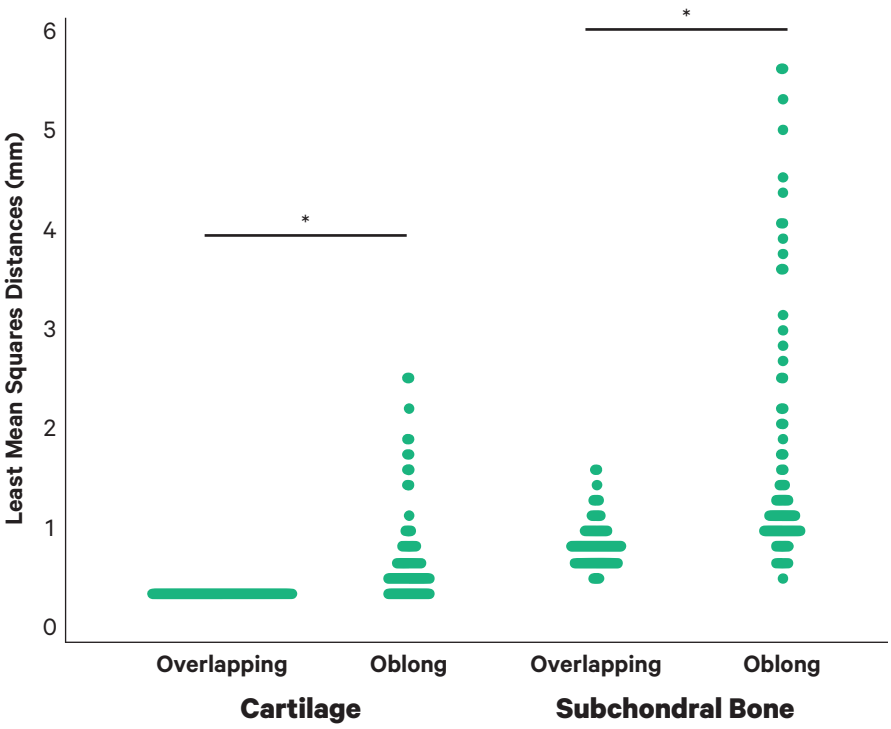


Figure 4. Least Mean Square Distances for Cartilage and Subchondral Bone Topographical Mismatch in Overlapping and Oblong Grafts.
*denotes *P* < .001.

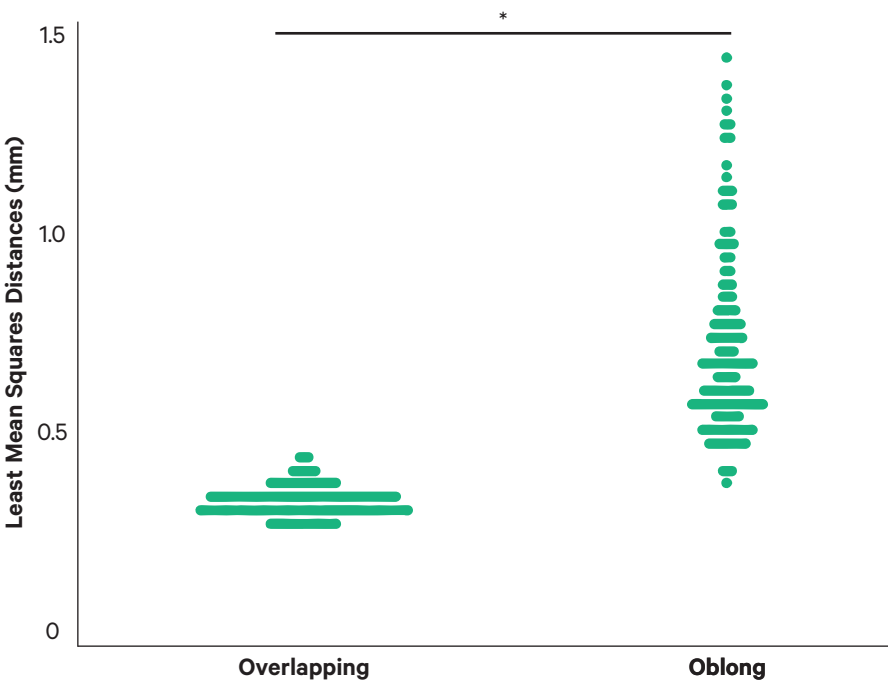


Figure 5. Least Mean Square Distances for Articular Cartilage Step-off in Overlapping and Oblong Grafts.
*denotes *P* < .001.

A mismatched OCA graft can have significant subsequent effects on the biomechanics of the knee joint. In an early study, Koh et al[11] found that peak contact pressures increase significantly when there is surface incongruity (0.5- and 1.0-mm differences) between the graft cartilage and the surrounding recipient cartilage in swine knees. They found significant increases in contact pressure with both sunken ($P < .01$) and proud ($P < .01$) grafts compared with intact cartilage at both 0.5 and 1.0 mm. In another study, Du et al[17] investigated how a large (> 20 mm) proud graft influences tibiofemoral contact forces in a cadaveric model. They found that increasing the proudness of a medial OCA graft in 20° of flexion by 0.5, 1.0, and 1.5 mm resulted in an increase in contact pressures of 80 N (36%), 155 N (70%), and 193 N (87%), respectively. The researchers observed a similar trend, although to a lesser degree, in the lateral compartment (0.5 mm, +44 N; 1.0 mm, +90 N; 1.5 mm, +118 N). In a finite element analysis of contact pressures before and after OCA implantation, D'Lima et al[18] found that although an OCA restores contact pressure to near-anatomic levels, a graft that is as little as 0.25 mm proud can produce increases in peak contact stresses, with a graft that is 0.5 mm proud nearly doubling the contact pressure of the native joint (6.7 vs 3.4 MPa).

Despite study results suggesting that even 0.25 mm of surface incongruity may result in altered contact pressures, the clinical consequences remain unclear. On the basis of current literature, we chose to use 2 thresholds of mismatch and step-off differences, 0.5 and 1.0 mm, to determine whether the topographic matching was clinically acceptable. In a previous study, we reported minimal differences in surface topography when using lateral femoral grafts for medial femoral defects, with "minimal" defined as less than 0.5 mm.[12,14] In contrast, Du et al[19] reported that 97.8% of lateral-to-lateral and 92.5% of

Table 2. Differences Between Overlapping and Oblong Grafts in Providing Clinically Acceptable Significant Step-off or Mismatch at Least Mean Square Distances Less Than 1.0 mm

Variable	Step-Off	Matching		
		Cartilage	Subchondral Bone	Both
Overlapping, No. (%)	132 (100)	132 (100)	115 (87)	115 (87)
Oblong, No. (%)	114 (86)	119 (90)	56 (42)	56 (42)
P Value	< .001	< .001	< .001	< .001

Table 3. Differences Between Overlapping and Oblong Grafts in Providing Clinically Acceptable Significant Step-off or Mismatch at Least Mean Square Distances Less Than 0.5 mm

Variable	Step-Off	Matching		
		Cartilage	Subchondral Bone	Both
Overlapping, No. (%)	132 (100)	132 (100)	0	0
Oblong, No. (%)	16 (12)	74 (56)	0	0
P Value	< .001	< .001	—	—

lateral-to-medial combinations would result in a clinically acceptable surface mismatch, with clinical acceptability defined as < 1.0 mm. There is no consensus on a clinically allowable amount of graft incongruity because of the scant amount of clinical literature on the effects of a proud or sunken graft. Therefore, on the basis of these studies, biomechanical studies, and the clinical experience of the senior authors, we evaluated oblong and overlapping grafts at 0.5- and 1.0-mm thresholds for determining clinically acceptable mismatch. In this study, cartilage surface incongruity ranged from 0.22 to 0.34 mm and from 0.29 to 2.48 mm for overlapping and oblong grafts, respectively. Thus, all overlapping grafts were clinically acceptable at both thresholds, whereas 90% of the oblong defect-graft pairs met the 1.0-mm threshold, and only 56% met the 0.5-mm threshold.

Investigators in previous studies have demonstrated that the ROC of the distal femoral condyles linearly increases from the posterior to the anterior aspect of the femoral condyle.[19] Thus, a large cartilage defect such as those used in this study involve a range of ROCs. However, despite this linear relationship, study results have shown that ROCs vary greatly across femoral condyle donors, which can complicate finding an ideal defect-graft match.[20] Because of the large range of ROCs within a defect, it is understandable that it would be more challenging to fit a single, large graft appropriately from a donor who may have differing ROCs from the recipient instead of 2 smaller grafts that can be harvested from 2 different areas with differing ROCs. The 2 grafts together can minimize the overall difference in ROCs, thereby minimizing average cartilage surface incongruity. These findings suggest that properly matching a femoral defect to an adequate femoral graft, which could involve matching based on the ROC, requires a thorough process. We randomly selected the hemicondyles used in this study from a large research bank and made no effort to match these samples on the basis of size or ROC. However, oblong grafts may provide improved and clinically adequate surface topography matching if the defect is matched to a hemicondyle on the basis of various factors such as size and ROC. Researchers in future studies should investigate and define a matching process that could render oblong grafts more viable in terms of surface topography matching.

Large osteochondral defects result in a substantially more complex surgical procedure. Therefore, understanding the advantages and disadvantages for each graft technique is essential.

A main advantage to using an oblong graft is eliminating the number of interfaces that need to incorporate, possibly decreasing synovial fluid penetration that may lead to loosening and cyst formation. However, literature on overlapping graft failure and incorporation remains limited. In contrast, using the oblong allograft is a more technically demanding procedure with minimal spare allograft tissue because of the amount of tissue needed to perform the transplant. The current study's results suggest that another disadvantage to using an oblong graft is that it may result in inferior surface topography matching compared with that of an overlapping

approach. However, harvesting and implanting multiple plugs in an overlapping approach may lead to cyst formation, as mentioned. Although this study's results suggest that multiple overlapping grafts provide improved surface topography matching, this result may be difficult for surgeons to achieve consistently. In the operating room, obtaining a good fit has as much to do with diligent measuring, cutting, and impaction as it does with the native topography of the graft. This study provides evidence that a perfectly executed overlapping graft is more likely to result in adequate surface topography matching, but how this translates to the operating room remains unclear.

There is a paucity of clinical outcome literature on graft approaches for large, irregular defects. Study results have shown lower graft survival rates in this clinical scenario (64.1%-66.7% at minimum 2 years), especially when compared with those for smaller, uniform defects (87.5% at 5 years).[10,21,22] Despite this lack of data, investigators in previous clinical studies have recommended the use of overlapping grafts for large defects and have shown improvement of statistical significance in postoperative, patient-reported outcomes.[10] However, there is scant literature available on the clinical outcomes of using an oblong graft, making it almost impossible to compare clinical outcomes directly for these 2 approaches. Although this study's results support the use of multiple smaller grafts instead of a single, large oblong graft for large, irregular defects, it is unclear how improved surface matching correlates with clinical outcomes and failure rates. This information is useful for any orthopedic surgeon who performs complex OCA procedures. Future clinical studies are needed to investigate the effect of cartilage surface incongruity on clinical outcomes.

Although the results of the present study provide insight into grafts for large osteochondral defects, there are several important limitations to consider when interpreting these results. The most substantial limitation is that we performed all analyses virtually, on computer models of cadaveric femoral hemicondyles. Whether surgeons can reproduce the same results in vivo remains unclear. However, computer simulations are common, and physicians have used them previously to test various defect and graft matching within the knee and shoulder; thus, we believe our computer-simulated findings are useful in understanding and potentially influencing graft choices. In addition, our measurements were limited to surface topography mismatch and step-off analyses. Other differences between the grafts may exist outside of the tested variables of this study. Furthermore, we used threshold cutoffs of 0.5 and 1.0 mm to define clinically acceptable surface mismatch and articular step-off, which we based on the senior authors' surgical experience and previously published literature.[14,16,17] However, it remains unclear whether a higher or lower cutoff would be more clinically relevant. Lastly, in this study, we do not address any biomechanical or clinical outcome differences between oblong and overlapping grafts. Thus, one should use the findings of this study in conjunction with existing biomechanical and clinical literature on graft selection.

CONCLUSIONS

Overlapping allografts provided reliably superior cartilage and subchondral topographical matching and decreased cartilage step-off compared with results with oblong allografts in a 3D point-cloud model. These findings suggest that overlapping grafts may be superior in treating large, osteochondral defects involving the femoral condyles. ✤

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

Building on a Legacy of Innovation

From augmented reality to biologics to big data, surgeons and scientists at Rush are using new tools to advance spine surgery

For generations, the Department of Orthopedic Surgery at Rush University Medical Center has been home to advances in spine surgery, including groundbreaking treatments for spinal deformities and minimally invasive reconstructive procedures. Beyond the operating suite, researchers at Rush also have made significant discoveries at the bench, including progress toward the "holy grail" of low back pain treatments: biologic solutions that may reverse disk degeneration.

Today, that spirit of innovation continues as physician-researchers at Rush test new surgical navigation systems, explore promising biologic treatments for back pain, and harness predictive analytics to improve patient care.

SPINE SURGERY ON THE CUTTING EDGE

The advent of internal instrumentation in the 1960s drove new treatments for patients with spinal deformities, led by pioneers such as Rush's Ronald DeWald, MD. In the 1990s, surgeons like Frank M. Phillips, MD, began developing minimally invasive techniques for spine surgery, helping patients with deformities, spinal instability, and other conditions recover more quickly and with less pain.

Today, it's not just new instrumentation and surgical skill driving innovation—it's also digital technology. This past June, Phillips, the Ronald L. DeWald,

MD, Endowed Professor of Spinal Deformities and director of the Division of Spine Surgery at Rush, became the first surgeon in the world to use an augmented reality navigation system during minimally invasive spine surgery.

Phillips has worked closely with Augmedics, which developed this innovative system, known as xvision. Xvision is different from other computer-assisted navigation platforms because it allows surgeons to view the patient's spinal anatomy in 3D through the skin. During a procedure, the surgeon wears a headset with a transparent, near-eye display, similar to Google Glass, which determines the position of surgical tools in real time. Then, 3D images of the spinal anatomy and 2D navigation images are projected directly onto the surgeon's retina and superimposed over the surgical field. This makes the workflow much more intuitive, eliminating the need for the surgeon to shift their attention away from the patient and look at a remote display.

"What that translates into is a quicker, more efficient surgery, which means less muscle damage and anesthetic time for the patient," says Phillips, who is also president of the International Society for the Advancement of Spine Surgery (ISASS). Besides reducing surgical time, the procedure is also highly precise, which should help reduce complications in patients with spinal instability or spinal deformities requiring thoracic or lumbar fusions. In fact, the technology achieved 99.1 percent overall accuracy for pedicle screw implant insertion according to a cadaveric study, co-authored by Phillips and Rush colleague Matthew W. Colman, MD, which is slated for publication in the *Journal of Neurosurgery*. Colman, who specializes in spine surgery and musculoskeletal oncology, is also studying the accuracy of the system to help remove musculoskeletal tumors.

Phillips expects augmented reality surgical navigation systems will be used for other spinal applications, such as cage placement during fusions or even decompression surgery. "At the end of the day, I don't think it's a stretch to say a big portion of spine surgeries could incorporate this technology," he says. He also believes augmented reality has the potential to make minimally invasive spine surgeries more reproducible by eliminating variations caused by differences in surgeons' skills and experience levels.

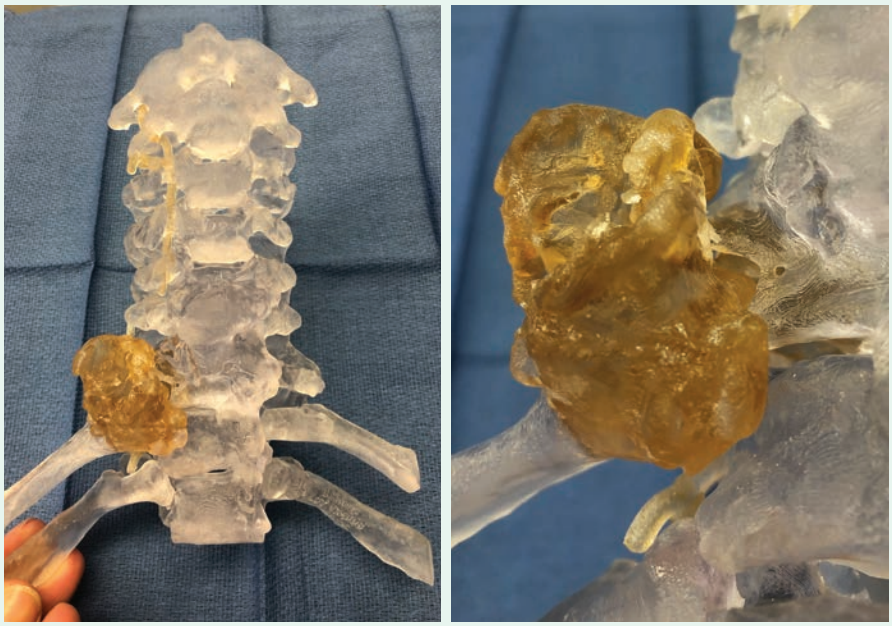
Residents and fellows who try the augmented reality technology pick it up quickly, perhaps because they have grown up with virtual-reality gaming technology. "For them, it's kind of second nature," Phillips says.

Kern Singh, MD, is also studying the utility of both augmented reality and virtual reality (see page 18). And he is currently developing and using another computer-assisted navigation technique, ultrasound-guided neural navigation, aimed at improving the predictability and safety of spine surgery.

To locate nerves, current neural monitoring technology relies on electromyography, which is prone to technical errors and does not provide a physical map of the anatomy. Instead of EMG, Singh uses quantitative imaging and ultrasound via a proprietary software algorithm to safely map the structure and location of nerves in real time during surgery.

During a procedure, Singh moves a disposable, pencil-sized probe and hears the frequency of beeps increase as he moves closer to a nerve or blood vessel, or he can use visual feedback. This technology, which is being commercialized by Singh's company, TDi, may be especially useful to reduce

Use of new technologies like Xvision, and 3D printed cutting guides and implants enable Matthew W. Colman, MD, and his colleagues to both customize oncologic surgery and achieve remarkable surgical precision.



Matthew W. Colman, MD, used this 3D-printed model of a complex cervicothoracic junction tumor to conceptualize and assist the tumor resection both pre- and intra-operatively.

the risk of injury to the lumbar plexus in lateral-access spine surgery. The technology has received FDA approval, and more than 25 surgeries have been performed without the need for neural monitoring. A full commercialization of the technology is expected in 2021.

Beyond new navigation techniques, spine surgeons at Rush are also exploring how 3D printing technology can be harnessed to improve patient care. Initially, 3D printing was used primarily for preoperative planning to model complex cases prior to surgery. But advances in new materials have allowed 3D-printed materials to be sterilized and used inside the body, such as for patient-specific implants.

"If I need a specific spacer to replace a vertebral body or unique bony defect, I can have that 3D-printed and make it fit to match the patient's anatomy," Colman says. These 3D-printed vertebral cages provide anterior support for spinal reconstructions when part of the spine has been destroyed or removed because of a tumor or other cause.

Colman also uses the technology to print patient-specific cutting guides that mount to the patient's anatomy and include slots for cutting, allowing him to remove complex tumors or place pedicle screws with greater precision. "It sets you up for the perfect trajectory and limits blind penetration of sharp cutting instruments," he says. He recently co-authored a study, published in the *Journal of Surgical Oncology,* on the use of 3D-printed cutting guides and computer navigation for sacroiliac joint cut accuracy.

Colman believes these advances add to Rush's legacy of innovation and will help to improve patient care. "At Rush, we're very technology-forward," he says. "But only inasmuch as we're always looking for ways to do things more efficiently, more safely, and more accurately to optimize outcomes." (Learn more about 3D printing in orthopedic oncology on page 22.)

UNDERSTANDING THE BIOLOGY OF THE SPINE

Researchers at Rush have been committed to understanding the link between back pain and intervertebral disk degeneration since then 1990s, when former department chairman Gunnar B. J. Andersson, MD, PhD, broke new ground while studying growth factors, stem cells, and other therapies to combat degeneration. This pioneering work was recognized at a national level in 2011, when a team led by Andersson and Howard An, MD, received the prestigious Elizabeth Winston Lanier Award, one of three annual Kappa Delta Orthopedic Research Awards, for their project, "Intervertebral Disc Repair or Regeneration by Growth Factor and/or Cytokine Inhibitor Protein Injection."

"For decades, our spine group has been very active in the basic science arena in terms of creating animal models and studying different growth factors in an attempt to regenerate disks, which, in theory, should lead to less pain for patients," Phillips says.

Today, researchers in Rush's Spine Biology Laboratory are studying the complexities of back pain using molecular biology, tissue cultures, and animal models so they can understand, design, and test biological therapies to treat intervertebral disk degeneration.

"Our overall objective of spine research at Rush is to develop more precise and tailor-made approaches to managing the right patients with the right treatment at the right time," says An, the Morton International Endowed Chair and Professor of Orthopedic Surgery, who leads this research.

In studies using intervertebral disk tissues from patients and donors, An and Ana Chee, PhD, who was also part of the team that received the Kappa Delta Award, found that pro-inflammatory cytokines and chemokines are associated with intervertebral disk degeneration

and back pain. This has opened the door to potential biological treatments for disk degeneration, inflammation, and low back pain. For example, after analyzing the cell surface expression of cytokine receptors on disk cells, the researchers found that treating the interleukin-4 cytokine has potential therapeutic effects.

An also has designed a multifactorial drug delivery system that slowly releases anti-inflammatories and growth factors. "Intradiskal delivery of biologics, such as growth factors and anti-inflammatories, is a promising therapy to reduce back pain and restore physical function," An says. "Yet, due to their short half-lives, a single treatment may not be sufficient to counter chronic conditions." That's why he is testing the effectiveness of this new delivery system in preventing disk inflammation and subsequent degeneration and back pain in an animal model.

An's colleagues have made important discoveries of their own regarding the biology of the spine. Chundo Oh, PhD, is focused on the role of the β-catenin protein in the development and progression of disk degeneration, and aims to define novel molecular targets to treat the disease.

Meanwhile, Dino Samartzis, DSc, who directs the International Spine Research and Innovation Initiative (ISRII) at Rush, has been advancing knowledge of the epidemiology of low back pain. He has found that certain spinal imaging phenotypes, including intervertebral disk degeneration and Modic changes (such as subchondral bone marrow lesions adjacent to the endplate), are associated with the development, severity, and chronicity of low back pain.

Researchers at Rush are also investigating how the gut microbiome and genetic, environmental, and other factors may influence the development of various spinal phenotypes and, ultimately, low back pain.

Rush, led by Howard An, MD, and scientists in the Spine Biology Lab, is a global leader in the quest to develop biologic therapies to treat interverteral disk degeneration, relieve low back pain, and restore physical function.

IMPROVING PATIENT CARE WITH PREDICTIVE ANALYTICS AND PROS

Although prior generations of Rush surgeons could not have predicted how much "big data" would transform spine surgery, the Department of Orthopedic Surgery has been a longtime advocate of evidence-based medicine.

Today, surgeons at Rush are using analytics tools to predict outcomes and guide treatment decisions at a time when reimbursement models are changing, and patients and payors want to ensure that surgical interventions deliver meaningful value. "At the end of the day, the more data we collect, the better position we're going to be in when we talk to payors and confirm that what we're doing for the patient is beneficial," says Phillips, who has numerous publications analyzing value-based care, including use of bundled payments in spine surgery.

Rush surgeons like Singh are using predictive analytics to enhance decision-making and improve surgical outcomes and patient safety. He is collaborating on a multidisciplinary study with Rush general surgeon Jonathan Myers, MD, to determine risk factors for complications and poor outcomes in anterior lumbar interbody fusion (ALIF). They have developed a scoring tool that surgeons can use to determine which surgical setting (outpatient, short-stay, or inpatient) is most appropriate for a patient based on several risk factors. In May, Singh and Myers published results of a retrospective study identifying the most relevant risk factors predisposing ALIF patients to an inpatient stay of 24 hours or more in *Spine*.

Soon, the tool will be available as a smartphone app that surgeons can use for patient planning and to discuss potential complications with their patients.

In addition to exploring a variety of new technologies to enhance surgical precision, Kern Singh, MD, and his Rush colleagues are using predictive analytics to improve surgical decision-making, outcomes, and patient safety.

Patient-reported outcomes, or PROs, also have the potential to improve patient care. More than 15 years ago, the National Institutes of Health developed its Patient-Reported Outcome Measurement Information System, or PROMIS, so providers would have new ways to measure pain, physical functioning, and other PROs across multiple diseases. Tools like PROMIS that use computer-adaptive testing, which adjusts questions based on the user's responses, can increase the efficiency and accuracy of acquiring data on how patients are doing physically and emotionally.

"By far the biggest impact that PROs have on innovation is shortening the feedback loop for surgeons and helping them understand outcomes," says sports medicine surgeon Adam B. Yanke, MD, PhD. "Traditionally, it would take surgeons months or even years to collect and analyze data to understand how an intervention affected patients. But big data is helping surgeons determine if their treatments are truly making a difference in patients' lives."

For more than a decade, orthopedic surgeons at Rush have been leaders in using PROs and electronic health record data to advance research and improve patient care. Starting Jan.1, 2021, Midwest Orthopaedics at Rush will use a new platform called PatientIQ to engage patients and collect PROs.

The platform, which is being rolled out at nearly 50 institutions around the country, also allows researchers to share and analyze data from multiple organizations. For spine surgery patients, the platform collects and analyzes outcomes such as general health and wellness; disease-specific outcomes such as the Oswestry Disability Index or modified Japanese Orthopedic Society score for cervical myelopathy; and even social/emotional metrics such as PROMIS Depression or PROMIS Pain Interference.

"The goal is not just to improve care for patients at Rush," says Yanke, who is also vice president of research for PatientIQ. "When it comes to big data, there's always the question of how big is big enough? And no matter how busy an institution is, it's usually not big enough to come up with game-changing data in a silo."

Having a platform like PatientIQ also will facilitate research protocols in the era of COVID-19 by offering a better tool for remote monitoring as organizations seek to minimize in-person provider-patient interactions, Yanke says. The platform allows patients to complete their clinical trial consent forms electronically. And it augments telemedicine visits by giving surgeons more insight into patients' pain and function levels without requiring them to come into the office, so patients can stay safely at home unless absolutely necessary.

Yanke expects that collecting PROs will also help improve patient and provider decision-making and communication about procedures like spine surgery. "With predictive analytics, we can give patients risk scores specific to certain procedures so they can understand the whole process much better," he says. "That is very big change for medicine." ✣

Disclosures: Dr Phillips and Dr Colman have an equity ownership in Augmedics. Dr Singh is a founder of TDi. Dr Yanke is an owner and executive of Patient IQ.

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