The Burden of Craft in Arthroscopic Rotator Cuff Repair: Where We Have Been and Where We Are Going

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Abstract

The rather turbulent history of arthroscopic rotator cuff repair went through stages of innovation, conflict, disruption, assimilation, and transformation that might be anticipated when a new and advanced technology (arthroscopic cuff repair) displaces an entrenched but outdated discipline (open cuff repair). The transition from open to arthroscopic rotator cuff repair has been a major paradigm shift that has greatly benefited patients. However, this technical evolution/revolution has also imposed a higher "burden of craft" on the practitioners of arthroscopic rotator cuff repair. Technological advancements in surgery demand that surgeons accept this burden of craft and master the advanced technology for the benefit of their patients. This article outlines the author's involvement in the development of arthroscopic rotator cuff repair, and it also explores the surgeon's obligation to accept the burden of craft that is imposed by this discipline.

I am very honored that Dr. Rob Bell, past president of the American Shoulder and Elbow Surgeons, invited me to give last year's Neer Lecture. Dr. Bell asked me to specifically address my role in the development of arthroscopic rotator cuff repair and to recount the significant resistance that the early arthroscopic shoulder surgeons faced from the shoulder establishment as we struggled to achieve mainstream acceptance for this new technology. Tasked with such a personal topic, I find myself in a position analogous to that of Winston Churchill at the end of World War II. When a journalist asked him to speculate on how historians would portray his role in the war, he replied without hesitation, "History will be kind to me because I intend to write it."

So let's start at the beginning. And for me it makes the most sense to travel back to the year I started my practice: 1981. The world then was very different from today's world. On January 20, 1981, Ronald Reagan was inaugurated President of the United States. The same day, 52 US hostages in Iran were released after having been held captive for 442 days. In March 1981, Reagan survived an assassination attempt; 3 months earlier, John Lennon had not been so lucky. Lennon's hit song "Starting Over" garnered the highest musical awards posthumously.

The world of shoulder surgery was also very different in 1981. The arthroscope was the "instrument of the devil," according to Dr. Rockwood. And shoulder surgery was ruled by the *Charlies*—Dr. Charles Neer, Dr. Charlie Rockwood, and any other Charlie who felt compelled to marginalize shoulder arthroscopy.

My personal world in the early 1980s was daunting as well. I had just completed my residency at the Mayo Clinic and my sports medicine fellowship in Eugene, Oregon. I had a young son, a new daughter, and a new job with the San Antonio Orthopaedic Group. I had a new house with a 21% mortgage loan and a "new" used car with a 23% car loan.

I was simultaneously energized and intimidated by my new job, where I was doing general orthopedics with a "special interest" in shoulder surgery and sports medicine. I was initially very proud and humbled by the fact that my senior partners had entrusted me with the care of the most difficult shoulder cases within the practice. But that pride got cut down to its appropriate size the day after I had thanked one of my partners, Dr. Lamar Collie, for his confidence in my potential as a shoulder surgeon. Dr. Collie replied matter-of-factly, "Sure … but you need to understand that we always make the new guy the shoulder expert because shoulders never do worth a damn."

For shoulder arthroscopy, the early 1980s were exciting. Most of us who were scoping shoulders had already been doing knee arthroscopy and were trying to adapt knee instruments to the shoulder. This worked for some simple excisional cases. For example, I recall excising the bucket-handle portion of a type III SLAP (superior labral tear from anterior to posterior) lesion in 1983. In general, however, shoulder problems were different from knee problems and usually involved repair rather than excision of damaged tissues. Therefore, the technology used in knee arthroscopy was often not directly transferable to the shoulder. Furthermore, treatment of the rotator cuff neces-

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sitated development of arthroscopic techniques in a virtual space, the subacromial space, and this was an entirely new arthroscopic concept.

Development of Arthroscopic Rotator Cuff Repair

A major mind-expanding turning point for me occurred in 1984 when I attended one of Dr. Jim Esch's early San Diego shoulder courses. During that course, Dr. Harvard Ellman of Los Angeles demonstrated to me on a cadaver shoulder how he created a virtual subacromial working space that allowed enough visualization for an arthroscopic acromioplasty. At that moment, I knew that arthroscopic rotator cuff repair was just around the corner. Up until then, I had not been able to envision complex extra-articular reconstructive surgery, as all previous arthroscopic surgery had been intra-articular. But now, having realized a virtual working space could always be created, I knew it would be relatively straightforward to develop the portals to approach the cuff as well as the implants and the instruments to repair it. But I also knew that progression to all-arthroscopic repair techniques would have to be stepwise and that the final repair constructs would need to be at least as strong as those of open repair in order to be acceptable. With an undergraduate degree in mechanical engineering, I had a reasonably clear idea of the concepts I wanted to apply to the instrumentation and techniques, though I could never have envisioned how circuitous the route to the end result would be.

First Steps

I sketched out my ideas for arthroscopic suture passers and knot-tying instruments and presented them to a couple of the major arthroscopy companies in the United States, but the companies were not interested. They did not believe arthroscopy would have any meaningful applications in the shoulder. So, I enlisted the services of a local San Antonio aircraft machinist to fabricate instruments for me. By 1987, I was doing arthroscopic side-to-side *margin convergence*[1] cuff repairs for U-shape tears on a regular basis. And I was doing these at the most hostile point in the universe for arthroscopic shoulder surgery: San Antonio, Texas.

Only a few surgeons were doing arthroscopic shoulder surgery in the 1980s and early 1990s, and without exception these surgeons became the leader-pioneers in the new discipline. In general, these were young surgeons who were in private practice and removed from academia and professional organizations, and thus relatively sheltered from the actions of the shoulder rule-makers of the day. They accepted their status as pariahs as they developed their techniques out of the view of mainstream orthopedics. These leaders included Jim Esch, Steve Snyder, Dick Caspari, Lanny Johnson, Gene Wolf, Gary Gartsman, Rob Bell, and Howard Sweeney. We shared our techniques and our ideas with one another, encouraged one another, and generally became good friends.

Thomas Kuhn, in his classic book *The Structure of Scientific Revolutions*,[2] observed that paradigm shifts within a given field were usually achieved by practitioners who were either very young (naïve) or outside the established hierarchy in the field. The surgeons who contributed most to the shift of shoulder surgery from open to arthroscopic techniques were generally young men who were in private practice and had little to lose by inciting the disdain of the shoulder establishment. Predictably, resistance from the mainstream open shoulder surgeons increased as arthroscopic techniques became more successful and more threatening to the primacy of the open shoulder surgeons. The disdain yielded to disruption and finally to transformation as the paradigm shift occurred. The conflict between the open shoulder surgeons and the arthroscopic shoulder surgeons passed through all the phases that Mahatma Gandhi had described many years before. "First they ignore you; then they laugh at you; then they fight you; then you win."

Building a Ship in a Bottle

At the start of the 1990s, I recognized that my progress in arthroscopic rotator cuff repair would be extremely slow unless I could find an industry partner who shared my vision for full-scale conversion to arthroscopic means of repair and would be willing to help make it a reality. In 1991, I happened to meet Reinhold Schmieding, the owner of Arthrex, a small arthroscopic device company in Naples, Florida. Reinhold invited me to visit him to discuss the feasibility of developing arthroscopic repair systems for the shoulder. At the time, the world headquarters of Arthrex was a 20×30-ft storage room in an office service center, and there were 2 employees. One employee, Don Grafton, was a talented engineer without medical experience. By the end of my first day there, Reinhold and Don and I had agreed that developing arthroscopic repair systems for shoulder instability and rotator cuff repair would become a top priority for Arthrex.

My initial bias toward arthroscopic cuff repair was that a transosseous bone tunnel technique not only would be possible but would be superior to suture anchor fixation. In fact, my first 2 patents with Arthrex were for instrumentation for an arthroscopic transosseous repair technique. I tested my hypothesis with 2 successive biomechanical studies. The first examined cyclic loading of bone tunnel repairs, and the second examined cyclic loading of anchor-based repairs.[3,4] Evaluating the data from these 2 studies, I was surprised to find that anchor-based repairs were significantly stronger than bone tunnel repairs. In addition, anchors shifted the weak link from the bone–suture interface to the tendon–suture interface; in essence, anchors optimized bone fixation by shifting the weak link in the construct to the tendon. I was then completely convinced of the superiority of suture anchors over bone tunnels, and that conviction has become even stronger over the years. After these 2 cyclic loading studies, I shifted my focus, and that of Arthrex, toward arthroscopic suture anchor repair of the rotator cuff.

Reconciling Technique and Instrumentation With Anatomy and Biomechanics

Having recognized the importance of the rotator cable attachments both anatomically[5] and biomechanically,[6,7] I thought it important to reinforce them as a routine part of performing rotator cuff repairs. Our anatomical and biomechanical studies

had had great translational implications in the development of our techniques and instrumentation.

As mentioned earlier, Don Grafton was the chief (and for a long time only) engineer at Arthrex. As he had no medical experience, I invited him to come to San Antonio to observe surgery. During Don's many visits, I showed him pathology in the operating room and pointed out what I could do with the instruments I had and what I could not do. Then in the evening we went to my house and brainstormed how to perform the "missing" surgical manipulations, how to improve manipulations that were suboptimal, and how to optimize final surgical constructs.

Passing suture through tendon was an early challenge. One must remember that, in the early 1990s, it was not possible for machinists to fabricate complex shapes. Therefore, straight tubular retrograde suture passers were the logical first option. We initially developed spring-loaded retrograde hook retrievers (**Figure 1**) and then curved suture hooks with shuttling wires (Lasso). To me, the most unappealing feature of retrograde suture passage was the oblique angle of approach through the tendon, which caused a length–tension mismatch between the upper fibers and the lower fibers of the muscle–tendon unit. We recognized we could eliminate the mismatch if we passed the suture antegrade, such that it would pass perpendicular to the tendon fibers. These insights and efforts culminated in development of the Viper suture passer and then the FastPass Scorpion suture passer, which has a spring-loaded trapdoor on the upper jaw for ergonomic self-retrieving of the suture once it is passed through the tendon.

To develop a knot pusher that optimized knot tying (yielding the highest knot security and the tightest loop security), we used prototype instruments to tie and test literally thousands of knots in the laboratory. We were thus able to verify that the Surgeon's Sixth Finger Knot Pusher (Arthrex) reproducibly tied optimized knots[8,9] and also optimized knot fixation and bone fixation. However, our suture was not yet optimized and was prone to breakage, and our suture–tendon interface was not yet optimized. Clearly, improvement was needed in 2 more areas.

Don came up with the idea for a virtually unbreakable suture and developed that idea into FiberWire.[10] Shortly thereafter, I contributed the idea and design for FiberTape, which dramatically enhanced suture pullout strength and footprint compression.

Anchor designs improved rapidly and dramatically. We made the second-generation BioCorkscrew fully threaded, which virtually eliminated anchor failure, even in soft bone.

Optimization of the suture–tendon interface took a giant step forward when Park and colleagues[11,12] introduced linked double-row rotator cuff repair. Much as with a Chinese finger trap, the harder you pull, the stronger it becomes, with yield load approaching ultimate load.

At this point, it seemed we had optimized virtually every segment of the rotator cuff repair construct. Each component was just about as good as it could be. Or was it?

The Accidental Quest for Knotless Fixation

In November 1998, I made my first trip to China as a guest speaker at the Congress of the Hong Kong Orthopaedic Association. My first view of the magnificent Hong Kong skyline across Victoria Harbour was truly breathtaking. As I admired the gleaming glass towers and the concrete canyons of the city, I had no idea that the very next day these modern skyscrapers would reveal an ancient secret that would change my approach to arthroscopic rotator cuff repair.

Figure 1. Spring-loaded retrograde suture passer (Arthrex) with straight tubular shape necessitated by degree of difficulty inherent in trying to fabricate more complex shapes in early 1990s.

Figure 2. Lashings that secured bamboo poles of Hong Kong scaffolding had no knots but were secured by turning back on themselves and wrapping in a knotless manner. Reprinted from *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, volume 19, Stephen S. Burkhart, Kiriacos A. Athanasiou, The twist-lock concept of tissue transport and suture fixation without knots: observations along the Hong Kong skyline, pages 613-625, Copyright 2003, with permission from Elsevier.

The day after my arrival, Dr. James Lam took me to lunch. As we approached the restaurant, he pointed across the street to a tall building that was being renovated and had scaffolding supporting workers alongside the first 9 stories of the exterior wall. Dr. Lam said that, after lunch, he would take me to the construction site for a closer look at the scaffolding.

After lunch, we walked to the base of the scaffolding. Dr. Lam told me it was constructed entirely of bamboo poles held together with lashings but no knots (**Figure 2**). Lashings were secured by turning them back on themselves and wrapping them in an entirely knotless manner.[13] I found it incredible that this knotless fixation was so secure that it could support the weight of workers many stories above the ground. I resolved to determine how this fixation method worked and see if the same mechanism might help us achieve reliable knotless fixation in surgery.

When I returned home, I broke out my college engineering books and reacquainted myself with the concept of cable friction. As has happened so often in the past, however, it took a practical lesson from the ranch to truly illustrate for me how cable friction works.

Every cowboy knows that a spirited horse cannot be re-

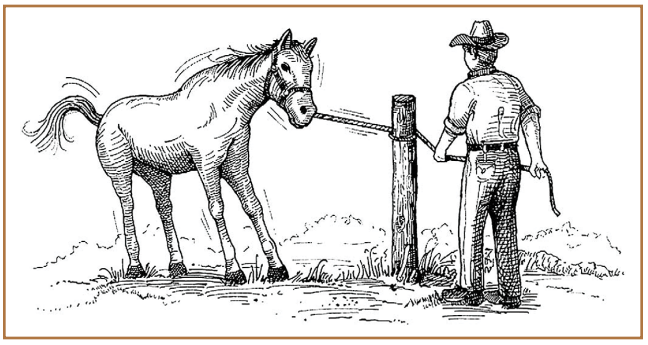

Figure 3. Cable friction is so powerful that a single throw of lead rope around a "snubbing post" is enough to allow control of a much larger, much stronger horse. Reprinted from *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, volume 19, Stephen S. Burkhart, Kiriacos A. Athanasiou, The twist-lock concept of tissue transport and suture fixation without knots: observations along the Hong Kong skyline, pages 613-625, Copyright 2003, with permission from Elsevier.

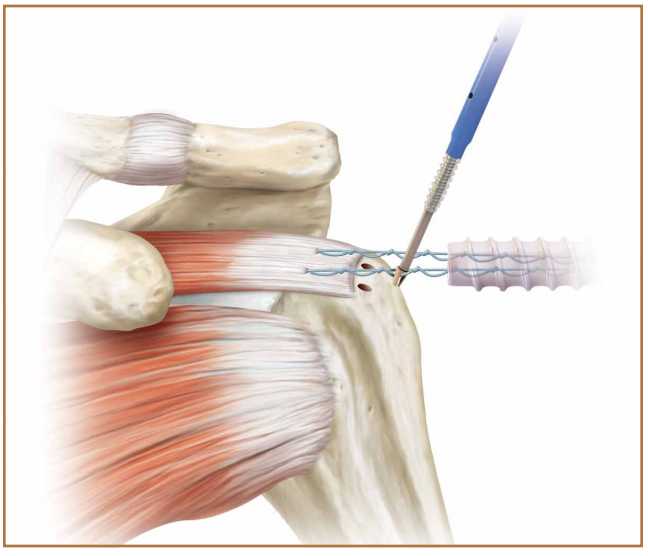

Figure 4. Forked eyelet of Biocomposite SwiveLock (Arthrex) captures second link from lateral edge of torn rotator cuff. Reprinted with permission from *The Cowboy's Companion: A Trail Guide for the Arthroscopic Shoulder Surgeon*, by Stephen S. Burkhart, Ian K. Y. Lo, Paul C. Brady, and Patrick J. Denard, Copyright 2012 Lippincott Williams & Wilkins/Wolters Kluwer.

strained with only one lead rope. However, a cowboy can wrap a lead rope around a "snubbing post" and thereby gain complete control over the animal, despite the horse's superior size and strength. The cable friction between the rope and the post creates such a large restraining force that the cowboy can easily hold the animal without the help of a knotted rope (**Figure 3**). In similar fashion in the Hong Kong scaffolding, fixation strength results from the significant amount of cable friction produced when the lashings wrap around one another and around the bamboo poles.

The cable friction concept was pivotal in the development of knotless fixation in arthroscopic rotator cuff repair. In lateral row fixation, the eyelet of the PushLock and SwiveLock suture anchors (Arthrex) produces significant cable friction at the eyelet–suture interface, in addition to frictional force wedging the suture between anchor and bone.

As with so many other devices in shoulder arthroscopy, the SwiveLock suture anchor developed in stages. In the first stage, a chainlike suture with consecutive intersecting links was used (FiberChain). The idea for an adjustable fixation construct came to me because I thought that a forked eyelet on a SwiveLock would provide a firm fixation point when inserted into the appropriate suture link, yet would be totally adjustable simply by choosing a tighter or looser link (**Figure 4**). Although the system worked very well, it was technically challenging. The process was greatly simplified after Don Grafton and I developed FiberTape and recognized that the power of cable friction was dramatically increased by the larger contact area between the eyelet and the braided FiberTape. The SpeedBridge construct (Arthrex), which enhanced cable friction fixation by means of passing FiberTape through the anchor eyelets, also provided a larger compressive interface at the repair site by using FiberTape rather than conventional suture. These incremental improvements led to what I would characterize as today's gold standard for arthroscopic rotator cuff repair: a largely knotless linked double-row construct using FiberTape, with cinch-loop sutures

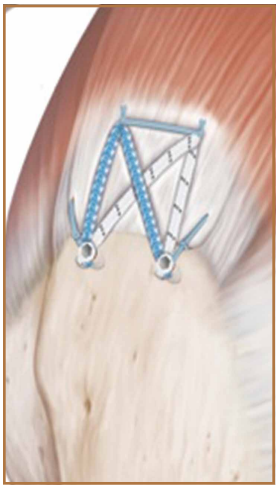

Figure 5. Schematic of reinforced SpeedBridge (Arthrex) rotator cuff repair. Cinch-loop sutures reinforce anterior and posterior rotator cable attachments and simultaneously reduce dog-ears in tendon. Double-pulley medial mattress sutures (double mattress sutures linking 2 medial anchors) further reinforce construct in case of poor-quality tendon. Reprinted with permission from *The Cowboy's Companion: A Trail Guide for the Arthroscopic Shoulder Surgeon*, by Stephen S. Burkhart, Ian K. Y. Lo, Paul C. Brady, and Patrick J. Denard, Copyright 2012 Lippincott Williams & Wilkins/Wolters Kluwer.

at the anterior and posterior margins of the tear to reinforce the cable attachments and simultaneously reduce the dog-ears that typically occur in those locations, and a double-pulley medial mattress if tendon quality is poor (**Figure 5**).

The Burden of Craft

With all the recent enthusiasm for level I studies, I think we need to examine whether they will accelerate technological advancement in rotator cuff repair. The answer, in my opinion, is a resounding no. This answer is based on a major disconnect I have detected in how we evaluate these studies in rotator cuff disease and repair.

An irony related to technological advancement in surgery is that the more technically advanced the surgery becomes, the

more skill is required. This fact is completely at odds with the public's perception that technological advances make procedures easier. In arthroscopic rotator cuff repair, the surgeon must look, feel, and be aware to a greater degree than in open surgery.

Edward Tenner, in his book *Why Things Bite Back*, described the burden of the practitioner of any advanced technology as the *burden of craft*.[14] The burden of craft is the inherent demand on all craftspeople, but particularly surgeons, to "up our game" if we are to be successful in our craft. For arthroscopic rotator cuff repair, the burden of craft requires patience, attention to detail, and the ability to work in a virtual space. Not everyone has these skills. But anyone who wants to practice in this discipline has an obligation to learn the skills required, and then to teach them to others and assess how well they are being applied.

The problem with relying on level I studies to assess the efficacy of a surgical procedure is that they are inherently biased by the surgeons involved. As results depend on surgeons' skills, and surgeons' skill levels are not equal, level I studies cannot prove what is possible, cannot demonstrate the limits of a technique, and cannot demonstrate the equivalence of techniques.

Amazingly enough, there are still rotator cuff repair "deniers" who confidently assert from the podium that a large percentage of massive cuff tears cannot be repaired and that, even if they can be repaired, they do not have the biological potential to heal. Given the disparity in surgeons' skills and results, however, one must ask whether poor results are a consequence of a biological deficit in the patient, or of a skill deficit in the surgeon.

What I know is that we have techniques for predictable arthroscopic repair and healing of the vast majority of rotator cuff tears, even massive tears,[15-17] and patients do very well clinically. Yet, among many orthopedic surgeons, there is a trend to go straight to reverse total shoulder arthroplasty (rTSA) for massive tears—despite the evidence against it. As reported in the literature, rTSA results are not as good as arthroscopic cuff repair results, and the complication rate for rTSA is much higher.

Why has this trend toward rTSA for massive tears gained so much momentum? The only reason I can surmise is that, for the average surgeon, rTSA is easier and quicker than arthroscopic repair for massive tears. But the reason for choosing a specific type of surgery for a given problem should not be that it is easiest for the surgeon; it should be that it is best for the patient.

The surgeon should start by asking what procedure he or she would want if the roles were reversed—if the surgeon were the patient with the massive rotator cuff tear. If a surgeon does not have the skill set for the best procedure for a particular patient, he or she is obligated to send that patient to a surgeon who does have the skills. In addition, given that infection is the most feared complication in most shoulder surgeries, the surgeon should ask which infection rate would be personally acceptable. Arthroscopic rotator cuff repair has a reported infection rate of 1.6 per 1000, or .0016,[18] whereas rTSA has an infection rate about 25 times higher, or .04.[19] Further, the surgeon must consider the relative severity of the consequences of infection. By any measure, an infected arthroscopy is a straightforward treatable complication, but an infected shoulder replacement is a human tragedy. Patients vastly prefer the minimally invasive arthroscopic approach, and through online searches can easily identify who can offer an arthroscopic solution.

To reproducibly achieve successful arthroscopic repair of massive rotator cuff tears, the surgeon must know advanced techniques, including subscapularis repair techniques,[20,21] interval slides,[22,23] and self-reinforcing constructs.[24,25]

"It's a poor carpenter who blames his tools." This 18th-century English proverb is as true today as it was 300 years ago. The tools for arthroscopic cuff repair exist, and they are excellent. The burden of craft is the surgeon's burden and obligation. As surgeons, we must accept that obligation and the responsibility of that burden.

As mentioned earlier, Dr. Rob Bell's charge to me when he invited me to give the Neer Lecture was to sum up my involvement in the development of arthroscopic shoulder surgery. The short version is that I have been doing shoulder arthroscopy for 31 years; have received 28 US patents related to shoulder instruments and implants and have 12 US patents pending; have published 167 peer-reviewed articles, a couple dozen book chapters, and 2 textbooks on shoulder arthroscopy; have trained 25 fellows; and have hosted approximately 3000 visiting surgeons in my operating room. My greatest professional dream was to see the standard of care for rotator cuff repair and shoulder instability transition from open to arthroscopic techniques, and I have been fortunate enough to have observed that paradigm shift during my career.

What do I envision over the next 31 years? As we all know, history runs in both directions, and some things simply have not happened yet. In terms of rotator cuff treatment, I think over the next few years the guiding principle of treatment will be joint preservation. All rotator cuff tears, even massive tears, will be repaired arthroscopically. Patients and insurers will demand arthroscopic repair, and surgeons without the skill set will migrate to other subspecialties. As for the role of arthroplasty in the treatment of rotator cuff tears, rTSA will be indicated only for pseudoparalysis after failed cuff repair in low-demand elderly patients.

In rotator cuff treatment, I envision a standard of care that is almost entirely arthroscopic. This standard will demand that surgeons who treat rotator cuff tears be proficient in arthroscopic repair of the full range of tears. Acquiring the skills for arthroscopic repair may not be easy, but then "there's the easy way, and there's the Cowboy Way." As my dad used to tell me when I complained about working too hard, "No man ever drowned in his own sweat." We shoulder surgeons must accept the burden of craft that accompanies the new standard of arthroscopic cuff repair, and we must offer our patients the same level of care we would choose for ourselves.

Happy trails!

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Commentary

Peter D. McCann, *Editor-in-Chief*

"The Burden of Craft in Arthroscopic Rotator Cuff Repair" is a summary of the annual Neer Lecture that was delivered by Stephen S. Burkhart, MD, at the 2014 annual meeting of American Shoulder and Elbow Surgeons. It is a fascinating personal story of the 35-year evolution of arthroscopic rotator cuff surgery presented by one of the most respected arthroscopic innovators of our times. I especially enjoyed his apt citations of classic leaders—Churchill and Gandhi—but 3 points I believe deserve special comment.

First, Steve describes the challenges he faced bringing new products to market in the 1980s. How do we resolve the inherent conflict between innovation that introduces new technology and the "tried and true" standards of established practice? Do the hard work that Steve has done over the years: pose a hypothesis, design a study to answer the question, publish results in peer-reviewed journals, and embrace the techniques that demonstrate better outcomes for patients.

My second point relates to surgeon–device industry relationships, a subject of great interest to *The American Journal of Orthopedics* dating back to 2006.[1-3] Dr. Burkhart learned early on that he could not fashion new arthroscopic instruments in his garage. Nor could a company develop useful instruments without a knowledgeable surgeon's input. Hence, a partnership between the innovator-surgeon and the device industry is essential to bring new and effective "tools" to market. Dr. Burkhart's partnership with Arthrex has benefited many thousands of patients.

The agreements announced in 2007 between the US Department of Justice and 5 orthopedic device manufacturers (interestingly, current presidential candidate and Governor of New Jersey Chris Christie was the lead US Attorney on the case!) dramatically altered the surgeon–industry interaction and established strict guidelines that governed these relationships.[4] These were needed reforms. However, the changes did not preclude an entrepreneurial surgeon with

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great ideas and a device manufacturer from profiting from excellent products that advanced patient care, provided, quoting from my editorial of 2006, "that these partnerships comply with legal and ethical standards" and are transparent as well as fully disclosed.[1]

Finally, Steve's last point focuses on the "burden of craft," a topic dear to all orthopedic surgeons and our professional societies. All of us are committed to improving our surgical skills and, as a profession, we are consistently engaged in learning from our talented colleagues, who are only too willing to share their expertise. The burden of craft requires eager students and dedicated teachers, all committed to the same goal—better outcomes for our patients. We are indeed fortunate that, as orthopedic surgeons, we fundamentally support a culture of continued learning.

I thank Steve for his eloquent paper on this important principle.

References

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4 Five companies in hip and knee replacement industry avoid prosecution by agreeing to compliance rules and monitoring [press release]. US Department of Justice website. http://www.justice.gov/usao/nj/Press/files/pdffiles/Older/hips0927.rel.pdf. Published September 27, 2007. Accessed July 14, 2015.