Radiostereometric Analysis (RSA) of the Anatomical Total Shoulder Arthroplasty and Reverse Total Shoulder Replacement: An Analysis of Component Stability and Polyethylene Wear

Reuben Gobezie, M.D., Kyle P.Lavery, B.A., Charlie Bragdon, Ph.D., Laurence D. Higgins, M.D., Henrik Malchau, M.D., Jon J.P. Warner, M.D.

Massachusetts General Hospital

INTRODUCTION

Conventional total shoulder replacement is an important treatment alternative for patients with debilitating joint destruction from a wide variety of etiologies. As a discipline, shoulder arthroplasty is one of the fastest growing areas in joint replacement surgery and the prospects for future growth appear assured as the population of elderly expands rapidly over the next few decades.[1]

The clinical importance and utilization of the reverse total shoulder replacement is even more staggering. This prosthesis was first developed by Grammont in the early 1970's.[2] Several generations of this prosthesis have since been developed and the reverse total shoulder replacement has been used widely in Europe for more than 15 years as a salvage operation for rotator cuff arthropathy. The introduction of this prosthesis to the United States in March of 2004 has resulted in an almost instantaneous adaptation of this technology for our patients. In fact, the incorporation of this prosthesis into our treatment arsenal has been encouraged by some of the first mid-term clinical outcomes studies from the French indicating that the survivorship of these prosthesis, even at 10 years, may be comparable to that for historical data from conventional shoulder arthroplasty even if the complications rate for this procedure is significantly higher. [3-5]

Despite our extensive experience with shoulder arthroplasty and numerous clinical outcomes studies validating the effectiveness of this treatment in relieving pain and restoring function, relatively little is understood about component stability or polyethylene wear with these prostheses. The development of improved prosthetic design and, ultimately, greater longevity and function for our patients is dependent on a better understanding of these factors. The purpose of this paper is to introduce the application of radiostereographometric analysis (RSA) in the analysis of conventional and reverse total shoulder replacements as a means of deepening our understanding of these issues in shoulder arthroplasty.

Reuben Gobezie M.D. is a Shoulder Fellow at Massachusetts General Hospital.
Kyle Lavery B.A. is a research assistant for the Harvard Shoulder Service.
Charlie Bragdon Ph.D. is member of the Orthopedics Biomechanics and Biomaterials lab.
Laurence D. Higgins M.D. Co-Chief of the Harvard Shoulder Service.
Henrik Malchau M.D.is a Visiting Professor of Orthopedic Surgery at Harvard Medical School.
Jon J.P. Warner M.D. is Co-Chief of the Harvard Shoulder Service.

Address correspondence to:

Jon J.P. Warner M.D.
Massachusetts General Hospital
55 Fruit St.
Boston, MA 02114

THE PROBLEMS: COMPONENT STABILITY AND WEAR

Component stability

Several of the clinical studies with long-term follow-up after total shoulder replacement have indicated that the 'weak-link' for component stability in these prosthesis is the glenoid.[1, 4, 6-12] While migration or rotation of the glenoid component on serial radiographs is a dramatic and definitive indicator for failure of fixation, the identification of early loosening has primarily been made by observing the progression of radiolucent lines with time. The reliability of this technique for identifying early loosening has been studied and been shown to be poor since many patients have radiolucent lines on their first postoperative xray, reproducible positioning of the patient is difficult and the anatomic variation of the glenoid version greatly influences the frequency of observed radiolucencies.[14-16] Consequently, the reported rate of radiolucency has ranged from 22-95%.[4, 12, 17-19]

The need for accurate and precise analysis of component stability in total shoulder arthroplasty is not trivial. The potential complications that may result from loose prosthesis may include osteolysis of the glenoid, glenohumeral instability, dislocation of the component, pain and loss of function.[20]

Wear

To date, the issue of polyethylene wear has simply not been studied in total shoulder arthroplasty. The need to gain a better understanding of the potential role that polyethylene wear may have in glenoid loosening, osteolysis and component failure is clear based on our collective experience from hip and knee arthroplasty. It is now well established that hip and knee periprosthetic osteolysis is a direct result of particulate debris generated from the implants.

The relatively recent development of ultrahigh molecular weight highly cross-linked polyethylene developed at the Harris Orthopaedic Biomechanics and Biomaterials Laboratory at Massachusetts General Hospital and the laboratory data supporting the marked reduction in particulate debris has resulted in the use of this material clinically since 1999.[21-24] Now, virtu-

ally all manufactured soft-bearing component systems for total hip arthroplasty use highly cross-linked UHMWPE as the standard liner for their prostheses. The early clinical results with this new polyethylene in THA have verified a reduction in polyethylene with reduced rates of femoral head penetration.[25, 26] [27, 28]

The importance of expanding our understanding of polyethylene wear to total shoulder replacements is particularly crucial since none of the total shoulder replacement systems currently on the market utilize highly cross-linked polyethylene as a bearing surface.

ROENTGEN STEREOPHOTOGRAMMETRIC ANALYSIS (RSA)

What is it?

RSA is a technique that was developed by Selvik et al. [29] in order to accurately and quantitatively measure the relative displacement of components on the axial skeleton. RSA is widely accepted as the most accurate method to determine the magnitude of relative displacements between rigid objects using radiographs. The technique has been expanded and refined for a wide variety of purposes including the study of growth plate integrity, joint kinematics, implant stability, spinal fusion integrity and polyethylene wear. [30, 31] [26, 32, 33] Using RSA, relative motion as little as 0.1-0.7 mm between two rigid bodies (implant and bone) can be reproducibly and accurately determined.[20, 34, 35]

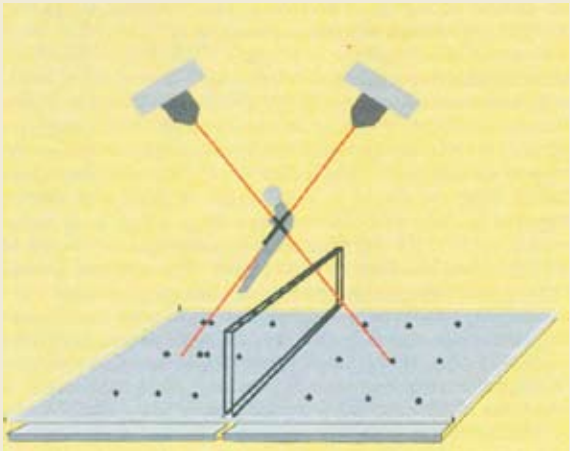

Figure 1. The RSA calibration cage has two groups of tantalum beads used to created a three dimensional coordinate system. Using this coordinate system, the precise location of the *in vivo* markers can be calculated. On serial radiographs, the accuracy of these measurements is between 0.1-0.7mm. (Drawing courtesy of Dr. Johan Karrholm)

RSA requires the implantation of small tantalum beads. Tantalum is used since its high density makes its visualization on radiographs optimal. A pair of stereo-radiographs is taken with the patient positioned in front of a calibration cage so that a three-dimensional coordinate system can be generated. (Figure 1)[36] Sequential radiographs are obtained and analyzed using an automated image analysis tools and relative displacements can be determined.

What's been done with this technique?

Only two studies using RSA to analyze component stability after total shoulder arthroplasty have been reported. In a study by Nagels et al, five patients after TSR using a keeled cemented glenoid were analyzed using RSA at a minimum of 3 years after implantation.[20] Three of the five patients had evidence of glenoid loosening based on component migration ranging from 1.2-5.5 mm; only one patient with gross loosening had radiographically visible evidence consistent with the RSA findings. Despite the small sample size, these investigators were able to suggest that traditional radiographs likely underestimated the degree of early loosening for the glenoid component.

Rahme et al. reported on a larger series of 14 shoulders with keeled cemented glenoids evaluated using RSA at a minimum of two-years follow-up.[16] Translation of the glenoid of greater than 1mm was observed in four of the shoulders and rotation of greater than 2° was observed in ten shoulders. Eleven of the 14 shoulders studied had evidence of radiolucent lines about the glenoid component although most of the lines were not progressive and were less than 0.1mm in width. Interestingly, the presence of radiolucent lines did not correlate with component migration based on the RSA findings.

What are we doing and how are we doing it?

We have recently commenced a five-year prospective RSA study in order to provide insight into the relevant questions

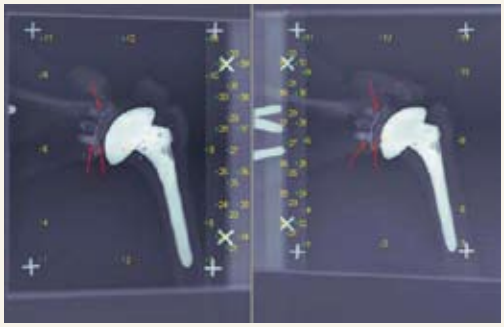

Figure 2. RSA images with the Anatomical Total Shoulder System (Zimmer, Warsaw, IN) from our pilot studies. The numbering is from the calibration cage projecting from the orthogonal radiographs. The arrows indicate tantalum beads in the glenoid used on serial radiographs to determine implant stability, polyethylene wear and shoulder joint kinematics.

regarding component stability and polyethylene wear in both conventional Anatomical total shoulder replacements and the reverse prosthesis. (Figure 2) In addition to conducting an adequately-powered study, the goals of this research project incorporate three unique experimental design features: (1) the study of pegged cemented glenoids, (2) the first study of reverse total shoulder replacements, (3) the application of RSA to the quantification of polyethylene wear in addition to component stability.

If we are able to achieve the goals of our study, the quantification of component mobility and polyethylene wear in these two arthroplasty systems, we believe several significant contri-

butions to our understanding of shoulder arthroplasty will be attained. First, this information would enable us to assess the short-term performance of current component designs quantitatively providing a basis of comparison between prosthesis that does not exist today. Second, the RSA wear data would answer the potentially important questions regarding what clinically significant role, if any, does polyethylene wear play in the failure of total shoulder replacements and the glenoid component, in particular. Third, these studies would provide insight into the kinematics of total shoulder arthroplasty in these two very different devices. Finally, the information we learn from these studies may enable us to enhance our collective efforts to optimize the design of total shoulder replacements in a manner that maximizes their *in vivo* longevity and improves the function of our patients' shoulders.

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