Reachable Workspace: An Observer-Independent Functional Outcomes Measure for Upper Extremity Pathology after Surgical Interventions

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INTRODUCTION: Physical examination and imaging studies remain central in assessing functional outcomes following shoulder surgery, but patient-reported outcome measures (PROs) are increasingly employed to evaluate success from a patient-centric perspective. Each type of outcomes metric is limited, particularly when evaluating the results of complex interventions that have multiple endpoints—as is the case for both arthroscopic and arthroplasty procedures. Furthermore, existing outcome measures are even more difficult to interpret for uncommon surgeries like nerve transfers for brachial plexus injuries. Physical examinations and observer evaluations are also constrained by inter- and intra-rater variability and interpretation, and PROs are subjective and include variables such as patient fluency and medium of administration. Here we present the Reachable Workspace (RWS), a novel, objective, and rater-independent outcomes metric to quantify functional range of motion after surgical intervention for upper extremity injuries.

METHODS: IRB approval was obtained to evaluate patients' upper extremity function using the Reachable Workspace pre- and postoperatively following surgical procedures for treatment of brachial plexus injuries and shoulder arthroplasty. The assessment was performed during routine clinical visits using the standardized RWS protocol. Briefly, subjects are seated 229 cm in front of a Microsoft Kinect 2.0 sensor (Redmond, WA), set to a height of 115cm. Measured arm movements include a combination of vertical and horizontal sweeping movements in the frontal plane (abduction, abduction in the scapular plane, forward flexion, cross-body adduction, and a horizontal sweep at umbilicus and above shoulder levels) in addition to an extension reaching movement in the posterior plane. Back-end algorithms reconstruct movement paths (i.e., trajectories) for each arm and automatically calculate the extent of reachability for both injured and non-injured (control) arms. Results are expressed via 4 frontal quadrants: 1) upper medial, 2) lower medial, 3) upper lateral, 4) lower lateral, and as a total (summation of all 4 quadrants). Operationally, all data produced from the reachable workspace is presented as relative surface area (RSA), which represents the area of space an individual can reach, normalized by individual arm length. RWS data was compared to other clinically relevant physical examination measures, including muscle strength (Medical Research Council score) and clinician-measured extremity motion.

RESULTS SECTION: Significant improvements in shoulder functional ROM (Reachable Workspace) from baseline were documented in all patients as early as 5 months after nerve transfer surgery for treatment of brachial plexus injury and 4 months after shoulder arthroplasty. Clinical strength MRC measurements also improved over this time course, from 0/5 (no visible muscle contraction) at baseline to 3/5 (movement against gravity). RWS data directly correlated with clinical observations and quantitative functional ROM measurements.

DISCUSSION: This work demonstrates the first use of Reachable Workspace to quantify and track upper extremity post-surgical functional improvement in a uniquely challenging brachial plexus injury model system and after shoulder arthroplasty. Our results indicate that this tool has compelling potential as an objective and clinically meaningful assessment tool for clinicians and researchers. The ability of RWS to quantify the time course of shoulder functional improvement after surgery—with meaningful output parameters generated during routine clinical visits—adds a valuable data dimension to surgeon clinical decision-making and provides a potent resource for future data acquisition. Further optimization and application of this tool is warranted to continue to quantify upper extremity surgical outcomes to improve both surgeon and patient decision making.

SIGNIFICANCE/CLINICAL RELEVANCE: The introduction of Reachable Workspace (RWS) provides an objective, clinician-independent method for assessing functional outcomes in patients undergoing surgical intervention for upper extremity pathology. By offering a quantitative metric that aligns with other clinical observations and measures, RWS may enhance surgical decision-making and opens the door for more nuanced, patient-centric evaluations in upper extremity orthopedic surgery.

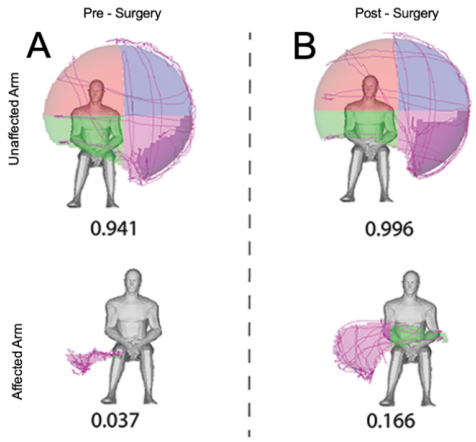

Figure 1. Example of upper extremity function recovery in a radial to axillary nerve transfer patient (Patient 2). (A) Pre-surgery reaching in unaffected (top panels) arm vs. affected arm (bottom panels). Before surgery, only minimal reaching in the lower lateral quadrant (pink) is present. (B) By 6 months post-surgery, there is marked improvement in the lower lateral (pink) quadrant and the appearance of reach into the lower medial quadrant (green).