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AI-Based Wireless Sensor System for Tracking Muscle Activity and Kinematics of the Shoulder joint

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INTRODUCTION: The Center for Medicare & Medicaid Services (CMS) recognizes the population of American ages 65 and older will double by 2040 and shoulder pain remains a common clinical problem in the geriatric population. According to clinical literature, rotator cuff tendinitis or impingement, rotator cuff tear, osteoarthritis are the most common shoulder problems and more likely three times higher in elderly people[1]. Treatment options involve both non-operative and surgical interventions. The majority of patients initially pursue a trial of moderate physical therapy. Over 460,000 rotator cuff surgeries per year are performed in the U.S. and the rotator cuff Injury treatment market size was estimated at USD 195.02 million in 2021, USD 200.55 million in 2022, and is projected to grow at a CAGR 4.75% to reach USD 257.68 million by 2027. Patients with shoulder problems typically are unable to lift even small (2lb) weights overhead. In particular, adhesive capsulitis ("frozen shoulder") is a common problem after rotator cuff surgery that would benefit greatly from early intervention[2]. Patients who suffer from adhesive capsulitis after shoulder surgery, experience limitation in active and passive motions. While these patients' plain x-rays typically show normal condition, they are not able to do several activities including putting on a coat or scratching their back[1]. Surgical interventions are often intended to eliminate these limitations. The outcome of surgical interventions is commonly measured by improvement in shoulder pain, range of motion (ROM), strength and patient reported outcomes. There has been great progress in developing and standardizing patient reported outcome measures in recent years. However, we still rely on physical examination to assess patient's ROM and strength which has been shown to be highly variable and inaccurate. Additionally, timely assessment of ROM and appropriate interventions by physical therapist are key to avoid stiffness and development of adhesive capsulitis during the postoperative period. Physical therapists do not have access to history of joint activity and muscle function of the patients' joints in between subsequent visits.

METHODS: We propose a system that can provide quantitative and reliable information to the patient and treating physician regarding patient's recovery and gain of function. Our technology is an artificial intelligence (AI) based wearable device for tracking joint kinematics and muscle activity of patients after shoulder surgery. The device is a mobile app controlled wireless wearable adjustable upper arm/shoulder brace that can monitor and measure joint range of motion and muscle activity, transmit these data wirelessly to a mobile app, then along to cloud storage for data analysis. Patients will use the wearable device for a predefined period per day and if it fails to achieve expected individualized ROM set by the AI algorithm, they will receive instructions to complete specific exercises and the machine trained system will track their compliance and improvement during the rehabilitation period. This highly sensitive and AI-based monitoring system can depict deviation from normal recovery and give real-time feedback during postoperative rehabilitation to support physical therapy, improve range of motion (ROM) and optimize pain control. Our proposed platform can close the gap among patient, orthopedic surgeon and physical therapists during postoperative rehabilitation time.

Figure.1. Proposed conceptual intelligent wearable device

Our device was utilized in a pilot study of healthy subjects with no history of shoulder girdle muscle or joint disease or surgery and patients with history of rotator cuff injury-related shoulder surgery. Subjects initially stand upright in the neutral position for 5 to 10 s, with their arms relaxed by their sides (palms inward, facing the body). Sensor data will be recorded for 10 s to establish sensor baseline orientation and noise. Each subject will perform four active and passive movements: shoulder abduction, elbow flexion, elbow extension, and shoulder external rotation. In each performance, subjects will have a 3-minute break to avoid any muscle fatigue and tiredness. To assess the reliability, three repeated trials is performed on the same day for each side and also in two different sessions after a baseline visit at 1 and 3 months. Calculated and measured variables are summarized in Table.1. A one-way repeated measure of analysis of variance (ANOVA) is used to determine the reliability during each activity. Individual error scores of zero indicate reliability. We also examine the interclass correlation coefficient (ICC) of each of the three trials and make Bland-Altman plots for each session as well as for the three different sessions (baseline, month 1, and month 3).

Table 1. Summary of Outcome Variables
ROM (degree) for each performance (*i.e.,* shoulder abduction, elbow flexion, elbow extension, and shoulder external rotation) during the going phase (0-180°)
ROM (degree) for each performance during returning phase (180-0°)
Maximum ROM for each performance (degree)
Angular velocity (degree/second) during going phase
Angular velocity (degree/second) during returning phase
Average jerk (AJ, m/S3)
Mean value of the RMS going phase (μV)
Mean value of the RMS returning phase (μV)
Muscle contribution (%) for each ROM

RMS:root mean square; ROM: range of motion.

RESULTS SECTION: Fig. 2 shows the ROM of subjects during shoulder abduction and EMG (root mean suare)RMS (bottom). The plot is one combination of handedness (left, right) and task (flexion), as labeled. The presented subjects in Fig.2 were an 82-year-old right-handed healthy man with no history of shoulder girdle muscle or joint disease or surgery, and a 74-year-old right-handed man with right shoulder stiffness due to right rotator cuff injury-related shoulder surgery.The injured subject had lower ROM than the healthy subject for all three movements. In flexion movement, a deltoid muscle contribution calculation in the injured subject was 6.53%, while in the healthy subject it was 16.1%. The maximum flexion angle in the affected right shoulder of the injured subject was 110°, compared to 146° in the same shoulder of the healthy subject.

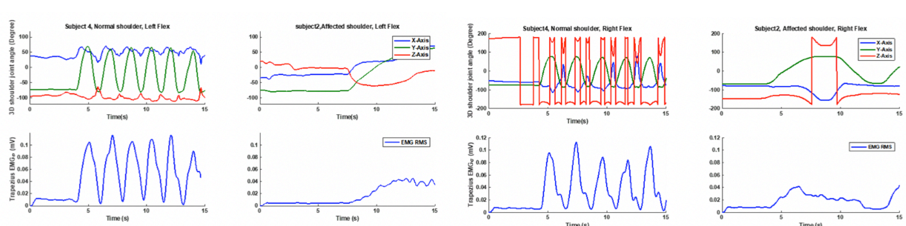

Figure 2. Comparison of ROM of both shoulders (flexion movement) of healthy control [Subject 4] and subject with right shoulder stiffness due to right rotator cuff shoulder surgery [Subject 2].

DISCUSSION: Our powered adjustable brace aims to reduce recovery time by giving real-time feedback to the user during postoperative rehabilitation, improve ROM and optimize pain control. Measurements from the device's four surface EMG sensors and the triaxial accelerometer-gyroscope can be transmitted wirelessly to healthcare cloud/storage for further processing. In the healthcare cloud, an AI-based algorithm will estimate the impairment of individual shoulder girdle muscles.

SIGNIFICANCE: This technology can be used for remote at-home telemedicine delivery of rehabilitation services while tracing tele-visit sessions in compliance with billing standards as in-person visits.

REFERENCES:

[1] Le, H.V., et al., Shoulder Elbow, 2017. [2] Geary, M.B. et al., Geriatr Orthop Surg Rehabil, 2015.