Collaborative Synchronous Comparison of Multiple Wearable Lumbar Biomechanics Sensor Systems

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INTRODUCTION: Chronic low back pain (cLBP) is a significant medical issue that is challenging to treat. One approach to identifying effective treatment paradigms is to utilize biomechanical information to phenotype groups of cLBP individuals who may have similar disease etiology and progression. Previous studies have attempted to leverage this approach by using wearable sensor systems to collect biomechanical measurements of functional movements completed by those with chronic low back pain and controls to attempt to match them with an effective treatment method. A key limitation of this strategy is that wearable sensor systems vary substantially across research labs. These differences include sensor hardware, sensor positioning guidelines, data acquisition systems, data processing, data extraction, and protocols for acquiring subject movements. In short, it is currently very challenging to directly cross-compare biomechanical data collected from different wearable sensor systems. In the present work, we leverage an unique opportunity for collaboration facilitated by participation of 7 different research institutions within the NIH Back Pain Consortium (BACPAC), each of which uses disparate wearable sensor systems for capturing lumbar spine biomechanical information. The purpose of this work is to synchronously utilize multiple wearable sensor systems to cross-compare lumbar biomechanical measurements during both an in-clinic functional motion evaluation and an at-home 48-hour evaluation of the movements of daily living.

METHODS: Five sensor systems were used to conduct the in-clinic portion of the research including a high deformation strain gauge based wearable sensor array (SPINE Sense, Brigham Young University), 3 IMU based wearable systems with distinct capabilities, sensor positioning instructions, and data processing algorithms (University of Pittsburgh: Lifeware Labs, Ohio State University: Conity System, Harvard University: Movella Xsens Dot), and a camera-based full body wireframe skeletal tracking system based on the Kinect camera system (University of California, San Francisco). The subject's back was prepared for the in-clinic portion by palpation and marking of the T1/T2, T12/L1, and L5/S1 spinous processes directly on the skin. The BYU SPINE Sense array was then placed directly on the subject's back, aligned with the L5 and the spine, while in a prone position. After placing the SPINE Sense array on the subject, each IMU system was prepared individually by calibrating and synching each group of sensors together (4 for Lifeware Labs, 2 for the Conity System, and 3 Movella Xsens Dots for Harvard). Lifeware Labs IMUs were placed directly on the skin at the marked T1/T2, and on top of the SPINE Sense array using Velcro at T12/L1 and L5/S1. A Catapult sports monitoring top was then placed on the upper body of the subject (over the Lifeware Labs IMU) and a Movella Xsens Dot sensor was placed on top of the garment at T5/T6. Two thigh straps were then placed on the upper thigh of the subject with a Movella Xsens Dot IMU located on the posterior aspect of the muscle body. The final Lifeware Labs IMU was placed on the lateral side of right thigh, on the thigh strap also used for Harvard's IMU's. The Conity System IMUs were positioned in their predesigned harnesses then the harnesses were placed on the subject over all the other previously described systems. UCSF's Kinect camera system was then prepared by placing the Kinect camera on a tripod approximately 5 feet away from the front edge of the foot mat. A set of 20 functional movements was carried out by the subject, while biomechanics data was synchronously collected using the 5 listed systems. Data collected using the SPINE Sense array, Lifeware Labs IMUs, and Conity IMUs was automatically uploaded to Cloud databases, while the Kinect and Movella Xsens Dot data was manually uploaded.

The at-home portion of the research was conducted immediately following the in-clinic portion. Three sensor systems were used to collect the at-home portion of the research, including the BYU SPINESense array, the U Pitt Lifeware Labs IMU system, and a hip-mounted Actigraph sensor data collection and analysis protocol used by Stanford. All systems except for the BYU SPINE Sense array were removed from the subject in the reverse order of the placement described previously. Two U Pitt Lifeware Labs at-home sensors were then turned on, calibrated, and secured to the SPINE Sense array using Velcro and KT tape. The Actigraph sensor was then mounted onto a belt and placed on the right hip of the subject. The subject wore the three systems while continuously collecting biomechanics data for a full 48 hours. After removing each system from the subject, data from each system was then manually uploaded to Cloud databases when the 48-hour data collection period was complete.

RESULTS: Biomechanical data for the in-clinic test was collected for each of the systems used (BYU: skin strain/impedance; UPitt, OSU, Harvard: range of motion, velocity, and acceleration; UCSF: overall movement quality score). Biomechanical data was also collected by each system used for the at-home portion of the research (BYU: skin strain/impedance; UPitt: range of motion, velocity, and acceleration; Stanford: activity levels, steps, acceleration, and light levels). For example, Figure 1 shows both a 30-minute comparison and a 5-minute comparison of the 48-hour data from the 3 relevant wearable sensor systems for one subject.

DISCUSSION: Each sensor system demonstrated unique strengths. The waist mounted Actigraph system (Stanford) provided whole body acceleration data while the Kinect camera system (UCSF) provided whole body joint movement information. Each of the 3 IMU based systems (OSU, U Pitt, Harvard) had distinct mounting locations, distinct analysis processes, and distinct sampling resolutions, but in general provided composite lumbar motion information. The strain sensor-based system (BYU) provided higher spatial fidelity (i.e., segmental level biomechanics information) than the other systems, but relied upon a machine-learning based algorithm for computing kinematic information as opposed to directly measuring it. Synchronous collection of lumbar biomechanics information from all of the wearable systems allowed for comparison of the sensitivity of each system to functional movements. Additionally, synergistic combinations of wearable systems which provided enhanced biomechanics information were identified.

SIGNIFICANCE: Each system used in the in-clinic and at-home portions of this research provide an enhanced understanding of the lumbar spine movement in both individuals with cLBP and asymptomatic controls.

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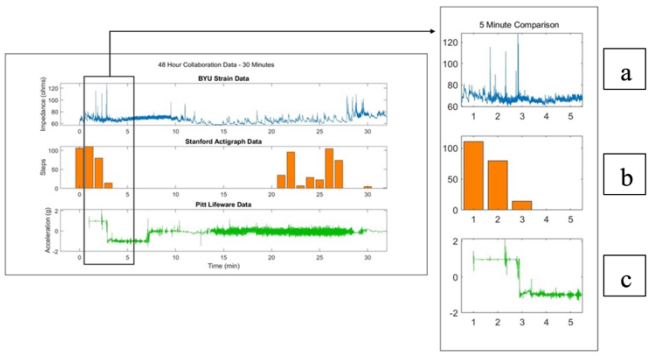

Figure 1: Photo of all 5 wearable sensor systems used for in-clinic research placed on a participant prior to simultaneous data collection.

Figure 2: At-home test data of (a) strain sensor impedance (S15) from the SPINE Sense array (b) step count from the Actigraph (c) x-acceleration from L5 Lifeware IMU.