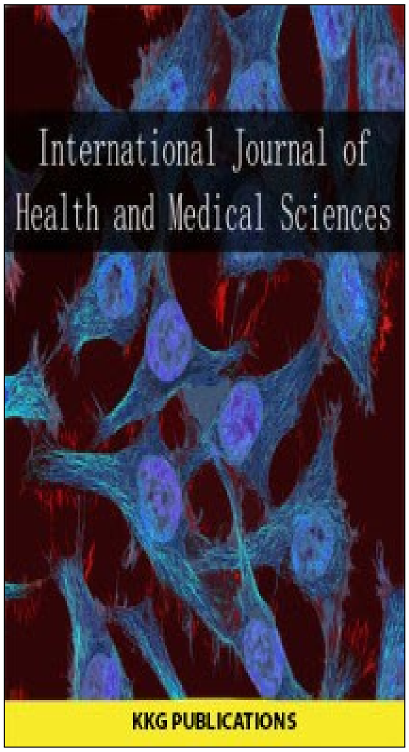

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A CADAVERIC STUDY OF SYNOVIAL FLUID KINEMATICS AT THE SCAPHOLUNATE JOINT

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Abstract. Studies on carpal bone kinematics have been conducted before. However, fewer have been done to investigate the synovial fluid kinematics in the scapholunate joint during repetitive wrist movements. We hypothesize that such repetitive wrist movements, i.e., ulnar deviation, could potentially cause the synovial fluid pressure to change accordingly. The objective of this study is to conduct an experimental study to measure synovial fluid pressure changes at the scapholunate joint of a cadaveric hand ($n = 1$) under repetitive ulnar deviation. A cadaveric hand with the elbow intact was mounted on a custom-made motion simulator at the neutral position, and the wrist was moved passively towards ulnar deviation. Intact synovial fluid was extracted from the scapholunate joint with the aid of ultrasound. Hylan GF-20 (Synvisc, USA) was then injected till its synovial fluid cavity was filled. The used needle was then connected to a pressure transducer via a rigid tube primed with saline solution. The synovial fluid pressure was measured continuously when the cadaveric wrist was moved 20○ towards ulnar deviation at 60 cycles per minute. Two independent sets of real-time data were recorded for 15 sec using a Data Acquisition system. The average magnitude of synovial fluid pressure from each dataset was calculated. The synovial fluid pressure change in the scapholunate joint was 174.7 Pa (± 26.4). The changes in pressure over time corresponded to the neutral to maximum ulnar deviation positions of the hand, suggesting synovial fluid pressure changes induced by the wrist movements. Clinically, we postulate that the synovial fluid pressure generated during ulnar deviation may weaken the scapholunate interosseous ligament after a prolonged period of repetitive wrist motion.

INTRODUCTION

Wrist or carpal injuries are categorized under static and dynamic instabilities, according to observable symptoms under each condition [1], [2], [3], [4]. A complete Scapholunate Interosseous Ligament (SLIL) rupture could result in static wrist instability, while a partial tear may cause dynamic wrist instability. Both static and dynamic wrist instabilities could subsequently cause chronic pain5 and progressive joint degeneration or post-traumatic wrist osteoarthritis [5], [6] , [7], [8].

Most of these studies investigated that the intra-articular pressure in human subjects or cadaveric specimens, focused on either bone contact pressures or synovial fluid accumulation in larger joints, such as the knee [9], [10], [11], [12], shoulder [13], hip [14], [15] and radiocarpal or metacarpophalangeal wrist joints [16], [17]. To our knowledge, no study has been conducted to measure synovial fluid pressure changes at the scapholunate joint due to repetitive wrist motions, reason being the technical challenge in accessing the small synovial cavity in the scapholunate joint.

The objective of the present study is to present a method to investigate the effect of repetitive ulnar deviation on synovial fluid pressure at the scapholunate joint. We hypothesize that such repetitive wrist movements, i.e., ulnar deviation, could potentially cause the synovial fluid pressure to change accordingly.

METHODS

Following the approval of the Institutional Review Board, a cadaveric right-hand with intact elbow and no history of wrist injury or instability was used in this study.

As shown in Figure 1, the fresh-frozen cadaveric hand was thawed at room temperature first and mounted onto a custom-made motion simulator at neutral position. Any intact synovial fluid was aspirated from the scapholunate joint, with the aid of an ultrasound system (ACUSON P300, Siemens Healthcare, California, USA).

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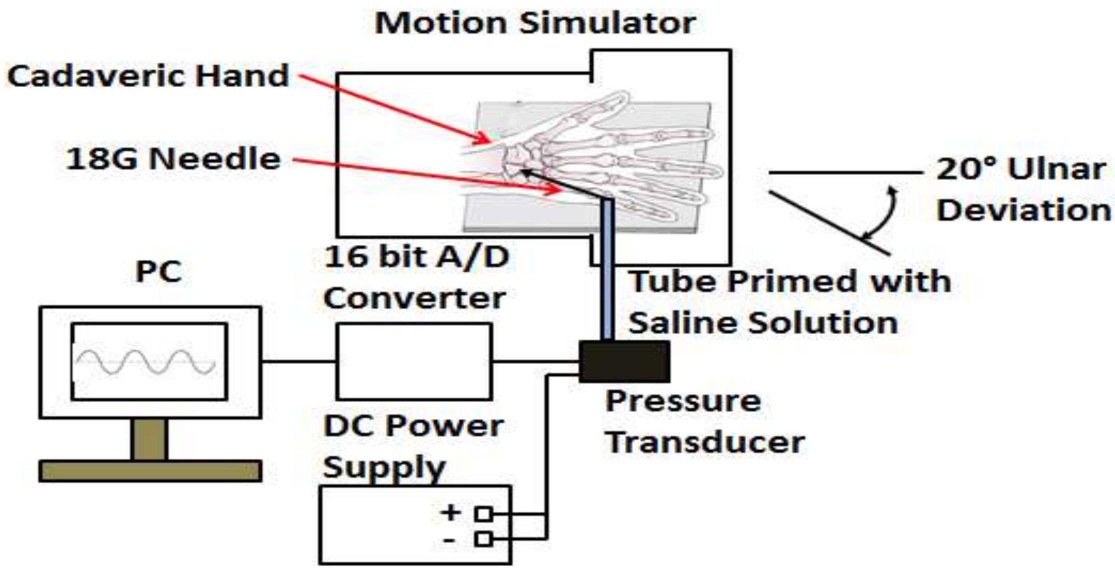

Fig. 1. Schematic diagram of experimental setup

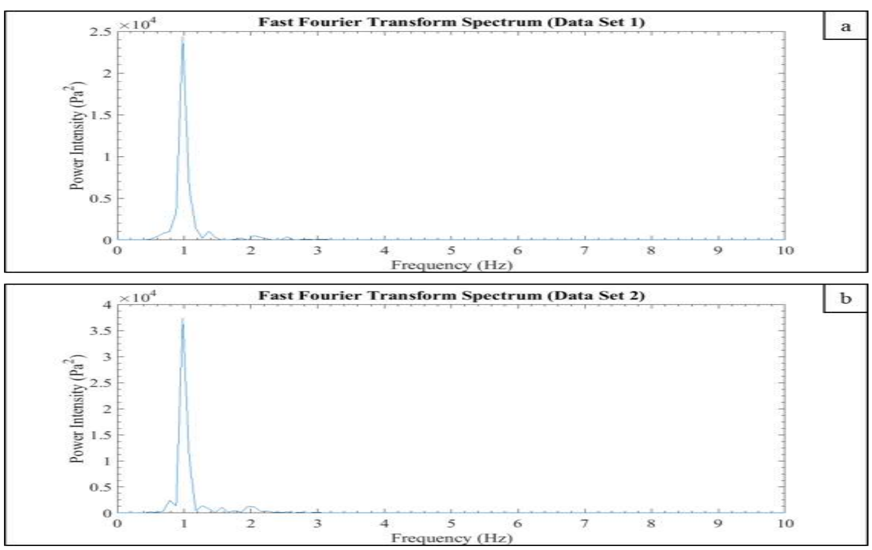

Fig. 2. Fast fourier transform spectra for (a) dataset 1 and (b) dataset 2

Approximately, 4 ml of commercially available synovial fluid (SYNVISC Hylan G-F 20, Genzyme Biosurgery, New Jersey, USA) was injected into the scapholunate joint via an 18G needle. The same needle was connected to a pressure transducer via a rigid tube primed with saline solution. The pressure transducer was then powered by 12 V via a DC power supply.

Synovial fluid pressure was measured whilst the cadaveric hand was moved repetitively at 60 cycles per minute, 20° towards ulnar deviation. Two independent sets of pressure signals were recorded over 15 sec, which we were sufficient for data analysis. The data acquisition system consists of a 16-bit analog to digital (A/D) converter (PXIe-6361, National Instruments, Texas, USA) with 100 Hz sampling rate (National Instruments, Texas, USA). After the signals were digitized, they were post-processed by implementing butterworth bandpass filter in MATLAB (MathWorks, Natick, Massachusetts, USA), to filter out the signal noise. Subsequently, Fast Fourier Transform (FFT) featured in MATLAB was used to calculate the power intensity of the signals. As shown in Figure 2, the FFT spectra demonstrated the signals power intensity in the frequency domain. The average synovial fluid pressure change was calculated by taking the square root of the average power intensity at frequency = 1 Hz.

RESULTS

As shown in Figure 3, pressure was initially recorded as 0 Pa with respect to atmospheric pressure. To demonstrate the coherence of the pressure change with respect to the wrist movement, one ulnar deviation cycle has been marked along blue line: the neutral hand position is denoted by ○, while that of 20° ulnar deviation is denoted by •. Another pressure data presented in red color was inversed 180° so that it can be shown clearly in the graph.

As the motion simulator moved the cadaveric hand from the neutral position towards 20° ulnar deviation, synovial fluid pressure decreased from atmospheric to sub-atmospheric pressure. As the motion simulator approached the pre-set maximum ulnar deviation angle of 20°, velocity of motion became momentarily zero and synovial fluid pressure measured returned to atmospheric pressure.

Synovial fluid pressure increased from atmospheric to supra-atmospheric pressure when the motion simulator moved the cadaveric hand from 20° ulnar deviation back to neutral position. As the motion simulator approached neutral position, motion stopped transitorily and synovial fluid pressure decreased to atmospheric pressure.

The average synovial fluid pressure change of the scapholunate joint during each half ulnar deviation cycle was calculated as 174.7 Pa (± 26.4).

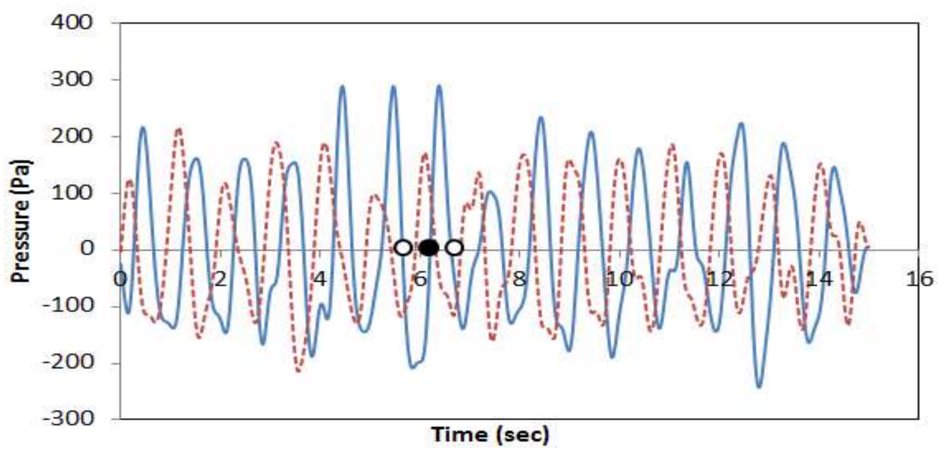

Fig. 3. Fast Fourier Transform Spectra for (a) Data Set 1 and (b) Data Set 2.

DISCUSSION

In our study, we have demonstrated that the synovial fluid pressure in a small joint like the scapholunate could be measured with the proper design of experimental setup. The novelty of this study is to fix a small needle at the scapholunate joint and measure the synovial fluid pressure via a rigid tube primed with incompressible saline solution connected to the pressure transducer. This allows us to measure the intact synovial fluid pressure change even in a small joint.

The average synovial fluid pressure change at the scapholunate joint containing approximately 4 ml of synovial fluid was 174.7 Pa during repetitive ulnar deviation. In comparison, studies on fully extended arthritic knee joints at rest recorded higher synovial fluid pressures of 0.3 to 10.7 kPa [12], 0.8 to 4.4 kPa [9] and 2.5 kPa (± 1.4 kPa) [10], for synovial fluid volume ranges 0 to 110 ml, 6 to 190 ml and 23.6 ml ±21.4 ml, respectively. Similarly, studies involving static cadaveric hip joints containing 10 ml synovial fluid recorded higher synovial fluid pressures of up to 16 kPa in hip extension, an average of 24.9 kPa (±4.1 kPa) or up to 60 kPa in internal rotation, and an average of 0.6 kPa (± 0.3 kPa) or up to 4 kPa in 45° hip flexion [14], [15]. Therefore, we postulate that the lower synovial fluid pressure obtained from our results could be attributed to the nature of the scapholunate joint being small, with injected synovial fluid volume of approximately 4 ml.

The major challenge in this study was how to retain the synovial fluid volume in the scapholunate joint, especially during the wrist movement for pressure measurement. This is because the synovial fluid could have possible connections that link to the joints of other adjacent carpal bones, thus affecting the accuracy of the experimental results. We injected commercially available synovial fluid into the scapholunate joint until it was full, so that within a certain period of time, usually less than 1 to 2 minutes, before the synovial fluid flowed out to the other joints. Nevertheless, the fluid volume was sufficient for pressure measurement during the ulnar wrist movement because only 15 sec of data were recorded.

This experimental study has other limitations. Synovial fluid pressure changes of the scapholunate joint was investigated based on an in vitro model. Therefore, the model was not able to reveal any other in vivo conditions. Although only one cadaveric hand was used for experimentation, it should be reasonable to demonstrate the change in synovial fluid pressure within the scapholunate joint.

In this study, we presented an experimental setup to allow for the measurement of synovial fluid pressure change under movement of small joint like the scapholunate of a cadaveric hand. The configuration can be possibly used for investigating the pathologies associated with the change of synovial fluid properties in the joints.

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