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Skin deformation during shoulder movements and upper extremity activities☆,☆☆

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ABSTRACT

Background: The necessity of sternal precautions for patients following cardiac surgery with median sternotomy has been questioned by clinicians, researchers, and even patients. The primary purpose was to determine if sternal skin deformation during shoulder movements and upper extremity activities is compressive or distractive and if there are any significant differences between the skin deformation at different positions during shoulder movements and upper extremity activities. The secondary purpose was to determine if sternal skin deformation is correlated with scapular stabilizer muscle strength.

Methods: The research design was a cross-sectional non-experimental descriptive study. A 3D electromagnetic tracking system was used to measure sternal skin deformation quantified by strain.

Findings: The sternal skin strain was − 10.8 (SD 6.2) % and − 9.8 (SD 6.1) % at 90 and 180-degree flexion ($P = 0.45$), − 2.7 (SD 3.4) % and − 10.4 (SD 7.9) % at 90 and 180-degree abduction ($P < 0.01$), − 3.6 (SD 4.1) %, − 4.9 (SD 6.4) %, and − 6.8 (SD 5.2) % when lifting 0, 5, and 10-pound weights ($P = 0.07$), 0.7 (SD 2.5) % for extension, and − 1.1 (SD 5.0) % for pushing up from a chair. There is a trend of strain magnitude decrease with the increase of rhomboid strength without significant association ($R = 0.14$).

Interpretation: Our data does not support the restriction for most of the shoulder movements and upper extremity activities following cardiac surgery. The only exception is bilateral shoulder extension. We propose a strategy for preoperative physical therapy to stabilize scapular muscles to decrease mechanical loading translated from shoulder to sternum.

1. Introduction

Heart disease is the leading cause of death worldwide, especially in high-income countries such as the US (World Health Organization, 2014; Xu et al., 2016). Although age-adjusted mortality rates for heart disease has demonstrated notable declines, there has been substantial slowing in the decline recently, and the annual number of deaths from heart disease has been increasing (Johnson et al., 2014; Sidney et al., 2016). Cardiac surgery with median sternotomy is considered the gold standard of surgical treatment for both congenital and acquired heart diseases (Reser et al., 2015). Physical therapists have particular interests in the processes of normal sternal healing and the prevention of potential complications during rehabilitation for patients after cardiac surgery via median sternotomy (Cahalin et al., 2011). However, the optimal perioperative physical therapy practice for patients following cardiac surgery is not well established, and some of the treatment techniques are not supported by evidence in the literature (Overend et al., 2010). In addition, the practice of sternal precautions after median sternotomy by physical therapists significantly varies in the type or duration of restrictions across different facilities in both inpatient and outpatient settings (Cahalin et al., 2011; Overend et al., 2010; Balachandran et al., 2014; Tuttle et al., 2010; Tuyl et al., 2012).

Sternal precautions are based on the belief that avoiding certain movements will decrease the stress at the healing site and reduce the risk of sternal complications for patients who have undergone median sternotomy, including superficial skin infections, integumentary dehiscence, mediastinitis, and sternal dehiscence with instability (Cahalin et al., 2011; Reser et al., 2015; Tuyl et al., 2012). Sternal precautions include a list of restricted shoulder movements and upper extremity activities that are routinely instructed to the patients following cardiac

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surgery with median sternotomy in physical therapy intervention including patient education. A wide variety of protocols with differing restrictions usually include prohibiting shoulder flexion or abduction over 90 degrees, no pushing or pulling, no lifting over certain pounds, and no reaching back. Activities such as dressing, driving, and using assistive devices may also be restricted. The weight limit for lifting is usually 5 to 10 lb but can be as high as 20 lb. The duration of the restrictions is usually 4 to 6 weeks but can be as long as 8 or even 10–12 weeks postoperative.

The necessity of sternal precautions for patients following cardiac surgery with median sternotomy has been questioned by clinicians, researchers, and even patients due to the concerns that the restrictions on shoulder movements and upper extremity activities may unnecessarily cause shoulder dysfunction associated with immobility and negatively impact patient's activities of daily living (Brocki et al., 2010; Cahalin et al., 2011; Parker and Adams, 2008; Parker et al., 2008). The negative impacts on patients are significant, including reinforcing fear of injury, decreasing strength and physical ability, increasing convalescence time, increasing physical dysfunction, and inducing emotional stress. In addition, it increases the caregiver's burden as well as the direct and indirect cost of patient care. Interestingly, there is a lack of commonly accepted scientific theory and experimental data to support the practice of sternal precautions during rehabilitation after surgery. In fact, it is difficult to even locate the exact origin and rationale of sternal precautions for patients after cardiac surgery with median sternotomy (Cahalin et al., 2011). There is a lack of evidence to support the belief that forces from typical activities of daily living may be sufficient to distract the closure site and further cause dehiscence. Coughing, for example, is difficult to prevent and can cause more mechanical disturbance than the restricted shoulder movements and upper extremity activities but often occurs in post-surgery patients without causing significant damage (Adams et al., 2016). However, we should note that, although it is rare, sternal wound dehiscence from intense coughing could happen, especially for obese patients (Santarpino et al., 2013).

The direct measurement of force at the sternum of a patient after cardiac surgery (or of a research subject without cardiac surgery) is invasive and raises ethical concerns. As the mechanical loading at the sternum from shoulder movements and upper extremity movements can be at least partially reflected in the overlying skin, researchers have investigated the effects of the restricted movements and activities on the sternal skin to provide new insights into sternal precautions (Irion et al., 2005; Irion et al., 2006a; Irion et al., 2006b; Irion et al., 2007; Irion et al., 2013). However, the methodology of measuring skin stress using a piezoelectric force transducer or a commercial laser Doppler flow probe positioned perpendicular to the sternal skin appears to be arguably appropriate. Unfortunately, their device is subject to the ceiling effect for some subjects, particularly for males (Irion et al., 2006b). Confounding factors include the fact that compressive force for sensor contact can vary and that the speed of the upper extremity movements paced by a metronome cannot be controlled accurately. In addition, the predetermined speed of the movement is arbitrary. Most importantly, it is difficult to interpret the data from a biomechanical perspective and to differentiate the direction of the stress. In other words, it can only specify the relative magnitude of the skin thickness change from Doppler shift but cannot specify if it is compressive stress or distractive stress, which is a very important distinction to determine the necessity of sternal precautions. Lastly, the general terminology of stress is easily confused with the same terminology in biomechanics, where both the amount of force and area are required to calculate stress, defined precisely as the amount of force per unit area (Fung, 1993). Therefore, the terminology of strain, defined as the percent change of the length in biomechanics, might be a better alternative to quantify the skin stress. Needless to say, skin strain can be measured without implanting force sensors along the direction of the force.

We developed a methodology to measure sternal skin deformation (strain) non-invasively during shoulder movements and upper extremity activities through the use of an electromagnetic tracking system (Ge et al., 2015). The primary purpose of this research project was to determine if sternal skin deformation during shoulder movements and upper extremity activities is compressive or distractive and if there are any significant differences between the skin deformation at different positions during shoulder movements and upper extremity activities. The secondary purpose was to determine if sternal skin deformation is correlated with scapular stabilizer muscle strength. The latter may provide insights for preoperative physical therapy interventions.

2. Methods

2.1. Subjects

All subjects were recruited on the university campus using a convenience sampling. Inclusion criteria included normal shoulder active range of motion (AROM), ability to lift 10 lb overhead with their dominant arm, and ability to lie prone. Exclusion criteria included previous sternotomy/shoulder pathology including but not limited to adhesive capsulitis, rotator cuff tear, and fracture obstructing normal upper extremity range of motion. Ethics approval for this study was sought and obtained from the Institutional Review Board at Youngstown State University.

2.2. Procedure

The research design was a cross-sectional non-experimental descriptive study. A 3D electromagnetic tracking system (Liberty 240/8, Polhemus, Colchester, Vermont, USA) was used to measure sternal skin deformation quantified by strain. The accuracy for the position measurement of the tracking system is 0.03 in. Two sensors were attached to skin at the clavicular heads in areas of the bony prominent on either side. The two sensors were placed where the clavicles connect to the sternum to transfer the force from the scapular and related musculature. Participants were verbally instructed and given a demonstration of each movement to be performed. Shoulder movements included bilateral shoulder flexion at 90 and 180 degrees, bilateral shoulder abduction at 90 and 180 degrees, and bilateral shoulder extension to end range (Fig. 1). Upper extremity activities included lifting (0, 5, or 10 lb) weights overhead unilaterally using shoulder scaption at the dominant-hand side and pushing up from a chair (Fig. 2). The 3D position of each sensor was recorded in the computer at 0, 90, and 180 degrees for flexion and abduction and 0 and end range for the extension, as well as at the beginning and at the end of lifting and pushing. Two trials were performed and the average was used for data analysis.

Rhomboid muscles were selected as the representative muscles for the scapular stabilizing muscles for feasibility (Hislop et al., 2014). The subjects would assume the Rhomboid muscle test position in prone on a testing table with their dominant hand positioned palm up near their lower back. Subjects were instructed to lift their hand upwards off their back and to hold it there while resisting the opposing downward force of the investigator through a digital dynamometer (Lafayette Manual Muscle Tester, Model 01163, Lafayette Instrument Company, Lafayette, Indiana, USA) positioned inferior to the elbow. Three trials were performed and the average was used for data analysis.

2.3. Data analysis

Skin deformation was quantified as skin strain, the percent change of the distance between the 2 sensors. Skin strain for each shoulder movement and upper extremity for each trial was calculated and averaged. The mean strain for all subjects was calculated as descriptive analysis. A strain with a positive value indicates that the skin is stretched or expanded, and a strain with a negative value indicates that the skin is compressed or shrunk. Paired *t*-test was used to