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Shoulder joint kinetics and pathology in manual wheelchair users

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Abstract

Background. Manual wheelchair users rely heavily on their upper limbs for independent mobility which likely leads to a high prevalence of shoulder pain and injury. The goal of this study was to examine the relationship between shoulder forces and moments experienced during wheelchair propulsion and shoulder pathology.

Methods. Kinetic and kinematic data was recorded from 33 subjects with paraplegia as they propelled their wheelchairs at two speeds (0.9 and 1.8 m/s). Shoulder joint forces and moments were calculated using inverse dynamic methods and shoulder pathology was evaluated using a physical exam and magnetic resonance imaging scan.

Findings. Subjects who experienced higher posterior force (Odds Ratio (OR) = 1.29, $P = 0.03$), lateral force (OR = 1.35, $P = 0.047$), or extension moment (OR = 1.35, $P = 0.09$) during propulsion were more likely to exhibit coracoacromial ligament edema. Individuals who displayed larger lateral forces (OR = 4.35, $P = 0.045$) or abduction moments (OR = 1.58, $P = 0.06$) were more likely to have coracoacromial ligament thickening. Higher superior forces (OR = 1.05, $P = 0.09$) and internal rotation moments (OR = 1.61 $P = 0.02$) at the shoulder were associated with increased signs of shoulder pathology during the physical exam.

Interpretation. Specific joint forces and moments were related to measures of shoulder pathology. This may indicate a need to reduce the overall force required to propel a wheelchair in order to preserve upper limb integrity. Potential interventions include changes to wheelchair setup, propulsion training, or alternative means of mobility.

Keywords: Shoulder; Joint kinetics; Spinal cord injury; Biomechanics; Pathology; Inverse dynamics

1. Introduction

It is well documented that manual wheelchair users (MWUs) with paraplegia have a high prevalence of shoulder pain and injury (Ballinger et al., 2000; Bayley et al., 1987; Boninger et al., 2001; Escobedo et al., 1997; Lal, 1998; Nichols et al., 1979; Pentland and Twomey, 1991; Sie et al., 1992; Subbarao et al., 1995). Estimates of shoulder pain among manual wheelchair users with paraplegia range from 30% (Ballinger et al., 2000) to 73% (Pentland and Twomey, 1991). A recent review article noted that shoulder pain is often a result of musculoskeletal pathology (Dyson-Hudson and Kirshblum, 2004). Another study reported that the acromioclavicular joint of the shoulder is the most susceptible to degenerative changes (Lal, 1998). MWUs rely on their upper extremity for independent

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mobility and other critical functions, and thus shoulder pain can be debilitating. One study found that pain was the only factor correlated with lower quality-of-life scores (Lundqvist et al., 1991).

"Overuse syndrome" has been described as one potential cause for pain in MWUs (Bayley et al., 1987; Nichols et al., 1979; Subbarao et al., 1995). Manual wheelchair propulsion places repeated loads on the upper limbs, with a stroke cycle time of less than a second. The shoulder joint experiences loading throughout the propulsion cycle (Cooper et al., 1999; Finley et al., 2004; Kulig et al., 1998; Mulroy et al., 2005; Rodgers et al., 1994). Ergonomics literature has previously identified a link between repetitive loading tasks and musculoskeletal disorders (Andersen et al., 2003; Frost et al., 2002; Leclerc et al., 2004; NIOSH, 1997). In a report of musculoskeletal disorders in the workplace, the National Institute for Occupational Safety and Health defined repetitive activities for the shoulder as activities that involve cyclical flexion, extension, abduction, or rotation of the shoulder joint (NIOSH, 1997). Wheelchair propulsion, while not an occupational task, fits this definition. The effects of repetition can be magnified when combined with awkward postures or loading of the upper extremity such as occurs in wheelchair propulsion (Andersen et al., 2002; Frost et al., 2002; NIOSH, 1997).

It is important to understand what biomechanical factors may predispose individuals to musculoskeletal shoulder pathology so that interventions can be developed. Task performance modification based on ergonomic analysis has proven effective in reducing risk factors for pain and upper extremity pathology in various work settings (Carson, 1994; Chatterjee, 1992; Orgel et al., 1992). Additionally, research has shown that many interventions can be applied to alter propulsion biomechanics (Boninger et al., 2005).

Previous studies have reported shoulder joint forces and moments during propulsion (Cooper et al., 1999; Finley et al., 2004; Kulig et al., 1998; Mulroy et al., 2005; Rodgers et al., 1994), but none have investigated a relationship to shoulder pathology. Since shoulder pain and injury are so common among MWUs, we hope to elucidate biomechanical risk factors for shoulder injury so that potential interventions can be developed. The goal of this study was to calculate shoulder forces and moments during two speeds of manual wheelchair propulsion and determine if biomechanics were related to shoulder pathology. We hypothesized that higher shoulder forces and moments during wheelchair propulsion would be correlated to a higher incidence of shoulder pathology as measured by physical examination and magnetic resonance imaging (MRI).

2. Methods

2.1. Subjects

Subjects were recruited from two primary sources: wheelchair vendors and discharge records from a large inpatient spinal cord injury (SCI) rehabilitation unit. A letter was sent to all potential subjects stating the purpose of the study and asking them to contact the laboratory if they wished to participate in the study. This recruiting method allowed us to identify all individuals with SCI, not just those currently being followed through regular clinic visits. The study was approved by our institutional review board and 33 individuals, 23 males and 10 females, provided informed consent prior to participation in this study. All subjects used a manual wheelchair as their primary means of mobility and had a spinal cord injury below the level of T1 that occurred after the age of 18. Subjects were excluded from this study if they had a history of fractures or dislocations in the arms including the shoulder, elbow and wrist or upper limb dysthetic pain as a result of a syrinx or complex regional pain syndrome Type II (formerly known as reflex-sympathetic dystrophy [RSD]). Subjects were also excluded if they had upper limb pain that prohibited them from propelling a manual wheelchair. We also asked all subjects if they had experienced pain while propelling their wheelchair in the last month, but did not exclude subjects based on their response. Each subject propelled his or her own wheelchair during testing. All analyses for this study were performed using data collected from the non-dominant side of the subject. Four of the 33 subjects were left-handed, while all others were right-hand dominant.

2.2. Instrumentation and data collection

2.2.1. Kinetic data

Each subject's own wheelchair was fitted bilaterally with SMART^{Wheels} (Three Rivers Holdings, LLC, Mesa, AZ) (Cooper et al., 1997) and secured to a dynamometer system using a four-point tie-down system. The SMART^{Wheel} measures three-dimensional forces and torques applied to the pushrim. Attaching the SMART^{Wheel} to the subject's own wheelchair does not change the wheel placement, alignment, or camber. All subjects were instructed to acclimate themselves to the dynamometer setup prior to testing. Kinetic data were collected at 240 Hz and digitally filtered with a 8th order zero-phase lowpass Butterworth filter with a 20 Hz cutoff frequency. Kinetic data was downsampled to 60 Hz for comparison with the kinematic data.

2.2.2. Wheelchair dynamometer

The dynamometer is comprised of two independent rollers, one for each wheel. The resistance of the rollers is comparable to propelling over a tile surface (DiGiovine et al., 2001). Real time speed and direction feedback were displayed on a monitor in front of the subject during the trials. During testing, subjects were instructed to propel at two speeds: 0.9 m/s and 1.8 m/s (2 and 4 mph). After each subject reached a steady-state speed, data were collected for 20 s. Subjects were given a rest period of at least one minute between trials.