Department of Veterans Affairs

Journal of Rehabilitation Research and Development
Vol. 38 No. 4, July/August 2001
Pages 401–408

Shoulder imaging abnormalities in individuals with paraplegia

Michael L. Boninger, MD; Jeffrey D. Towers, MD; Rory A. Cooper, PhD; Brad E. Dicianno; Michael C. Munin, MD

Human Engineering Research Laboratories, a VA Center of Excellence, VA Pittsburgh Healthcare System 151R-1, Pittsburgh, PA; Department of Physical Medicine and Rehabilitation, School of Medicine, University of Pittsburgh, Pittsburgh, PA; Department of Rehabilitation Science and Technology, School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA; Department of Radiology, School of Medicine, University of Pittsburgh, Pittsburgh, PA

Abstract—Shoulder pain and rotator cuff tears are highly prevalent in individuals with paraplegia (PP). The purpose of this study was to use magnetic resonance imaging (MRI), plain radiographs, questionnaires, and physical examination to gain insight into the prevalence of shoulder disorders in individuals with PP. A total of 28 individuals with PP was recruited (mean age=35; mean year from injury=11.5). Each subject completed a questionnaire designed to identify arm pain, had a standard physical examination focusing on the shoulder, and underwent imaging studies (radiographic and MRI). Nine of the thirty-two subjects (36 percent) experienced shoulder pain in the month prior to testing. The MRI studies documented only one rotator cuff tear. Five subjects showed osteolysis of the distal clavicle by plain radiographic study. In two subjects this was seen bilaterally. Although no relationship was seen between pain and imaging abnormalities, stepwise linear regressions found a statistically significant positive relationship between imaging abnormalities and body mass index (BMI) (radiographic: β= 0.56, $p<0.01$; MRI: β=0.52, $p<0.01$). This study found a low prevalence of rotator cuff tears and a high prevalence of distal clavicle osteolysis in a sample of relatively young individuals with PP. Although there was only one tear identified by MRI, a number of subclinical abnormalities were seen and found to correlate with BMI.

Key words: *magnetic resonance imaging, paralysis, radiographs, shoulder injury.*

INTRODUCTION

Individuals with paraplegia (PP) are at high risk for shoulder pain and injury. Survey studies of individuals with PP report an absolute prevalence of shoulder pain between 31–73 percent (1–4). Because individuals with PP rely on their arms for mobility, transfers, and activities of daily living, shoulder injuries can be devastating to quality of life. Subbarao, Klopfstein, and Turpin (5) found that 51.5 percent of 451 individuals with spinal cord injury had reported upper-limb pain to their doctors, and the majority had not found relief with the offered treatments. In addition, all subjects in the Subbarao study cited increased dependence on caretakers with fluctuations in upper-limb pain. In another study, pain was the only factor found to correlate with lower quality-of-life scores (6).

This material is based upon work supported by the U.S. Department of Veterans Affairs Rehabilitation Research & Development Services (Project B689-RA), National Center for Medical Rehabilitation Research of the National Institutes of Health (NIH K08 HD01122-01, 5 P01 HD33989 03), and the Paralyzed Veterans of America.

Address all correspondence and requests for reprints to Michael L. Boninger, MD, Human Engineering Research Laboratories, VA Pittsburgh Healthcare System 151R-1, 7180 Highland Drive, Pittsburgh, PA 15206; email: mlboning@pitt.edu.

To better understand the cause and nature of shoulder pain, a number of investigators have used imaging studies to examine the shoulder. Wylie (7) reviewed medical and surgical records of 51 individuals with PP who were all greater than 20 years out from a spinal cord injury (SCI). Radiographic shoulder abnormalities were seen on plain films in 32 percent of the subjects. This study did not comment on an association between age and abnormalities; however, less-active subjects were found to have a greater prevalence of injury. Bayley, Cochran, and Sledge studied 94 individuals with complete PP (8). Five subjects were found to have aseptic necrosis of the humeral head, whereas 15 subjects had a rotator cuff tear documented by arthrography. In this study individuals with shoulder pain were found to be older than those with no pain; however, this difference was not tested statistically. Lal performed bilateral shoulder radiographs of subjects with both tetraplegia and paraplegia followed in an outpatient SCI clinic (9). In that study, 72 percent of the 53 subjects had radiographic evidence of degenerative changes at the shoulder. This study also found a positive association between radiographic findings and age.

Recent advances in magnetic resonance imaging (MRI) have allowed for more thorough evaluation of shoulder pathology. To date, only one study has examined MRI abnormalities in individuals with PP (10). This study involved 23 consecutive patients seen during routine annual care in a Veteran Affairs Medical Center. Fourteen of the 23 subjects had MRIs performed bilaterally with 57 percent of all shoulders showing rotator cuff tears. The severities of the tears were related to increased patient age and duration of SCI.

In summary, previous studies have found a high prevalence of radiographic abnormalities in individuals with PP. Two of these studies also found that these abnormalities increased with age. This is in agreement with studies that have shown that shoulder pain increases with age (4). Recent work has shown that upper-limb injury may be related to subject weight and/or body mass index (BMI) (11). This finding is not surprising, as the amount of work done by individuals with PP during transfers and while propelling a wheelchair is directly related to their weight.

The purpose of our study was to investigate MRI and radiographic abnormalities in individuals with PP who were wheelchair users. Unlike previous studies, subjects were recruited in a manner that did not depend on their receiving medical care as part of an SCI clinic. In addition, each subject completed a standardized questionnaire and underwent a uniform physical examination. We hypothesized:

1. Individuals with PP would have a high prevalence of imagining abnormalities such as rotator cuff tears.

2. Abnormalities seen on imaging studies would correlate directly with years since SCI, subject age, weight, and BMI.

METHODS

Subjects

The study was approved by the institutional review board of the University, and the human studies subcommittee of the VA Medical Center. Subjects were recruited from two primary sources: wheelchair vendors and discharge records following initial, acute, inpatient rehabilitation from a large regional SCI unit. A letter stating the purpose of the study was sent to each potential subject, requesting that they participate in the research. Subjects were recruited in this manner to identify all individuals with SCI, not just those currently being followed through regular clinic visits. Inclusion criteria for this study encompassed having a traumatic SCI at the fourth thoracic level or below, the SCI having occurred more than 1 year before the start of the study, and subjects being between the ages of 18 and 65 years. Subjects needed to use a manual wheelchair full-time for mobility and be able to provide informed consent.

Subject Evaluation

Subjects recorded whether they experienced any shoulder pain in the month before testing. In addition, subjects were asked if they had ever seen a physician or had to curtail activities because of shoulder pain. Subjects then underwent a physical examination focusing on signs and symptoms of shoulder injury. The physical examination recorded whether pain occurred with the following maneuvers: adduction and internal rotation, resisted internal rotation, resisted external rotation, resisted abduction, palpation over the greater deltoid bursa, and palpation of the biceps tendon. Findings were scored from 0 to 2, where 0 indicates the sign is absent, 1 indicates an equivocal finding, and 2 indicates a strongly positive finding. A summated physical examination total index score was calculated for each subject, for both the right and the left

sides. The maximum possible score for each side was 12, and the minimum score was 0, indicating no abnormalities.

Each subject was asked his or her height. In addition, subjects were weighed on a force platform while in their wheelchair. Their wheelchair was then weighed empty, and the subject weight was calculated. The BMI was calculated by dividing the weight by the height squared.

Plain Radiographic (X-ray) Imaging

Each subject had anteroposterior (AP) internal rotation, scapular AP external rotation, and supraspinatus outlet views of both shoulders using standard plain radiographic techniques.

One fellowship-trained musculoskeletal radiologist with extensive experience interpreted all the radiographic images. The radiologist was blinded to the pain complaints of the subjects, physical examination outcomes, and BMI. Plain radiographs were evaluated for subacromial spur formation, cuff enthesis abnormalities, acromioclavicular (AC) joint degeneration, and distal clavicle osteolysis. Each finding was graded on a 0–3 scale, where 0 is normal, 1 is minimal, 2 is moderate, and 3 is a marked abnormality. A summated plain radiographic imaging index score was obtained for each patient. The maximum score for this index was 12, indicating maximal abnormalities, and the minimum score was 0, indicating no abnormalities.

Magnetic Resonance Imaging

The MRI study consisted of a clinical protocol modified to maximize detection of rotator cuff abnormalities. All subjects were scanned in the same machine (GE Signa 1.5T, 5x software) with the use of a standard linear shoulder coil. Sequences were obtained for axial fast spin echo fat suppressed T2 (FSEFST2, TR>2500, TE 36ef, ET8), oblique coronal fast spin echo proton density (FSEPD, TR>2200, TE 17ef, ET4), oblique coronal fast spin echo T2 (FSET2, TR>2200, TE 102ef, ET8), and oblique sagittal fast spin echo proton density, as well as fast spin echo fat suppressed T2 (TR>2200, TE72ef, ET8). Single acquisitions were made for each fast spin echo series, with field of view varying between 14–15 cm and 192–256 phase steps with 256 frequency steps.

The MRI scans were first reviewed for presence or absence of a rotator cuff tear. Other pathology was then noted, which included distal clavicular edema and erosion, acromioclavicular degenerative arthrosis, subacromial spur formation, acromial marrow edema, coracoacromial ligament thickening, and periligamentous edema. All findings were recorded with a scale of 1–3, and graded as 0 for absent, 1 for mild, 2 for moderate, or 3 for severe. For one to further evaluate abnormalities with multiple characteristics, a standard severity scale was devised. For example, mild acromioclavicular degenerative arthritis was characterized by abnormal signal in the AC joint without spur formation, moderate arthritis had abnormal signal and osteophytosis without distortion of the subjacent tendons, and severe arthritis had abnormal signal with large osteophytes distorting the underlying tendon. A summated MRI index score was obtained by adding the scaled scores for each subcategory. The maximum MRI index score was 18 and the minimum was 0, from most to least severe.

Analysis

Separate summated index scores for the physical examination, the plain radiographic imaging, and the MRI imaging were obtained for each shoulder. The summated scores create an ordinal scale that is useful in evaluating the data statistically. Because there was a significant ($p<0.05$, $r>0.50$) correlation of scores between left and right sides, the two sides were averaged together rather than analyzed separately. All statistical analyses were carried out using SPSS (SPSS, Inc., Chicago, IL). Descriptive statistics were calculated for each variable.

Group differences between individuals who had and had not experienced pain in the last month were examined with the use of a Mann-Whitney U for nonparametric variables or an independent sample t-test for normally distributed variables. We looked for correlations between the physical examination, radiographic scores, and MRI scores using a Spearman's Rho. Three separate, stepwise linear regressions were completed, with the use of the summated index scores for the physical examination, plain radiograph imaging, and MRI imaging as the dependant variables. The independent variables for each linear regression were weight, BMI, age, and years living with a SCI. Pearson's Chi square statistics were used to investigate the relationship between the dependent variables.

RESULTS

Subject Characteristics

A sample of 19 male and 9 female individuals with PP who used manual wheelchairs gave informed consent

to participate in this study. **Table 1** lists the subject characteristics. Because of scheduling conflicts, one patient did not undergo x-ray and another received only a unilateral MRI.

Descriptive Statistics

Of the 28 subjects, nine (32 percent) reported shoulder pain during the previous month. Eight subjects (29 percent) had seen a physician at one time for shoulder pain and three subjects (11 percent) had experienced pain that forced them to curtail their activities. Fifteen (54 percent) of the subjects had one or more abnormality on physical examination. Thus, more subjects had documented abnormal examination findings than self-reported shoulder pain.

The frequency and types of abnormalities identified radiographically are presented in **Table 2**. Of note, seven of the 54 (13 percent) radiographs showed osteolysis of the distal clavicle (**Figure 1**). Only nine subjects had radiographs that were read as entirely normal. The MRI abnormalities of one type or another were identified in all of the subjects. However, only one subject was found to have a rotator cuff tear. **Figure 2** shows distal clavicular edema, the most common abnormality seen on MRI in this study. **Figure 3** (**a–c**) provides examples of other abnormalities seen and their associated grades. The

Table 1.
Subject characteristics.

	Mean	Range	St. dev.
Weight (kg)	74.26	51.40 to 154.50	17.08
BMI (kg/m2)	24.34	17.92 to 37.45	4.25
Age (years)	35.00	23.41 to 68.78	9.92
Years post injury	11.54	1.33 to 23.04	5.27

kg=kilograms, BMI=body mass index, m=meters

Table 2.
Plain radiographic imaging abnormalities.

n = 27	abnormal n (%)	abnormal bilaterally n (%)
Subacromial spur	11 (41)	7 (26)
Rotator cuff enthesis	10 (37)	2 (7)
AC joint DJD	8 (30)	2 (7)
Distal clavicular osteolysis (**Figure 1**)	5 (19)	2 (7)

AC=acromioclavicular, DJD=degenerative joint disease

Figure 1.
Distal clavicle osteolysis. Anteroposterior radiograph of the right shoulder shows loss of distal clavicular subchondral plate (arrowhead) with lack of degenerative changes at remainder of acromioclavicular joint. This was scored as 2, moderate radiographic osteolysis.

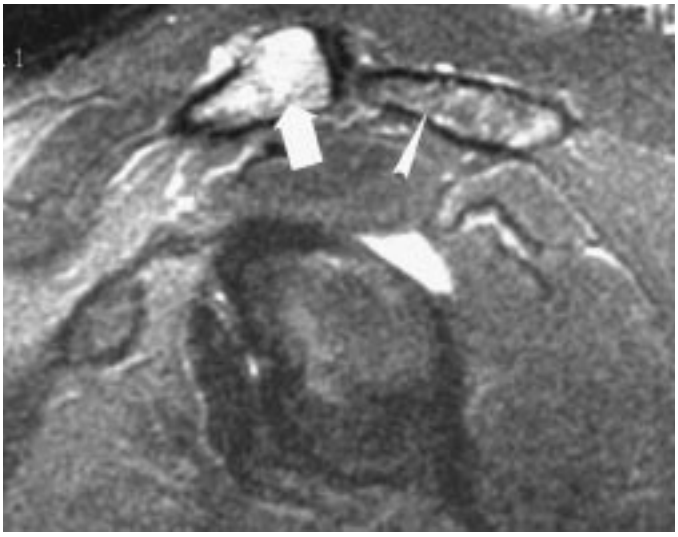

Figure 2.
Distal clavicle edema by MRI. Oblique sagittal FSE T2 image with fat suppression at the level of the acromioclavicular joint shows increased signal in the distal clavicle (arrow), indicating increased free water. The adjacent acromion has normal marrow signal (arrowhead). This received a score of 2, signifying moderate distal clavicular edema.

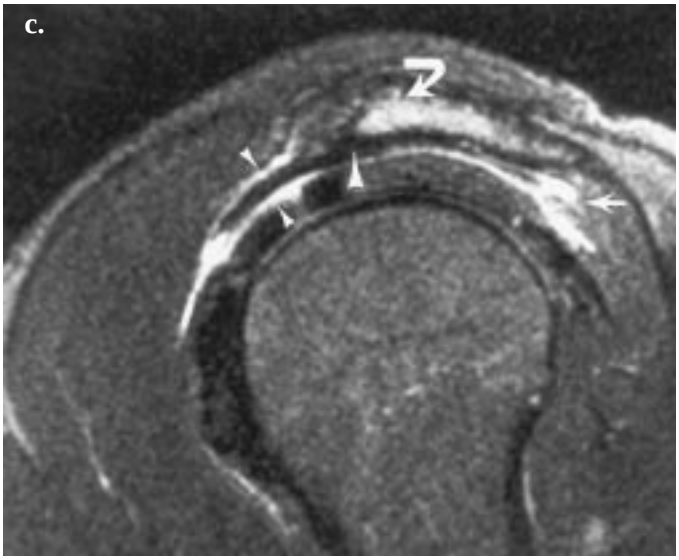

Figure 3.
Radiographic and MRI Abnormalities in a Single Subject. **a.** Supraspinatus outlet view of the left shoulder. No subacromial spur can be identified at its anterior margin (arrow). **b.** FSE Proton Density MRI. Oblique sagittal image at the level of the mid acromion shows normal acromial signal (curved arrow) with coracoacromial ligament thickening and periligament edema (small arrowheads). The coracoacromial ligament thickening was graded as moderate (score of 2) and extended to the enthesis (large arrowhead). Subacromial-subdeltoid bursal fluid is barely detectable at posterior margin of acromion (arrow). **c.** FSE T2 Fat Sat MRI. Oblique sagittal image, at the same level as panel **3b**, shows abnormal increased marrow signal in the anterior half of the acromion (curved arrow). This was graded as mild (score of 1) acromial edema. Coracoacromial ligament edema (small arrowheads) was graded as moderate (score of 2). Subacromial-subdeltoid bursal fluid (arrow) is more conspicuous than with proton density sequence (see panel **3b**). Without radiographic calcification (panel **3a**), the dark signal at the coracoacromial enthesis (large arrowhead) is consistent with hypertrophic fibrosis.

frequency and type of abnormalities seen on MRI are displayed in **Table 3**. **Table 4** lists descriptive statistics for the summated index scores for the physical examination, plain radiographic imaging, and MRI studies.

Analytical Outcomes for Physical Examination, Plain Radiographic Imaging, and MRI Abnormalities
Relationships with Pain

An independent sample t-test found no differences in age, years from SCI, weight, or BMI between subjects with and without pain in the past month. In addition, the Mann-Whitney U found that individuals who had experienced pain were not significantly more likely to have abnormalities in physical examination, plain radiographic imaging, or MRI, as measured by the summated index. A Spearman's Rho found the scores for the summated MRI index and the plain radiographic imaging index to be significantly related ($r=0.58$, $p<0.01$). No relationship was seen between the summated physical examination index scores and either the plain radiographic or MRI index scores.

Table 3.
MRI abnormalities.

n = 28	Abnormal n (%)	Abnormal bilaterally n (%)
Distal clavicular edema (**Figure 2**)	20 (75)	9 (32)
AC joint DJD	18 (64)	11 (40)
AC joint edema	12 (43)	9 (32)
Acromial edema (**Figure 3c**)	17 (61)	6 (21)
Osseous spur	11 (39)	9 (32)
Entheseal edema	23 (82)	16 (57)
CA ligament edema **(Figure 3c)**	27 (96)	23 (82)
CA ligament thickening **(Figure 3b)**	20 (71)	13 (46)

AC=acromioclavicular, DJD=degenerative joint disease, CA=coracoacromial

Table 4.
MRI abnormalities.

N = 28	Physical exam index score	Radiograph index score	MRI index score
Mean	0.8750	1.0536	6.4821
Median	0.5000	1.0000	5.7500
Mode	0.00	0.00	5.50
Maximum	6	5	14.5

Relationships with Subject Characteristics

Stepwise linear regression found no significant relationship between the summated physical examination, plain radiographic imaging, and MRI index scores with respect to age, weight, and years since SCI. The BMI was significantly related to the summated physical examination index (β=0.45, $p<0.05$), plain radiographic index (β=0.56, $p<0.01$) and MRI index (β=0.52, $p<0.01$).

DISCUSSION

To our knowledge, this study represents the largest series incorporating MRI imaging in the investigation of shoulder injuries in individuals with PP. MRI imaging is widely recognized as the most sensitive and specific noninvasive test for rotator cuff tears and tendonitis (12,13). Probably the most surprising finding of this study is the relative absence of rotator cuff tears. In the 28 subjects tested (55 shoulders), only a single rotator cuff tear was seen. This finding is in marked contrast to the MRI study by Escobedo et al. (10) in which 57 percent of individuals with PP showed rotator cuff tears. In addition, Bayley, Cochran, and Sledge (8) found that 65 percent of subjects who had pain and signs of impingement had rotator cuff tears.

The most likely cause for the difference between this study and that of Escobedo is differences in the populations. The average age of the subjects in the Escobedo study was 59 years old, and the average number of years since injury was 26. This is in marked contrast to our study where the average age was 35 years old, and years since SCI was 11.5. If our subjects were followed for an additional 15 years, the prevalence of rotator cuff tears and pain would likely increase. Escobedo's study did find an increased prevalence of pain with both increased age and duration of SCI. The differences between this study and that of Escobedo highlight the need for longitudinal evaluation.

Another difference between the current study and those of Escobedo et al. (10) and Bayley, Cochran, and Sledge (8) is how the population was selected. By recruiting subjects through discharge records of an inpatient rehabilitation facility and mailings from client lists of wheelchair vendors, we have avoided selecting only individuals regularly seen as part of a single clinic. In order to be included in the studies of both Escobedo and Bayley, subjects had to be seen as part of a routine medical examination at a Veterans Affairs Medical Center. In addition, only subjects with symptoms were fully evaluated in Bayley's study. This selection bias may have eliminated individuals with minimal or no symptoms. Thus, both of these prior studies may have overestimated the prevalence of rotator cuff tears in individuals with PP.

Another interesting finding of this study was the high prevalence of osteolysis of the distal clavicle seen on plain radiographs. Osteolysis of the distal clavicle is characterized by progressive resorption of the lateral end of the clavicle. This is the most advanced bone degeneration detected in this study (14). Thirteen percent of the shoulders studied had osteolysis of the distal clavicle, which is in agreement with Roach and Schweitzer (15). Unlike that study, which used chest radiographs to look for osteolysis, our study used radiographs focusing on the shoulder. These two studies, combined, make a strong case for adding osteolysis of the distal clavicle to commonly

seen shoulder abnormalities in individuals with PP. As stated by Roach and Schweitzer, the most likely cause of this finding is repetitive trauma to the upper limb caused by transfers and wheelchair propulsion. Repetitive trauma causing osteolysis of the distal clavicle has been reported in other populations, such as weight lifters (16).

Another potentially important finding of this study is that subjects with higher BMI had a greater degree of abnormality detected by physical examination, plain radiographic imaging, and MRI. However, no relationship was found between these same findings and pain. The addition of fat-suppressed T2 images in this study enhanced our ability to detect and localize small areas of edema or inflammation compared to traditional MRI. Although this study cannot prove the clinical relevance of the MRI and radiographic abnormalities, it is possible that they are precursors to clinically important rotator cuff disease. This could only be assessed with a longitudinal study.

Many authors have hypothesized that shoulder injuries are due to the repetitive loading that occurs during transfers and wheelchair propulsion (8,15,17). Since individuals with PP load their shoulders with their own weight during these activities, an increase in subject weight and thus BMI would theoretically increase the risk of injury. The fact that weight alone was not related to abnormality detected by physical examination, plain radiographic imaging, and MRI, while BMI was, is interesting. One possible explanation is that tall individuals who weigh more may have a musculoskeletal system that is better able to handle increased stresses.

Recent work has shown an association between weight and abnormalities of the median nerve in a population of wheelchair users (11). In addition, other studies have shown that body mass is directly related to the amount of propulsive work an individual with PP has to do and the amount of strain he or she experiences (18,19). Based on these associations, it seems wise to advise individuals with PP about the relationship between increased weight and injury. The correlation between BMI and the imaging and physical examination, although statistically significant, was low. This low correlation indicates that other factors, such as intrinsic shoulder anatomy (20), poor conditioning (21), work activity (22), transfer technique (23), and wheelchair propulsion technique (11), may contribute to injury.

CONCLUSIONS

This study found a lower rate of rotator cuff tears in individuals with PP than has been reported previously. Although this finding could be explained by the age and duration of injury of our subjects, it is possible that other studies have overestimated the prevalence of rotator cuff tears in individuals with PP. Osteolysis of the distal clavicle was seen in a number of subjects. This finding, together with those of other studies, indicates that osteolysis of the distal clavicle is a commonly seen shoulder abnormality in individuals with PP. Radiographic and MRI abnormalities seen were found to be related to BMI, but not to pain. Longitudinal studies are needed to determine if the imaging abnormalities seen in this study are a risk factor for future injury and pain and to determine if increased BMI is actually causative of shoulder injuries. Insights in these areas may lead to much-needed preventive measures.

REFERENCES

1. Pentland WE, Twomey LT. The weight-bearing upper limb in women with long term paraplegia. Paraplegia 1991;29:521–30.
2. Gellman H, Sie I, Waters RL. Late complications of the weight-bearing upper limb in the paraplegic patient. Clin Orthop 1988;233(August):132–5.
3. Nichols PJ, Norman PA, Ennis JR. Wheelchair user's shoulder? Shoulder pain in patients with spinal cord lesions. Scand J Rehabil Med 1979;11:29–32.
4. Sie IH, Waters RL, Adkins RH, Gellman H. Upper limb pain in the postrehabilitation spinal cord injured patient. Arch Phys Med Rehabil 1992;73:44–8.
5. Subbarao JV, Klopfstein J, Turpin R. Prevalence and impact of wrist and shoulder pain in patients with spinal cord injury. J Spinal Cord Med 1994;18(1):9–13.
6. Lundqvist C, Siosteen A, Blomstrand C, Lind B, Sullivan M. Spinal cord injuries. Clinical, functional, and emotional status. Spine 1991;16(1):78–83.
7. Wylie EJ, Chakera TM. Degenerative joint abnormalities in patients with paraplegia of duration greater than 20 years. Paraplegia 1988;26:101–6.
8. Bayley JC, Cochran TP, Sledge CB. The weight-bearing shoulder. The impingement syndrome in paraplegics. J Bone Joint Surg Am 1987;69:676–8.
9. Lal S. Premature degenerative shoulder changes in spinal cord injury patients. Spinal Cord 1998;36(3):186–9.
10. Escobedo EM, Hunter JC, Hollister MC, Patten RM, Goldstein B. MR imaging of rotator cuff tears in individuals with paraplegia. Am J Roentgenol 1997;168(4):919–23.
11. Boninger ML, Cooper RA, Baldwin MA, Shimada SD, Koontz AM. Wheelchair pushrim kinetics, weight and median nerve function. Arch Phys Med Rehabil 1999;80(8):910–5.

12. Iannotti JP, Zlatkin MB, Esterhai JL, Kressel HY, Dalinka MK, Spindler KP. Magnetic resonance imaging of the shoulder. Sensitivity, specificity, and predictive value. J Bone Joint Surg Am 1991;73:17–29.
13. Frieman BG, Albert TJ, Fenlin Jr JM. Rotator cuff disease: a review of diagnosis, pathophysiology, and current trends in treatment. [Review]. Arch Phys Med Rehabil 1994;75:604–9.
14. Yu YS, Dardani M, Fischer RA. MR observations of postraumatic osteolysis of the distal clavicle after traumatic separation of the acromioclavicular joint. J Comput Assist Tomogr 2000;24(1):159–64.
15. Roach NA, Schweitzer ME. Does osteolysis of the distal clavicle occur following spinal cord injury? Skeletal Radiol 1997;26(1):16–9.
16. Scavenius M, Iversen BF. Nontraumatic clavicular osteolysis in weight lifters. Am J Sports Med 1992;20(4):463–7.
17. Boninger ML, Cooper RA, Shimada SD, Rudy TE. Shoulder and elbow motion during two speeds of wheelchair propulsion: a description using a local coordinate system. Spinal Cord 1998;36(6):418–26.
18. Coutts KD. Dynamics of wheelchair basketball. Med Sci Sports Exerc 1992;24(2):231–4.
19. Hollander AP, van der Woude LH. Changes in physical strain and physical capacity in men with spinal cord injuries. Med Sci Sports Exerc 1996;28(5):551–9.
20. Fu FH, Harner CD, Klein AH. Shoulder impingement syndrome. A critical review. [Review]. Clin Orthop 1991;269:162–73.
21. Curtis KA, McClanahan S, Hall KM, Dillon D, Brown KF. Health, vocational, and functional status in spinal cord injured athletes and nonathletes. Arch Phys Med Rehabil 1986;67:862–5.
22. Bergenudd H, Lindgarde F, Nilsson B, Petersson CJ. Shoulder pain in middle age. A study of prevalence and relation to occupational work load and psychosocial factors. Clin Orthop 1988;231:234–8.
23. Wang YT, Kim CK, Ford III HT, Ford Jr HT. Reaction force and EMG analyses of wheelchair transfers. Percept Mot Skills 1994;79(2):763–6.

Submitted for publication June 16, 2000. Accepted in revised form September 25, 2000.