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Comparison of three methods to assess muscular strength in individuals with spinal cord injury

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The aim of the project was to compare three methods for measuring muscle strength in individuals with SCI: the manual muscle test (MMT), the hand-held myometry and the isokinetic dynamometry (Cybex). Thirty-eight (38) subjects, 31 men and seven women (age range = 14–63; lesion from C5 to L3) were included in this project. Muscle strength assessment of upper limbs was performed at admittance and discharge using MMT and myometry for the left and right side, and using Cybex dynamometer for the stronger side. The testing sessions were at least a day apart and performed by a single evaluator (trained physiotherapist). Significant and non-significant differences of myometry mean strength values were observed between consecutive levels of MMT. However, the range of myometry scores within each MMT grade led to significant overlaps between two adjacent MMT grades of each muscle group. Variables correlations were observed between the strength values measured by MMT and myometry with paraplegia ($0.26 \leqslant r \leqslant 0.67$) and tetraplegia ($0.50 \leqslant r \leqslant 0.95$). Similar results were observed when compared MMT and Cybex with the stronger side.

Moderate to strong correlations were observed between the strength values measured by myometry and Cybex with paraplegia ($0.70 \leqslant r \leqslant 0.90$) and tetraplegia ($0.57 \leqslant r \leqslant 0.96$). These results suggest that the MMT method does not seem to be sufficiently sensitive to assess muscle strength, at least for grade 4 and higher and to detect small or moderate increases of strength over the course of rehabilitation. Since outcome measures is an important issue in rehabilitation, objective measurements of strength should be used in clinical settings. Considering cost and assessment time, the myometry technique seems to be highly valuable.

Keywords: isokinetic dynamometry; manual muscle test; myometry; spinal cord injury

Introduction

Medical rehabilitation is an important part of a comprehensive rehabilitation process of individuals with spinal cord injury (SCI). In the conventional approach of caring for individuals with SCI, a major focus is placed to forestall the occurrence of secondary motor disabilities which can be induced by a decrease in articular range of motion, balance and muscle strength. Various strategies and treatments can be applied to attain this goal. Consequently, determining the effect of these interventions is becoming a major issue in the context of assessing cost-effectiveness in most rehabilitation facilities. A key-element in the process of outcome measures is the use of adequate techniques and instrumentations to monitor the progress over the course of rehabilitation.

The measurement of muscle strength is regularly performed and is used in the rehabilitation process of individuals with SCI for various purposes: neurological classification of injury, therapeutic planning and outcome evaluation. A few methods are available for assessing muscle strength such as manual muscle testing, myometry and isokinetic dynamometry. Manual muscle testing (MMT) is the most widely used clinical method of strength assessment.[1] It grades strength according to the ability of a muscle to act against gravity or against a resistance applied by an examiner.[2–5] The frequent utilization of MMT is largely attributable to the ease with which the technique is performed in a short period of time and with no specific cost of instrumentation. However, the accuracy and the sensitivity of MMT is relatively low.[6,7] Beasley[8] found that a variation of 25% in muscle strength for the knee extensor cannot be detected by MMT. Moreover, the force of a muscle reaching only 50% of the 'normal value' as measured by objective techniques could be rated as 'normal' by MMT. Similar results were observed for hip extensors and ankle plantarflexors. The quotation on a subjective ordinal scale requires a lot of experience from the evaluator in order to limit the influence of potential compensation of the subject

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and to standardize the positioning. MMT may also be sensitive to potential bias from the evaluator regarding various age groups and gender. A few studies reported a good level of reliability (intra and inter-rater) within one grade, but there is no consensus whether or not such a level of reliability is sufficient to support the MMT clinical utilization.[6,7,9–13]

Myometry is a quantitative and objective method of muscle assessment using a hand-held myometer (a portable device) that can be easily manipulated in various settings (physiotherapy rooms, at the side of a bed). Intra and inter-rater reliability of the hand-held myometry has been previously demonstrated with able-bodied subjects.[14,15] and subjects with neuromuscular or orthopaedic disorders.[7,16–18] This technique is less sensitive to potential bias from the evaluator for various age groups and gender.[13] Nonetheless, the isometric strength measurement might be influenced by the resistance that can be applied by the evaluator and by the ability to hold the myometer in a stable position, perpendicular to the segment.[7,19] Myometry requires much more time for positioning than MMT and the initial cost of the device can be seen as a limitation to its general use.

Isokinetic dynamometry might be considered as the 'gold standard' to assess muscle strength. Previous studies have shown that reliable and reproducible objective measurements of muscular strength can be made with devices such as the Cybex II isokinetic dynamometer.[14] Its clinical use is, however, limited because of its high cost, the dimension of the apparatus, the time required for the subject's positioning and the assessment procedures in some conditions.[20]

Some studies were carried out to establish the relationship between MMT and myometry. In individuals with various impairments, Bohannon[6] found a significant correlation between MMT and myometry (Kendall tau = 0.74) for knee extensors. Hayes[18] found a much lower correlation for the same muscle group in individuals with osteoarthritis (Kendall tau = 0.24). The magnitude of this relationship was specifically documented in individuals with SCI. Schwartz[13] found a variable association between MMT and myometry (Spearman rank correlation $r = 0.59-0.94$) for elbow flexors and wrist extensors in 122 individuals with tetraplegia. The association was stronger in lower grades (MMT < 4) while substantial overlaps of strength values were observed for two consecutive grades in the higher levels (MMT $\geqslant 4$). Herbison[21] compared changes in the strength of elbow flexors after SCI as measured by a hand-held myometer and MMT. Myometric measurements and their coefficients of variations were greater for each half grade difference in MMT. A wide variability was reported in the myometric measurement of strength into one MMT grade, suggesting that a hand-held myometer detected changes in muscle strength not detected by MMT.

Only a few studies addressed the association between myometry and isokinetic dynamometry. Sullivan[20] obtained a variable Pearson correlation ($r = 0.52$ on day 1 and $r = 0.78$ on day 2) between the two procedures when measuring isometric strength of external rotators of the shoulder in able-bodied individuals, while Bohannon[19] reported an intra-class coefficient of 0.80 for the knee extensors. Bohannon[22] obtained an intra-class coefficient over 0.94 between the two procedures for isometric knee extension torque in stroke patients. Surburg[23] obtained a good correlation (Pearson $r = 0.74$ for knee extensors, $r = 0.77$ for elbow flexors) in individuals with mental retardation.

To our knowledge, no published study has been performed to determine the magnitude of the association between the three procedures (MMT, myometry and isokinetic dynamometry) to assess muscle strength in individuals with SCI. Therefore, the aim of the project was to compare the three methods of measuring muscle strength in individuals with SCI: manual muscle testing (MMT), hand-held myometry and isokinetic dynamometry.

Methodology

Thirty-eight (38) individuals with SCI admitted at the Rehabilitation Institute of Quebec City (RIQ) were included in this project. Level of SCI ranged from C5 to L3. Level and severity of injury were assessed according to American Spinal Injury Association standards for neurological classification of spinal injury patients. When the health status of the person permitted it, (usually within the first 2 weeks after admittance into the rehabilitation center), each subject was met and explained the assessment procedure which was part of a larger project on rehabilitation outcomes. Exclusion criteria were as follows: level of injury higher than C5, unstable medical condition (deep venous thrombosis, heart disease, diabetes, symptomatic hypotension, unstable fracture), admittance exceeding 3 months post-injury. All participants signed an informed consent form after the objectives and procedures of the study were described as approved by the RIQ Committee on Human Experimentation. Table 1 presents the characteristics of the sample.

Muscle strength was measured for six upper limb muscle groups (elbow flexors-extensors, shoulder flexors-extensors, and shoulder abductors-adductors) at admittance and discharge. Both sides were assessed by manual muscle testing (MMT) and myometry, and the stronger side by isokinetic dynamometry (Cybex). The three procedures were performed at least 1 day apart over the course of 1 week. The myometry and the isokinetic dynamometry were performed by a single evaluator (a trained physiotherapist). MMT was also carried out by this evaluator when the usual clinical evaluation reported a score of 4.5 or less.

Manual muscle testing
Modified MMT was performed in standardized positions.[2,3,5,24] For the elbow flexors and extensors, and the shoulder adductors, the subject was in a supine position. For the shoulder flexors, extensors and abductors, the subject was sitting on a wheelchair and the evaluator stabilized the trunk, if necessary. For each muscle group, the subject was asked to perform the movement with or without gravity, or against a resistance according to the level of strength that can be generated. The resistance applied distally to the segment by the therapist was measured subjectively on a 10-grade scale adapted from the Modified Medical Research Council Scale (Table 2).[25]

Table 1 Characteristics of the sample

	Paraplegia (n=23)	*Tetraplegia (n=15)*
Age (years)	28.2±13.9	30.1±13.4
Sex	M=18 F=5	M=13 F=2
Severity of lesion (ASIA)* grade at admittance	A=15 B=3 C=1 D=4	A=6 B=6 C=3 D=0
Time since injury (months)	admittance 1.6±0.7 discharge 4.3±1.1	admittance 2.1±2.1 discharge 7.9±3.2
Length of stay (days)	82.8±23.4	176.0±67.2

*Neurological classification of spinal injury patients

Table 2 Manual muscle strength testing grade scale used for the MMT procedure*

Grade scale	*Description*
0	no muscle contraction
1	trace muscle contraction
1.5	muscle can perform partial range of motion with gravity eliminated
2	muscle can perform full range of motion with gravity eliminated
2.5	muscle can perform partial range of motion against gravity
3	muscle can perform full range of motion against gravity
3.5	muscle can perform full range of motion and provides a slight resistance
4	muscle provides moderate resistance
4.5	muscle provides considerable resistance but not quite normal
5	normal muscular strength

*Adapted from the Modified Medical Research Council Scale

Myometry
A Penny and Giles hand-held myometer was used to measure maximal isometric strength of the six muscle groups as described by van der Ploeg[26] and Lennon.[27] All muscle groups were assessed with the subject in a supine position. Elbow flexors and extensors were tested with the shoulder adducted to the trunk, the elbow flexed to 90° and the forearm placed in a neutral position relative to pronation and supination. The head of the myometer was placed proximally to the styloid processes. Shoulder flexors and extensors were tested with the ipsilateral shoulder flexed to 90°, the arm placed on the neutral position of rotation and the elbow flexed to 90° (the forearm was fixed by the evaluator if needed). The head of the myometer was placed proximally to the humeral epicondyles. Shoulder abductors and adductors were tested with the ipsilateral shoulder abducted to 90°, the arm placed on the neutral position of rotation and the elbow flexed to 90° (the forearm was fixed by the evaluator if needed). The head of the myometer was placed proximally to the humeral epicondyles.

The sequence for the tests followed the order as above. For each procedure, the subject was instructed to perform a maximal contraction with a rest period of 10 s between each trial ($n=3$). The evaluator stabilized the myometer to ensure an isometric test, and consistent verbal encouragement was provided to the subjects. The mean value of the three trials was used as the strength data for each muscle group.

Isokinetic dynamometry
Assessment was performed with a calibrated Cybex II isokinetic dynamometer set at 60°/s. The six muscle groups were tested on the stronger side only, which was previously determined by the trained physiotherapist according to the results of muscle strength recorded from the myometry procedure. The subject was transferred to the upper-body exercise and testing table (U.B.X.T.) and stabilized by three velcro straps (chest, pelvic, legs). Elbow flexors-extensors and shoulder flexors-extensors were consecutively assessed with the subject lying supine. For the elbow muscle groups, the shoulder was abducted to 90°, the arm positioned on a support, the elbow flexed to 90°. For the shoulder muscle groups, the shoulder was adducted to the trunk and the elbow extended. In both cases, the subject held the hand grip or the hand was fixed with a glove, if necessary. The respective joint axes were aligned with the dynamometer input shaft, and blockers ensure a constant and normal range of motion.

Shoulder abductors-adductors were assessed with the subject sitting with a thigh-trunk angle of 45°. The shoulder adducted to the trunk, the elbow extended, and the hand fixed on the hand grip with a glove, if necessary. The joint axis was aligned with the dynamometer input shaft tilted at 45°. Cushions placed at the two extremities of the course ensured a constant and normal range of motion.

After an appropriate warm-up, the subjects were asked to perform five biphasic maximal contractions for each muscle group. During the test, consistent verbal encouragement was provided to the subjects. The peak torque generated by each muscle group was recorded as maximal strength.

Statistical analysis
Distributions of muscle strength (myometry and dynamometry) for each MMT level was displayed using box plots. An analysis of variance and tests of multiple comparisons (Tukey) were used to identify significant differences of mean myometric values between consecutive MMT levels. Spearman correlations were used to determine the strength of association between MMT and myometry, and Pearson correlations were used to illustrate the association between myometry and dynamometry scores (for the stronger side of upper limb). Significance for all statistical analyses was fixed at the 0.05 level.

Results

The strength values of each muscle group (myometry) are graphically displayed for the MMT levels. The distributions of strength values for each muscle group showed a large range with extensive overlaps within most MMT levels in both types of injury (paraplegia and tetraplegia). Thus, data from all subjects were grouped together (Figures 1–3). Despite this variability, a progressive increase of myometry mean strength values was observed between most consecutive levels of MMT. Significant and non-significant differences of mean values were noted. Nonetheless, for all muscle groups, the distribution of strength values showed large overlaps between all pairs of adjacent MMT scores for grade 4 and higher. Between grades 3.5 and 4, this overlap was less important for the elbow extensors, shoulder extensors and adductors. Between grades 3 and 3.5, more distinct differences with smaller overlaps was observed except for shoulder abductors.

Variable levels of association were observed between the strength value measured by MMT and myometry in individuals with paraplegia ($0.26 \leqslant r \leqslant 0.67$) or tetraplegia ($0.50 \leqslant r \leqslant 0.95$) (Table 3). The highest correlations were found with the elbow extensors, the shoulder flexors and the shoulder adductors in tetraplegia. All other correlations were low or moderate. We noted that the correlations decreased at discharge for three muscle groups in paraplegia (elbow flexors, shoulder abductors and adductors) and for most muscle groups in tetraplegia (except shoulder abductors).

Comparisons between adjacent MMT grades were also performed for the strength values measured by dynamometry. Overlaps of comparable magnitudes between consecutive MMT grades were observed for the stronger side of each muscle group. Similar correlations were also observed between the strength values measured by MMT and dynamometry in individuals with paraplegia ($0.19 \leqslant r \leqslant 0.65$) or tetraplegia ($0.35 \leqslant r \leqslant 0.91$).

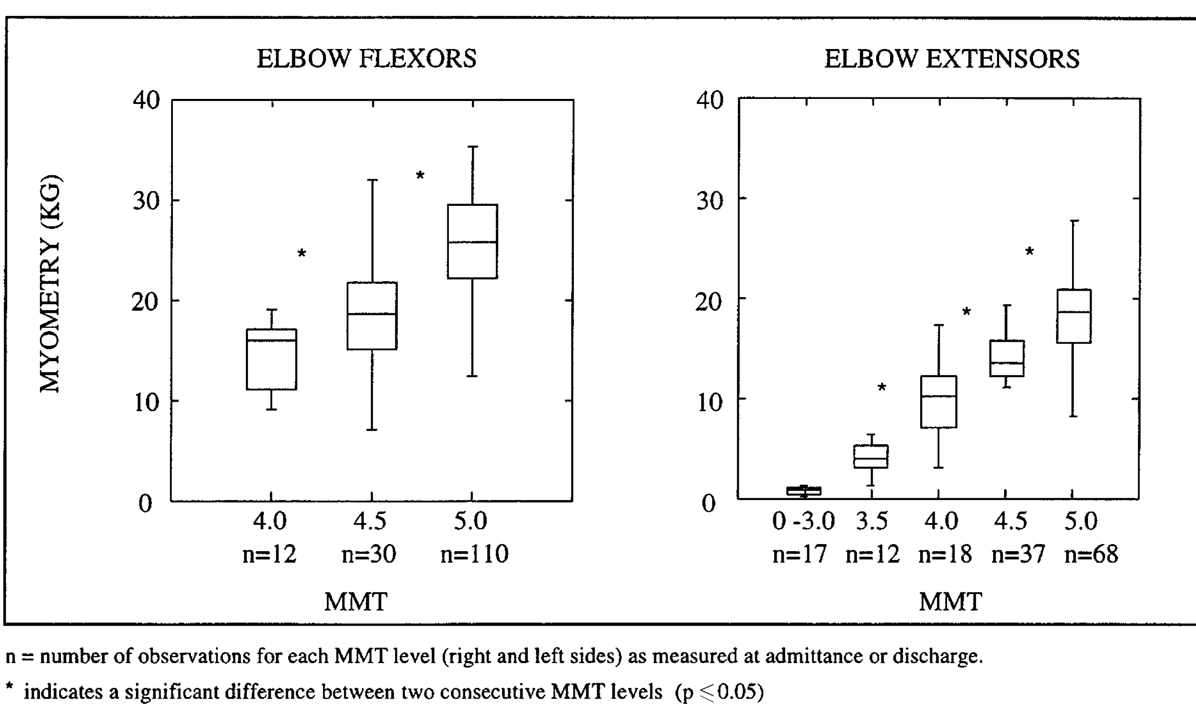

Figure 1 Muscle strength of elbow flexors and extensors (right and left side) measured by myometry and MMT in individuals with SCI ($n=38$)

Finally, moderate to strong correlations were observed between the strength values measured by myometry and dynamometry in individuals with paraplegia ($0.70 \leqslant r \leqslant 0.90$) or tetraplegia ($0.57 \leqslant r \leqslant 0.96$) (Table 4). The lowest correlations were observed with the elbow extensors and the shoulder

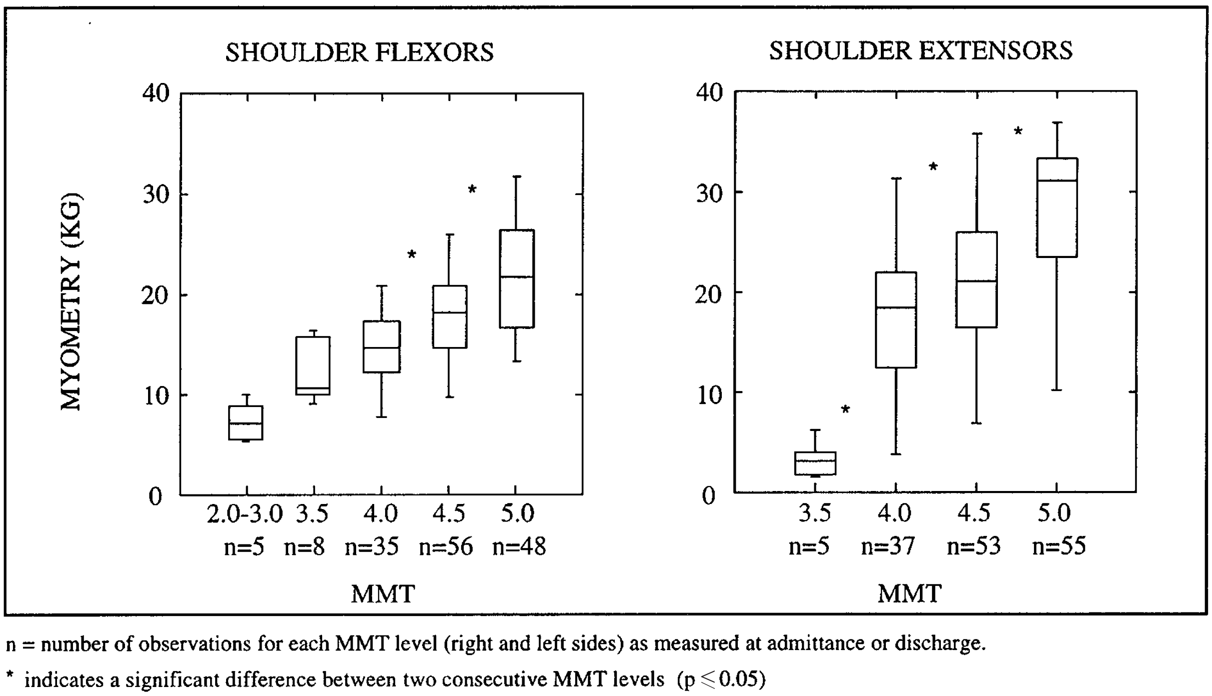

Figure 2 Muscle strength of shoulder flexors and extensors (right and left side) measured by myometry and MMT in individuals with SCI ($n=38$)

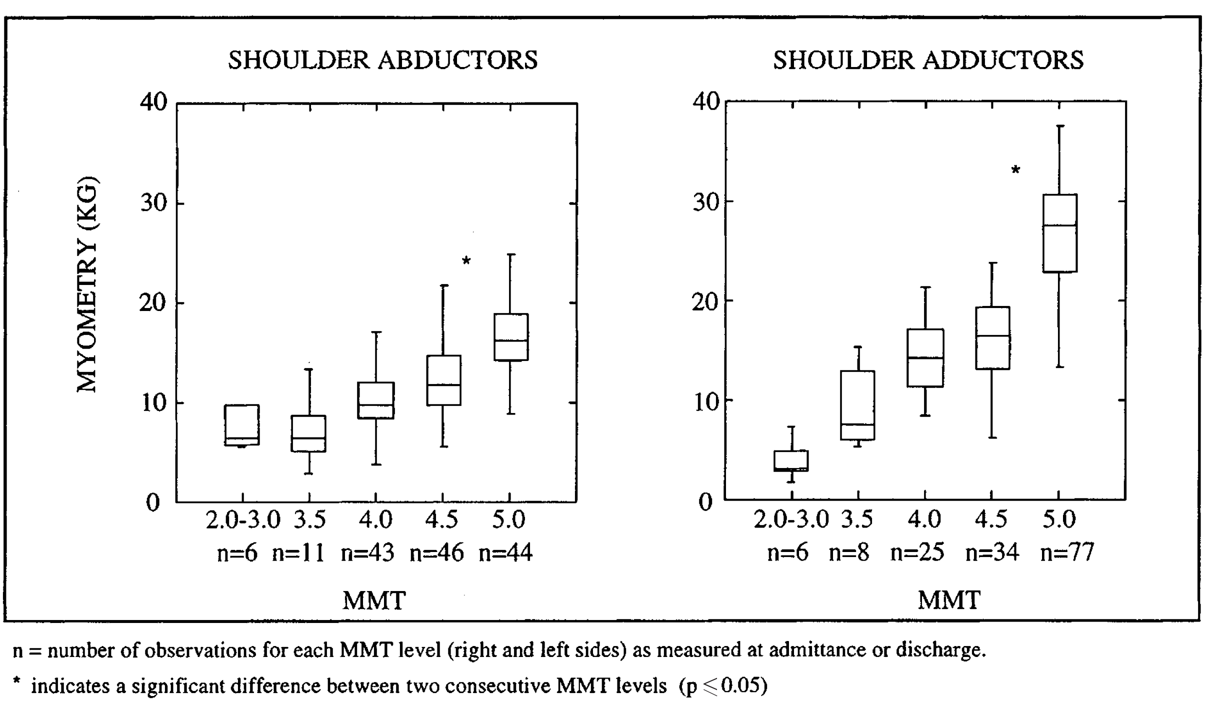

Figure 3 Muscle strength of shoulder abductors and adductors (right and left side) measured by myometry and MMT in individuals with SCI ($n=38$)

Table 3 Spearman correlation coefficients between the strength values measured by MMT and myometry for six muscle groups (tested on both sides) in individuals with SCI ($n=38$)

	Paraplegia (n=23)		*Tetraplegia* (n=15)	
Muscles	*Admittance*	*Discharge*	*Admittance*	*Discharge*
Elbow flexors	0.48	0.26¥	0.58	0.48*
Elbow extensors	0.46	0.55	0.95	0.88
Shoulder flexors	0.63	0.60	0.83	0.50*
Shoulder extensors	0.44*	0.49	0.67	0.57
Shoulder abductors	0.64	0.57	0.55*	0.59
Shoulder adductors	0.67	0.34*	0.84	0.73

*$0.001 < P \leqslant 0.05$, otherwise $P \leqslant 0.001$. ¥$P=0.084$

Table 4 Pearson correlation coefficients between the strength values measured by myometry and isokinetic dynamometry for six muscle groups (tested on stronger side) in individuals with SCI ($n=38$)

	Paraplegia (n=22)[a]		*Tetraplegia* (n=15)	
Muscles	*Admittance*	*Discharge*	*Admittance*	*Discharge*
Elbow flexors	0.76	0.75	0.81	0.75
Elbow extensors	0.70	0.82	0.92	0.96
Shoulder flexors	0.89	0.89	0.82	0.78
Shoulder extensors	0.85	0.83	0.59*	0.87
Shoulder abductors	0.73	0.82	0.57*	0.76
Shoulder adductors	0.81	0.90	0.91	0.90

*$0.001 < P \leqslant 0.05$, otherwise $P \leqslant 0.001$ [a]one missing value

abductors in paraplegia, and with the shoulder extensors and abductors in tetraplegia. We noted that the correlations increased at discharge for three muscle groups in paraplegia (elbow extensors, shoulder abductors and adductors) and for two muscle groups in tetraplegia (shoulder extensors and abductors).

Discussion

The aim of this project was to establish the relation between manual muscle testing (MMT), hand-held myometry and isokinetic dynamometry for determining the most appropriate method of measuring muscle strength in individuals with SCI. To our knowledge, this is the first study addressing the relation between these three procedures in individuals with spinal cord injury. The results of this study showed a variable relationship between MMT and myometry. Conversely, moderate to strong associations were observed between myometry and isokinetic dynamometry. One of the main findings of this study is the large overlap of strength values recorded by myometry between consecutive MMT grades.

As expected, an increase of mean myometry values corresponded to a proportional increase of MMT scores. This finding has been previously observed in individuals with SCI.[13,21] Between consecutive levels of MMT, there existed significant differences of mean myometry values. Some differences, however, were not significantly detectable due to a small sample size of some specific MMT levels (potential type II error). For example, we can hypothesize that the means of the 3 and 3.5 grades of the shoulder flexors and the shoulder adductors (Figures 2 and 3) were sufficiently distinct to be significant in a large sample.

Results also revealed a large variability in the myometry values within each MMT grade. This variability and the observed overlapping is progressively emphasized as the MMT grade increases. In fact, we observed much variability and overlapping of the myometry values for all muscle groups rated four or more. These findings correspond to previous observations in able-bodied subjects[28] and in individuals with SCI.[13,21] For most grades 3.5, less variability of myometry values were present and the overlapping with grades 4.0 was smaller, except for the shoulder flexors and abductors. A potential explanation for the MMT's lower accuracy for the latter two muscle groups might come from different subject's positioning. While the subjects are lying in supine position for myometry procedure, they are seated in a wheelchair for the MMT procedure of shoulder flexors and abductors which inherently provides less trunk support as the evaluator applied resistance to the tested body segment. This might influence the evaluator's quotation. Likewise, the muscle group being evaluated must overcome the force of gravity in the sitting position. Low variability and light overlapping were observed at MMT grades 3 and 3.5 for five out of six muscle groups. These results confirmed Schwartz's[13] observations that the range of myometry values for a particular MMT grade appears to be most specific for MMT scores less than 4. The unexpected result for the shoulder abductors might also be partly explained by the lack of trunk stabilization in the wheelchair.

Low to moderate correlations between MMT and myometry were observed in individuals with paraplegia. Actually, the majority of muscle groups evaluated obtained MMT scores of four or more. The large variability and overlapping observed for these MMT scores explain this low correlation. As described by Schwartz,[13] in the case of a large overlapping between myometry values and MMT consecutive grades, correlation between the two procedures decreases. In individuals with tetraplegia, we noted that the correlation is generally stronger but tended to decrease upon discharge in comparison with admittance which might be due to the enhancement of strength over the course of rehabilitation, given that small gains may not be observable with MMT.

A second element could also explain in part these low correlations. To measure the strength of muscles rated >3 with the MMT, the usual procedure is a break test. In the present study, the procedure adopted with the myometer consisted of using a make test. Bohannon[29] found a significant difference in the force produced during make tests and break tests, with a greater force produced during the latter one. This finding suggests that the muscle strength graded by MMT might be over estimated in relation to the ones evaluated by the myometer. Bohannon[6] was already proposing such an explanation when comparing the MMT and the myometer for knee extensors.

For most muscle groups, moderate to strong correlations were observed between the strength values recorded by myometer and isokinetic dynamometer. The lowest correlations were observed for the shoulder extensors and abductors in individuals with tetraplegia at admittance. However, we noted that the same correlations are those showing the greatest increases at discharge. This suggests that while the subject shows a low level of muscle strength (at admittance), the specific procedure for these two muscle groups using Cybex dynamometer present very significant execution problems for individuals with tetraplegia, which limit their capabilities of producing a maximum effort. Indeed, the evaluation position for the shoulder abductors requires the subject to overcome gravity for the whole range of motion, which intensifies the test's difficulty for subjects with a weak muscle strength. Shoulder extension can also present execution difficulties when the subject has to overcome gravity in order to initiate movement starting from a complete shoulder flexion. Another element increasing the difficulty of the procedure is the lack of joint proximal stability. For example, the shoulder needs to be stabilised by the fixators in individuals with SCI to generate representative maximal efforts across the joint. Therefore, the capabilities of producing real maximal contractions may be affected by a lack of passive stabilization of the shoulder girdle attributable to secondary laxity or to muscle imbalance.

Other factors might have limited the relationship between strength values recorded by myometer and isokinetic dynamometer. First, in this study, we compared an isometric force (myometer) with an isokinetic force (Cybex). Given that some studies supported the concept of specificity of muscle strength,[30] the inherent differences between the two methods might affect their association. Nonetheless, the correlations obtained in this study were similar to those reported by previous studies using both procedures in isometric mode.[20,23] Second, we also used different positions to evaluate certain muscle groups. For example, shoulder abductors and adductors were assessed in a 45° sitting position with Cybex while gravity was eliminated with the myometer. For the elbow flexors and extensors, we modified the shoulder position which was fixed at 90° of abduction for the Cybex and the arm was adducted to the trunk for the myometer. Bohannon[31] demonstrated a significant difference in the strength of the elbow extensors influenced by the shoulder's position of able-bodied subjects. Third, the lever arm on which resistance is applied is also very different for the two procedures. For the myometer, the apparatus' head is applied distally for the evaluated segment while for Cybex the subject held a handle in his hand. In the latter way, the hand transmitted the shoulder or elbow's torque to the apparatus. Likewise, the lever arm is much longer and even crossed two joints for the shoulder muscle testing, which requires good muscle control of the evaluated joints. Sullivan[20] discussed the necessity of good control of the wrist's flexion/extension to explain these inter-instrument correlations for the shoulder's external rotators. The variable level of the person's stabilization between the two procedures could also influence the strength measurements.

Conclusion

The present study compared three methods for measuring muscle strength in individuals with SCI: MMT, myometry and isokinetic dynamometry. Despite its wide use, MMT does not appear to be sufficiently sensitive to determine improvements in muscle strength over the course of rehabilitation. Its accuracy is acceptable for muscle groups with low MMT scores, but is definitely unsuitable for MMT scores of four and higher. Given the increased importance of outcome measures in rehabilitation, an objective method for the measurement of muscle strength should be strongly encouraged in clinical settings. Considering the cost and time required for assessment, myometry is obviously a valuable procedure to obtain an accurate evaluation of improvement in muscle strength.

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