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ARTICLE

Responsiveness of the Motor Capacities Scale to upper limb reconstructive surgery in persons with tetraplegia due to cervical spinal cord injury

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Abstract

Study design Psychometric Study.

Objectives To assess responsiveness of the Motor Capacities Scale (MCS) in people with tetraplegia who have undergone upper limb reconstructive surgery.

Settings Rehabilitation clinics in France.

Methods The MCS is an arm/hand function test with 31 basic tasks, subdivided into four sub-categories (MCS A, MCS B, MCS C, and MCS D). Data were recorded preoperatively and following full completion of the surgical program. The Functional Independence Measure (FIM) and a ten-point numeric scale related to patients' satisfaction with the overall surgical result were included. Data were analyzed using responsiveness measures—the effect size (ES), the standardized response mean (SRM), and the minimal clinically important difference (MCID).

Results Twenty-seven participants were included. Fourteen patients underwent unilateral surgery and 13 bilateral surgery. ES and SRM were moderate or good (ES/SRM of MCS B = 0.76/0.81, ES/SRM MCS C = 0.68/0.77, and ES/SRM MCS D = 0.77/0.88). For MCS A and FIM, both SRM and ES showed a small degree of responsiveness. For the MCS total score, the ES value indicated a moderate degree of responsiveness while SRM was excellent. Total MCS score, MCS C subscore and MCS D subscore showed significantly higher ES values in the "bilateral surgery" group than in the "unilateral group". The estimation of MCIDs showed low threshold values of MCS scores changes (total score and subscores) beyond which the satisfaction rate is >6.

Conclusions This study provides evidence of acceptable responsiveness of the MCS to changes using the SRM following upper limb reconstruction in patients with tetraplegia.

Introduction

The functional benefits of upper limb reconstructive surgery in people with tetraplegia have been well documented in the literature. Therapists consider the International Classification of Functioning, Disability and Health, a biopsychosocial model of health, as the conceptual framework for interpreting outcomes measures following this reconstructive surgery [1, 2]. It emphasizes the importance of the dimension of participation, which is known to be correlated with the quality of life [3]. Based on this model, rehabilitation teams have reached consensus on the choice of measurement tools. However, it is still necessary to have a thorough knowledge of the effects of this surgery, regardless of the influence of environmental factors [4]. The purpose of an "analytical" approach is to help surgeons make appropriate choices and adapt and modify their

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Table 1 Motor Capacities Scale (please refer to Appendix 1 for further details on administration and scoring).

A	Transfers	Date: / /	
1	Putting the legs on a level equal to the level of the wheelchair seat		Scoring levels for the items 1–15 5: no human aid and no technical aid 4: only technical aid 3: human supervision with or without technical aid 2: partial human aid 1: full human aid
2	Transferring from Bobath's couch to wheelchair, legs bent and/or extended and vice-versa		
	Repositioning on bobath's couch		
3	Moving the pelvis sideways, in a sitting position, with the lower limbs stretched out		
4	Sitting in a cross-legged position		
5	Turning over from the ventral or lateral position to the dorsal position and vice versa		
6	Rising from a supine position to a seated position on the edge of the Bobath's couch		
	Repositioning on wheelchair seat		
7	Moving the buttocks forward and backward		
8	Raising the buttocks off the seat		
9	Crossing the legs at the knees		
10	Putting the feet on the footrests		
11	Rising from a bent position using the upper limbs		
	Locomotion in a manual wheelchair		
12	Propelling on a flat surface		Scoring levels for the items 16 and 17 5: possible with a standard joystick without wrist orthosis 4: possible with a standard joystick and wrist orthosis or possible with modified joystick and/or wrist orthosis 3: possible with a modified or standard joystick but with forearm support 2: possible with a head control (regardless of the modality) 1: impossible
13	Positioning and removing the armrests or the clothing guards		
14	Engaging and releasing the breaks		
15	Rocking on the back wheels and maintaining balance		
	Locomotion in an electric wheelchair		
16	Propelling on a flat surface		
17	Using the commands		

Table 1 (continued)

B	Score A (total score of items 1–17)							
	Motor capacities of spatial exploration	Patient in wheelchair		Scoring levels for the items 18–19 2: performed 1: not performed				
	18 right hand-side: Touching a predetermined target							
	19 left hand-side: Touching a predetermined target							
	Score B (total score of items 18 and 19)							
C	Motor capacities for grasping and gripping	Patient in wheelchair		Scoring levels for Grasp function 4: with one hand without compensating movements 3: with one hand with compensating movements (pronation or supination) 2: using the mouth or the other hand or the environment 1: the object cannot be grabbed		Scoring levels for Hold function 4: with one hand without compensating movements 3: with one hand with compensating movements (pronation or supination) 2: using the other hand or the environment 1: the object cannot be held		Scoring levels for Release function 4: with one hand without compensating movements 3: with one hand with compensating movements (pronation or supination) 2: using the mouth or the other hand or the environment 1: the object cannot be released
	Right hand-side		C1:Grasp		C2: Hold		C3: Release	
	20 Soda can (grasp)							
	21 Bottle of water (grasp)							
	22 Playing card (key-pinch)							
	23 Pen (key-pinch)							
	24 Fork (key-pinch)							
	25 Chocolate tablet (key-pinch)							
		SCORE C (C1 + C2 + C3)	Score C1		Score C2		Score C3	
D	Left hand-side		D1: Grasp		D2: Hold		D3: Release	
	26 Soda can (grasp)							
	27 Bottle of water (grasp)							
	28 Playing card (key-pinch)							
	29 Pen (key-pinch)							
	30 Fork (key-pinch)							
	31 Chocolate tablet (key-pinch)							
		Score D (D1 + D2 + D3)	Score D1		Score D2		Score D3	

surgical strategy. This approach is mainly based on force measurements using dynamometers and ranges of motion using goniometers. Although their reproducibility and internal consistency have been widely acknowledged, most of these devices are too insensitive to document small but meaningful functional gains [5]. They do not provide therapists with a current functional evaluation of the operated arm and/or hand, nor do they provide patients with motivating feedback on their progress, as most of the measures remain abstract for them [6].

In 1994, Wuolle stressed an important issue in arm and hand function assessment in patients with tetraplegia, namely the difficulty in distinguishing between what relates directly to the hand and what relates to the participation of the entire upper limb and trunk [7]. Lo et al. also pointed out that tests assessing hand function separately were more sensitive to change than tests including hand function in the assessment of the whole upper limb and trunk [8]. Following the same principles that guided the design of the MCS, the Grasp Release Test (GRT) was also presented as a manual function test dedicated to the evaluation of basic tasks. It was originally designed to assess the use of a hand neuroprosthesis [4]. People were asked to grasp, move and release three objects with the palmar grip and three with the lateral grasp. Time pressure was applied as they were instructed to do so as many times as possible in three 30-s trials for each object. However, a disadvantage of the GRT was that it required formatted objects, marketed in a dedicated set for evaluation. Unfortunately, this set is no longer marketed. In 2006, Spooren published a metrological study on the Van Lieshout Test (VLT) designed to assess skilled upper limb performance in patients with cervical SCI. Although its responsiveness was significantly correlated with that of the GRT, the VLT has never been published in the context of upper limb reconstructive surgery [9].

Based on these findings, we developed the Motor Capacities Scale (MCS) a few years ago in order to meet the need for a specific assessment tool to evaluate the abilities of a patient to perform basic functional tasks regardless of contextual influences (environmental and personal factors). Activities of daily living (ADL) are widely evaluated in clinical settings by dedicated tools [4, 9]. As the initial article pointed out, the MCS does not address the basic ADL such as eating, dressing, bathing etc. The purpose of the MCS is to explicitly focus on elementary motor skills required for ADLs that are typical of people with SCI. We also assumed that the assessment of hand function requires that body movement and trunk stability be taken into consideration.

The MCS is an arm/hand function test with 31 basic tasks to be completed prior to and following upper limb reconstructive surgery (Table 1). The process of selecting the tasks was already reported [10, 11]. All tasks involve the

Table 2 Surgical procedures according to the ICHST classification.

Group 0	Neuroprosthesis (no longer commercially available) Forearm supination deformity correction
Group 1	Elbow extension (transfer Posterior Deltoid–Triceps)[a] ± “Buntine” procedure[b] Forearm supination deformity correction Active wrist extension (transfer BR–ECRB) Finger extensor tenodesis (EPL/ED) Key-pinch tenodesis (FPL) Thumb stabilization procedure[c]
Group 2	Elbow extension Elbow extension (transfer Posterior Deltoid–Triceps)[a] ± “Buntine” procedure[b] Finger extensor tenodesis (EPL/ED) Active key pinch (transfer BR–FPL)/Otherwise active grasp (transfer BR–FDP) Thumb stabilization procedure[c]
Group 3	Elbow extension (transfer Posterior Deltoid–Triceps)[a] ± “Buntine” procedure[b] Finger extensor tenodesis (EPL/ED) Active key pinch (transfer BR–FPL) Active grasp (transfer ECRL or ECRB–FDP) Thumb stabilization procedure[c]
Group 4	Elbow extension (transfer Posterior Deltoid–Triceps)[a] Finger extensor tenodesis (EPL/ED) Active key pinch (transfer BR or PT–FPL) Active grasp (transfer ECRL or ECRB–FDP) Zancolli lasso procedure
Group 5	Elbow extension (transfer Posterior Deltoid–Triceps)[a] Active finger extension (transfer BR–EPL and ED) Active key pinch (transfer PT–FPL) Active grasp (transfer ECRL–FDP) Zancolli lasso procedure
Group 6	Active key-pinch (transfer PT-FPL) Active grasp (transfer EDRL-FDP) Zancolli lasso procedure ± activated by the BR
Group 7	Active key pinch (transfer PT–FPL) Active grasp (transfer ECRL–FDP) ± Active thumb opposition Zancolli lasso procedure ± activated by the BR
Group 8	Active thumb opposition Zancolli lasso procedure ± activated by the BR
Group 9	Active thumb opposition Zancolli lasso procedure ± activated by the BR
Group 10	Exceptions

BR brachioradialis, *ECRL* extensor carpi radialis longus, *ECRB* extensor carpi radialis brevis, *PT* pronator teres, *FCR* flexor carpi radialis, *ED* extensor digitorum, *EPL* extensor pollicis longus, *FDP* flexor digitorum profundus, *FPL* flexor pollicis longus, *ICSHT* International Classification for Surgery of the Hand in Tetraplegia.

[a]Medialization of the anterior deltoid used to compensate for the absence of the clavicularis head of the pectoralis major and for a posterior deltoid strength that graded less than 3/5 MRC.

[b]By means of a spare leg tendon or a prosthetic tendon–Dacron or SEM®, and *tensor fasciae latae* (TFL) or TFL + Dacron for the older persons.

[c]Trapezio-metacarpal joint arthrodesis, thumb interphalangeal (IP) joint fusion, split flexor pollicis longus (FPL)-extensor pollicis longus (EPL) distal thumb tenodesis, metacarpo-phalangeal (MP) joint capsulorraphy.

motor skills of the hand and upper extremity. The grid includes four sub-categories: A, B, C and D. Each task takes into account the possible benefits of hand surgery by individually assessing the motor skills of the hand and upper extremity in performing basic tasks. MCS A tests transfers, repositioning and locomotion; MCS B tests the motor capacities for spatial exploration; MCS C tests these capacities for grasping and gripping of the right hand; MCS D assesses them for grasping and gripping of the left hand. “Reference” objects were selected from objects that patients are likely to use in their daily lives. The objects are similar in each assessment phase, before and after surgery. They can thus be used to analyze the two types of grips most often performed by the patient with tetraplegia, the key-pinch and grasp.

Notably the psychometric study of the MCS [10, 11] showed that it had excellent construct validity and repeatability. Its convergent and divergent validity was demonstrated and its interrater reliability was extensive with ICC = 0.99. However, the responsiveness to change has never been studied and the standardized instructions for the administration have never been published.

The main objective of this study was to investigate the sensitivity to change and responsiveness of the MCS in individuals with tetraplegia who have undergone upper limb reconstructive surgery. Three secondary objectives were as follows: (a) to determine the ability of the MCS to discriminate those who had undergone a unilateral program and those who had benefited from a bilateral program; (b) to determine the correlation between postoperative MCS scores and patient satisfaction; (c) to estimate the minimal clinically important differences (MCIDs) of the MCS.

Table 3 Demographic and surgical data.

Number of participants	27	
Gender (male/female)	21/6	
Median age at the first surgical time (years)[a]	28/P 25%: 24, P75%: 37	
Median interval time between the onset of SCI and the 1st surgical time (years)[a]	3/P 25%: 2, P75%: 4	
Median interval time between the last surgical time and follow-up examination (years)[a]	2/P 25%: 1 P75%: 4.5	
Age at the postoperative assessment (years)[a]	35/P 25%: 27, P75%: 44	
ASIA Impairment grade: AIS A/B/C	22/3/2	
SNL C5/C6/C7	3/18/6	
Dominant hand prior to SCI Right/Left	27/0	
Dominant hand since SCI Right/Left	23/4	
ICSHT grade (0–10)	Right arm/hand	Left arm/hand
Group 0	1	2
Group 1	1	3
Group 2	4	3
Group 3	8	5
Group 4	5	4
Group 5	6	7
Group 6	0	1
Group 7	2	1
Group 8	0	0
Group 9	0	0
Group 10	0	1
Unilateral surgery ($n = 14$)	Bilateral surgery ($n' = 13$)	
RH	RE + RH + LH	3
3		
LH	RE + LE + RH	3
3		
LE	RE + LE + LH	2
1		
LE + LH	RE + LE + RH + LH	4
2		
RE + RH	RH + LH	1
5		

ASIA American Spinal Injury Association, *SNL* single neurological level, *ICSHT* International Classification for Surgery of the Hand in Tetraplegia, *RE* right elbow, *LE* left elbow, *RH* right hand, LH left hand.

[a]Median/percentiles P25%, P75%.

Methods

Study participants

An observational study was conducted with a sample of 27 individuals from a cohort of 131 persons with tetraplegia who had undergone functional upper limb surgery between 1 January 1990 and 31 April 2014. Since the first publication on the MCS was in 2004, only patients who had had this surgery from 2005 onwards were invited to join the study on the basis of the following inclusion criteria: adults who were medically and neurologically stable, people who had completed their surgical program. None declined the invitation. They were all informed verbally and in writing and were also asked to sign a written informed consent form.

The “surgical” history included the following data: age at first surgery, time interval between onset of SCI and first surgery, single neurological level and AIS grade in reference to the International Standards for Neurological and Functional Classification of Spinal Cord Injury [12], time lapse between last surgical time and follow-up examination, age at the postoperative assessment. The upper limbs were classified according to the International Classification for Surgery of the Hand in Tetraplegia (ICSHT) which takes into consideration the remaining active muscles graded at least 4/5 MRC in the forearm and the hand [13].

All patients benefited from the surgical procedures and proven techniques described in the literature (Table 2). Restoration of elbow and/or wrist extension was performed if it was prerequisite for hand surgery. Hand surgery included a two-stage approach: (1) finger extension

Table 4 Outcome data: MCS, FIM and satisfaction scores before and after surgery.

N = 27	Before the first surgical time	After the last surgical time	
Age at the last evaluation (years)		35/CI 95 [27–42]	
Interval time 1st surgical time/last evaluation (years)		2/CI 95 [1–4]	
Total MCS score	132/CI 95 [99–151]	161/CI 95 [126–87]	
MCS A subscore	46/CI 95 [25–60]	51/CI 95 [25–65]	
MCS B subscore	2/CI 95 [2–4]	4/CI 95 [3–4]	
MCS C subscore	45/CI 95 [35–50]	52/CI 95 [49–58]	
MCS D subscore	42/CI 95 [34–47]	49/CI 95 [43–60]	
FIM	65/CI 95 [59–74]	72/CI 95 [63–80]	
Satisfaction		Unilateral surgery ($n = 14$ patients)	Bilateral surgery ($n' = 13$ patients)
		8/CI 95 [5–10]	8/CI 95 [6–8.3]

Values expressed as median/95% CI (Confidence Interval).

N number of participants, *MCS* Motor Capacities Scale, *FIM* Functional Independence Measure.

Table 5 Correlation coefficients between post and preoperative data (Spearman Correlation Test).

	Postoperative					
	MCS A subscore	MCS B subscore	MCS C subscore	MCS D subscore	Total MCS score	FIM
Preoperative						
MCS A subscore	0.9299	0.5765	0.6876	0.5564	0.8754	0.8580
MCS B subscore	0.6048	0.4708	0.3636	0.3686	0.5774	0.5180
MCS C subscore	0.6345	0.3869	0.5138	0.5871	0.6499	0.4601
MCS D subscore	0.6296	0.3970	0.4989	0.6176	0.6732	0.5482
Total MCS score	0.8715	0.5316	0.6616	0.6159	0.8539	0.7464
FIM	0.8524	0.7178	0.5747	0.5673	0.8335	0.7362

MCS Motor Capacities Scale, *FIM* Functional Independence Measure.

restoration and finger joints stabilization; (2) finger flexion reconstruction.

Outcome data

The MCS and the Functional Independence Measure (FIM) were administered preoperatively in the month preceding the first intervention and following full completion of the surgical program. Data were collected through direct observation. Examiners were occupational therapists employed at two rehabilitation centers.

The MCS is subdivided in four sub-categories of items (Table 1). For each sub-category, a subscore for A, B, C, and D is determined. The execution of each task is scored differently, depending on the sub-category: a 5-point scale for the 17 items of the sub-category A, a 2-point scale for both items of the sub-category B, a 4-point scale for the 12 items of the sub-categories C and D. A total score is calculated by summing the subscores of each category. The minimum score is 55 and the maximum score is 233 (see Supplementary Appendix 1 for the guide for use).

The FIM is still extensively used for people with SCI but it is not specific to this population. It is a generic functional scale mainly used to track changes in a person's ability to carry out an activity in an independent manner [14]. It evaluates motor (13 items) and cognitive (5 items) impairments. Each item of the FIM scale is scored from 1 to 7 (where 1 indicates total assistance and 7 complete independence). The scale ranges from 18 to 126. It was demonstrated that the FIM and, more specifically, the "motor" items are able to detect changes over time in patients with tetraplegia [15].

Finally, patients were also asked to provide a satisfaction score for the overall surgical result using a numeric scale from 0: very dissatisfied to 10: very satisfied. The change was considered significant when the satisfaction rate was >6.

Data analysis

Customary descriptive statistics were used to describe the demographics and the outcome data: the total MCS score,

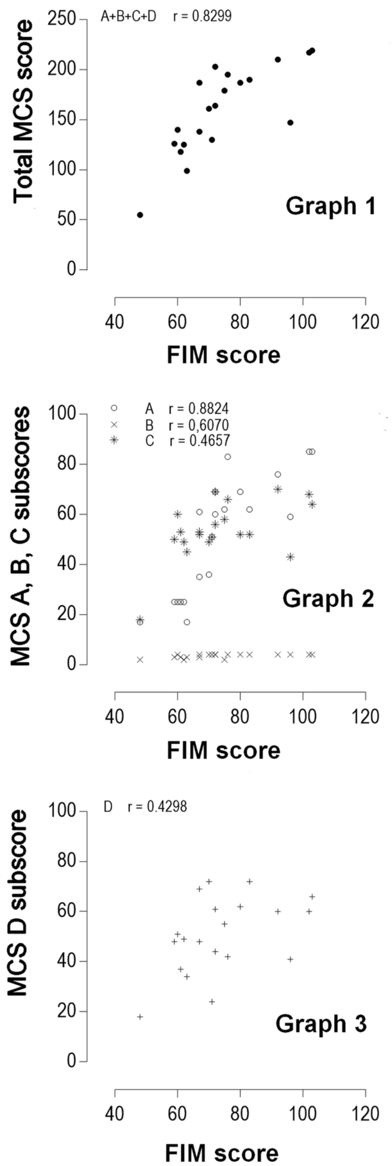

Fig. 1 Correlations and associations between scores. Associations between the *postoperative* FIM score and the *postoperative* total MCS score (Graph 1), the MCS A, B, and C subscores (Graph 2), the MCS D subscore (Graph 3).

MCS A, B, C, and D subscores, and the FIM score before and after surgery, as well as the satisfaction index after surgery. The D'Agostino-Pearson Normality Test [16] was applied on the MCS data and revealed nonnormally distributed data. The correlations between pre- and postoperative data were therefore calculated using the nonparametric Spearman's rank-correlation coefficient (r) [17]. Hypotheses were confirmed when p was <0.05. Correlation was considered to be excellent if $r > 0.91$, good if $0.90 < r < 0.71$, moderate if $0.5 < r < 0.70$, low if $0.31 < r < 0.50$ and null if $r < 0.30$ [18].

To detect the sensitivity to change between preoperative and postoperative scores, we used the Wilcoxon matched pairs signed-rank test. An alpha level of 0.05 (95% confidence interval) was considered significant and boxplots using the Tukey method were built [19].

To calculate standard response mean (SRM) and effect size (ES) for two pairs of scores –for the total MCS score, for each subscore: MCS A, MCS B, MCS C, and MCS D and for the FIM score, we used the original definitions. SRM corresponds to the mean change in scores divided by the standard deviation (SD) of the patients' change scores. Cohen's ES was calculated by dividing the mean change score by the SD of the baseline score. An absolute value of 0.2–0.4 was considered as a small degree of responsiveness, a value of 0.5–0.7 was considered as a moderate degree and a value ≥0.80 as a large effect of an intervention [20].

The ESs calculated from the difference between pre- and postoperative data were used to investigate correlations with the satisfaction score. The nonparametric Spearman correlation test computed the p values and correlation coefficients, with a 95% confidence interval by an approximation. We then separated the total sample of participants into two groups: "unilateral surgery" vs. "bilateral surgery". The Mann–Whitney test was applied to compare ranks and detect differences between groups, considering a 95% confidence interval represented by boxplots (Tukey method).

Last, we estimated the MCID defined as the "smallest difference in score in the domain of interest which patients perceive as beneficial" [21, 22]. The method that we applied to calculate the MCIDs was the anchor-based method combined with the distribution-based method. The "anchor" question was "how much are you satisfied with the overall surgical result" as a reference to determine if the patient is satisfied after completing his surgical program [23]. A score >6 was considered to be at least a good level of satisfaction (7–8) and at best a very good level of satisfaction [9, 10].

Results

Twenty-seven individuals were enrolled in the study. Demographic and surgical data are reported in Table 3. The surgical program was unilateral in 14 people and bilateral for the other 13 people. All patients from group 6 (ICSHT) had function in the triceps. The largest ICHST groups were groups 3, 4, and 5. When the program was bilateral, both elbows were operated in most cases. A complete surgical program (both elbows and both hands) was carried out for four patients. MCS, FIM, and satisfaction scores are presented in Table 4. (See Supplementary Appendix 2).

Correlations and associations between scores

Correlations studies showed excellent correlations between pre- and postoperative total MCS score, MCS A subscore

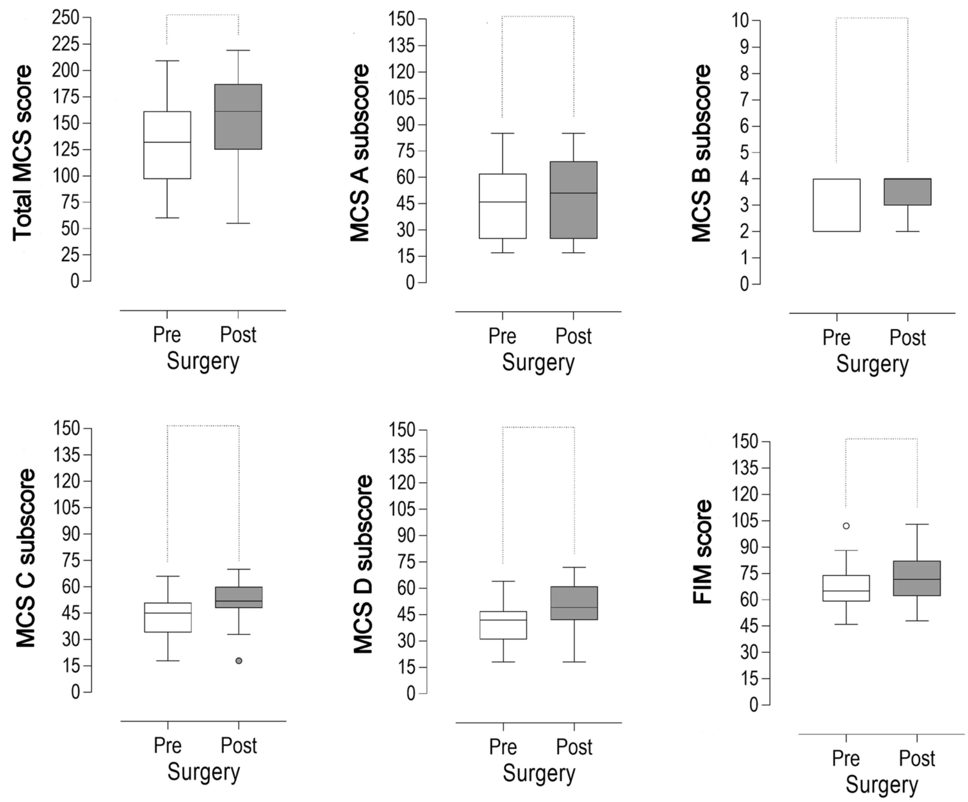

Fig. 2 Changes of pre- and postoperative data. Changes are indicated by a superior horizontal connection dotted line when detected by the Wilcoxon matched pairs signed rank test (significant differences $p < 0.05$).

and FIM (Table 5). These findings were corroborated by the scatter plots showing a strong association between the postoperative FIM score with both the postoperative total MCS score ($r = 0.83$) and the MCS subscore A ($r = 0.88$) (Fig. 1).

Responsiveness of the different scores

Boxplots showed significant differences for each score before and after surgery ($p < 0.05$) (Fig. 2). The ES and SRM were moderate or good for MCS B, MCS C, and MCS D (Table 6). For MCS A and the FIM, both SRM and ES showed a small degree of responsiveness. For the total MCS score, the ES value indicated a moderate degree of responsiveness and the SRM was excellent.

Associations with satisfaction scores

The median satisfaction index following surgery was 8 with a 25th percentile of 6 and a 75th percentile of 8.1. Only variations of total MCS score, MCS A subscore and FIM score showed significant associations with satisfaction but with low magnitude (Fig. 3). However, the total MCS score, MCS C subscore and MCS D subscore showed significantly higher ES values in the bilateral surgery group than in the unilateral group (Fig. 4).

Table 6 Effect size and standardized response mean.

	MCS A subscore	MCS B subscore	MCS C subscore	MCS D subscore	Total MCS score	FIM
ES	0.19	0.76	0.68	0.77	0.54	0.51
SRM	0.47	0.81	0.77	0.88	1.04	0.6

MCS Motor Capacities Scale, *ES* effect size, *SRM* standardized response mean, *FIM* Functional Independence Measure.

Minimal clinically important differences

The MCIDs revealed low thresholds of change in MCS scores beyond which a patient or a therapist would consider changes as significant and positive (satisfaction rate >6). The corresponding values for the MCIDs are reported in Table 7.

Discussion

The high correlation between MCS A and FIM underlines the conceptual link between the two assessments regarding the overall contribution of upper limb reconstructive surgery for patients with tetraplegia. Conversely, the low correlation observed between the MCS B, C, and D subscores and the FIM score reflects the importance that these

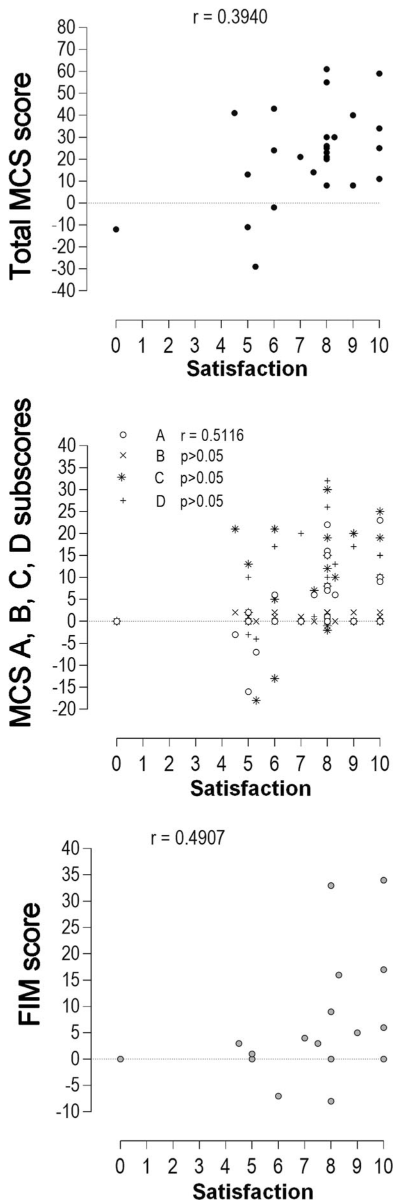

Fig. 3 Associations between satisfaction scores (*x* axis) and the differences pre- and postoperative (*y* axis) for the total MCS score, MCS A, B, C, and D subscores FIM score. When significant ($p < 0.05$), the correlation coefficient (r) showing the magnitude of the association was described in the body of the scatted graphs.

sub-categories give to the motor functions of the operated upper limb. Importantly, in the original 2004 study [10], a strong relationship was established between MCS and the Sollerman test, known to assess basic motor skills not subject to the "influence" of contextual factors. This emphasized the external validity of the MCS within the applied theoretical framework.

With regard to sensitivity to change, the results of this study show that the MCS as a whole and sub-categories MCS B, C, and D are responsive to the changes provided by upper limb reconstructive surgery. Only MCS A showed low responsiveness consistent with the low sensitivity of the FIM. This is crucial because it indicates that the B, C, and D subscores are the main determinants of sensitivity to change. Yet all scores showed a positive and significant variation as presented in Fig. 2.

The bilateral surgical group (as opposed to unilateral) was associated with greater variations in the total MCS score and the MCS C and D subscores. These results suggest the potential power of the MCS to discriminate between the two groups.

To our knowledge, MCS is the only evaluation scale that attempts to control the influence of environmental factors while addressing the space exploration function and gripping function in its three facets: grasp, hold, and release. By breaking down the evaluation into different sequences, it enables the rehabilitation team and the surgeon to better assess the adverse effects of certain procedures. Last, it should be stressed that MCS does not require any specific material. The objects used for the evaluation come from everyday life. It can be administered in a common environment in a rehabilitation center.

Given the good responsiveness of each sub-category, the MCS is likely to provide relevant information on changes over time. SRM and MCIDs values confirm the ability of the MCS to reflect significant changes.

Limitations and future perspectives

The development of the MCS was prompted by a gap in outcome assessment of upper limb reconstructive surgery in patients with tetraplegia. The findings of this study are limited to people with tetraplegia. For a more complete demonstration of the psychometric properties of the MCS, a control group of nonoperated patients seems unavoidable; the ceiling and floor effects of the MCS must be investigated in both groups and a Rasch analysis would help determine if there are any obsolete elements in the MCS.

Given the inconclusive results for sub-category A, the question of whether it should remain in the grid is relevant. At this stage of the psychometric analysis, it seems premature to remove it. The subscore A appears to be a good measure of the subject's overall level of motor skills, and it is not impossible that this score will increase with hindsight. It also provides a measure of the subject's overall disability status.

Moreover, to better demonstrate that MCS is sensitive to small changes, future research should include the evaluation of subscores after each surgery depending on the extent of the surgical program (right elbow, left elbow, right hand, and left hand). This would also provide additional information on the strategies used by patients to perform manual tasks after each surgical stage and also make it possible to

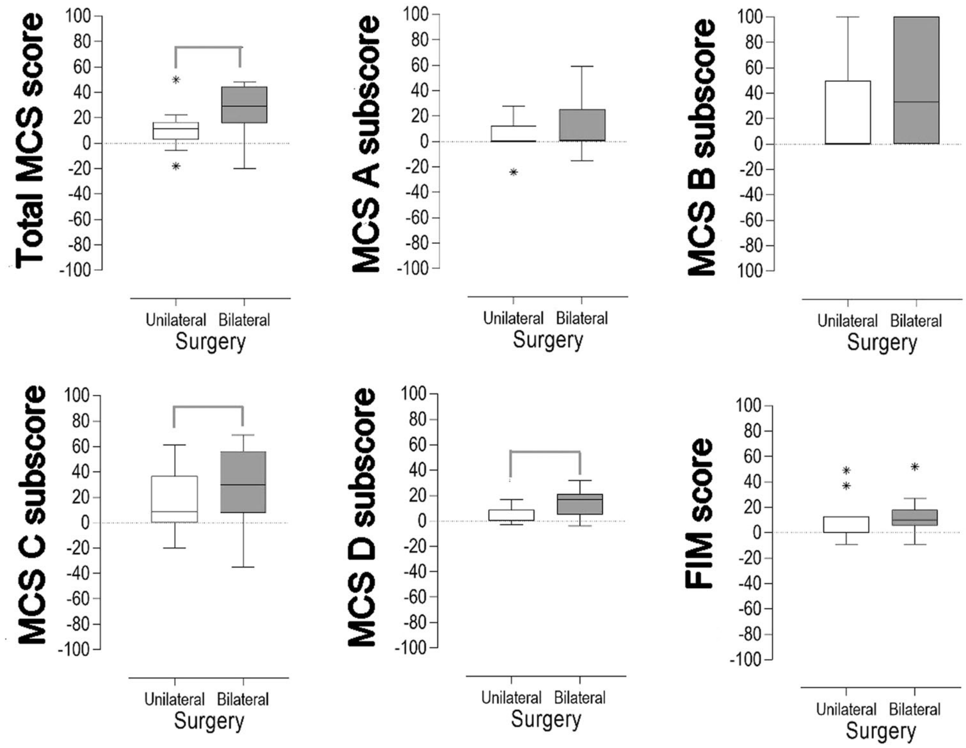

Fig. 4 Boxplots built by Tukey method showing the differences between pre- and postoperative records for groups separated by unilateral (14 patients) vs bilateral surgery (13 patients) and for total MCS score and MCS A, B, C, and D subscores as well for the Functional Independence Measure (FIM) score. The significant differences ($p < 0.05$) are indicated by a superior horizontal connection line (Mann–Whitney test).

Table 7 Minimal clinically important differences (MCID) defined by satisfaction as a meaningful external anchor combined with distribution-based approaches.

	Score max	MCID **Satisfaction score** > 6
MCS A subscore	85	6.8
MCS B subscore	4	0.7
MCS C subscore	72	11.4
MCS D subscore	72	9.8
Total MCS score	233	28.4

question the capacity of each subscore to increase over the course of training and rehabilitation.

The estimation of MCID refers to a significant relationship between changes in MCS scores and patient satisfaction. In our study, satisfaction was assessed only in the postoperative period. Monitoring changes in satisfaction over time from a preoperative baseline to the postoperative period would have been preferred. Moreover, incorporating health and quality of life assessment tools in the MCID estimation would be fruitful to demonstrate the real added value in the daily life of the patient.

Although the MCS is primarily dedicated to the therapists who need to refer to a tool that can value small meaningful changes and generate satisfaction, it should provide the patient with the opportunity to monitor his or her own progress.

Data availability

MCS, FIM, and satisfaction data generated and analysed during this study are included in this published article (see Supplementary Appendix 2). Demographics and clinical data are not publicly available due to the personal nature of the data but are available from the corresponding author on reasonable request.

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Author contributions CF was responsible for designing the protocol, supervising the data collection, the statistical analysis, interpreting the results, and writing the report. EF-M conceived, designed, and performed the statistical analysis. ME contributed to the study design and the revision the article. All authors discussed the results and commented on the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Informed consent All participants provided their written consent prior to inclusion in the study.

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