Development of a Clinical Algorithm to Triage Potential Candidates for Upper Extremity Tendon Transfer Surgery in Individuals with Tetraplegia: A Retrospective Study

Bich-Han Nguyen1, Dany Gagnon2, Alain M. Danino4, Antoinette De l ure1, Isabelle Robidoux1, Marie Riley-Nobert1 and Geraldine Jacquemin1

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Introduction

A cervical spinal cord injury (SCI) results in significant upper extremity (U/E) impairments, reducing functional capacity and social participation. Many individuals with tetraplegia would rather optimize U/E function over other key issues such as sphincter continence, sexual function or walking [1]. Reconstructive U/E tendon transfer surgeries emerged in the 1950s to optimize function by improving elbow extension, grip and pinch strength [2]. Following surgery, range of motion, grip and pinch strength may improve considerably and individuals may complete daily living and leisure activities more quickly and efficiently [3-6].

Authors have previously suggested that 60-75% of individuals with tetraplegia are eligible for restorative U/E surgeries [2,6]. However, a strong epidemiological study by Curtin et al. [7] demonstrated that only 7% of individuals with tetraplegia actually undergo U/E surgeries. Curtin et al. purported that this discrepancy could be explained by a lack of literature and information concerning these surgeries, and the need for taking the individuals’ personal desires into account. However, due to the design of the Curtin study, data was lacking on the number of individuals with tetraplegia who were potential surgical candidates, and the percentage of these who were eventually operated, since only individuals who underwent U/E surgery were computed. Moreover, to our knowledge, no set of defined criteria exists to triage potential individuals with tetraplegia who could then be referred to specialized and/or surgical teams for further assessment.

The main objectives of the present study were 1) to propose objective criteria that could be used to identify individuals with tetraplegia who could be potential candidates for presurgical assessment prior to reconstructive U/E surgery; 2) to apply these criteria to a cohort of individuals with tetraplegia to determine the percentage of potentially...
Figure 1: Proposed decisional algorithm to target individuals with tetraplegia who may be eligible for comprehensive assessment by the Tendon Transfer Surgery Interdisciplinary Team prior to reconstructive upper extremity (U/E) surgery.

1. Individuals were considered ineligible for restorative elbow extension if triceps was already at least 3/5, for restorative wrist extension if wrist extensors were already at least 3/5, and/or for restorative prehension surgery if they already had a sufficient pinch strength. Sufficient key pinch strength was determined qualitatively by reviewing occupational therapy reports detailing the individuals' performance in functional tasks requiring key pinch grip.

2. Since muscles used as donor sites (e.g., biceps, brachioradialis, deltoid, extensor carpi radialis brevis) typically lose one Medical Research Council (MRC) grade after transfer, the team at our institution is careful to consider transferring only if these muscles have a MRC grade of 5/5, or expected grade of 5/5 after a strengthening program.

3. Charts were screened for medical comorbidities such as recurring infections, contractures or severe spasticity, as these are known to potentially hinder the surgery or rehabilitation process by their nature or their cumulative effect.

4. E.g., during inpatient rehabilitation, non-attendance to outpatient follow-up appointments, or unstable psychosocial situation such as homelessness. Issues such as these were considered in the interest of appropriate resource allocation, as rehabilitation following reconstructive U/E surgery is a long and demanding process for an individual with SCI.
eligible subjects; and 3) to compare the results to figures previously reported in the literature. The secondary objective was to study trends of neurological level, SCI severity and age across eligibility subgroups.

Methods

Study population

This retrospective study reviewed the medical charts of individuals admitted with a diagnosis of tetraplegia at the Institut de réadaptation Gingras-Lindsay-de-Montréal. This facility offers inpatient rehabilitation to all individuals in western Quebec who have sustained a traumatic SCI, as well as individuals with more complex or severe cases of non-traumatic SCI that cannot be managed at other rehabilitation facilities. Approximately 125 individuals with SCI are admitted yearly into the specialized SCI rehabilitation program.

Chart review

Charts were reviewed between September and December 2011. The inclusion criteria were as follows:

- Individuals aged 18 years or over
- Medical diagnosis of tetraplegia
- Admitted to and discharged from inpatient rehabilitation in the period between April 1, 2006 and March 31, 2010.

Individuals with other pre-existing neurological conditions were excluded from data collection. The most recent ASIA Impairment Scale (AIS) [8] was recorded for each individual. Each chart was reviewed by two experienced clinicians to ensure proper classification of all participants.

Identification of eligible individuals

The criteria for targeting potential surgical candidates were determined after consensus meetings between the surgeon (AMD) and rehabilitation professionals involved in this study, based on available knowledge about these surgeries as well as experience reported to date by the actual surgical candidates (Figure 1). These criteria are a systematization of the general approach previously used by local rehabilitation professionals to target individuals and then refer them to the Tendon Transfer Surgery Interdisciplinary Team. Locally, a comprehensive assessment conducted by this team is mandatory prior to meeting with the surgeon, and includes a detailed physical examination by a physiatrist and a physiotherapist using the modified International Classification for Surgery of the Hand in Tetraplegia (modified Giens classification) [9]; a functional assessment by an occupational therapist; and a psychosocial assessment by a psychologist and social worker.

Potential eligibility for surgery was first determined by screening the U/E motor function of each individual by using the most recent neurological examination or AIS available in the chart. Individuals were considered ineligible for referral to the Tendon Transfer Surgery Interdisciplinary Team if they already possessed sufficient key U/E strength (i.e. triceps extension, grip and/or key pinch) or if they lacked any potential donor muscle with a Medical Research Council (MRC) grade of 5/5.

The remaining individuals were considered ineligible if they were aged 70 or over, had significant medical comorbidities or compliance issues, or if they had already expressed disinterest in surgery.

However, U/E strength preceded the above factors. For instance, if a 78-year old homeless man with C4 AIS D tetraplegia showed sufficient U/E strength, he was considered ineligible for surgery based on his U/E strength (primary criteria), not his age or psycho-social issues (secondary criteria). Lastly, if an individual had already undergone a comprehensive assessment by the Tendon Transfer Surgery Interdisciplinary Team, or if surgery already taken place, this information was recorded.

Ethical approval was granted by the Research Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal. Institutional approval was obtained to access medical records and extract data for this study.

Statistical analysis

Descriptive statistics, expressed as frequency distribution and measures of central tendency and dispersion, were calculated for categorical and continuous outcome measures for the total sample and for the subgroups of participants.

Between-group differences were calculated using a Kruskal-Wallis one-way analysis of variance to verify if age (continuous variable), level of SCI (categorical variable) and severity of the SCI (categorical variable) differed across the following three sub-groups of participants:

1. Potential surgical candidate;
2. Ineligible for surgery due to insufficient U/E motor function;
3. Ineligible for surgery due to sufficient U/E motor function with no added function expected with surgery.

Whenever a significant difference (p ≤ 0.05) was confirmed across groups, non-parametric two-sample Kolmogorov-Smirnov tests were conducted using an adjusted statistical threshold set at 0.0167 (p value=0.05/3 possible pairwise comparisons) to identify differences between two groups. Data were analyzed using SPSS® 17.0 statistical analysis software.

Results

A total of 221 medical records were reviewed. Figure 2 summarizes the neurological level and severity of the study population.

Potential eligibility for surgery

One hundred and seventy six (176) individuals were deemed ineligible for referral for pre-surgical assessment due to sufficient (n=140; 63.3%) or insufficient (n=36; 16.3%) motor function. Following a further in-depth chart review, twenty-nine (13.1%) individuals were considered unsuitable candidates due to issues such as age or compliance. Twelve (5.4%) individuals underwent a comprehensive assessment by the interdisciplinary team. Only three (1.4%) individuals underwent surgery during the study period. Interestingly, upon chart review, four (1.8%) initially overlooked subjects were identified as potential candidates based on the study criteria (Figure 3).

Thus, based on objective criteria, approximately seven percent (7.2%) of individuals with tetraplegia initially admitted for intensive functional inpatient rehabilitation could eventually become potential candidates for reconstructive U/E surgery, while 1.4% of individuals actually underwent surgery.

Effect of age, injury level and severity

The neurological level and injury severity for all three subgroups are plotted in Figure 4. There were statistically significant differences among the three eligibility subgroups with respect to age, neurological level and injury severity (Table 1). All three subgroups differed significantly in terms of neurological level. Severity of SCI was significantly different...
between the group with sufficient U/E motor function (group 3) and the other two groups.

The mean age across the study population was of 55.4 years (19-97 years; median 56). The mean age of group 1 was 34.3 (19-53 years; median 29), 58 for group 2 (20-93; median 60) and 57.6 for group 3 (21-97; median 57.5). Age differed significantly between potential candidates (group 1) and those with sufficient U/E motor function (group 3), and showed a trend towards significance between potential candidates (group 1) and those with insufficient U/E motor function (group 2).

Discussion

Based on the proposed criteria, sixteen (7.2%) out of 221 individuals with tetraplegia were potential surgical candidates. Among those, three (1.4%) underwent surgery during the study period. Most individuals considered ineligible for surgery (N=140/221) had sufficient U/E motor function and had sustained an incomplete SCI. Furthermore, only 14.5% (n=32/221) had suffered an injury with AIS A severity. This reflects a change in cervical SCI epidemiology where a high percentage of incomplete SCI is now encountered in clinical practice [10,11]. This most likely results from health and health promotion policies such as seatbelt laws, prompt first responder interventions, earlier surgery, better acute hospital care and prevention of secondary complications [10]. This also reflects a shift in the causal mechanism of tetraplegia, where more incomplete injuries result from falls in older individuals with cervical spinal stenosis [10].

Our figures differ drastically from those previously reported in the literature (i.e. 60-75%) [2,6] but suitably compare with those in the Curtin et al study [7]. Fewer individuals underwent surgery in our population compared to those who received surgery in the Curtin study (1.4% vs. 7%). This may be due to differences in study design and regional resource allocation due to our publicly funded universal access health care system. Moreover, Curtin et al’s study sampled populations from 1988 to 2000, and a greater percentage of individuals underwent surgery in 1988 and 1989 than in 1999 and 2000 [7]. This may again be representative of the evolving epidemiology of tetraplegia, with fewer individuals requiring U/E surgery nowadays due to more incomplete injuries. Given the extremely low rate of eligibility and evolving epidemiology, a future reassessment of surgical techniques and indications could be considered to identify ways in which this growing slice of population can be aided through U/E rehabilitation and/or surgery.

Neurological level, injury severity and age were all significantly associated with potential eligibility for reconstructive U/E surgery. Neurological level was the most consistent factor, which is readily explained by clinical practice. Elbow extension restoration requires at least a C5 neurological level to allow a biceps or deltoid transfer to the triceps. Similarly, grip-strengthening or pinch surgery typically requires a C6 or C7 level to allow the transfer of a wrist extensor and/or brachioradialis to long finger flexors. An individual with a complete C4 injury would be too weak to undergo these surgeries, and an individual with a C8 injury would likely have sufficient functional grip or pinch.
strength. Level of injury cannot be considered alone, however. Eighty-eight individuals out of 140 who possessed sufficient U/E strength making them ineligible for surgery (Group 3) had in fact a neurological level of injury of C1 through C4 (Figure 4c), which may seem counter-intuitive. However, most had AIS C or D severity, and UE strength was often of at least 3 or 4 in most muscle groups, therefore rendering them ineligible for surgery according to our algorithm.

Injury severity is also a significant factor between groups. A great proportion of our study population turned out to have an AIS D classification, and as mentioned previously, this possibly reflects the changing epidemiology of cervical SCI. In addition, this may also be indicative of local practice, where these individuals are usually admitted in inpatient rehabilitation in a specialized SCI programme rather than referred to community services, as proposed by the current model of service care delivery in the Province of Quebec. Since most individuals with an incomplete injury often recover sufficient U/E function, one might wonder if AIS D subjects should have been excluded from data collection. However, the AIS does not fully reflect U/E function and the clinical presentation of AIS D can be quite variable. As a matter of fact, one individual with C5 AIS D tetraplegia was considered as a potential candidate for pre-surgical evaluation, but was found to have gained further sensorimotor recovery at the time of his assessment by the interdisciplinary team. Moreover, out of the 36 individuals who were considered ineligible for surgery due to possessing insufficient U/E motor strength (Group 2), 19 had an AIS C classification and 5 had an AIS D classification (Figure 4b). Since we are careful in our institution not to consider surgery in individuals whose donor muscle groups are not expected to attain 5/5 strength, individuals who had grades 3 or 4 strength in potential donor groups were considered ineligible according to our algorithm. For these reasons, the research team felt

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**Figure 3:** Results of the chart review and screening for potential eligibility to U/E reconstructive surgery among individuals with tetraplegia initially admitted to the inpatient SCI intensive functional rehabilitation program at the Institut de réadaptation Gingras-Lindsay de Montréal, and discharged between April 1st, 2006 and March 31st, 2010.
it was important to consider the U/E neurological examination rather than solely the AIS or the level of injury.

Age also differed between potential candidates (group 1) and individuals with sufficient U/E strength (group 3), again reflecting the different causal mechanisms of tetraplegia. Older individuals mostly sustain cervical SCIs due to falls, are more likely to have an incomplete injury and therefore retain some U/E function. A potential bias to these results comes from our study protocol, where individuals’ suitability for surgery was also influenced by their age. However, only five out of the total of 173 excluded individuals had been rejected due to their age. The cut-off of 70 years was chosen based on previous data in the literature indicating the impact of older age on motor learning [12].

To our knowledge, the present study is the first to propose objective criteria to identify potentially eligible individuals with tetraplegia who can be referred for reconstructive U/E surgery evaluation. Although not yet validated by peers, this inexpensive algorithm is quick and easy to use, and through its logical and systematic approach, decreases the possibility of overlooking an individual’s potential eligibility for U/E surgery evaluation. In fact, four additional subjects in our study population were identified as potential candidates with these criteria,
allowing for subsequent referral to the Tendon Transfer Surgery Interdisciplinary Team for comprehensive assessment. Moreover, our database constitutes a representative sample of individuals with tetraplegia, gathered in an environment where most potential U/E surgery candidates are likely to undergo initial rehabilitation following SCI.

There are some limitations with the present study. Being a retrospective study based on medical records, the data was limited to the information contained in the charts. It is therefore possible that the charts do not accurately represent the individuals’ present neurological status and function. However, since the initial injury occurred more than a year before the chart review study, the authors felt enough time had elapsed for sufficient neurological recovery and stability at the time of data collection.

The modified International Classification for Surgery of the Hand in Tetraplegia (Giens classification) has been devised during international meetings in 1978 [13] and 1984 [9] by experts in the field of reconstructive U/E surgery in individuals with tetraplegia. This classification aids the surgeons in the surgical planning for a given individual and is meant to be applied to patients who have met the prerequisites for the intended surgical reconstruction [13]. However, at this present time the modified Giens classification is not routinely used to assess all individuals with tetraplegia in our institution, and this unfortunately prevented its use in our study protocol. However, since the aim of this study is to use our algorithm as an initial triage tool to detect potential candidates for surgery, a simple neurological examination appears sufficient in this context. This information was readily available through medical records, since most individuals undergo a neurological examination by a physiatrist or physiotherapist upon discharge from inpatient rehabilitation. As this is performed in almost all SCI rehabilitation programs, this algorithm has a high potential for generalisation. The authors feel that this algorithm can be a useful complement to the modified Giens classification to target (and avoid overlooking) potential candidates to be referred.

Finally, the criteria were designed based on factors previously identified in the literature and on the authors’ current experience with reconstructive U/E surgeries. These criteria will certainly be refined in the future as clinical knowledge expands on potential surgical indications for this population of individuals that may also be potentially eligible for pre-surgical assessment, and less than two (1.4%) percent underwent surgery. Neurological level, injury severity, and age modulated eligibility for reconstructive U/E surgery. Most of the ineligible individuals had sufficient U/E motor function, suffered incomplete injuries and were older. This reflects a shift in the epidemiology of tetraplegia. The use of an objective stepwise decisional algorithm, such as the one developed in the present study, is advocated when clinicians assess potential tendon transfer surgical candidates. Surgical indications for this population of individuals may also be revisited in the future.

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13. McDowell CL, Moberg EA, Smith AG (1979) International meetings in 1978 [13] and 1984 [9] by experts in the field of reconstructive U/E surgery in individuals with tetraplegia. This classification aids the surgeons in the surgical planning for a given individual and is meant to be applied to patients who have met the prerequisites for the intended surgical reconstruction [13]. However, at this present time the modified Giens classification is not routinely used to assess all individuals with tetraplegia in our institution, and this unfortunately prevented its use in our study protocol. However, since the aim of this study is to use our algorithm as an initial triage tool to detect potential candidates for surgery, a simple neurological examination appears sufficient in this context. This information was readily available through medical records, since most individuals undergo a neurological examination by a physiatrist or physiotherapist upon discharge from inpatient rehabilitation. As this is performed in almost all SCI rehabilitation programs, this algorithm has a high potential for generalisation. The authors feel that this algorithm can be a useful complement to the modified Giens classification to target (and avoid overlooking) potential candidates to be referred.

Finally, the criteria were designed based on factors previously identified in the literature and on the authors’ current experience with reconstructive U/E surgeries. These criteria will certainly be refined in the future as clinical knowledge expands on potential surgical techniques and their outcomes. Future areas of research would include discussion of this algorithm with other rehabilitation and surgical teams involved in reconstructive U/E surgery in tetraplegia, and the application of this algorithm to cohorts of individuals with tetraplegia in other geographical areas. Percentage eligibility may vary due to local epidemiology and clinical practice. Moreover, if the modified Giens classification were to be used more regularly, its inclusion in the algorithm would also improve it as a clinical tool. The addition of manometric testing of grip and key pinch strength could serve to objectify and strengthen that area of data collection. Other scales to measure U/E function in tetraplegia could also be considered, such as the Graded Redefined Assessment of Strength, Sensibility and Prehension (GRASSP) or the Van Lieshout hand function test for Tetraplegia.

Conclusion

A set of objective criteria was devised by an interdisciplinary team experienced in reconstructive U/E surgery and rehabilitation, to target individuals with tetraplegia who could potentially be eligible for such surgeries. Using these criteria in a population of individuals with tetraplegia initially admitted for functional inpatient rehabilitation, roughly seven (7.2%) percent of these individuals were found to be potentially eligible for pre-surgical assessment, and less than two (1.4%) percent underwent surgery. Neurological level, injury severity, and age modulated eligibility for reconstructive U/E surgery. Most of the ineligible individuals had sufficient U/E motor function, suffered incomplete injuries and were older. This reflects a shift in the epidemiology of tetraplegia. The use of an objective stepwise decisional algorithm, such as the one developed in the present study, is advocated when clinicians assess potential tendon transfer surgical candidates. Surgical indications for this population of individuals may also be revisited in the future.