Age as a Predictor of Long-Term Results in Patients with Brachial Plexus Palsies Undergoing Surgical Repair

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Received, March 24, 2017.
Accepted, July 17, 2017.

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It is well established that certain factors play an important role in the outcomes experienced by patients who undergo brachial plexus reconstructive surgery. Among these factors, the time from trauma to surgery, the number of axons that reach the target muscle(s), and the extent of the primary lesion, determined by the number of avulsed roots, seem to be most important. Recently, other factors like compliance with postoperative rehabilitation,1,2 and the patient’s body mass index,3-5 have been considered, though they seem to be less major determinants. A patient’s age might also impact the final results of brachial plexus surgery. In the present paper, we analyzed the role of age as a predictor of outcome in 60 of our own brachial plexus injury (BPI) cases.

Specific objectives of our study were as follows: (1) to identify any difference between patients under age 20, 20 to 29, and 30 yr old or older in 3 outcomes: (a) elbow flexion strength measured using the British MRC (Medical Research Council) Scale; (b) active shoulder abduction, measured in degrees; and (c) overall outcome as a binary variable (a good outcome vs a poor to fair outcome); (2) to identify any correlation between age and the 2 outcomes elbow flexion strength and shoulder range of movement (ROM); (3) to identify any other age threshold besides age 20 (distinguishing between children/adolescents and adults) that might distinguish between patients likely to have a good vs poor to fair outcome; and (4) to

BACKGROUND: Among other factors, like the time from trauma to surgery or the number of axons that reach the muscle target, a patient’s age might also impact the final results of brachial plexus surgery.

OBJECTIVE: To identify (1) any correlations between age and the 2 outcomes: elbow flexion strength and shoulder abduction range; (2) whether childhood vs adulthood influences outcomes; and (3) other baseline variables associated with surgical outcomes.

METHODS: Twenty pediatric patients (under age 20 yr) who had sustained a traumatic brachial plexus injury were compared against 20 patients, 20 to 29 yr old, and 20 patients, 30 yr old or older. Univariate, univariate trend, and correlation analyses were conducted with patient age, time to surgery, type of injury, and number of injured roots included as independent variables.

RESULTS: A statistically significant trend toward decreasing mean strength in elbow flexion, progressing from the youngest to oldest age group, was observed. This linear trend persisted when subjects were subdivided into 4 age groups (<20, 20-29, 30-39, ≥40). There were no differences by age group in final shoulder abduction range or the percentage achieving a good shoulder outcome.

CONCLUSION: Our data suggest that age is somehow linked to the outcomes of brachial plexus surgery with respect to elbow flexion, but not shoulder abduction strength. Increasing age is associated with steadily worsening elbow flexion outcomes, perhaps indicating the need for earlier surgery and/or more aggressive repairs in older patients.

KEY WORDS: Brachial plexus injury, Pediatrics, Age, Surgical outcomes
identify other nonsurgical predictors of a good vs poor to fair outcome.

METHODS

Clinical Series

From January 2006 to July 2014, a total of 24 patients who had sustained a nonpenetrating, traumatic BPI underwent reconstructive surgery at our institution prior to age 20 yr. Of those patients, only 20 completed a minimum of 2 yr of follow-up and were included in this series as group #1. Patients under 3 yr old, those with shorter follow-up, those who had an obstetrical brachial plexus lesion, and those with superior limb amputations or penetrating brachial plexus trauma were excluded. Written informed consent was obtained from each patient or one of their guardians, if appropriate. The ethics committee of our institution approved the present study, which was performed in full accordance with the Declaration of Helsinki II. Variables like patient age, gender, time from trauma to surgery, and the extent of the lesion were recorded. Two comparison groups were constructed, with 20 patients in each group (total = 40 patients) all sequentially recruited over the same time span, starting January 1, 2006. Patients in group #2 were between 20 and 29 yr old, inclusive, while group #3 consisted of patients 30 yr old or older at the time of surgery. Both groups used the same exclusion criteria as group #1.

Each preoperative patient evaluation included neurophysiological studies, preoperative respiratory function tests, and myelo-magnetic resonance imaging. Informed consent was obtained before surgery. The surgical technique included a supraclavicular incision, which allowed for complete exposure of the proximal brachial plexus, its branches, and other extraplexual donors. For partial brachial plexus injuries (C5-C6 and C5-C6-C7), wherein no good donor roots could be identified, either on previous imaging studies or by visual examination intraoperatively, a second, medial arm incision was used to perform a distal nerve transfer (eg, ulnar nerve fascicle to biceps branch). In those patients in whom a single root was available for reconstruction, we used that root as a target different than the biceps, like the posterior division of the upper trunk, a triceps branch or the suprascapular nerve. Only when 2 roots were available did we use that root for elbow flexion recovery via the anterior division of the upper trunk. Once donor and corresponding target nerves, according to availability, were decided upon, direct neurorrhaphy, or autologous nerve grafts were employed to bridge the gap. Our surgical priorities were to restore the following: (1) elbow flexion, (2) shoulder stability and abduction, (3) elbow extension, and (4) hand sensation, wrist extension, and finger flexion. When no enough donors were available due to the severity of the lesion, we did not try reinnervate the shoulder and decided to perform shoulder arthrodesis, a procedure that gives good stability and some shoulder abduction, allowing us to use the few donors for other targets. Postoperative evaluations were performed every 3 mo by an independent examiner and an intense rehabilitation program was started 3 wk after surgery. Shoulder ROM was evaluated measuring the separation between the thorax and the humerus (in degrees), taking care to avoid any spinal deviation that could alter our results.

Statistical Analysis

To summarize group data, continuous variables were expressed as means with standard deviations, while categorical variables (nominal or ordinal) were expressed as percentages. The primary outcomes of interest were elbow flexion strength, measured using the British MRC scale (M1-M5), and shoulder ROM in degrees. Two additional binary variables, which might be of greater clinical interest, indicated whether each patient achieved a good vs only fair-to-poor outcome, with good elbow strength defined as MRC 4 or 5, and good active shoulder ROM as 30° active flexion against gravity or better, since this would permit patients to at least feed themselves. For intergroup comparisons (eg, comparing children/adolescents vs adults; comparing different age groups), nonpaired Student’s t-tests were used to compare group means when comparing children (<20) vs adults, while analysis of variance (ANOVA) was used when more than 2 age groups were assessed (<20, 20-29, ≥30), with Pearson χ² analysis used to compare group percentages with the 2 binary outcomes. To detect linear trends between age group and outcomes, weighted polynomial linear ANOVA and linear-by-linear Pearson χ² analyses were conducted. Final analyses were performed to assess whether trends toward worse outcomes with advancing age extended past age 39, by subdividing the 30 and over age group into subjects 30 to 39 yr old, and those 40 and over; these results are also presented graphically.

Pearson correlation coefficients were calculated for the variable pairs; eg, elbow flexion strength/shoulder ROM, elbow flexion strength/patient age, and shoulder ROM/patient age. An a priori decision was made to consider statistically significant correlation coefficients (r) up to but not including 0.30 indicative of a weak correlation, between 0.30 and 0.69 a moderate correlation, and 0.70 and above a strong correlation. For all analyses, P = .05 was set as the threshold for statistical significance, and P values between .051 and .10 set as the range indicating a borderline result. All statistical tests were 2-tailed, and all analyses were conducted using the statistical software package SPSS version 24 (IBM, Armonk, New York).

RESULTS

Overall Sample

For this study, we sequentially recruited 20 patients under age 20 (mean age 13.9, standard deviation 4.9, range 3-18, summarized in Table 1), 20 patients between the ages of 20 and 29 yr (24.5, 3.2, 20-29, Table 2), and 20 patients of 30 yr or greater (38.8, 9.5, 30-61, Table 3). Of this number, 47 were male and 13 were female. Forty-seven had sustained their BPI during a motorcycle accident, 7 during a car accident, and 6 from some other cause (iatrogenic, n = 3; fall from a height, n = 1; bicycle injury, n = 1; stretch injury, n = 1). Thirty-six of the patients (60%) had complete disruption of their brachial plexus, clinically affecting the C5 through D1 roots. The next most common injuries were C5-C6 (n = 16); C5-C7 (n = 6, one of whom also had a phrenic nerve injury); and C5-C8 (n = 2). The overall mean time to surgery was 5.7 mo (standard deviation = 2.2, range 2-13 mo). Among the overall 60, 45 (75.0%) would achieve the optimum outcome of an M4 level of strength, while an additional 7 patients (15.6%) achieved a return of strength from complete palsy to an MRC level of M3, 3 (6.7%) to M2, and 5 (11.1%) only M1; the youngest patient among those last 5 was 28 yr old, with the remaining 4 all over 30 (31, 35, 46, and 50 yr old; Tables 4-6). No
pulmonary complications were observed in any patient in whom phrenic nerve transfer was performed.

Comparing Youths vs Older Patients

Comparing patients under age 20 (n = 20) vs their older counterparts (n = 40) revealed no statistically significant difference in the nature of the injury (motorcycle vs car vs other) or in the time period between the injury and surgery (Table 5). There was no statistically significant difference in the mean absolute number of roots involved (4.3 vs 3.8, t = 1.54, P = .13); however, there was a significant difference in the distribution of injuries, with more than one-third of adults having a C5-C6 injury (2 roots) vs just 1 in 20 children/adolescents (χ^2 = 12.41, df = 3, P = .006). In terms of outcomes, younger patients trended toward having greater elbow flexion strength at final follow-up (3.8 vs 3.4, P = .055), but there was no statistically significant difference in shoulder ROM (P = .68), or in the percentage who experienced good elbow flexion (P = .21) or shoulder (P = .45) outcomes.

Comparing Patients Under 20 yr old

<table>
<thead>
<tr>
<th>Age</th>
<th>FSP</th>
<th>Physical exam</th>
<th>Time trauma-surgery (mo)</th>
<th>Surgical technique</th>
<th>Final outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Motorcycle</td>
<td>CSD1</td>
<td>4</td>
<td>Pfr-ADUT (G = 2 cm), C5-PDUT (G = 2 × 2.5 cm), XI-Sp</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>17</td>
<td>Motorcycle</td>
<td>C567</td>
<td>5</td>
<td>Ulnar-BB, C5-PDUT (G = 3 × 2.5 cm), XI-Sp</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>3</td>
<td>Car accident</td>
<td>C567</td>
<td>6</td>
<td>Ulnar-BB, XI-Sp, IC (x 2)-Tr, Md-Ax</td>
<td>Elbow flexion M4, shoulder 90°, triceps M3</td>
</tr>
<tr>
<td>17</td>
<td>Motorcycle</td>
<td>C567</td>
<td>5</td>
<td>Ulnar-BB, Pfr-PDUT (G = 1 cm), XI-Sp (G = 3 cm), C5-Tr (G = 12 cm)</td>
<td>Elbow flexion M3, shoulder 45°, triceps M1</td>
</tr>
<tr>
<td>17</td>
<td>Motorcycle</td>
<td>C567</td>
<td>7</td>
<td>Ulnar-BB, IC-Ax</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>15</td>
<td>Iatrogenic</td>
<td>C567</td>
<td>8</td>
<td>Ulnar-BB, XI-Sp (post approach), Tr-Ax</td>
<td>Elbow flexion M4, shoulder 110°</td>
</tr>
<tr>
<td>14</td>
<td>Motorcycle</td>
<td>C567</td>
<td>5</td>
<td>C5-Mc (G = 13 cm), XI-Sp</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>16</td>
<td>Motorcycle</td>
<td>C567</td>
<td>7</td>
<td>Pfr-Mc (G = 13 cm), C5-Ax (G = 10 cm), XI-Sp (posterior approach)</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>17</td>
<td>Motorcycle</td>
<td>C567</td>
<td>5</td>
<td>XI-BBMc (G = 16 cm), shoulder arthrodesis</td>
<td>Elbow flexion M3</td>
</tr>
<tr>
<td>4</td>
<td>Car accident</td>
<td>C567 + Phrenic</td>
<td>4</td>
<td>Ulnar-BB, XI-Sp + long thoracic, IC-Tr</td>
<td>Elbow flexion M4, shoulder 90°, triceps M4</td>
</tr>
<tr>
<td>13</td>
<td>Motorcycle</td>
<td>CSD1</td>
<td>3</td>
<td>XI-Mc (G = 7 cm), Pfr-Ax (G = 7 cm), C5-Md*(G = 8 cm)</td>
<td>Biceps M4, shoulder 90°</td>
</tr>
<tr>
<td>18</td>
<td>Motorcycle</td>
<td>CSD1</td>
<td>4</td>
<td>Pfr-BBMc (G = 15 cm), XI-Sp</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>17</td>
<td>Motorcycle</td>
<td>C567</td>
<td>5</td>
<td>Pfr-ADUT (G = 3 cm), XI-Sp</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>17</td>
<td>Motorcycle</td>
<td>C567</td>
<td>5</td>
<td>CS-BBMc (G = 20 cm)</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>17</td>
<td>Motorcycle</td>
<td>C567</td>
<td>5</td>
<td>XI-Sp, Pfr-ADUT</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>17</td>
<td>Motorcycle</td>
<td>C567</td>
<td>3</td>
<td>CS-ADUT (G = 3 × 3 cm), C6-PDUT (G = 3 × 3 cm), XI-Sp</td>
<td>Elbow flexion M4, shoulder 60°</td>
</tr>
<tr>
<td>14</td>
<td>Motorcycle</td>
<td>CSD1</td>
<td>13</td>
<td>XI-BBMc (G = 16 cm), shoulder arthrodesis</td>
<td>Elbow flexion M2</td>
</tr>
<tr>
<td>3</td>
<td>Car accident</td>
<td>CSD1</td>
<td>5</td>
<td>XI-BBMc (G: 10 cm), C5-Sp (G = 4 cm), Pfr-Rd (G = 10 cm)</td>
<td>Elbow flexion M4, shoulder 30°, triceps M3, carpal extension M3</td>
</tr>
<tr>
<td>11</td>
<td>Car accident</td>
<td>CSD1</td>
<td>5</td>
<td>XI-BBMc (G = 15 cm), shoulder arthrodesis</td>
<td>Elbow flexion M4</td>
</tr>
<tr>
<td>15</td>
<td>Motorcycle</td>
<td>CSD1</td>
<td>5</td>
<td>Pfr-BBMc (G = 18 cm), shoulder arthrodesis</td>
<td>Elbow flexion M4</td>
</tr>
</tbody>
</table>

XI: spinal accessory nerve; Sp: suprascapular nerve; Pfr: Phrenic nerve; ADUT: anterior division of upper trunk; PDUT: posterior division of upper trunk; Ulnar-BB: a fascicle of the ulnar nerve was transferred to the biceps branch of the musculocutaneous nerve; IC: intercostal nerves; Md: median nerve; Ax: axillary nerve; Tr: triceps branches; Mc: musculocutaneous nerve; Md*: medial contribution for the median nerve; BBMc: biceps branches of musculocutaneous nerve; Rd: radial nerve; UT: upper trunk; NL: neurelisis; G: graft.
age 10 (n = 3), those 10 to 15 yr old (n = 7), and those 16 to 19 (n = 10). By ANOVA, no intergroup difference was identified (mean M = 4.0, 3.7, and 3.8, respectively; F = 0.29, P = .75). Neither was any trend identified (F_{LINEAR} = 0.115, P = .74).

**Correlations**

Calculating Pearson correlation coefficients revealed a moderately strong direct correlation between elbow flexion strength and shoulder ROM (r = 0.50, P < .01; Table 7), and a weak direct correlation between elbow flexion strength and patient age (r = 0.29, P = .03), but no significant correlation between shoulder ROM and patient age (r = 0.18, P = .22). Moderate and borderline-weak direct correlations were detected, respectively, between time to surgery and the 2 outcomes elbow flexion strength (r = 0.46, P < .001) and shoulder ROM (r = 0.27, P = .06). Weak to moderately strong correlations were identified between the number of nerve roots involved and both outcomes (r = 0.29, P = .03 and r = 0.38, P = .006, respectively; Table 4).

**DISCUSSION**

**Pediatric BPI in the Literature**

Non-neonatal traumatic BPI in children are 10 times less common than in adults.\(^6\) In pediatric patient populations, a greater proportion attributed to car or pedestrian vs motorcycle accidents is observed.

Extracting data from the National Pediatric Trauma Registry, Dorsi et al\(^8\) retrospectively analyzed 113 pediatric patients suffering a BPI injury, excluding obstetrical cases. Interestingly, pediatric BPI was found to be associated with high kinetic trauma, as well as a higher incidence of associated injuries. Also, plexus lesions tended to be more severe and were associated with more root avulsions. Complete brachial plexus palsy (flail arm) can either refer to the extent of the lesion—indicated by the number of affected roots, in this case, C5 to D1—or to the severity of the injury, referring to the presence of complete vs incomplete palsy and anesthesia of the upper limb. Missios et al\(^9\) also analyzed epidemiological and socioeconomic data on pediatric BPI from the National Trauma Data Bank. In this pediatric population, BPI accounted for 0.56% of all trauma cases. The investigators found that BPI became increasingly common as patient age increased, as did the severity of trauma.

Chim et al\(^10\) state that their surgical strategy varies according to the age of their patients. In patients under 4 yr old, their first priority is to reconstruct the hand, as in obstetrical cases. They tend to treat patients younger than 12, with their skeleton fully developed, in the same way as adults. Meanwhile, in patients between 4 and 12 yr old, they tend to use donors that are less typical and somewhat controversial, like contralateral C7 transfers. They avoid using free muscle transfers or secondary reconstructive procedures like tendon transfers or joint fusions.

Regarding the outcomes of surgery in pediatric population, Dumontier et al\(^11\), El-Gammal et al\(^12\), Gilbert et al\(^13\), and Garg

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**TABLE 2. Description of Patients 20 to 29 yr old**

<table>
<thead>
<tr>
<th>Age</th>
<th>FSP</th>
<th>Physical exam</th>
<th>Time trauma-surgery (mo)</th>
<th>Surgical technique</th>
<th>Final outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>6</td>
<td>Phr-Mc (G = 18 cm), shoulder arthrodesis</td>
<td>Elbow flexion M4</td>
</tr>
<tr>
<td>26</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>4</td>
<td>XI-Mc (G = 13 cm), Phr-Ax (G = 10 cm)</td>
<td>Elbow flexion M4, shoulder 60°</td>
</tr>
<tr>
<td>21</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>5</td>
<td>XI-Mc (G = 13 cm), shoulder arthrodesis</td>
<td>Elbow flexion M4</td>
</tr>
<tr>
<td>20</td>
<td>Motorcycle</td>
<td>C5C6</td>
<td>6</td>
<td>Ulnar-BB, XI-Sp, CS-PDUT (G = 3 × 3 cm)</td>
<td>Elbow flexion M3, shoulder 30°</td>
</tr>
<tr>
<td>27</td>
<td>Motorcycle</td>
<td>C5C6</td>
<td>3</td>
<td>Ulnar-BB, XI-Sp, Tr-Ax</td>
<td>Elbow flexion M3, shoulder 90°</td>
</tr>
<tr>
<td>21</td>
<td>Bicycle</td>
<td>C5C6</td>
<td>3</td>
<td>Ulnar-BB, XI-Sp, CS-PDUT (G = 2 × 3 cm)</td>
<td>Elbow flexion M4, shoulder 45°</td>
</tr>
<tr>
<td>20</td>
<td>Motorcycle</td>
<td>C5C6</td>
<td>2</td>
<td>Ulnar-BB, Med-BrB, XI-Sp, CS-PDUT (G = 3 × 4 cm)</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>23</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>4</td>
<td>Phr-BBMc (G = 20 cm), XI-Sp</td>
<td>Elbow flexion M2, shoulder 30°</td>
</tr>
<tr>
<td>20</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>2</td>
<td>Phr-BBMc (G = 18 cm), XI-Sp</td>
<td>Elbow flexion M4, shoulder 110°</td>
</tr>
<tr>
<td>27</td>
<td>Car accident</td>
<td>C5C6</td>
<td>10</td>
<td>C6-ADUT (G = 2 × 6 cm), CS-PDUT (G = 2 × 6 cm) + Sp (G = 5 cm)</td>
<td>Elbow flexion M4, shoulder 90°</td>
</tr>
<tr>
<td>26</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>6</td>
<td>XI-ADUT, CS-PDUT + Sp (G = 3 × 5 cm)</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>27</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>5</td>
<td>Phr-BBMc (G = 20 cm), XI-Sp (G = 1.5 cm)</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>24</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>4</td>
<td>Phr-ADUT (G = 3 cm), XI-Sp</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>25</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>5</td>
<td>Phr-ADUT (G = 3 cm), shoulder arthrodesis</td>
<td>Elbow flexion M4</td>
</tr>
<tr>
<td>21</td>
<td>Motorcycle</td>
<td>C5C6</td>
<td>6</td>
<td>Ulnar-BB, XI-Sp, Tr-Ax</td>
<td>Elbow flexion M4, shoulder 60°</td>
</tr>
<tr>
<td>29</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>3</td>
<td>C5-Mc (G = 10 cm), XI-Sp (G = 1.5 cm)</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>28</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>8</td>
<td>XI-Mc (G = 18 cm), shoulder arthrodesis</td>
<td>Elbow flexion M1</td>
</tr>
<tr>
<td>29</td>
<td>Motorcycle</td>
<td>C5C6</td>
<td>7</td>
<td>Ulnar-BB, XI-Sp, Tr-Ax</td>
<td>Elbow flexion M4, shoulder 30°</td>
</tr>
<tr>
<td>28</td>
<td>Motorcycle</td>
<td>C5C6</td>
<td>5</td>
<td>Ulnar-BB, CS-PDUT (G = 3 × 3 cm), Tr-Ax</td>
<td>Elbow flexion M4, shoulder 60°</td>
</tr>
<tr>
<td>23</td>
<td>Motorcycle</td>
<td>C5D1</td>
<td>7</td>
<td>Phr-ADUT, XI-Sp, CS-PDUT (G = 3 × 3 cm)</td>
<td>Elbow flexion M3, shoulder 30°</td>
</tr>
</tbody>
</table>

Phr: Phrenic nerve; Mc: musculocutaneous nerve; XI: spinal accessory nerve; Ax: axillary nerve; Ulnar-BB: a fascicle of the ulnar nerve was transferred to the biceps branch of the musculocutaneous nerve; Med-BrB: a fascicle of the median nerve was transferred to the brachialis branch of the musculocutaneous nerve; Sp: suprascapular nerve; Tr: triceps branches; PDUT: posterior division of upper trunk; BBMc: biceps branches of musculocutaneous nerve; ADUT: anterior division of upper trunk; G: graf.
et al.\(^{14}\) presented series on 25, 11, 21, and 33 patients, respectively. All groups described good results for both shoulder and elbow reconstruction. Other data on traumatic BPI in children are limited to various small series that combine adults and children without comparing them, and single case reports.\(^{15-21}\)

### General Considerations Regarding the Current Series

In our series, we found that patients under 20 yr old generally had sustained more severe injuries than their older counterparts, in concordance with the aforementioned reports. This might have biased our results toward worse results in children, but this is not what we observed, lending further credence to our conclusion that children experience better outcomes after BPI surgery than adults.

The most important finding of the present study was the inverse relationship we detected between age and elbow flexion strength. To the best of our knowledge, this is the first report that describes this association in a mixed series of pediatric and older BPI patients. This trend toward worsened elbow outcomes with advancing age was apparent comparing children against adults, and again as a trend across the 3 age groups (children/adolescents <20 yr; young adults 20-29; and those 30 and over). There also was a statistically significant inverse correlation between age and flexion strength, albeit with variance in 1 only accounting for about 10% of the variance in the other. The relative weakness of this correlation likely is secondary to the apparent lack of any meaningful trend toward reduced flexion strength with increased age within the pediatric population itself, with a mean British MRC strength of 3.7 among the 7 children 10 to 15 yr old, and 3.8 in those 16 to 19. We also note that time to surgery, long considered a significant predictor of surgical outcome in palsy patients, was also only weakly to moderately inversely correlated.
TABLE 5. Comparing Youths vs Older Patients

<table>
<thead>
<tr>
<th></th>
<th>Children</th>
<th>Adults</th>
<th>Test statistic</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean age (standard deviation)</td>
<td>13.9 (4.9)</td>
<td>31.63</td>
<td>t = 9.22</td>
<td>P &lt; .001</td>
</tr>
<tr>
<td>Age range</td>
<td>3-18</td>
<td>20-61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle accident</td>
<td>15 (75.0%)</td>
<td>32 (80.0%)</td>
<td>χ² = 2.58</td>
<td>P = .28</td>
</tr>
<tr>
<td>Car accident</td>
<td>4 (20.0%)</td>
<td>3 (7.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other form of injury</td>
<td>1 (5.0%)</td>
<td>5 (12.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 roots injured</td>
<td>1 (5.0%)</td>
<td>15 (37.5%)</td>
<td>χ² = 12.41</td>
<td>P = .006</td>
</tr>
<tr>
<td>3 roots injured</td>
<td>5 (25.5%)</td>
<td>1 (2.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 roots injured</td>
<td>1 (5.0%)</td>
<td>1 (2.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 roots injured</td>
<td>13 (65.0%)</td>
<td>23 (57.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean time to surgery (mo)</td>
<td>5.5</td>
<td>5.8</td>
<td>t = 0.58</td>
<td>P = .56</td>
</tr>
<tr>
<td>Mean elbow flexion strength (MRC)</td>
<td>3.8</td>
<td>3.4</td>
<td>t = 1.96</td>
<td>P = .055</td>
</tr>
<tr>
<td>Mean shoulder ROM (degrees)</td>
<td>43.6</td>
<td>45.2</td>
<td>t = 0.18</td>
<td>P = .86</td>
</tr>
</tbody>
</table>

Boldface values indicate statistically significant differences.

TABLE 6. Comparing 3 Age Groups: Under 20, 20-29, and 30 and Over

<table>
<thead>
<tr>
<th></th>
<th>Age &lt; 20</th>
<th>Age 20-29</th>
<th>Age ≥ 30</th>
<th>Test statistic</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean age (standard deviation)</td>
<td>13.9 (4.9)</td>
<td>24.5 (3.2)</td>
<td>38.8 (9.5)</td>
<td>F = 76.1</td>
<td>P &lt; .001</td>
</tr>
<tr>
<td>Age range</td>
<td>3-18</td>
<td>20-29</td>
<td>30-61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle accident</td>
<td>15 (75.0%)</td>
<td>18 (90.0%)</td>
<td>14 (70.0%)</td>
<td>χ² = 5.55</td>
<td>P = .24</td>
</tr>
<tr>
<td>Car accident</td>
<td>4 (20.0%)</td>
<td>1 (5.0%)</td>
<td>2 (10.0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other form of injury</td>
<td>1 (5.0%)</td>
<td>1 (5.0%)</td>
<td>4 (20.0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 roots injured</td>
<td>1 (5.0%)</td>
<td>8 (40.0%)</td>
<td>7 (35.0%)</td>
<td>χ² = 13.54</td>
<td>P = .035</td>
</tr>
<tr>
<td>3 roots injured</td>
<td>5 (25.5%)</td>
<td>0</td>
<td>1 (5.0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 roots injured</td>
<td>1 (5.0%)</td>
<td>0</td>
<td>1 (5.0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 roots injured</td>
<td>13 (65.0%)</td>
<td>12 (60.0%)</td>
<td>11 (55.0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean time to surgery (mo)</td>
<td>5.5</td>
<td>5.1</td>
<td>6.6</td>
<td>F = 2.64</td>
<td>P = .080</td>
</tr>
<tr>
<td>Mean elbow flexion strength (MRC)</td>
<td>3.8</td>
<td>3.6</td>
<td>3.2</td>
<td>F = 2.25</td>
<td>P = .11</td>
</tr>
<tr>
<td>Mean shoulder ROM (degrees)</td>
<td>43.6</td>
<td>50.3</td>
<td>39.4</td>
<td>F = 0.61</td>
<td>P = .55</td>
</tr>
</tbody>
</table>

Boldface values indicate statistically significant differences.

TABLE 7. Correlations Between Variables

<table>
<thead>
<tr>
<th>Variables tested for correlation</th>
<th>Degree of correlation</th>
<th>Correlation strength</th>
<th>Statistical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow flexion strength × shoulder abstraction</td>
<td>r = 0.50</td>
<td>Moderate</td>
<td>P &lt; .001</td>
</tr>
<tr>
<td>Age × elbow flexion strength</td>
<td>r = 0.29</td>
<td>Weak</td>
<td>P = .03</td>
</tr>
<tr>
<td>Age × shoulder abduction</td>
<td>r = 0.18</td>
<td>None</td>
<td>P = .22</td>
</tr>
<tr>
<td>Time to surgery × elbow flexion strength</td>
<td>r = 0.46</td>
<td>Moderate</td>
<td>P &lt; .001</td>
</tr>
<tr>
<td>Time to surgery × shoulder abduction</td>
<td>r = 0.27</td>
<td>Borderline</td>
<td>P = .06</td>
</tr>
<tr>
<td>No. of roots involved × elbow flexion strength</td>
<td>r = 0.29</td>
<td>Weak</td>
<td>P = .03</td>
</tr>
<tr>
<td>No. of roots involved × shoulder abduction</td>
<td>r = 0.38</td>
<td>Weak</td>
<td>P = .006</td>
</tr>
</tbody>
</table>

Elbow flexion strength as measured on British MRC scale; shoulder abduction in degrees. Boldface values indicate statistically significant differences.

with elbow strength, the former accounting for only 21% of the variance in the latter. Clearly, other patient or procedural characteristics that we did not assess must impact elbow outcomes as well.

Unfortunately, we were unable to statistically confirm any relationship between patient age and outcomes for shoulder reinnervation, which is not what we expected. Probably, the small number of patients (only 47 received any attempt at shoulder...
reinnervation) and the heterogeneity of our series in terms of shoulder procedures explain this finding. Many of our adult patients, especially those who had severe injuries whereby no other donors were available, underwent a shoulder arthrodesis, as suggested by others.22 It might be that, in future prospective studies involving more homogeneous surgical techniques and a larger number of patients, a trend between age and shoulder reinnervation outcomes will be found.

Limitations
Among the limitations of the current study is the small number of subjects, just 60 in total divided between 3 age groups. As such, some intergroup differences that might be considered of clinical relevance (eg, 85% vs 65% good elbow flexion outcomes in patients under 20 vs 30 and over) failed to achieve statistical significance. We compensated for this, however, by performing trend analyses, which did, in some cases, identify trends where
intergroup differences were not detected but a clearly steady decline in outcomes was.

We also assessed only a small number of baseline variables, excluding others that might have impacted outcomes. On the other hand, the small number of subjects precluded the inclusion of large numbers of variables in models, lest there be inadequate power to detect significant associations. Moreover, the baseline variables we assessed (patient age, type of accident, time to surgery, and the number of roots involved) all were easily verified.

Another limitation that pertains to our statistical analysis is that, despite performing multiple univariate comparisons, we attempted no $P$ adjustments, creating the potential of type 1 error merely on the basis of chance. This being said, that our multivariate analysis (data not shown) essentially identified the same
associations observed on univariate analysis must be considered reassuring.

We recognize the retrospective nature of the present study as another limitation.

A discussion regarding the best method to determine the results of BPI surgery is currently taking place and could be seen as another limitation, as we used the classically employed methods like ROM and BMRC. The use of dynamometer-based measurements and computerized assessments of movement will certainly change this approach in the future.

A final limitation of potential importance was the relatively more severe injuries (more roots involved) in our children. However, if anything, this would be expected to decrease, rather than increase the inverse association we observed between elbow flexion strength and age.

CONCLUSION

Although perhaps not as influential as the number of roots disrupted or the time duration between the initial injury and reparative surgery, our data suggest that age is linked to the outcomes of brachial plexus surgery with respect to elbow flexion, but we could not demonstrate the same statistical tendency for shoulder abduction ROM. This apparent effect of age is not limited to distinguishing between children/adolescents and adults. Rather, it appears that increasing age is associated with steadily worsening elbow flexion outcomes, perhaps indicating a need for earlier surgery and/or more aggressive repairs in older patients.

Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES


COMMENTS

It has long been known that the pediatric nervous system has greater plasticity and regenerative potential than the adult, and it is common experience that younger adults recover faster and more robustly than older adults. This has not been formally studied with brachial plexus reconstruction outcome studies, and the authors here have provided their data to confirm what is usually taken for granted. For recovery of elbow flexion there is clearly a relationship between age and outcome. It is perhaps surprising that their analysis could not identify even a trend toward superior outcomes for shoulder abduction in relationship to younger age. Their theory is that the small numbers of subjects combined with the different management strategies used for the shoulder may explain the failure to identify a correlation between outcome and age. It is also notoriously difficult to examine shoulder function properly, with trick movements and alternate muscle groups contributing to apparent shoulder abduction. We also do not have specific information about the direction of the shoulder ROM, whether there is combined flexion, scapular gliding, and tilting of the spine to compensate for weak glenohumeral motion. Shoulder external rotation was also not studied. More useful data would include electrophysiological outcomes and patient-reported outcomes in terms of activities of daily living. Home use of
motion monitors and pain scales will also provide more accurate measures of the true functional success of plexus reconstruction.

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Jared Pisapia
Philadelphia, Pennsylvania

The authors executed a well-conceived retrospective review to test the primary hypothesis that age at the time of surgery influences outcome. They also evaluated the influence of injury severity (based on number of rootlet involvement) and the timing of surgery. The authors were able to identify a reasonable cohort of patients by age-cohort, allowing for the comparison of children and adolescents to young adults and older adults.

One of the challenges of this analysis is that the primary outcome for elbow flexion was manual motor testing, based on Medical Research Council (MRC) grade. Fundamentally, the mean differences between groups - which ranged from 0.2 to 0.3 grade difference in MRC between groups for elbow flexion and was not statistically significant - is hard to appreciate on clinical exam. MRC is widely different between observers and within repeated observer. Furthermore, the “in-between” MRC grades which are commonly used, eg 4+ or 4−, are not apparently utilized or accounted for in the analysis. A 4+ is meaningfully different from a 4−; this difference often determines whether the limb is used at all by the patient, as many patients with a deficient limb will ignore it. Shoulder function was even less meaningfully different between groups, both in clinical and statistical evaluation. Thus, the primary conclusion of the paper is limited by statistically insignificance and lack of clinical relevance.

These deficits are remediable by better assessment. For example, Active Movement scores, computerized joint angle measurements, and dynamometer tools can provide discrete data with greater range of values - which would like provide statistical significance and greater objectivity.

There are 2 additional considerations the reader should consider. The greater incidence of more severe BPI in kids makes the finding of greater strength all that more impressive. Yet, since the MRC evaluation compares against the normal limb, adult patients will be at a fundamental disadvantage by the timing of the evaluation. Reinnervated muscles undergo delayed contractile muscle isoform switching. That is to say, it may take years to express adult muscle isoforms on the previously denervated side, whereas the uninjured side will be stronger simply due to adult skeletal muscle contractile proteins. The 2-year follow-up is admirable in any study - but cannot account for delayed strength development from muscle isoform switching. The authors use of independent motor evaluation is valuable and not easily achieved.

Based on my experience, the authors’ conclusion is correct. Children demonstrate remarkable plasticity and tenacity in therapy. It is not uncommon to achieve results in children that cannot be achieved in adults. I applaud the authors for a thoughtful, well-designed retrospective review. They report substantial motor results in pan-plexus injuries. More objective outcome data would likely make the conclusion statistically and clinically meaningful.

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