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Peripheral Nerve

Factors Affecting C5 Viability and Demographic Variability in Two Brachial Plexus Centers

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Background: Complete brachial plexus injuries are devastating injuries. A viable C5 spinal nerve can offer additional sources of axons and alter surgical treatment. We aimed to determine factors that portend C5 nerve root avulsion.

Methods: A retrospective study of 200 consecutive patients with complete brachial plexus injuries at two international centers (Mayo Clinic in the United States and Chang Gung Memorial Hospital in Taiwan) was performed. Demographic information, concomitant injuries, mechanism, and details of the injury were determined, and kinetic energy (KE) and Injury Severity Score were calculated. C5 nerve root was evaluated by preoperative imaging, intraoperative exploration, and/or intraoperative neuromonitoring. A spinal nerve was considered viable if it was grafted during surgery.

Results: Complete five-nerve root avulsions of the brachial plexus were present in 62% of US and 43% of Taiwanese patients, which was significantly different. Increasing age, the time from injury to surgery, weight, body mass index of patient, motor vehicle accident, KE, Injury Severity Score, and presence of vascular injury significantly increased the risk of C5 avulsion. Motorcycle (≤150cc) or bicycle accident decreased the risk of avulsion. Significant differences were found between demographic variables between the two institutions: age of injury, body mass index, time to surgery, vehicle type, speed of injury, KE, Injury Severity Score, and presence of vascular injury.

Conclusions: The rate of complete avulsion injury was high in both centers. Although there are a number of demographic differences between the United States and Taiwan, overall the KE of the accident increased the risk of C5 avulsion.
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INTRODUCTION

Adult traumatic complete brachial plexus injuries (BPIs) result in tremendous physical disability and economic hardship.[1] A postganglionic injury (nonavulsed root) offers additional axons for potential grafting of targets. In complete BPIs, a viable spinal nerve can drastically change the treatment algorithm and outcome.[2] Reported viable spinal nerve amenable for grafting in pan-BPI varies globally, ranging between 35% and 88%.[3–5]

Factors affecting the surgical outcomes include age and body mass index (BMI) as well as mechanism of trauma.[6–13] Mechanisms include motorized vehicle trauma, falls, and penetrating injuries.[1] The most common etiology is reported as road traffic accidents with sparse specific details of the injury (speed or energy).[14–16] The kinetic energy (KE) of injury is related to mass and speed, and its importance in BPIs is understated. An indirect measure of the energy is the Injury Severity Score (ISS), which correlates linearly with mortality, morbidity, and duration of hospitalization.[17–19] Few BPI publications report KE or ISS.

Regional differences in patient demographics and mechanism of injury may be unique, and these differences

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make comparisons of outcomes of reconstruction challenging, if not impossible. We hypothesize that differences of C5 viability and BPI severity are directly related to the energy imparted at injury. The purpose of this study was to determine if mechanism and energy had a relationship to the viability of brachial plexus spinal nerves.

METHODS

A retrospective study after institutional review board approval of the most recent 200 consecutive patients with a complete BPI injury was undertaken at the Mayo Clinic, Rochester, Minnesota, USA, and Chang Gung Memorial Hospital (CGMH), Taipei-Linkou, Taiwan. Both institutions have prospectively maintained institutional BPI patient databases. One hundred patients were identified for each institution from April 2021 or earlier. Inclusion criteria were age older than 16 years, complete traumatic BPI, and reconstructive nerve surgery between 2 and 10 months from injury. Patients were excluded if they had spontaneous recovery of function, sustained open/penetrating injuries, did not undergo supraclavicular exploration, had intact/functioning nerves upon exploration, had incomplete data sets, or refused to participate in research. Clinical examination findings were reviewed to ensure complete BPI immediately prior to surgery. For incomplete data sets, including speed of injury, review of patient medical records or telephone interviews were conducted.

Demographic information (age, gender, weight, height, and BMI) at the time of injury was recorded. Evaluation and accident details [time from injury to first visit, time from injury to surgery, mechanism of injury [motor vehicle accident (MVA), motorcycle accident (MCA), fall from height, recreational vehicle or struck by falling object], vehicle type [car, truck, motorcycle ≥500cc, motorcycle ≤150cc, bicycle, snowmobile, all terrain vehicle (ATV)], helmet use, and speed (kilometers per hour, km/h) were recorded. Height and mass of object (if striking injury) were obtained. KE was calculated and reported in kilojoules (kJ) (KE = 1/2 mass × velocity^2; if fall from a height or object struck patient from a height, potential energy was calculated and estimated as KE of impact: potential energy = mass × gravity × height).

ISS, associated vascular injury, the presence of Horner sign and diaphragmatic paralysis, and loss of consciousness were detailed. ISS was calculated by assigning an abbreviated injury scale (AIS) score (0–6) to six major body areas at the time of injury (Table 1).[20] (**See appendix, Supplemental Digital Content 1,** which shows the AIS. **http://links.lww.com/PRSGO/C617**.) ISS is the sum of the square of the AIS from the three most severely injured body areas (ISS = $AIS_1^2 + AIS_2^2 + AIS_3^2$).[17]

Determination of Viable Root

The senior operating surgeons determined nerve root status (avulsed versus ruptured) using clinical examination, preoperative electrodiagnostic and imaging studies [CT myelogram (Mayo) or MRI (CGMH)], and intraoperative evaluation with or without intraoperative neuromonitoring (IOM). Senior surgeons (AYS, ATB, RJS, DCCC) all have over 25 years of experience with BPI reconstruction. The C5–C7 spinal nerves were surgically explored for all cases. IOM was performed in all Mayo patients unless the neuroforamen was empty or dorsal root ganglion was identified.

Each institution had their own algorithm of preoperative imaging (CT myelogram versus MRI) and intraoperative root assessment. At Mayo, nerve roots were considered suspicious for avulsion on CT myelogram if there was a meningomyelocele or nerve roots appeared discontinuous with the spinal cord. Nerves were considered avulsed if IOM (when available) somatosensory evoked potential (SSEP) and motor evoked potential (MEP) demonstrated absent responses. For SSEP a probe is placed on the nerve root in question and multiple signal pulses delivered. If there is signal received in the subdermal neck and scalp needles, SSEP is considered positive. To test the ventral rootlets, MEPs are performed. Multiple signals are delivered to the scalp and receiving probes placed on the nerve root being tested. Detection of a signal at the root is considered positive MEP. In cases where SSEP and MEP are inconsistent, a combination of peroperative imaging, exam and neurodiagnostics are used to determine if a root can be grafted.

At CGMH, surgical exploration complemented by knowledge of MRI evaluation of the spinal nerves was used to determine graftable stump. Evidence of partial avulsion of one to two ventral rootlets within a spinal nerve on MRI with surgical confirmation of a good stump is grafted for elbow, hand, or shoulder.[21] Evidence of partial avulsion on MRI of three ventral rootlets is graftable for shoulder. There is often scarring within the stump, and fascicles are often not healthy; however, this stump would still be grafted. Avulsion of four rootlets on MRI typically correlates with inability to find stump, and if it is found, it is of poor quality and is not grafted. However, intraoperatively in these cases of four rootlet avulsion, if a nerve stump is found with an acceptable cut surface of visible fascicles, the spinal nerve is grafted.[22] Poor quality of the spinal nerve during operative exploration precluded grafting in both institutions.

> **Takeaways**
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> **Question:** What are the factors that may explain global variations in rates of C5 avulsion in pan-plexus injuries?
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> **Findings:** Body mass index, kinetic energy of accident, mechanism of injury, and injury severity score influence risk of C5 avulsion.
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> **Meaning:** Global variations in rates of C5 avulsion may be explained by differences in patient and accident-related demographics intrinsic among countries. Specifically, higher severity accidents have higher rates of C5 avulsion. Inclusion of these variables should be considered when publishing literature regarding nerve root avulsion and reconstruction in traumatic BPI.

Table 1. Injury Severity Score

Body Area	AIS Score*
Head and neck	0–6
Face	0–6
Chest	0–6
Abdomen	0–6
Extremity + pelvis	0–6
External	0–6

ISS is the sum of the AIS[2] of the three most severely injured body systems.
*0: no injury, 1: minor injury, 2: moderate injury, 3: serious injury, 4: severe injury, 5: critical injury, and 6: unsurvivable injury.

The senior surgeons of the study agreed before study that if the spinal nerve of C5, C6, or C7 was grafted by the surgeon, it was considered to have a postganglionic element (ie, viable) and if a spinal nerve was not grafted, it was avulsed. For lower spinal nerves, electrodiagnostics and imaging were used to confirm avulsion, and operative exploration was not consistently performed.

Statistical Analysis

The data are reported using standard summary statistics, including means and standard deviations for continuous variables, and counts and percentages for categorical variables. Comparisons of patient demographics, accident and injury characteristics, and spinal nerve involvement between the two institution cohorts were performed using two-sample *t* tests (assuming unequal variance) and chi-square tests for continuous and categorical variables, respectively. The analysis focused on the risk of C5 avulsion as the primary outcome. As the overall rate of C5 avulsion was high (over 50%), logistic regression was avoided because the odds ratios would greatly overestimate the true relative risk with such a high observed outcome rate. Rather, the risk ratios (RRs) were calculated using Poisson regression with 95% confidence intervals (CIs) calculated using the robust error variance to correct for any potential over- or underdispersion.[23,24] All statistical tests were two-sided, and *P* values less than 0.05 were considered statistically significant. The analysis was conducted using SAS version 9.4M6 (Cary, N.C.). No funding was obtained for this investigation.

RESULTS

In the US institution, 100 consecutive pan-BPIs spanned a 12.2-year period from January 21, 2009 to April 15, 2021. Over this period, 489 primary brachial plexus surgeries were performed for acute injuries. For the Taiwanese institution, this spanned a 9.3-year period from November 29, 2011 to March 25, 2021. Over this period, 498 primary brachial plexus surgeries were performed for acute injuries.

Nerve root status is summarized in Table 2. The number of ruptured C5 spinal nerves available for grafting was significantly less in the US center (Mayo 33%, CGMH 57%, *P* = 0.0011). Rates of C6 and C7 viability did not differ between the two centers. Sixty-two percent of United States and 44% of Taiwanese patients had a complete avulsion of their brachial plexus (*P* = 0.011). Results of IOM and CT myelogram and MRI relative to graftable roots are summarized in Tables 3 and 4.

Table 2. Nerve Root Involvement

	Institution		
	Mayo (N = 100)	CGMH (N = 100)	*P*
C5 status, n (%)			0.0011
Avulsed	67 (67.0%)	44 (44.0%)	
Ruptured	33 (33.0%)	56 (56.0%)	
C6 status, n (%)			0.2587
Avulsed	86 (86.0%)	80 (80.0%)	
Ruptured	14 (14.0%)	20 (20.0%)	
C7 status, n (%)			>0.999*
Avulsed	96 (96.0%)	95 (95.0%)	
Ruptured	4 (4.0%)	5 (5.0%)	
At least one nerve graftable, n (%)			0.0108
No: total avulsion	62 (62.0%)	44 (44.0%)	
Yes: partial avulsion	38 (38.0%)	56 (56.0%)	
Two nerves graftable, n (%)			0.0926
No	91 (91.0%)	83 (83.0%)	
Yes	9 (9.0%)	17 (17.0%)	
Three nerves graftable, n (%)			0.6827*
No	98 (98.0%)	96 (96.0%)	
Yes	2 (2.0%)	4 (4.0%)	

**P* value based on Fisher exact test. All other *P* values are based on chi-square tests.

Table 3. Results of Preoperative Imaging and Intraoperative Neuromonitoring by Root in Mayo Patients

		MEP+/ SSEP+	MEP+/ SSEP–	MEP– / SSEP+	MEP– / SSEP–	CT Myelo Avulsed
C5	Number	25	8	7	33	39
	Grafted n (%)	25 (100%)	4 (50%)	3 (43%)	1 (3%)	4 (10%)
C6	Number	12	3	1	34	66
	Grafted n (%)	12 (100%)	1 (33%)	0 (0%)	0 (0%)	3 (4.5%)
C7	Number	4	0	1	6	85
	Grafted n (%)	4 (100%)	0 (0%)	1 (100%)	0 (0%)	1 (1.2%)

SSEP, Somatosensory evoked potential. MEP+/SSEP+Both MEP and SSEP had detectable single. MEP+/SSEP–, MEP had detectable signal; SSEP did not have detectable signal. MEP–/SSEP–, Neither MEP or SSEP had detectable signal. All intraoperative was performed with neurologist in operating room. Not all nerves underwent intraoperative monitoring.

Regression analysis demonstrated that increasing age at injury (RR, 1.14; *P* = 0.002), the time from injury to surgery (RR, 1.04; *P* = 0.001), weight of patient (RR, 1.06; *P* = 0.037), BMI of patient (RR, 1.02; *P* = 0.004), MVA (RR, 1.51; *P* = 0.001), KE (RR, 1.03; *P* = 0.011), ISS (RR, 1.05; *P* = 0.026), and presence of vascular injury (RR, 1.33; *P* = 0.022) all significantly increased the risk of C5 avulsion (Table 5). Motorcycle ≤150cc or bicycle accident significantly decreased the risk of avulsion (RR, 0.74; *P* = 0.045) (Table 5). The strongest predictors of C5 avulsion were presence of vascular injury and MVA. For the Taiwanese cohort, KE increased the risk of vascular injury by RR of 3.27 (95% CI, 1.6–6.68; *P* = 0.001). This was not seen for the US cohort.

Table 4. Results of Preoperative Imaging in CGMH Patients

		MRI Indicated Avulsed*	MRI Indicated Ruptured
C5	Number	46	54
	Grafted n (%)	8† (17%)	49 (91%)
C6	Number	76	23
	Grafted n (%)	4† (5%)	13 (54%)
C7	Number	89	11
	Grafted n (%)	1 (1%)	4 (36%)

*Nerve root was considered avulsed on MRI if three or more ventral rootlets were avulsed.[21]
†Used to augment another donor nerve for shoulder or elbow extension.

Table 5. Factors Affecting C5 Root Avulsion in Pan-plexus Injuries

Variable	RR	95% CI	P
Age at injury (per 10 y increase)	1.14	1.05–1.24	0.002
Injury to surgery (per 30 d increase)	1.04	1.02–1.06	0.001
Weight (per 10 kg)	1.06	1.01–1.11	0.037
Body mass index	1.02	1.01–1.03	0.004
Mechanism of injury			
MCA/rec vehicle			
MVA	1.51	1.17–1.95	0.001
Fall/struck by object	1.05	0.67–1.65	0.825
Vehicle type			
Motorcycle ≥ 500cc/snowmobile/ATV			
Car/truck	1.22	0.92–1.62	0.175
Motorcycle ≤150cc/bicycle	0.74	0.55–0.99	0.045
Speed (per 10 km/h)	1.03	0.99–1.06	0.086
Kinetic energy (per 10 kJ)	1.03	1.01–1.05	0.011
Injury Severity Score (per 5 points)	1.05	1.01–1.10	0.026
Presence of vascular injury	1.33	1.04–1.70	0.022

RR is reported as percent increase per unit change for continuous variables (Age, d, kg, BMI point, km/h, kJ, ISS) and as an increase in risk relative to set variable for categorical variables (mechanism, vehicle type). MCA: motorcycle accident.

Table 6. Patient Demographics

	Institution		
	Mayo (N = 100)	CGMH (N = 100)	P
Age at injury			0.04101†
Mean (SD)	31.6 (12.1)	28.1 (11.7)	
Gender, n (%)			0.69972
Men	83 (83.0%)	85 (85.0%)	
Women	17 (17.0%)	15 (15.0%)	
Body mass index			<0.0001*
Mean (SD)	28.0 (7.2)	24.5 (4.7)	
Laterality, n (%)			0.83652
Right	45 (45.5%)	44 (44.0%)	
Left	54 (54.5%)	56 (56.0%)	

*Unequal variance two sample *t* test.
†Chi-square *P*.

Table 7. Accident Characteristics

	Institution		
	Mayo	CGMH	P
Injury to first visit (d)			<0.0001*
N	100	100	
Mean (SD)	134.0 (67.6)	78.3 (102.3)	
Injury to surgery (d)			0.04821
N	98	100	
Mean (SD)	180.0 (44.7)	154.6 (119.2)	
Mechanism of injury, n (%)			<0.0001†
MVA	21 (21.0%)	3 (3.1%)	
MCA	45 (45.0%)	87 (89.7%)	
Fall	5 (5.0%)	5 (5.2%)	
Recreational vehicle	21 (21.0%)	0 (0.0%)	
Struck by object	8 (8.0%)	2 (2.1%)	
Vehicle type, n (%)			<0.0001†
Car or truck	22 (25.6%)	3 (3.5%)	
Motorcycle >500cc	43 (50.0%)	6 (7.0%)	
Motorcycle <150cc	0 (0.0%)	74 (86.0%)	
Bicycle	1 (1.2%)	3 (3.5%)	
Snowmobile	12 (14.0%)	0 (0.0%)	
ATV	8 (9.3%)	0 (0.0%)	
Helmet at injury, n (%)			0.0003†
No	17 (25.0%)	2 (3.1%)	
Yes	51 (75.0%)	62 (96.9%)	
Speed (km/h)			<0.0001*
N	88	71	
Mean (SD)	86.7 (40.6)	55.6 (17.1)	
Kinetic energy (kJ)			<0.0001*
N	94	74	
Mean (SD)	30.3 (38.4)	9.0 (6.4)	

*Unequal variance two sample *t* test.
†Fisher exact test.
MCA, Motorcycle Accident; SD, Standard deviation; kJ, kilojoules; N, number patients in analysis if less than full cohort.

Patient demographics are summarized in Table 6. Age at injury ($P = 0.04$) and BMI ($P < 0.0001$) were significantly lower in the Taiwanese cohort (Table 6). Accident demographics are summarized in Table 7. Time from injury to first visit ($P < 0.001$), time from injury to surgery ($P = 0.048$), speed ($P > 0.001$), and KE ($P < 0.0001$) were significantly less in Taiwanese patients. Helmet use was significantly less in the US patients ($P < 0.001$). There were significant differences in distribution of mechanism of injury ($P < 0.0001$) and vehicle type, with Taiwanese patients riding motorcycles ≤150cc and US patients, motorcycles ≥500cc ($P < 0.0001$). Injury characteristics are summarized in Table 8. ISS ($P < 0.0001$) and presence of vascular injury of the subclavian, axillary, or brachial artery ($P < 0.001$) were significantly higher in the US cohort. Initial diaphragmatic paralysis was significantly higher in the Taiwanese cohort ($P = 0.01$) (Table 8).

DISCUSSION

BPIs are a global problem resulting in tremendous disability, pain, and socioeconomic burden.[25] Complete BPIs present a reconstructive challenge for surgeons.[5] A viable C5 spinal nerve can drastically alter the treatment algorithm and outcomes in complete BPIs.[2] Regional differences in patient demographics determine the treatment strategy for these patients.[25,26] Although global literature compares and contrasts the various methods of reconstruction and outcomes after adult traumatic BPIs, few reports critically evaluate regional differences of patient demographics and injury mechanisms. These differences

Table 8. Injury Characteristics

	Institution		
	Mayo (N = 100)	CGMH (N = 100)	*P*
Horner syndrome, n (%)			0.21582
No	22 (22.0%)	14 (15.1%)	
Yes	78 (78.0%)	79 (84.9%)	
Diaphragm paralysis, n (%)			0.01362†
No	86 (86.0%)	71 (71.7%)	
Yes	14 (14.0%)	28 (28.3%)	
Loss of consciousness, n (%)			0.81352
No	17 (17.2%)	17 (18.5%)	
Yes	82 (82.8%)	75 (81.5%)	
Injury Severity Score			<0.0001*
Mean (SD)	26.3 (12.4)	19.4 (10.7)	
Vascular injury, n (%)			0.00052†
No	69 (69.0%)	89 (89.0%)	
Yes	31 (31.0%)	11 (11.0%)	

*Unequal variance two sample *t* test.
†Chi-Square *P*.

can vary widely and may have profound effects on outcomes despite similar reconstructions.[6,7,11] In this study, several patients and accident characteristics that increased the risk of C5 nerve root avulsion were identified and were significantly different between institutions.

The diagnosis of nerve root avulsion remains controversial. In the US cohort, 4% of spinal nerves that appeared avulsed on CT myelogram were grafted based on intraoperative examination of the spinal nerve and IOM studies. All spinal nerves with MEP+/SSEP+ were grafted, while 11% with MEP−/SSEP− were determined to have an intact nerve root based on intraoperative examination. Previous data demonstrate good sensitivity but lower specificity of IOM, which correlates with the findings of this study.[27] Mixed IOM results were more difficult to interpret. Twenty spinal nerves had either MEP+ or SSEP+ (not both), nine of which were grafted, with preference for MEP+ spinal nerves. Zhao et al found that in cases of severe but incomplete root lesions, SEPs still could be recorded, leading to false conclusions that the root was intact and viable.[27] This may have led to artificially increased rates of grafting in these cases. Seventeen percent of C5 nerve roots reported to be avulsed on MRI were still grafted during intraoperative exploration in the Taiwanese cohort, which is higher than previous studies.[21] This is likely due to a low threshold to use partially avulsed roots to graft to shoulder or elbow extension in pan-BPI patients with a scarcity of available donor nerves.

A minimum of one graftable (nonavulsed) spinal nerve was found in 38% of US and 57% of Taiwanese patients. This is consistent with previous reports.[3,8] Birch et al found a 35% rate of graftable spinal nerves, whereas Chuang et al found a rate of 57% in 1999.[3,8] The rates of avulsion in this study are vastly different when compared with other regions of the world. Bertelli et al in 2017 reported one graft-eligible nerve in 88% of pan-plexus injuries in Brazil.[5] Diagnosis of postganglionic injury was made based on CT myelography, surgical examination of the spinal nerve, and intraoperative stimulation.[5] Bentolila from France similarly found at least one graft-eligible root in 82% of pan-plexus injuries; however, advanced diagnostics were not used, and the mechanism of diagnosis of avulsion was not reported.[28] Without understanding the regional differences of injury mechanisms and patient demographics as well as method for diagnosis, it is impossible to ascertain the reason that there was such a high rate of a viable root available for grafting.

A number of accident-related factors significantly increased the risk of C5 nerve root avulsion, including MVA, ISS, and presence of a vascular injury. Motorcycles ≤150cc decreased the risk of C5 avulsion by 26% compared with those injured on a motorcycle ≥500cc, snowmobile, or ATV. MVA increased the risk of C5 avulsion by 51% relative to MCA or recreational vehicle. MVAs resulted in more serve BPI, likely secondary to the improved survivorship at high speeds due to the safety features in the modern vehicles.

The risk of C5 avulsion increased with ISS and presence of vascular injury. For a five-point increase of ISS, there was a 5% increase in risk of C5 avulsion. The ISS is known to correlate with mortality, morbidity, and hospitalization after trauma.[29] This study confirms its utility in prediction of severity of neurologic injury in complete traumatic BPI. The rate of concomitant vascular injury was 30% in the US cohort and 11% in the Taiwanese patients, which is consistent with previously published rates.[30] The presence of vascular injury increased the risk of C5 avulsion by 33% when compared with patients without vascular injury. Previous reports demonstrate that patients who underwent brachial plexus reconstruction with concomitant vascular injury have lower postoperative elbow flexion and shoulder abduction strength.[31]

KE imparted during trauma is related to patient mass and velocity and is rarely, if ever, reported. Terzis et al reported a speed of injury of 87.7 km per hour for their US-based patients,[30] which is consistent with the US cohort in this study. Socolovsky et al reported faster speed was a predictor of complete BPI.[32] In this study, speed of accident did not significantly increase the risk of C5 avulsion, but KE did. For every increase of 10 kJ of KE, the risk of C5 avulsion increased by 3%. KE accounts for both mass and speed of accident, emphasizing that the size of the patient needs to be considered. Both speed and mass (or BMI) enabled a more accurate reflection of the energy of the accident and correlated with C5 injury.

Both the time from injury to first visit and time from injury to surgery was significantly less in the Taiwanese cohort. This may reflect referral patterns, insurance type, and travel distance for patients between countries. The cohort from the United States had significantly higher ISS, presence of vascular injury, and decreased helmet use. Patients with more severe injury may have had delayed time to presentation secondary to recovery from their other injuries. Several other demographic variables were significantly different between institutions including mechanism of injury, type of vehicle, BMI, weight, and age at injury. The presence of these differences and their influence on C5 viability should be considered when examining the international literature of traumatic BPIs.

We recognize the limitations of this study as well as those inherent in retrospective studies. The absence of a gold standard to judge a nerve root a complete avulsion makes quantification of root viability difficult and the lack of routine histological testing makes exact diagnosis of rupture or avulsion impossible. The presence of nerve avulsion was determined by senior surgeons with different strategies for the diagnosis of viable spinal nerves. To overcome the differences in strategies, it was agreed upon that a nerve that was grafted was considered viable, and if it was not, it was considered avulsed. Without this convention, comparisons could not be made. However, it is possible that one surgeon had a higher or lower threshold to graft so-called partial avulsions, leading to differences in rates of grafting not reflecting actual nerve root viability. We also may have introduced selection bias by operating on only surgically treated patients. Similarly, if a root was found to be not avulsed and functioning during surgery, they were excluded from the study. This excludes patients who underwent spontaneous recovery of an injured nerve root. There were also likely inaccuracies in the reporting of speed, mass of falling object or heights of fall by the patient, police or family, which would affect the calculation of KE. Additionally, KE does not account for the energy or speed of surrounding objects that may be involved in an accident. However, the ISS correlates well with KE, demonstrating consistent reporting of accident data. Lastly, data are from a single institution in the United States and a single institution in Taiwan. Although both serve as national referral centers, they may not be generalizable of the entire population of the country.

These limitations notwithstanding, this international, multi-center study clearly demonstrated factors that affected C5 spinal nerve viability across both cohorts. There were regional differences in these variables that were statistically significant and should be considered when examining literature regarding nerve root avulsion and reconstruction in traumatic BPI. Inclusion of these variables in future studies is important to allow for equitable global comparisons and assist in counseling patients about the natural history, treatment and prognosis of BPI.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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