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Indirect Cost of Traumatic Brachial Plexus Injuries in the United States

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Background: Traumatic brachial plexus injuries (BPIs) disproportionately affect young, able-bodied individuals. Beyond direct costs associated with medical treatment, there are far-reaching indirect costs related to disability and lost productivity. Our objective was to estimate per-patient indirect cost associated with BPI.

Methods: We estimated indirect costs as the sum of (1) short-term wage loss, (2) long-term wage loss, and (3) disability payments. Short-term (6-month) wage loss was the product of missed work days and the average earnings per day. The probability of return to work was derived from a systematic review of the literature, and long-term wage loss and disability payments were estimated. Monte Carlo simulation was used to perform a sensitivity analysis of long-term wage loss by varying age, sex, and return to work simultaneously. Disability benefits were estimated from U.S. Social Security Administration data. All cost estimates are in 2018 U.S. dollars.

Results: A systematic review of the literature demonstrated that the patients with BPI had a mean age of 26.4 years, 90.5% were male, and manual labor was the most represented occupation. On the basis on these demographics, our base case was a 26-year-old American man working as a manual laborer prior to BPI, with an annual wage of $36,590. Monte Carlo simulation estimated a short-term wage loss of $22,740, a long-term wage loss of $737,551, and disability benefits of $353,671. The mean total indirect cost of traumatic BPI in the Monte Carlo simulations was $1,113,962 per patient over the post-injury lifetime (median: $801,723, interquartile range: $22,740 to $2,350,979). If the probability of the patient returning to work at a different, lower-paying job was doubled, the per-patient total indirect cost was $867,987.

Conclusions: BPI can have a far-reaching economic impact on both individuals and society. If surgical reconstruction enables patients with a BPI to return to work, the indirect cost of this injury decreases.

Level of Evidence: Economic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Traumatic brachial plexus injuries (BPIs) are devastating injuries that can cause pain, loss of function, and psychological stress. The reduction in quality of life and the inability to work have social and economic implications for the patient and society, particularly when considering medical expenditures and lost workforce productivity[1-3].

Even after successful surgical reconstruction, many individuals do not return to the same occupation or return to work at all after a BPI[4-6]. Furthermore, there are inefficiencies in care delivery for patients with BPI in the U.S., which may compromise clinical outcomes given the time-sensitive nature of the injury[7]. Estimation of the costs associated with BPI from a societal perspective would support continued allocation of resources for clinical care and research, with the ultimate goal of optimizing return to work and improving quality of life after a BPI. In order to better understand the societal impact of traumatic BPI, we used economic analysis methods to estimate the per-patient lifetime indirect cost of these injuries.

Materials and Methods

Literature Review

With the assistance of a medical librarian, we performed a systematic review of the published literature to determine

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demographic information and return-to-work data after BPI reconstruction. These search strategies (see Appendix 1) were established using a combination of standardized terms and keywords and were implemented in Ovid MEDLINE (includes articles from 1946 to the present), Embase (1947 to the present), Scopus (1823 to the present), Cochrane Database of Systematic Reviews, Cochrane Register of Controlled Trials, Database of Abstracts of Reviews of Effects, ProQuest Dissertations & Theses, and ClinicalTrials.gov. All searches were executed in May 2017. Abstracts were evaluated by 2 authors for inclusion in the study. Exclusion criteria included articles not written in English; <5 patients in the study; patients treated for thoracic outlet syndrome, iatrogenic BPI, or brachial plexus birth injury; and articles published before 1970. The references of all papers that met the inclusion criteria were then hand-searched to identify additional articles for inclusion (Fig. 1; see Appendix 2).

Indirect Cost of BPI

Overview

The total cost of BPI can be estimated by summing direct and indirect costs. Direct costs include all charges associated with BPI surgery, including physician and hospital fees at the initial presentation through follow-up appointments. We did not estimate direct cost in this study, instead focusing on indirect cost, which can be more difficult to quantify. As BPI can cause temporary (and possibly permanent) disability, wage loss should include loss of fringe benefits as well. The work loss estimates were determined with methods presented in the Web-based Injury Statistics Query and Reporting System (WISQARS) Cost of Injury module[8] and then were adapted with an approach that stratifies non-fatal work losses into short and long-term losses described by Finkelstein et al.[9].

While there is debate about which method of estimating indirect cost should be used, we employed the human capital method to estimate indirect costs as the sum of short-term and long-term wage losses as well as disability payments[10-12]. The human capital method was chosen as it accounts for productivity costs from the patient's perspective and has been the method of choice for most cost-of-illness studies[13,14].

Short-Term Wage Loss

Short-term wage loss was calculated as the product of missed work days and the average earnings per day accounting for fringe benefits:

$$\text{short term wage loss} = (\text{missed days}) \times (8 \times \text{hourly wage}) \times (1 + \text{fringe fraction})$$

In previous studies, 6 months has been used as the cutoff between short-term and long-term work losses, on the basis of the availability of data regarding duration of work loss[15]. On the basis of the opinion of 3 attending surgeons who treat patients with BPI, we assumed that patients would miss all 6 months of work in the period immediately following the BPI (Table I). The average earnings per day were estimated from the Bureau of Labor Statistics (BLS) Occupational Employment Statistics (OES)[16] (Table II). As most patients with BPI are manual laborers, only certain occupations

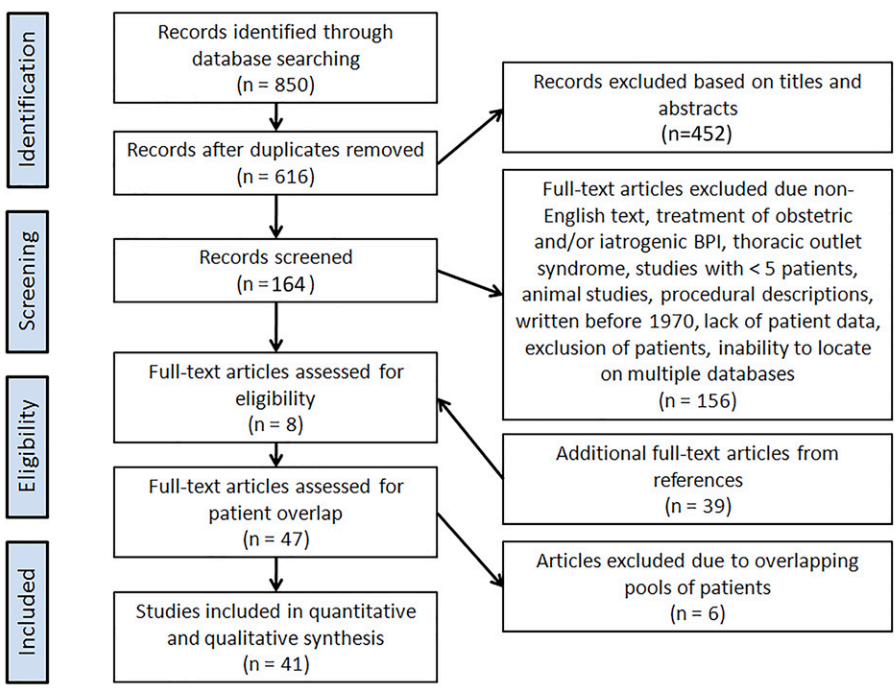

Fig. 1
Flowchart of the selection of papers included in the literature review.

TABLE I Data Sources for Economic Model

	Source
Patient characteristics	
Age	Systematic review
Sex	Systematic review
Return to work	Systematic review
Short-term wages	
Time off work (6 mo)	Expert opinion
$/day	Bureau of Labor Statistics (BLS) Occupational Employment Statistics (OES)[16]
Fringe benefits	Bureau of Economic Analysis (BEA) Archive of National Accounts (NIPA)[22]
Long-term wages	
Survival probability	CDC National Vital Statistics Reports United States Life Tables[23]
Earnings	Integrated Public Use Microdata Series (IPUMS) archives[24]
Disability	
Disability payment amount	Social Security Administration[25]
Partial versus complete disability	Systematic review; expert opinion

were included in our estimate[17-20]. The most recent OES estimates were from May 2017, and all wages were inflated to 2018 dollars using the most recent employment cost indices from the BLS[21]. Fringe benefits were calculated as described by Lawrence et al.[15]. The Bureau of Economic Analysis (BEA) Data Archive: National Accounts (NIPA) was used to access 2018 Personal Income and Outlays data[22] (Table I). This included data up to 2017; thus, data from 2010 to 2017 were used for estimation of fringe benefits.

Long-Term Wage Loss

Long-term wage loss was estimated using a combination of permanent total and partial disabilities. Permanent total disability was estimated as being equal to a loss of lifetime earnings[15]. The equation to calculate lifetime earnings for a person of age a and sex b is as follows:

$$\mathrm{Earn}_{a,b} = \sum_{k=a}^{100} \left\{ P_{a,b}(k) \times Y_{k,b} \times \left(\frac{1+g}{1+d}\right)^{k-a} \right\}$$

where $P_{a,b}(k)$ is the probability that a person of age a and sex b will live until age k, $Y_{k,b}$ is the average value of annual earnings with fringe benefits for a person of age k and sex b, g is the productivity growth rate, which was set at 0.01 for earnings, and d is the discount rate, which was set at 0.03. Probabilities of survival ($P_{a,b}[k]$)) were calculated from 2014 Centers for Disease Control and Prevention (CDC) National Vital Statistics Reports United States Life Tables[23] (Table I). Earnings by age and sex were obtained from the Annual Social and Economic Supplement of the Current Population Survey obtained through the University of Minnesota's Integrated Public Use Microdata Series (IPUMS) archives[24] (Table I). The earnings data from 2010 to 2017 were combined and adjusted to 2018 dollars using the Employment Cost Index[21].

A Markov model was assembled to simulate 3 different return-to-work scenarios (Fig. 2): (1) return to work at the same job with no disability payout, (2) return to work at a different job with no disability payout, and (3) no return to work with full disability payout. The probability of each outcome was derived from return-to-work data from the systematic review of the literature, which indicates that 40% of patients with a BPI do not return to work, resulting in 100% wage loss and 100% disability payment reliance through 67 years of age; 27% return to a different job, which we arbitrarily estimated as entailing a 50% wage loss and 0% disability payment reliance; and 33% return to the same job with 0% wage loss and 0% disability reliance[4-6]. During 1-way sensitivity analysis, the percentage of patients who do not return to work (40%) was altered to 30% and to 20% to demonstrate the societal benefit of improving the ability of patients with a BPI to return to some type of employment.

TABLE II Bureau of Labor Statistics (BLS) Occupational Employment Statistics (OES) Included in Estimating Short-Term Wage Losses, May 2017[16]

Occupation Code	Occupation Title	Mean Wage (*$*) Hourly	Mean Wage (*$*) Annual
35-0000	Food preparation and serving related occupations	11.88	24,710
37-0000	Building and grounds cleaning and maintenance occupations	13.91	28,930
45-0000	Farming, fishing, and forestry occupations	13.87	28,840
47-0000	Construction and extraction occupations	24.01	49,930
49-0000	Installation, maintenance, and repair occupations	23.02	47,870
51-0000	Production occupations	18.30	38,070
53-0000	Transportation and material moving occupations	17.82	37,070
Mean		17.22	35,817

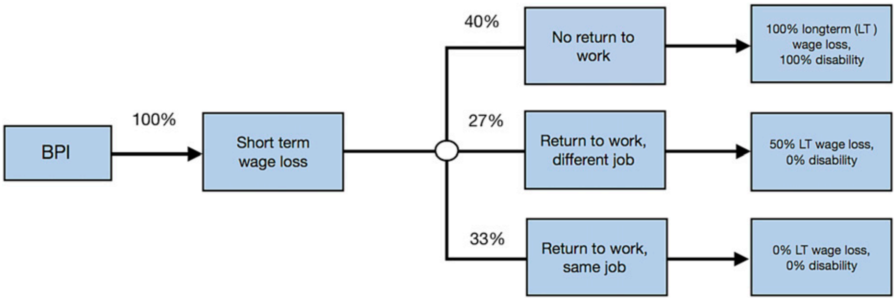

Fig. 2
Markov model for indirect cost calculation.

Disability Payments

Disability benefits paid were estimated using the U.S. Social Security Administration (SSA) online calculator[25]. Monthly disability payments were estimated for a typical patient with a BPI who would have otherwise retired at age 67. It was assumed that they would earn an average annual salary of a blue collar worker, as estimated with the BLS OES, starting at age 18 (allowing 8 years in the workforce prior to BPI at age 26 in our base case). Future payments were discounted at a rate of 0.03.

Monte Carlo Simulation

To test assumptions for age, sex, and return to work in our base economic model, we performed a Monte Carlo simulation that varied all 3 variables simultaneously. We used Midha's age and sex distributions for patients with traumatic BPI, as it is the only epidemiologic study of BPI in North America of which we are aware and in-depth details regarding age and sex distributions were provided[26] (see Appendix Fig. 1).

Results

Literature Review

The literature review identified 616 papers (Fig. 1) after removal of duplicate entries. Of these articles, 452 did not pertain to BPI, 10 were not written in English, 2 were meeting abstracts only, 6 did not contain patient data, 18 had <5 patients, 50 were about obstetric and/or iatrogenic BPI, 9 were about thoracic outlet syndrome, 11 were written before 1970, 11 were animal studies, and 37 were basic science/anatomic studies, review articles, or surgical/procedural/outcomes-measurement descriptions. In one article, patients were excluded from study if they did not have pain or disturbances of sleep or life, and 1 article could not be located on multiple databases. This left 8 articles that were read in full with hand-searching of their reference lists, which resulted in 39 additional papers for assessment. After removal of 6 articles that reported on overlapping pools of patients, 41 papers (with a total of 1,821 patients) were assessed. The average age of the subjects of these studies was 26.4 years, 90.5% were male, and the majority were manual laborers prior to the BPI injury[17-20]. On the basis of this systematic review, our base case was a 26-year-old American man employed as a manual laborer prior to BPI.

Short-Term Wage Loss

OES estimates for mean hourly wages for manual laborers are listed in Table II. With adjustment to 2018 U.S. dollars, the mean annual wage was $36,590. Fringe benefits were estimated to be 24%. Therefore, short-term wage loss was estimated to be $22,740 for the base case.

TABLE III Sensitivity Analysis of Indirect Cost with Variation in Return-to-Work Probability After BPI*

	Return to Work *(% of Patients)*			Average Wage Loss Per Patient *($)*			
	Do Not Return to Work	Return to Different Job†	Return to Same Job‡	Short-Term	Long-Term	Average Lifetime Disability Payment Per Patient *($)*	Average Lifetime Indirect Cost Per Patient *($)*
Case 1*	40 (derived from systematic review)	27	33	$22,740	813,652	384,606	1,220,998
Case 2	30	37	33	$22,740	735,521	284,784	1,043,045
Case 3	20	47	33	$22,740	658,145	187,102	867,987
Case 4	50	27	23	$22,740	970,136	485,283	1,478,159
Case 5	60	27	13	$22,740	1,119,146	579,624	1,721,510

*Base case: 26-year-old male manual laborer who sustained a BPI. Cases 2 through 5 vary the proportions of return-to-work possibilities. †At 50% of the former wage, with 0% disability payments. ‡At 100% of the former wage, with 0% disability payments.

Long-Term Wage Loss

Sampling from sex and age-appropriate distributions of the BPI population at the time of the BPI and using an estimated productivity growth rate of 0.01, long-term wage losses resulting from total disability were estimated from the Monte Carlo simulation to be $737,551, with a range of $0 to $1,653,344. We estimated an average cost of $11,079 per year for the base case.

Disability Payments

Disability benefits paid were estimated using the SSA online calculator[25]. Monthly disability benefits for our base case was estimated as $1,638. Assuming that these benefits would be collected from age 27 to 67 years (492 months), maximum benefits for total disability over the course of a lifetime equal $384,606 for the base case. Monte Carlo simulation estimated the average disability payout as $353,671, with a range of $0 to $1,111,124.

Total Indirect Cost

In our base case scenario (26-year old male manual laborer with a 40% likelihood of not returning to work), we estimated an indirect cost of $1,220,998. The 1-way sensitivity analysis of return to work demonstrated that total indirect cost decreased to $1,043,045 and $867,987 when the likelihood of not returning to work decreased to 30% and 20%, respectively (with these patients returning to a lower-paying job, and the proportion of patients returning to the same job held constant) (Table III). Monte Carlo simulation in which age, sex, and return to work were simultaneously varied produced a mean of $1,113,962, a median of $801,723, and an interquartile range of $22,740 to $2,350,979 for total indirect cost per patient over a lifetime.

Discussion

Traumatic BPIs are devastating injuries that disproportionately impact young adults. Beyond loss of physical function for the patient, there are societal implications including loss of productivity at work, absence from work, and disability. From the Monte Carlo simulation, we estimate this indirect cost (the sum of short-term and long-term wage losses and disability payments) to be $1,113,962 per patient over the course of a post-injury lifetime. This estimate does not include the direct costs associated with medical care for BPI. Furthermore, we did not account for possible concurrent traumatic injuries that may have occurred in patients with BPI. Depending on their severity, these additional injuries may impact both impairment and disability after BPI and likely have a negative impact on the ability to return to work. Because these injuries are not consistently described in the BPI literature, we cannot reliably estimate their frequency and impact. As we did not include them in our economic models, our estimates of indirect cost may be relatively conservative.

Like all economic models, ours is subject to limitations related to the assumptions made. As routinely recommended for economic analyses[27-29], we performed numerous sensitivity analyses (including a Monte Carlo simulation that simultaneously varied many of the variables subject to assumption, such as age, sex, and likelihood of return to work) to test these assumptions and counter these limitations. While the absolute values of indirect cost shifted with the changes in the input variables, the overall impact of traumatic BPI was demonstrated, with a median total indirect cost of $801,723 in the Monte Carlo simulations. Because of the limited scope of our paper, it is difficult to definitively demonstrate the relative societal value of BPI interventions compared with those for other injuries. In comparison, the indirect cost of spinal cord injuries have been estimated to range between $13,566 (1996 dollars) and $72,047 (2015 dollars) per year[30,31]. Our estimation of long-term wage loss for patients with a BPI is $11,079 per year (2018 dollars), which falls within the range reported for spinal cord injuries. WISQARS reported the average work-loss cost for upper-extremity injuries to be $270,200, $109,200, and $89,400 (2010 dollars) for amputation, crush injuries, and nerve injuries, respectively[8]. Variations in cost among different debilitating injuries may be due to differences in age, work status, and wages in the patient populations. This aligns with the epidemiologic preponderance of traumatic BPIs affecting young males, the demographic group in which the highest long-term losses would be realized. Other factors accounting for a higher estimate may be related to increased wage loss due to a higher estimate of percent disability.

Estimation of these costs from a societal perspective supports the allocation of resources for clinical care and research. Given the substantial impact of a traumatic BPI on a patient, providing appropriate and timely referrals to a surgical team capable of reconstruction can have long-lasting effects on patient function and productivity. While the current BPI literature has not yet demonstrated an empirical link, we believe that improving patient function is reasonably likely to increase the odds of returning to work. This could then lead to a decrease in the total cost of BPI from a societal perspective.

As seen in the sensitivity analysis, increases in returns to the workforce can substantially decrease lifetime indirect cost. Increasing the percentage of patients who returned to employment at a decreased wage (instead of not returning to work at all) from 27% to 37% led to a 15% decrease in indirect cost. Reductions in indirect costs have previously been shown to offset the additional direct costs of surgery for rotator cuff injuries[32]. Although the direct costs of surgery for nerve reconstruction surgery after BPI likely exceed those of rotator cuff surgery, the reductions in long-term indirect cost may support the utilization of high-complexity high-cost care for patients with traumatic BPI[32].

Limitations of this study are similar to those of other studies performed using WISQARS cost estimates[8,9,15]. Our estimation of indirect cost includes only work loss costs and does not account for other sources of loss such as household costs, quality-of-life lost, or caretaker costs. In addition, our estimates are based on a base case and census data rather than actual workplace data specific to patients with BPI. Patients working in manual labor jobs may be less likely to return to work than those with less physically demanding jobs. To address this, sensitivity analysis was performed using Monte Carlo simulation to estimate the effects of simultaneously varying the initial assumptions. For long-term wage losses, it was assumed that work losses due to disability were 50% of those resulting from total disability. Future studies that quantify functional outcomes and level of disability in terms of post-injury income would be helpful in enabling more accurate estimates of long-term losses. In addition, we used several different data sources, which are all subject to reporting and measurement error. Wage and return-to-work data specific to BPI would have been preferable but are not available. Our analysis is limited to assumptions rooted in the published literature detected by our systematic review. The majority of articles found in our systematic review did not include detailed information about the distribution of occupations or demographics. We also based our estimates on internationally reported literature. The generalizability of demographic data and return-to-work estimates across countries and regions may be limited.

These estimates suggest that traumatic BPI has a far-reaching economic impact and supports the need for continued allocation of resources with the goals of improving patient outcomes and restoring the ability to return to work. If efforts to improve surgical outcomes are successful, more people with BPI may be able to return to work with a resultant decrease in the indirect cost of BPI.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/F357). ■

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