Primary prevention of road traffic accident–related traumatic brain injuries in younger populations: a systematic review of helmet legislation

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OBJECTIVE Road traffic accidents are the most frequent cause of severe traumatic brain injury (TBI), particularly among young populations worldwide. Helmets are proven to prevent injuries; however, estimates of helmet compliance are low globally. Surgical/critical care management of TBI is often used to treat these injuries, but primary prevention should be recommended. A key component in promoting TBI prevention among pediatric and young populations is through helmet legislation. The authors investigated helmet policies for motorcycles and bicycles globally to provide recommendations for how related legislation may impact TBI and guide advocacy in pediatric neurosurgery.

METHODS The authors conducted a systematic review of helmet laws and/or policies by using the National Library of Medicine PubMed and SCOPUS databases. Additional articles were identified using citation searches of key publications. Abstracts from articles of all sources were read and selected for full-text review. Details of relevant full articles were extracted and analyzed for the following: bibliographic data, study aim, design and duration, study participants, intervention characteristics, and intervention effect data.

RESULTS Of 618 search results, 53 full-text articles were analyzed for recommendations. Helmet legislation is associated with increased helmet use among bicyclists and decreased road traffic accident–related head injuries and fatalities among motorcyclists and bicyclists. Laws are more effective if comprehensive and inclusive of the following: both primary riders and passengers, all age groups, all modes of transportation made safer by helmets, a proper use clause, and standardized helmet quality measures. Cultural, socioeconomic, and infrastructural circumstances are important as well, and legislation must consider enforcement mechanisms with penalties significant enough to incentivize behavioral changes, but proportional to community socioeconomic status.

CONCLUSIONS Compulsory use laws are the optimal primary intervention; however, concurrent programs to support financial access to helmets, change cultural attitudes, increase health literacy, and improve road infrastructure will augment legislative benefits. Pediatric neurosurgeons are caretakers of children suffering from TBI. Although extensive study has explored the surgical management of TBI, the authors believe that primary prevention is instrumental to improving outcomes and reducing injury. All helmet laws are not equal; based on these findings, a comprehensive, context-specific approach is the key to success, especially in resource-limited countries.

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KEYWORDS traumatic brain injury; helmet; neurosurgery; public health; advocacy; pediatric; head injury; bicycle; motorcycle; trauma

TRAUMATIC brain injury (TBI) is the leading cause of morbidity and mortality among young people in low- and middle-income countries (LMICs),⁷ where the global incidence appears to be escalating the most. The most recent Global Burden of Diseases data on brain and spinal cord injury found a 3.6% (95% uncertainty inter-

val [UI] 7.4–4.0) increase in the incidence of TBI from 1990 to 2016, with the largest increase among LMICs.³¹ In 2016, the global incidence and prevalence of TBI was 27,082,033 (95% UI 24.30–30.30 million) and 55,494,674 (95% UI 53.40–57.62 million), respectively. TBI caused 8.1 million (95% UI 6.0–10.4 million) years of life lived

ABBREVIATIONS HICs = high-income countries; LMICs = low- and middle-income countries; RCT = randomized controlled trial; RTA = road traffic accident; TBI = traumatic brain injury; UI = uncertainty interval.

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with disability. The worldwide economic impact of the loss and decreased quality of life due to TBI is significant. The direct and indirect cost of TBI in the US alone is estimated to be \$76.5 billion (in 2010 US dollars).¹²

TBI occurs most often due to road traffic accidents (RTAs), specifically head injuries among pediatric and young populations riding motorcycles and bicycles.^{13,48} Head injuries are the leading cause of death in fatal motorcycle crashes.⁴⁴ Of the approximately 14,000 deaths from road traffic injuries in Vietnam per year, 70% were related to motorcycles, of which 78% were attributed to head injuries.⁴⁵ One estimate found that 40.2% of pediatric patients with head trauma in urban areas in the US were injured as bicyclists.¹⁹ Overall, RTAs are the most frequent cause of severe TBI and of TBI among younger populations worldwide.⁶¹ Helmet use can greatly decrease the morbidity and mortality from RTAs. A Cochrane review found that helmets reduced the risk of head, brain, and severe traumatic brain injury for all ages of bicyclists—by 63%–88%.⁷² A separate Cochrane review found that helmets reduced risk of death in motorcyclists by 42% and risk of head injury by 69%.⁴⁵

Despite evidence supporting helmet efficacy, their use is not standardized in most countries, and few countries have adopted and reinforced comprehensive laws. As of 2013, the WHO estimates that only 24.61% of countries worldwide have motorcycle helmet laws that require drivers and passengers to wear helmets and require helmets to meet specific quality standards.⁷⁷ In total, 38.77% have some form of helmet legislation requiring drivers and passengers to wear protective head gear. The lack of helmet legislation in LMICs is especially problematic, because motorcycles, scooters, and bicycles are often the most common method of wheeled transport.¹⁴ Motorcycles account for 95% of vehicles and are the primary mode of transportation for the majority of residents in Vietnam.⁴² In China, motorcycle ownership between 1987 and 2001 grew rapidly from 23% to 63%.⁸⁰ In Pakistan, 61.2% of registered vehicles are 2- or 3-wheeled vehicles.⁶³ In Kenya, motorcycles make up more than 80% of all registered vehicles.³ Bicycles, scooters, and motorcycles are increasingly popular modes of transportation in LMICs, with young people and pediatric populations dependent on these modes of transportation to attend school, gain employment, and so on. Often passengers are unhelmeted, and pediatric and adolescent patients suffering TBI from RTAs are an increasing public health concern among younger populations (from infants to young adults) around the world.⁶¹

In light of globally low rates of helmet use and increasing incidence of TBI, a systematic review was conducted to answer the following question: “Are helmet laws correlated with decreased incidence of TBI from RTAs among younger populations worldwide?” Because TBI from RTAs tends to disproportionately affect pediatric and young adults, and is a leading cause for morbidity and mortality,⁶⁰ this review focuses on the population ≤ 25 years of age. The aims of the study were as follows: 1) to identify existing evidence to support helmet advocacy and legislation; and 2) to provide a summary of the components of a successful helmet policy. The results of this

TABLE 1. Search terms

Database	Search String
PubMed/ MEDLINE	(((((“head injury”) OR “brain injury”)) AND (((legislation) OR law) OR program) OR policy)) AND helmet) AND (((child) OR pediatric) OR adolescent)
SCOPUS	(TITLE-ABS-KEY (child OR pediatric OR adolescent) AND TITLE-ABS-KEY (helmet) AND TITLE-ABS-KEY (legislation OR law OR policy OR program) AND TITLE-ABS-KEY (“head injury” OR “brain injury”))

study potentiate pediatric neurosurgery advocacy efforts and serve as groundwork for TBI public health measures and advocacy globally. We emphasize the importance of primary prevention of unhelmeted TBI in a holistic approach to management methodologies.

Methods

A systematic review using PRISMA guidelines was conducted to investigate the efficacy of helmet laws globally. No review protocol exists for this topic. The National Library of Medicine PubMed and SCOPUS databases were searched for articles published or translated into English by using keywords associated with 4 areas as defined by the PICO (Population Intervention Comparison Outcome) framework. The search structure included patient population ≤ 25 years of age, intervention of helmet law(s) in the context of improving transportation safety with helmets, and outcomes of bicycle- or motorcycle-related injuries or fatalities and helmet use. Databases were queried using the search terms detailed in Table 1.

After collection of search results, a citation search of key publications was performed to identify additional articles. Duplicate articles were removed and articles not available in English were excluded. All remaining articles were screened for full-text review based on the content of their title and abstract. Of articles deemed relevant for full-text review, the decision for final inclusion in analysis was determined based on criteria outlined in Table 2. A second reviewer replicated the search strategy and disagreements were reconciled.

Complete inclusion and exclusion criteria are summarized in Table 2. Studies were also excluded if they failed to include a mandatory helmet use law in some form. The primary outcomes of interest were decreases in bicycle- or motorcycle-related injuries or fatalities. Secondary outcomes of interest were increase in helmet use or negative consequences such as decreases in bicycle or motorcycle use.

After selection of articles for inclusion in the review, bibliographic data, study aim, design and duration, study participants, intervention characteristics, and intervention effect data were extracted from each article. Studies were categorized into the following domains for handling of results: efficacy of bicycle helmet legislation, efficacy of motorcycle helmet legislation, comprehensive helmet laws, impact of socioeconomic status, and additional/miscellaneous findings. The quality of evidence was evaluated

TABLE 2. Systematic review inclusion and exclusion criteria

Characteristic	Inclusion Criteria	Exclusion Criteria
Language	English or translated to English	Non-English
Time period	From inception of databases to 2019	NA
Study design	RCTs; non-RCTs; controlled before-&-after studies; interrupted time series studies; noncontrolled before-&-after studies; cohort studies; cross-sectional studies with comparators	Opinion papers; noncomparative studies; qualitative studies; traditional literature reviews; theoretical papers
Population	Inclusion of newborn, infant, child, teenager, adolescent, or young adult populations (≤ 25 years of age)	Interventions including only population ≥ 26 years of age
Intervention	Helmet legislation/law(s)	NA
Comparator	No exposure; time bound; geographical controls	No comparator
Context	Helmet use for methods of transportation made safer by helmets	Nontransportation-related injuries (e.g., sports, falls, etc.)
Outcomes	Primary outcomes: decrease in incidence of TBI; improved outcomes for TBI	NA
	Secondary outcomes: increase in helmet use; unintended negative consequences	NA

NA = not applicable.

based on study design grades extrapolated from Shadish et al.⁶⁸ Grades are outlined in Table 3. Of note, grade E studies were not included in this review.

Results

From a total of 618 search results, 53 eligible studies were included in the review. Figure 1 shows the PRIMSA flowchart for article selection. No randomized controlled trials (RCTs) or non-RCTs were found. There was significant variation in study design and quality, with most studies using interrupted time series, controlled before-and-after, noncontrolled before-and-after, cohort, or cross-sectional study designs. Most studies examined one or more outcome (head injury, mortality, facial or neck injury, fatality) in relation to helmet use, in addition to helmet use itself. Forty-eight (90.6%) studies were conducted in high-income countries (HICs). Of studies evaluating helmet legislation implemented in LMICs, all were restricted to the context of motorcycles. Included studies are detailed in Table 4. Forty-two (79.2%) studies investigated universal

mandatory restricted helmet laws for motorcycles or bicycles. Eleven studies investigated limited mandatory helmet laws with some age or region restrictions. Four studies investigated nonmandatory helmet interventions in addition to mandatory helmet laws. Studies were published from all continents except South America (Fig. 2).

Evidence Supports the Effectiveness of Bicycle Helmet Legislation

Among the 53 articles, 36 provided evidence of effectiveness in bicyclists. The evidence in this review supports the efficacy of mandatory use legislation in increasing helmet use and decreasing accident-related head injuries and fatalities among bicyclists ≤ 25 years of age.^{34,37} Macpherson and Spinks found that bicycle helmet legislation implemented in HICs increases bicycle helmet use and reduces both bicycle-related mortality and head injuries.⁴⁹ Two other meta-analyses of bicycle helmet laws in HICs found that legislation increases helmet use by varying magnitudes.^{27,35} Overall, 19 of 20 articles measur-

TABLE 3. Evidence level and quality of study design

Grade	Design
AA	Systematic review or meta-analysis of RCTs
A	Systematic review or meta-analysis of non-RCTs RCT or cluster RCT
B	Systematic review or meta-analysis of controlled studies without a pretest or uncontrolled study with a pretest Non-RCT Controlled before-&-after study Retrospective or prospective cohort study Interrupted time series
C	Systematic review or meta-analysis of cross-sectional studies Noncontrolled before-&-after study
D	Cross-sectional study
E	Case studies, case reports, traditional literature reviews, theoretical papers (excluded in this study)

FIG. 1. PRISMA flowchart outlining the process of collecting and selecting abstracts and full-length articles.

ing helmet use supported the finding that bicycle-specific legislation increases helmet use among bicyclists.^{6,8–10,15,17,22,25,27,29,32,33,35,50,53,65,68,70,77} Ten of 13 articles measuring head injuries supported the finding that helmet legislation decreases bicycle-related head injuries.^{5,8,18,33,39,49,50,54,63,73} Six of 7 articles measuring fatality supported the finding that helmet legislation decreases fatalities related to bicycling; mortality decreased by an estimated 15%–30% depending on the study.^{9,23,39,50,51,75}

Castle et al. found no significant decrease in the percentage of patients with head injury; however, injury severity did decrease during the postlegislation period.¹⁰ Two studies found no association between helmet legisla-

tion and bicycle-related head injury: Williams et al. found that children living in areas with helmet legislation were more likely to wear helmets across all ages, but observed no difference in injury pattern with helmet legislation,⁷⁸ and Leblanc et al. found higher helmet use postlegislation but no significant decrease in the proportion of head injuries among bicycle-related injuries.⁴³ Of note, unlike Castle et al., Williams et al. and Leblanc et al. did not include severity of head injury as an outcome measure.^{10,43,78} No studies were found investigating mandatory helmet use legislation for bicyclists in LMICs.

Evidence Supports the Effectiveness of Motorcycle Helmet Legislation

Among the 53 articles, 18 provided evidence in motorcyclists. Although less literature was found, the evidence in this review also supports the efficacy of helmet legislation in increasing helmet use, decreasing motorcycle-related head injuries, and decreasing fatalities. No existing systematic reviews or meta-analyses were found that evaluated the efficacy of helmet legislation for motorcyclists. In an interrupted time series study of the repeal of a universal helmet law in Michigan, Saunders et al. found a 2-fold increase in the rate of unhelmeted motorcycle patients during the postrepeal period.⁶⁴ Nine of 10 studies measuring head injuries supported the finding that helmet legislation reduces motorcycle-related head injuries.^{13,24,26,30,33,56,63,66,72,80} Six of 8 studies measuring fatalities supported the finding that helmet legislation reduces motorcycle-related fatalities.^{1,24,40,47,69,72} Of note, Saunders et al. and Ichikawa et al. found that motorcycle helmet laws decreased motorcycle-related head injuries but did not find an association with fatalities,^{30,64} whereas Tsai and Hem-enway and Ha et al. found that motorcycle helmet laws were associated with decreases in both motorcycle-related head injuries and fatalities.^{24,73} The only study not to find some positive association in measured outcomes of helmet legislation for motorcycles was Bachani et al., which found no statistical difference in the rate of helmet use among drivers or passengers in legislation and nonlegislation groups.² The authors hypothesized that this was probably due to poor enforcement of the helmet policy.

In a noncontrolled before-and-after study, La Torre et al. published the only study to explicitly and exclusively include low-powered 2-wheeled vehicles (e.g., scooters or mopeds) in their analyses.⁴¹ They found that scooter-related head trauma decreased after helmet legislation for scooters went into effect.

Comprehensive Laws Are More Effective

Ten studies compared the comprehensiveness of helmet legislation. Children and adolescents were found to benefit more from universal bicycle and motorcycle helmet laws than age-restricted helmet laws.^{27,55,74} For example, in the US, states with helmet laws restricted to motorcyclists ≤ 21 years of age had higher rates of motorcycle-related serious TBI among 18- to 20-year-olds than universal law states.⁷⁴ Jewett et al. found that children were more likely to wear helmets if their caretakers wore helmets, underscoring the importance of inclusivity.³² Additionally, geo-

TABLE 4. Summary of the 53 studies included in the review

Authors & Year	Study Design	Evidence Level	Country	Target Population	Context	Key Findings
Auman et al., 2002	Interrupted time series	B	USA	General public	Motorcycle	<ul style="list-style-type: none"> Motorcycle fatality rate dropped to 4.5 per 10,000 registered motorcycles in post-law period from 10.3 per 10,000 registered motorcycles Motorcyclists wearing helmets had a lower risk of TBI than those not wearing helmets
Bachani et al., 2017	Cohort study	B	Kenya	General public	Motorcycle (included passengers)	<ul style="list-style-type: none"> No statistical difference in rate of helmet use among drivers or passengers in legislation group & non-legislation group Motorcyclists less likely to wear helmets later in the day Helmet wearing among passengers was significantly lower than among drivers
Bonander et al., 2014	Interrupted time series	B	Sweden	≤15 yrs	Bicycle	<ul style="list-style-type: none"> Proportion of head injuries among male children dropped by 7.8% No evidence of decrease in head injuries among female children Overall number of cyclists did not change during study period
Borglund et al., 1999	Noncontrolled before-&-after study	C	USA	≤16 yrs	Bicycle	<ul style="list-style-type: none"> Known helmet use increased to 20.8% from 5.6% Greatest increase was in children ages 10–12 yrs Largest gains in bicycle helmet use came in age groups targeted by bicycle safety programs
Cameron, 1998	Interrupted time series	B	Australia	General public	Bicycle	<ul style="list-style-type: none"> Helmet-wearing rates were 1.8 times higher than expected after introduction of the law Fewer than expected cases of head & non-head injuries indicating potentially lower than expected overall number of bicycle accidents
Carpenter & Stehr, 2011	Cohort study	B	USA	≤30 yrs	Bicycle	<ul style="list-style-type: none"> States that adopted helmet laws reduced youth bicycling fatalities by ~19% & increased helmet use by 20–34% Unintentionally reduced bicycling by 4–5%
Castle et al., 2012	Interrupted time series	B	USA	≤18 yrs	Bicycle	<ul style="list-style-type: none"> Overall percentage of helmeted patients increased in postlegislation period Percentage of patients with head injury did not change; however, injury severity did decrease
Chiu et al., 2000	Noncontrolled before-&-after study	C	Taiwan	General public	Motorcycle	<ul style="list-style-type: none"> Helmet use among motorcyclists increased to 79.1–95.95%, depending on the city, from an average of 21% before the law Decrease in average length of stay for motorcycle-related head injuries from 2.14 days before legislation to 1.8 days after legislation Severity of injury decreased & outcomes improved among patients with motorcycle-related head injuries after legislation Statistically significant increase in upper-extremity injuries Motorcyclists wearing partial-coverage helmets were 1.76 times more likely to suffer fatal injuries
Coté et al., 1992	Controlled before-&-after study	B	USA	Children	Bicycle	<ul style="list-style-type: none"> Prelaw helmet use for children was 4% for Howard County (legislation), 8% for Montgomery County (community education program), & 19% for Baltimore County (no helmet activities) Post-law rates were 47%, 19%, & 4%, respectively
Dellinger & Kresnow, 2010	Cross-sectional study	D	USA	5–14 yrs	Bicycle	<ul style="list-style-type: none"> Bicycle law status was significantly associated with helmet use Statewide laws were more effective than region-restricted laws Helmet wearing was significantly associated with race, ethnicity, & the child's age but not with sex Other significant predictors included household income, household education, & census region

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Authors & Year	Study Design	Evidence Level	Country	Target Population	Context	Key Findings
Dennis et al., 2013	Controlled before-& after study	B	Canada	General public	Bicycle	<ul style="list-style-type: none"> Provinces with helmet laws had a 54% reduction in rate of head injuries requiring hospital admissions for people <18 yrs compared with a 33.2% reduction in provinces without legislation 26% reduction in the rate of admissions for adult head injuries compared with no significant reduction in provinces without laws No independent effect of helmet legislation on the rate of head injuries per hospital admission for a cycling-related injury 1 yr after the legislation
Gilchrist et al., 2000	Controlled before-& after study	B	USA	≤16 yrs	Bicycle	<ul style="list-style-type: none"> Before the program began, none of 97 observed riders wore a helmet During the next 5 mos, helmet use among 358 observed children averaged 45% (range 30–71%) In contrast, adult use did not change significantly 2 yrs after program initiation, 21 of 39 child riders (54%) were observed wearing a helmet
Grant & Rutner, 2004	Interrupted time series	B	USA	≤16 yrs	Bicycle	<ul style="list-style-type: none"> Bicycle helmet legislation reduces bicycling fatalities by ~15%
Ha et al., 2018	Noncontrolled before-& after study	C	Vietnam	General population	Motorcycle	<ul style="list-style-type: none"> Decreased proportion of road traffic injuries related to motorcycles Motorcycle-related injuries decreased from 235.2 to 125.6 per 100,000 population; head injuries from 183.4 to 64.7 per 100,000 population; severe head injuries from 20.8 to 9.7 per 100,000 population Decreased rates of deaths related to motorcycles from 23.7 per 100,000 in 2005 to 11 per 100,000 in 2010 Motorcycle injuries highest among males ages 15–29 yrs
Hagel et al., 2010	Controlled before-& after study	B	Canada	≤18 yrs	Bicycle	<ul style="list-style-type: none"> The overall prevalence of helmet use increased from 43% in 2000 to 53% in 2004 Helmet use did not change in those >18 yrs
Hassan et al., 2017	Cohort study	B	USA	≤21 yrs	Motorcycle	<ul style="list-style-type: none"> Lower incidence rate of TBI in states with universal helmet legislation compared with states with age-restricted helmet legislation Universal legislation lowered rate of TBI by factor of 2.15
Hoye, 2018	Meta-analysis of controlled studies	B	HICs	General population	Bicycle	<ul style="list-style-type: none"> Mandatory bicycle helmet legislation reduces injuries in general from crashes, & specifically serious head injuries Larger beneficial impact for children was found when bicycle helmet legislation applies to all cyclists compared with age-restricted laws
Hung et al., 2006	Cross-sectional study	D	Vietnam	General public	Motorcycle	<ul style="list-style-type: none"> Rates of helmet use were significantly higher on compulsory use-designated roads
Huybers et al., 2017	Interrupted time series	B	Canada	General public	Bicycle	<ul style="list-style-type: none"> Mandatory helmet law associated with increase in helmet use, & helmet use remained high with time
Ichikawa et al., 2003	Interrupted time series	B	Thailand	General public	Motorcycle	<ul style="list-style-type: none"> 33.5% reduction in number of injured motorcyclists between pre- & postlegislation periods Greatest reduction seen at night No change in mortality rate Increase in helmet use among injured motorcyclists (22.6% compared with 4.5%)
Jewett et al., 2016	Cross-sectional study	D	USA	General public	Bicycle	<ul style="list-style-type: none"> Children were more likely to always wear helmets when their caretakers always wore helmets (90%) compared with when their caretakers did not always wear helmets (38%) Children who lived in states with helmet laws were more likely to always wear helmets (47%) than those in states without a law (39%)

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Ji et al., 2006	Interrupted time series	B	USA	≤18 yrs	Bicycle	<ul style="list-style-type: none"> Increased helmet use during postlegislation period & decreased bicycle-related serious head injury Black patients & Hispanic patients were much less likely to wear helmets Negative correlation between helmet use & serious head injury Riders in counties where a state helmet use law was in place were twice as likely to wear a helmet
Kanny et al., 2001	Cross-sectional study	D	USA	≤16 yrs	Bicycle	
Karkhaneh et al., 2006	Meta-analysis of before-&-after studies	B	HICs	General public	Bicycle	<ul style="list-style-type: none"> Legislation increases helmet use but at varying magnitudes Helmet use increase is observed in long-term analysis No clear differences were found between age-restricted & universal legislation Enforcement of legislation is generally weak
Karkhaneh et al., 2011	Noncontrolled before-&-after study	C	Canada	General public	Bicycle	<ul style="list-style-type: none"> Significant association between legislation & bicyclist helmet use, without a concomitant enforcement initiative Over time, rate of helmet use returned to pre-legislation levels for low- & middle-income areas
Karkhaneh et al., 2013	Interrupted time series	B	Canada	General public	Bicycle	<ul style="list-style-type: none"> Large decline in child head injuries & adult non-head injuries during post-law period, but no significant changes for adolescents Does not account for overall increase in total number of cyclists
Kett et al., 2016	Controlled before-&-after study	B	USA	General public	Bicycle	<ul style="list-style-type: none"> Decrease in major head trauma as a proportion of all bicycle-related head trauma in legislation area compared with no-law areas No overall decrease in total head injuries
Kraus et al., 1994	Noncontrolled before-&-after study	C	USA	General public	Motorcycle	<ul style="list-style-type: none"> Motorcycle crash fatality rate decreased by 26.5%
La Torre et al., 2007	Noncontrolled before-&-after study	C	Italy	General public	Scooters	<ul style="list-style-type: none"> Scooter-related head trauma decreased, although all injury resulting from scooter accidents increased
Leblanc et al., 2002	Interrupted time series	B	Canada	General public	Bicycle	<ul style="list-style-type: none"> Postlegislation helmet use was 75% compared with 40% during pre-legislation period Helmet use lowest among adolescents throughout study period No significant decrease in the proportion of head injuries among bicycle-related injuries in postlegislation period
Lu et al., 2012	Interrupted time series	B	Taiwan	General public	Motorcycle	<ul style="list-style-type: none"> Drastic reduction in overall RTA mortality immediately after passage of helmet law in all cities Decrease in mortality persisted over a 10-yr period
Macpherson & Macarthur, 2002	Cohort study	B	Canada	5–19 yrs	Bicycle	<ul style="list-style-type: none"> 45% reduction in rate of bicycle-related head injuries in legislation provinces compared with 27% reduction in non-legislation provinces Lower bicycle-related death rates in legislation provinces
Macpherson & Spinks, 2008	Systematic review of controlled studies	B	HICs	General population	Bicycle	<ul style="list-style-type: none"> Found positive evidence that bicycle helmet legislation increases bicycle helmet use & reduces both bicycle-related mortality & head injuries No evidence was found to support or counter the possibility that legislation may lead to negative societal & health impacts such as reductions in cycling participation

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Markowitz & Chatterji, 2015	Interrupted time series	B	USA	≤19 yrs	Bicycle	<ul style="list-style-type: none"> For 5- to 19-yr-olds, helmet laws are associated with a 13% reduction in bicycle-related head injuries compared with 9% in no-law states
Meehan et al., 2013	Cohort study	B	USA	≤16 yrs	Bicycle	<ul style="list-style-type: none"> Lower fatality rate in states with helmet laws both before & after adjustment for confounding variables (adjusted incidence rate ratio of 0.83)
Nguyen et al., 2013	Interrupted time series	B	Vietnam	General public	Motorcycle	<ul style="list-style-type: none"> Helmet use increased to an average of 92.5% in postlegislation era from 40.1% before legislation took effect
Ni et al., 1997	Interrupted time series	B	USA	≤16 yrs	Bicycle	<ul style="list-style-type: none"> Observed helmet use among youth was 24.5% before the law was passed & 49.3% after the law was passed School-observed use increased from 20.4% to 56.1% Classroom survey self-reported "always" use of helmets increased from 14.7% to 39.4% Reported use on the day of the survey increased from 25.8% to 76.0% Telephone survey—reported "always" helmet use increased from 36.8% to 65.7% Younger children & girls were more likely to use helmets
Olivier et al., 2013	Interrupted time series	B	Australia	General public	Bicycle	<ul style="list-style-type: none"> Bicycle-related injury rates increased steadily from 1991 to 2010, possibly as a result of risk compensation or increases in overall number of cyclists However, head injury rates increased at a slower rate than other bodily injuries after implementation of helmet law Benefits of reduced incidence rate of head injuries was maintained over time Head injuries began declining after 2006 after improvement of cycling infrastructure
Olsen et al., 2016	Cross-sectional study	D	USA	General public	Motorcycle	<ul style="list-style-type: none"> Reported helmet use was higher in universal law states (88%) than in partial law states (42%) No significant difference in rate of head & facial injuries in universal law states compared to partial law states
Pai et al., 2017	Interrupted time series	B	Taiwan	General public	Motorcycle & bicycle	<ul style="list-style-type: none"> Taiwan has mandatory helmet use legislation for motorcyclists but not for bicyclists Risk of head injuries decreased with time, but decreased at a slower rate for bicyclists Proportion of bicyclists diagnosed with TBI higher than that of motorcyclists Higher rate of helmet use among motorcyclists than bicyclists
Passmore et al., 2010	Noncontrolled before-&-after study	C	Vietnam	General public	Motorcycle (included passengers)	<ul style="list-style-type: none"> Increase in helmet use for both passengers & drivers in all 3 districts after legislation
Saunders et al., 2018	Interrupted time series	B	USA	General public	Motorcycle	<ul style="list-style-type: none"> Helmet law repeal was not a predictor of mortality, but was a significant predictor of TBI Intoxicated subjects were 1.9 times more likely to have TBI than non-intoxicated 2-fold increase in the rate of unhelmeted motorcycle patients following repeal of universal helmet law
Schieber et al., 1996	Noncontrolled before-&-after study	C	USA	General public	Bicycle	<ul style="list-style-type: none"> Income & rider age were significantly associated with reported helmet ownership Among population <18 yrs of age, age was inversely associated with reported helmet use & ownership Annual household income positively correlated with helmet use & ownership
Scuffham & Langley, 1997	Interrupted time series	B	New Zealand	General public	Bicycle	<ul style="list-style-type: none"> Helmet law effectively increased helmet use rates in the 3-yr postlegislation period The reduction in head injuries for all cyclists attributable to the helmet law was 18.7%

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TABLE 4. Summary of the 53 studies included in the review

Authors & Year	Study Design	Evidence Level	Country	Target Population	Context	Key Findings
Servadei et al., 2003	Noncontrolled before-&-after study	C	Italy	General public	Motorcycle/moped	<ul style="list-style-type: none"> • 66% decrease in motorcycle-related TBI incidence after introduction of revised law • 71% reduction in admissions for motorcycle-related intracranial hemorrhages • No concurrent reduction in admissions for TBI not related to motorcycle/moped crashes • Greatest reduction seen in people ages 18–30 yrs
Shafi et al., 1998	Interrupted time series	B	USA	≤18 yrs	Bicycle	<ul style="list-style-type: none"> • 13-fold increase in helmet use associated with helmet law • However, up to 75% of children in study group still did not use helmets at the time of crash
Supramaniam et al., 1984	Interrupted time series	B	Malaysia	General public	Motorcycle	<ul style="list-style-type: none"> • Decrease in motorcycle rider fatalities • Simultaneous bicycle safety campaigns were conducted by the safety council of Malaysia, which is a confounding factor
Teschke et al., 2015	Cohort study	B	Canada	≥12 yrs	Bicycle	<ul style="list-style-type: none"> • Helmet use higher in provinces with helmet laws than without • No significant difference in hospitalization rates between helmet & no-helmet law provinces
Tsai & Hemenway, 1999	Noncontrolled before-&-after study	C	Taiwan	General public	Motorcycle	<ul style="list-style-type: none"> • Motorcycle fatalities decreased 14% after introduction of the helmet law • Head injury fatalities fell 22%, whereas fatalities from injuries to other bodily areas rose 20% • Nonfatal motorcycle injuries fell 31%, nonfatal head injuries fell 44%
Vulcan et al., 1992	Noncontrolled before-&-after study	C	Australia	General public	Bicycle	<ul style="list-style-type: none"> • Helmet use increased from 70% in primary school children, 20% in secondary students, & 40% in adults to 70–90% in all 3 groups • Preliminary data show that number of bicyclists with head injuries have dropped since legislation came into effect
Weiss et al., 2010	Cross-sectional study	D	USA	12–20 yrs	Motorcycle	<ul style="list-style-type: none"> • In states with a <21 yrs age-restricted motorcycle law, serious TBI among 18- to 20-yr-olds was 38% higher than in universal law states
Wesson et al., 2008	Interrupted time series	B	Canada	General public	Bicycle	<ul style="list-style-type: none"> • Decrease in the rate of death during postlegislation period for cyclists 1–15 yrs old • No significant decrease in rate of death during postlegislation period for cyclists >15 yrs
Williams et al., 2018	Cohort study	B	USA	Children	Bicycle	<ul style="list-style-type: none"> • Children living in areas with helmet legislation were more likely to wear helmets across all ages • Helmet legislation areas had significantly higher median incomes; no difference in injury pattern based on helmet legislation

FIG. 2. Map illustrating global distribution of published studies for motorcycle and/or bicycle helmet legislation impact. Figure is available in color online only.

graphically encompassing laws have a greater impact than region-restricted legislation.¹⁷ Another example is helmet legislation in Vietnam, which initially only included a limited number of roads;⁵² Hung et al. found the law's failure to encompass all road types negatively impacted the legislation's efficacy, further highlighting the importance of broadly impacting laws.²⁸

Although most studies examining helmet use patterns focused on the primary cyclist or driver, another consideration for a broader impact is the passenger. Bachani et al. found that helmet wearing among passengers on motorcycles in Kenya was significantly lower than for drivers.² Passmore et al. found that motorcycle laws in Vietnam successfully increased helmet use for passengers in addition to drivers.⁶⁰ By including riders and their passengers, laws can protect a larger number of people.

The last consideration for comprehensive legislation is whether or not the law standardizes the quality of the helmet as well as helmet type. Chiu et al. found that the number of motorcycle fatalities was influenced by high rates of poor-quality helmets; partial-coverage helmets were associated with a 1.76 times increased likelihood of fatal injury.¹³ By accounting for the quality of helmet protection, a higher level of safety can be promoted.

Impact of Socioeconomic Status

One important barrier to access and a special consideration, especially in low-income communities and countries, is the impact of socioeconomic status. Despite initial increases in helmet use among children of all socioeconomic levels after implementation of a bicycle helmet law in Canada, Karkhaneh et al. found that over time, the rate

of helmet use returned to prelegislation levels for low- and middle-income areas.³⁶ Dellinger and Kresnow also found that household income and household education were significant predictors for the impact of bicycle helmet laws on children ages 5 to 14 years old in the US.¹⁷ Additionally, in LMICs, bicycle helmet use and ownership was positively related to annual household income.⁶⁴ These findings underscore the importance of access to safety equipment when considering the implementation of helmet safety laws.

Additional Advocacy Considerations

The studies included in this review support helmet legislation as one of the most effective primary interventions to prevent TBI from RTAs; however, educational and safety initiatives should not be discounted. A study comparing bicycle helmet mandatory use legislation to an educational program in Maryland found that areas with mandatory use legislation had a greater increase in helmet use among children.¹⁵ However, Borglund et al. found that the largest increase in bicycle helmet use among those ≤ 16 years old occurred after helmet legislation was applied to groups targeted by bicycle safety programs.⁶ A final consideration is unintended consequences. Although legislation is often a supportive measure to ensure compliance with safety protocols, there can be unintentional negative impacts of restrictive laws. Carpenter and Stehr found that bicycle helmet legislation in the US was associated with a 4%–5% reduction in bicycling.⁹

Discussion

This systematic review underscores the importance of

safety legislation in aiming to reduce TBI globally. The overwhelming majority of studies identified in this review support the use of helmet laws to decrease the incidence of TBI from RTAs among younger populations worldwide. Helmet legislation is associated with increased helmet use among bicyclists and decreased RTA-related head injuries and fatalities among motorcyclists and bicyclists.

One consideration highlighted from this review is the differing impact of helmet legislation in HICs versus LMICs. Whereas principles such as education and helmet use for primary riders may be widely applicable, special considerations for LMICs must be taken into account, including road type, infrastructure, road traffic, helmet quality/availability, and law enforcement. Bachani et al. found that mandating helmet use for all motorcyclists, drivers, and passengers was not associated with significant increases in helmet use, and that knowledge of the benefits of helmet use was high but did not translate into actual use, perhaps due to low police enforcement of the motorcycle helmet legislation.³ Following initial introduction of helmet laws for motorcycles in Vietnam, poor compliance to helmet laws also was attributed to low penalties and limited enforcement.²⁸ Since their first iteration, however, several amendments to Vietnam's helmet laws were passed between 2005 and 2008, and helmet use has improved greatly as a result. The amendments made laws applicable to all road types, increased fines for not wearing a helmet, and strengthened provisions for quality assurance inspection of helmets to ensure they meet national standards.^{28,59} By broadening the reach of the law and including more considerations specific to their country, as well as more impactful penalties, enforcement of the law as well as outcomes were improved. After implementation of these comprehensive laws in Vietnam, Passmore et al. found that helmet use among both passengers and drivers exceeded 80% in all districts—a vast improvement from prelegislation compliance, which ranged between 25% and 65% for drivers and between 20% and 45% for passengers in the same provinces.⁶⁰

This review also brings up the concept of how best to implement and enforce helmet legislation. There is a need for adequate enforcement infrastructure in addition to the law itself.^{2,3,28,59} Not only is legislative infrastructure required, but organized groups to implement and effect change also are required for legislative success. Enforcement of helmet laws depends on sound legislation, invested organizational bodies to implement change locally, buy-in from the community and local stakeholders, access to affordable helmets, and a perceived need to effect change. Therefore, when setting enforcement policies, such as a threshold for fines or penalties, policy makers should balance the magnitude with potential unintended consequences. Penalties should aim to incentivize behavioral changes without being too restrictive, negatively impacting the ability of families to provide basic necessities such as education, food, power, and so on. After enforcement policies are implemented, governments also must carry out programs to audit compliance. This could include monitoring the rate of helmet noncompliance citations issued, monitoring the rate of helmet use among those injured in RTAs involving bicycles or motorcycles,

or stationing auditors at commonly used roads to collect data on helmet use rates.

Directly related to helmet legislation are barriers that impede compliance with helmet laws, including access to and financial barriers to acquiring helmets, health literacy regarding helmet use, and individual socioeconomic status. Schieber et al. found that lower socioeconomic status is correlated with reduced helmet compliance.⁶⁵ Similarly, Parkin et al. found that an educational strategy to increase helmet use was only effective for children living in high-income areas.⁵⁸ These authors later went on to study a helmet subsidy program to explore whether help with financial costs of a helmet could mediate decreased helmet use among families at lower socioeconomic levels, but found that this had no effect on helmet use in children living in low-income areas.⁵⁷ A cross-sectional survey of 1061 children living in low-income areas of Nottingham, UK, found that children in underprivileged areas were less likely to own a helmet, but were not less likely to wear the helmet if they owned one.³⁸ In helmet legislation implementation, barriers to helmet access and affordability are a significant challenge. Programs such as helmet subsidy or rebate initiatives are a possible solution when applied with community-based partners and target population input.

Another obstacle to helmet adherence is the quality of the helmets that are readily accessible. One of the most frequent reasons that younger people report for not wearing helmets is discomfort or ill-fitting equipment.^{3,11,14,20,46,62} Improved helmet comfort and fit may improve safety and compliance with helmet laws. In LMICs, the quality of helmets may not be regulated, posing another concern. Zamani-Alavijeh et al. estimated that approximately 23% of Iranian motorcyclists use nonstandard or partial helmets that cover only part of the head.⁷⁹ These helmets do not function properly and therefore do not effectively protect against head trauma morbidity or mortality.¹³ It is thought that failure to standardize helmets may limit the full impact of motorcycle helmet laws due to the widespread availability of cheap, nonstandard helmets.¹⁶

Regarding cultural acceptance of helmet use, establishing helmets as a social norm is important. Several studies have found that younger populations are more likely to wear helmets if the people who surround them also wear helmets, which may explain the apparent benefit of universal helmet laws.^{4,20,21,38} In general, improved helmet use among all populations can augment helmet use in young and pediatric populations. Another consideration to improve cultural acceptance of helmet laws is to apply a more tailored approach, incorporating considerations for transportation modes specific to locale, for example, scooters in Italy and boda bodas in Uganda.^{16,41} Failure to incorporate and enforce legislation for primary riders and passengers in such a context may limit the full benefits of helmets to reduce head injuries.

Although helmet legislation is more effective than nonmandatory helmet programs, such as education programs or public safety campaigns, nonmandatory initiatives still have value and should be implemented concurrently with compulsory use legislation. Four studies included in the review explicitly considered the impact of nonmandatory helmet programs in addition to mandatory helmet pro-

TABLE 5. Components of a successful helmet legislation to prevent TBI incurred during RTAs

• Comprehensive laws including passengers
• Comprehensive laws without age restrictions
• Inclusion of all relevant methods of transportation made safer by helmets
• Inclusion of proper use clause in legislation
• Inclusion of enforcement program
• Penalties significant enough to incentivize behavioral changes, but proportional to community socioeconomic status
• Establishment of standardized helmet quality measures
• Concurrent programs to:
» Support financial rebates/subsidies to improve access to helmets
» Improve cultural attitudes toward helmets
» Educate the community on proper helmet use & benefits
» Improve road infrastructure & safety

grams. Years before its first introduction of helmet legislation for bicyclists, Canada implemented myriad school-based programs and bicycle safety initiatives; it is thought that these programs acted as primers for community acceptance of helmet laws, changing cultural perceptions and augmenting compliance.⁴³ Last, an important aspect of bicycle and motorcycle safety that must be considered is the infrastructure of roads. Olivier et al. found that the improvement of road infrastructure amplified the decline in TBI after implementation of a bicycle helmet law in Australia.⁵⁵ Infrastructure projects are often large undertakings and expensive, requiring governmental finance and coordination; however, we believe a safer road is one of the key steps to a safe ride and a decrease in TBI for cyclists and riders.

Based on our findings, we propose several key considerations for the successful policy making and enforcement of compulsory use helmet laws to decrease TBI from RTAs; these considerations are displayed in Table 5. These considerations are for all caretakers of patients with TBI from RTAs, including but not limited to neurosurgeons. Laws should be comprehensive and include both primary riders and passengers, all age groups, all modes of transportation made safer by helmets, a proper use clause, and standardized helmet quality measures. Legislation enforcement methods also should be considered to improve compliance and outcomes. While policy change and enforcement are instrumental in safety and the prevention of TBI, community-specific factors must be considered when effecting change in different environments. No single approach will work for all communities, and special consideration must also be given to individual socioeconomic, cultural, and infrastructural barriers to helmet use. Additionally, these recommendations should be viewed with consideration of the poor quality of evidence. No RCTs or non-RCTs were found to support these findings. Further limitations are outlined in the following section.

Limitations of the Study

This systematic review has several limitations. Only published studies were included, putting results at risk for publication bias, in that our results overestimate the

number of positive and significant study results. Studies without intervention impact are less likely to be published and are generally underrepresented in the literature. The quality of evidence also was relatively poor and included no RCTs. The lack of RCTs means that all results are subject to selection bias. Overall, there is a need for more investigation into the impact of mandatory helmet use laws globally, especially in LMICs. Only 1 study systematically and explicitly observed for negative outcomes as a result of the helmet legislation. Although the results of this systematic review indicate that the impact of helmet legislation is generally positive, this review may overlook unintended or negative consequences, such as direct and indirect costs of helmet advocacy and legislation. Unfavorable outcomes include decreased use of more environmentally efficient transportation methods in favor of methods that do not require helmet use. Mandatory helmet legislation also may be viewed as an overbearing or authoritarian government action impeding individual freedoms. Also, articles were limited to the English language; therefore, studies not written in English or not yet translated were not included, and this may have excluded interventions that were well received and applied in non-English-speaking communities. Additionally, because our review excluded qualitative studies, some of the subtler nuances regarding cultural acceptance and barriers to helmet implementation and use in specific communities may not have been identified as part of this study. Last, no meta-analysis was conducted as part of this systematic review, allowing us to make assumptions from our findings but not to draw statistically significant conclusions.

Conclusions

We present a thorough review of the impact of legislative advocacy regarding helmet use in pediatric TBI. We identify key aspects of legislative objectives that aim to improve helmet use and safety. By better understanding the role of legislation in primary prevention of head injury, we believe that neurosurgeons can act as better advocates for their patients and communities in understanding the impact and prevention of pediatric unhelmeted TBI.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Lam, Du, LoPresti. Acquisition of data: Lam, Du, LoPresti. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Lam. Study supervision: Lam.

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