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Research article

The lifetime costs of pediatric abusive head trauma and a cost-effectiveness analysis of the *Period of Purple crying* program in British Columbia, Canada

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ABSTRACT

Background: Abusive head trauma (AHT) is a severe form of child abuse causing devastating outcomes for children and families, but its economic costs in Canada has yet to be determined. The *Period of PURPLE crying* program (*PURPLE*) is an AHT prevention program implemented in British Columbia for which success in reducing AHT events was recently reported.

Objective: This study estimated the lifetime costs to society of incidental AHT events and compared the benefits and associated costs of AHT before and after the implementation of the *PURPLE* program.

Participants and Setting: Children aged 0–24 months old with a definite diagnosis of AHT between 2002 and 2014 in British Columbia were included in this study.

Methods: An incidence-based cost-of-illness analysis, using the human capital approach was used to quantify the lifetime costs of AHT events according to their severity (least severe, severe and fatal). A cost-effectiveness analysis of the *PURPLE* program was conducted from both a societal and a health services' perspectives using decision tree models.

Results: There were sixty-four AHT events between 2002–2014, resulting in a total cost of $354,359,080 to society. The costs associated with fatal, severe and least severe AHT averaged $7,147,548, $6,057,761 and $1,675,099, respectively. The investment of $5 per newborn through the *PURPLE* program resulted in a $273.52 and $14.49 per child cost avoidance by society and by the healthcare system.

Conclusions: This study provides evidence to policymakers and health practitioners that investing upstream in well-developed AHT prevention programs, such as *PURPLE*, not only promote child safety and health, but also translates into avoided costs to society.

1. Introduction

Child maltreatment is a critical public health issue globally (INSPIRE Seven Strategies for Ending Violence Against Children, 2016). While many countries have ratified the United Nations *Convention on the Rights of the Child*, acknowledging the rights of all children to be properly cared for and protected from all forms of violence (Convention on the Rights of the Child, 1990), child maltreatment remains a concern for many children, including those in Canada (UNICEF Innocenti Research Centre & UNICEF Canada,

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2009). Abusive head trauma (AHT) is a particularly severe form of child abuse, and a large proportion of these cases results in death or permanent neurological deficits (King, MacKay, & Sirnick, 2003). At least 220 children suffered from AHT in Canada between 2005 and 2008 (Bennett, 2008; Ornstein & Dipenta, 2011). In addition to the devastating acute and long-term consequences of these events on the young victims, including vision loss, brain damage, specialized education, adaptive housing, etc., AHT is a tragedy for the child's family, the community and society in general. Studies from New Zealand (Friedman, Reed, Sharplin, & Kelly, 2012), and the United States (2014, Miller et al., 2017) have estimated that AHT costs, on average, more than 1-million dollars per child. While costs incurred as a result of medical care, child protection services, work production loss, and suffering likely place a similar heavy burden on the Canadian system (Barr et al., 2018; Ornstein & Dipenta, 2011), the acute and lifetime human and economic costs of pediatric AHT in Canada has yet to be determined.

Individual, social and environmental risk factors of AHT are well established (King et al., 2003; Lopes, Eisenstein, & Williams, 2013), indicating that most cases are highly preventable. Primary prevention is essential and preferable to interventions dealing with the consequences of the abuse. The *Period of PURPLE crying* (*PURPLE*) is a primary, universal evidence-based AHT prevention program that has been implemented in different countries, including Canada (National Center on Shaken Baby Syndrome - Canada, n.d.). It aims to reduce the incidence of AHT through educational support to parents and caregivers about the crying characteristics of normal infants, and the strong association between crying, caregiver frustration, and the dangers of shaking a baby (National Center on Shaken Baby Syndrome - Canada, n.d.). While studies assessing the effectiveness of the program in different locations and time periods have provided ambiguous results (2005, Altman et al., 2011; Dias et al., 2017; Zolotor et al., 2015), a recent study in the province of British Columbia (BC), Canada has shown a 35% decrease in AHT hospitalizations following the implementation of the *PURPLE* program (Barr et al., 2018). Given that no study has yet assessed the cost-effectiveness of the *PURPLE* program, such data provides opportune material to compare the outcomes of AHT prevention and relative costs to society before and after the implementation of the program.

This study aimed to estimate the lifetime costs to society of incidental AHT events among children 0–24 months old between 2002 and 2014 in BC, and then compared the benefits and associated costs of AHT events before and after the implementation of the *PURPLE* program. This information will provide policymakers, practitioners and scholars with greater understanding of the scale of AHT, and the associated social and economic consequences on society. Further, it will establish the evidence to inform investments in AHT prevention programs, such as the *PURPLE* program.

2. Methods

2.1. Population

British Columbia Children's Hospital (BCCH) is a Level I Pediatric Trauma Centre and tertiary pediatric hospital that treats all serious child abuse and child neurosurgery cases in BC requiring specialized care and potential pediatric intensive care. A retrospective review of all Child Protection Services (CPS) referrals with physical abuse as a primary or secondary referral and/or diagnosis was conducted in 2013 by CPS physicians, in order to identify AHT events that occurred between 2002-2006. Prospectively from January 2007, all CPS referrals were reviewed quarterly through a comprehensive chart review process by CPS physicians, nurses, social workers, and investigation team researchers. Child death data between 2002–2014 was reviewed through the BC Coroner's office in order to include children who died from AHT but who were not seen at the hospital. AHT events were identified by "the constellation of symptoms, physical signs, laboratory, imaging and pathologic findings that are a consequence of violent shaking, impact or a combination of the two", following the Canadian Pediatric Society and American Academy of Pediatrics definition and recommendations (Canadian Pediatric Society, 2008). Events were categorized as *definite*, *probable*, *possible*, *unknown* and *definitely not*, based on an adaption of certainty from Feldman et al. (Feldman et al., 2001). To ensure that no AHT events throughout BC were missed, those reported to the Inflicted Head Injury Surveillance program and to five child abuse and neglect teams at other hospitals throughout the province were reviewed and compared. Children aged 0–24 months old with a *definite* diagnosis of AHT between 2002 and 2014 were included in this study. Events were categorized as *fatal*-within 30 days of the event-, *severe* and *least severe*. As the severity of brain injury at discharge and long-term outcomes were not available, we assumed that 85% of AHT survivors would have at least moderate to severe disability including permanent neurologic impairment (defined as severe AHT events in this study), based on previously published Canadian estimates (Howes & Mellar, 2017; King et al., 2003). The study was approved by the University of British Columbia and Children's and Women's Research Ethics Board, Vancouver, BC (certificate #B06-0392).

2.2. Costs-of-illness analysis

An incidence-based cost-of-illness analysis, using the human capital approach (CADTH, 2017), was used to quantify the lifetime costs of new AHT events (least severe, severe and fatal) that occurred between 2002 and 2014. Costs were discounted to a present value in 2014 Canadian dollars using a discount rate of 1.5% per annum (CADTH, 2017). The burden of AHT was assessed from a societal perspective (Gabbe et al., 2015), through the following health care services and non-health care services: death, acute hospital services, projected lifetime health services, child protection services, criminal investigation and trials, punishment of offenders, special education, human capital suffering, and victims and caregivers productivity losses. Table 1 presents the cost categories used in the analysis, providing details of the category, sources of data and a description of the methods used to estimate costs.

Death costs were deduced from coroner and funeral costs, estimated in 2014 dollars at $1372 (BC coroner's office, personal communication, July 2012) and $6500, per fatal case (Life Insurance Canada, 2018), respectively.

Table 1
Cost category details and sources of methods used to determine costs.

Cost category	Details (cost converted to 2014 Canadian dollars)	References
Death	Coroner services ($1372) and funeral ($6500)	BC Coroners' office (personal communication, July, 2012) Funeral (Life Insurance Canada, 2018)
Acute hospital services	Ambulance ($644), emergency room and hospital care, health professional services, pharmaceutical drugs, and rehabilitation ($5820/day), physician services ($200-400/day)	BCIRPU 2015 (Rajabali, Ibrahimova, Barnett, & Pike, 2015) ERAT (Belton et al., 2015)
Projected lifetime health services	All health services following acute hospitalization discharge to lifetime, including additional hospitalizations, medical appointments, specialized treatment, equipment, and rehabilitation.	ERAT (Belton et al., 2015) Miller et al. (Miller et al., 1995)
Child protection services	Intake of notification, investigation, case management, case placement, foster-care allowances, supervision of access, therapy, specialist assessments, interpreters and monitoring (least severe AHT: $18,038, severe AHT: $46,105, fatal AHT: $7022)	Friedman et al. (Friedman et al., 2012)
Criminal investigation and trials	Police investigations where an offence was recorded (not specific for abusive head trauma), lawyers and their overheads, expert witnesses (least severe AHT: $12,294, severe AHT: $42,491, fatal AHT: $405,797)	Friedman et al. (Friedman et al., 2012)
Punishment of offenders	Prison and community-based sentences (least severe AHT: $12,801, severe AHT: $63,509, fatal AHT: $290,910)	Friedman et al. (Friedman et al., 2012)
Special education	Special education services from age 3 to 16, reflecting additional education services than was is provided to children without abusive head trauma ($18,308)	Friedman et al. (Friedman et al., 2012), MacLeod et al. (MacLeod and Emes, 2017)
Human capital suffering	Pain and suffering (general damages) including past and future loss of income, loss of competitive advantage in workplace, loss of enjoyment of life, etc. ($317,000)	Pain and Suffering (Tort) Claims :Toronto Law Firm, n.d.)
Victims Productivity Losses	Expected lifetime productivity and income of AHT victims had they not been victimized based on the 2014 BC participation rate of 65%, unemployment rate of 6.1% and average weekly earnings of $871	ERAT (Belton et al., 2015)
Caregivers productivity losses	Short-term: caregivers' wage and household production loss resulting from the average hospital length of stay of their child based on a median wage and benefits per day of $189 Long-term: dollar value of disability-adjusted life years (DALYs), adjusted to average earnings of parents of AHT victims ($177,168 per DALY)	Statistics Canada (Statistic Canada, 2019; Statistics Canada, 2019a, 2019b) Miller et al. (Miller et al., 2017) (Miller et al., 2014)

Acute hospital services costs for least severe, severe and fatal cases included emergency room and hospital care, health professional services, pharmaceutical drugs, and rehabilitation. The hospitalization costs were estimated using the average hospital length-of-stay of each AHT severity category and the Resource Intensity Weights (RIWs) obtained through cross-referencing hospitalization information from the Discharge Abstract Database (DAD) from the Canadian Institute for Health Information (CIHI) and applying to the RIW the average hospital case cost value for 2014, which was $5820 (CIHI). In the absence of reliable follow-up data on AHT victims disability status or brain damage severity, all children with least severe AHT, and 25% of those with severe AHT were assumed to have permanent partial disability – long-term consequences from AHT but able to work at some type of employment – while 75% of children with severe AHT were presumed to have permanent total disability, restricting them from work entirely. Average physician services and ambulance costs were added to hospital services costs. Average physician services costs per patient were estimated at $200/day for least severe AHT events, and $400/day for severe and fatal AHT events, based on Medical Services Plan (MSP) billing fees for pediatric intensive care physicians, neurosurgeons, general pediatricians and other pediatric specialists who may be involved in AHT care (MSC Payment Schedule Index Section, 2015). Ambulance services costs, including ground and air transport (CADTH, 2017), were estimated at $644/case in 2014 dollars (BC Emergency Health Services, 2012), and added to other hospital costs, assuming that 50% of admissions required ambulance services (Finkelstein, Corso, & Miller, 2006). The Electronic Resource Allocation Tool (ERAT) (Belton, Pike, Heatley, Cloutier, & Skinner, 2015), developed by Parachute (a Canadian non-governmental organization promoting injury prevention resources and reporting on cost of injury on a periodic basis) to model the full costs of unintentional and intentional injuries in a uniform way across Canada, was used to calculate acute hospital services costs.

A substantial portion of AHT survivors require extended treatment and care that may last a lifetime, including more frequent emergency department visits, doctor's office visits, hospitalizations, rehabilitation, etc. (Newton & Vandeven, 2005). Projected lifetime health services costs were based on estimated life expectancies of 82 years-old for children with least severe AHT (Canadian average), and 74 years-old for children with severe AHT (Miller et al., 2017). The cost was calculated using ERAT and the ratio of long-term medical care to facility costs (Miller, Pindus, Douglass, & Rossman, 1995), and adjusted upward to account for a 2% medical and rehabilitation costs growth rate prior to discounting, as recommended by ERAT.

Child protection, criminal investigation and trials, punishment of offenders, and special education costs were all estimated using an average cost per child for least severe, severe and fatal AHT events, consistent with a recent New Zealand study (Friedman et al., 2012). As these costs were not available for BC, New Zealand was selected as a comparative jurisdiction given its similar universal health care, population, topography, standard of living, indigenous culture and climate (OECD Interactive Tool: International Comparisons; Peer Countries, British Columbia, 2019). Costs in New Zealand dollars for each of the cost categories were converted to

2014 Canadian dollars (Table 1). Education costs in BC were calculated and subtracted to reflect only the additional costs incurred by society due to the needs for special education by survivors of AHT (MacLeod & Emes, 2017).

AHT results in considerable suffering, pain and grief for the child, the family and the community. Although these costs are intangible and difficult to articulate in monetary terms, their existence is very real to the people concerned. In Canada, the cap for pain and suffering damages was established at $100,000 by the Supreme Court in 1979 and indexed to keep up with inflation every year (Lindal v. Lindal - Supreme Court of Canada Cases (Lexum) (1981)), and estimated at $317,000 Canadian 2014 dollars (Law Reform Commission of British Columbia, 1984) (Pain and Suffering (Tort) Claims :Toronto Law Firm, n.d.). This maximum may be granted to a person with serious and permanent impairment from an injury such as, loss of limb, paraplegia and/or a brain injury. To provide a conservative estimate, we assumed that among the 75% of children with permanent total disability resulting from severe AHT (estimated for the acute hospital services costs), 50% of them were likely to receive the maximum amount of $317,000 for pain and suffering damages, while the remaining 50% were likely to receive half - $158,500 - of the maximum threshold allocated by the Canadian courts (Pain and Suffering (Tort) Claims :Toronto Law Firm, n.d.). We assumed that children with least severe AHT would not be eligible for compensation for pain and suffering.

The expected productivity and income of AHT victims, had they not been victimized (losses), were computed using BC 2014 data for unemployment rate, paid employment participation rate and average weekly earnings from Statistics Canada (Statistic Canada, 2019), and assumed productive work occurred between 15–65 years of age. Caregivers' short and long-term productivity losses must also be acknowledged and added to victims' productivity losses as a cost to society, given that the majority of AHT survivors present with lifetime disabilities requiring caregivers' full-time care. Short-term caregivers' wage (absenteeism) (Zhang et al., 2015), and/or household production loss, given some parents might have been on maternity leave, were estimated by the hospital length-of-stay according to AHT severity (least severe vs severe), to which the median hourly wage with benefits for individuals 15-years and over was applied (Statistics Canada, 2019b). For fatal AHT events, the total wage loss was based on applying the mean hourly wage with benefits to the days lost for personal or family responsibility (Statistics Canada, 2019a). Long-term caregivers' productivity losses were computed by assessing a dollar value to Disability-Adjusted Life Years (DALYs) of the victim, which were calculated as the sum of years of life lost due to premature death and the years of productive life that survivors lost due to disability (Metrics: Disability-Adjusted Life Year (DALY) (2014)), for children with least severe, severe and fatal AHT, as estimated by Miller et al. (Miller et al., 2014). The dollar value to DALYs was then adjusted to the average earnings of caregivers of AHT victims as identified by Miller (Miller et al., 2017), converted into 2014 Canadian dollars, assuming that this is inclusive of the impact of caregivers' health, quality of life, caring burden and work productivity.

2.3. Cost-effectiveness analysis

A decision tree was created to represent AHT occurrence and outcomes, and associated costs before and after the implementation of the *PURPLE* program. Two decision tree models were developed, including the lifetime societal costs (Fig. 1), and the lifetime

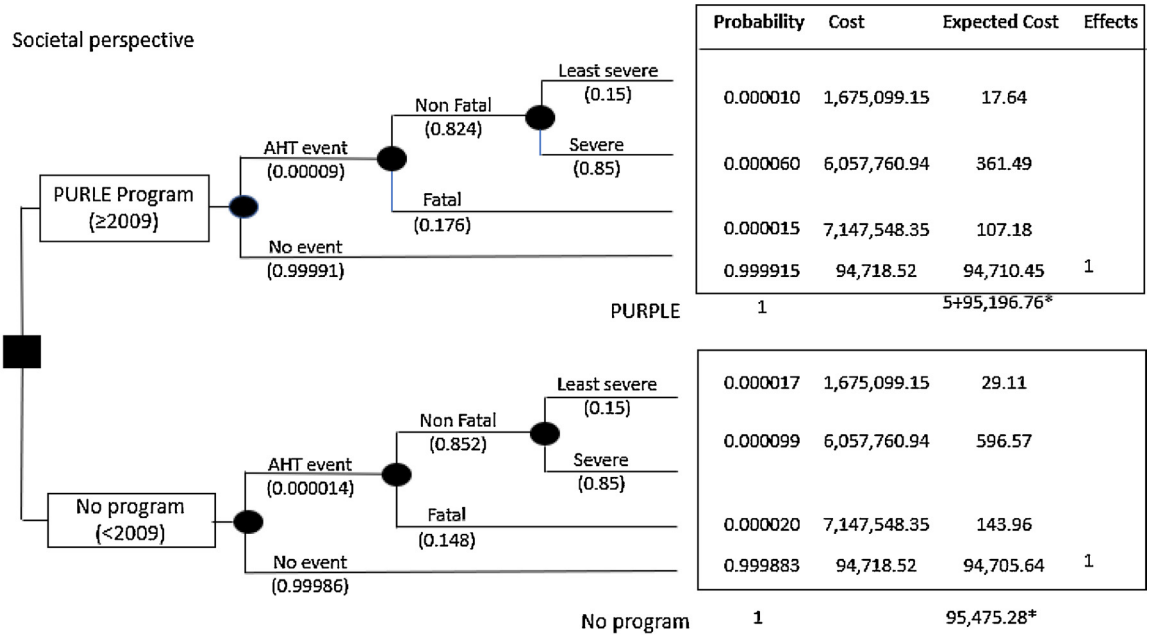

Fig. 1. Decision Tree showing AHT outcomes, probabilities and expected costs, before and after the implementation of the PURPLE program from a societal perspective, 2014 $CAD, BC 2002–2014.

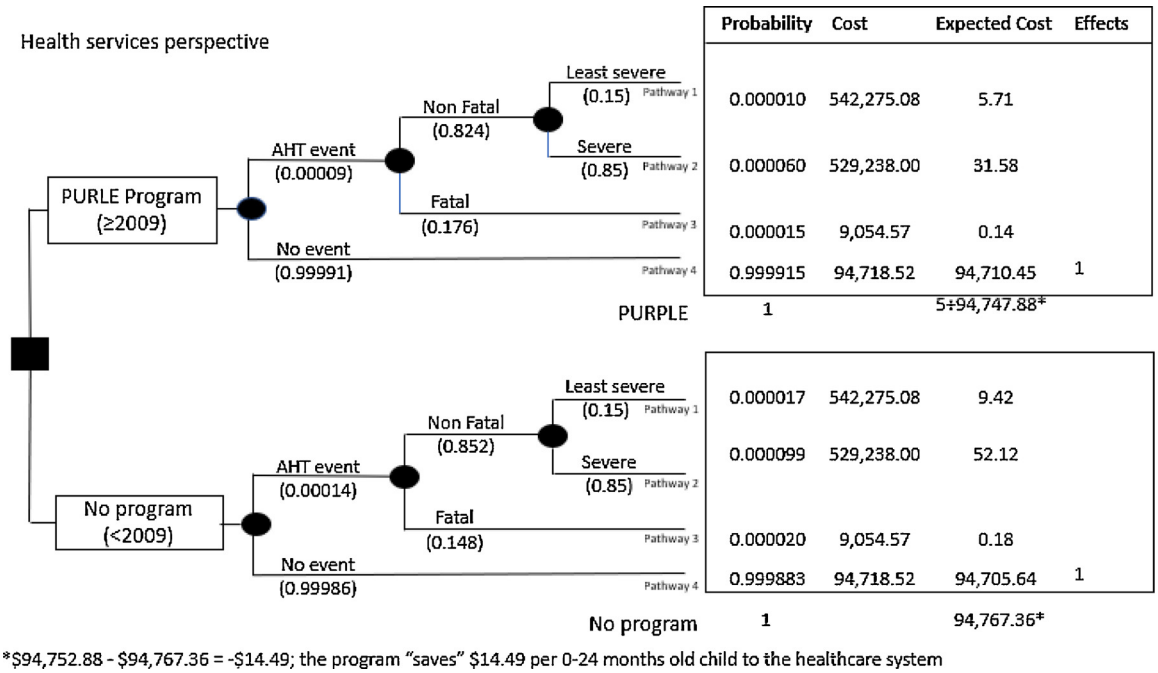

Fig. 2. Decision Tree showing AHT outcomes, probabilities and expected costs, before and after the implementation of the PURPLE program from a health services perspective, 2014 $CAD, BC 2002–2014.

health services costs (Fig. 2) incurred by a child with or without AHT, so as to conduct a cost-effectiveness analysis of the *PURPLE* program from both a societal and a health services' perspectives.

2.4. Outcomes

The *PURPLE* program development began in 2007 in BC, and was implemented universally province-wide by January 2009. It uses educational materials provided to parents of all newborns, post-partum reinforcement of the program key *Talking Points* by public health nurses, and an annual public education campaign to reduce the incidence of AHT (Barr et al., 2018). Before the universal implementation of the *PURPLE* program in 2009, interventions were not consistently used to address AHT, thus the period between 1995–2008 (given data available) was considered the comparator in this analysis. The implementation strategy of the *PURPLE* program in BC has been published previously (Barr, Rajabali, Aragon, Colbourne, & Brant, 2015, 2018). Secondary analysis of data reflecting AHT events and incidence in BC between 1995–2014 (Barr et al., 2018) was used to calculate probabilities of having an AHT event (either a non-fatal least severe event *-pathway 1-*, a non-fatal severe event *-pathway 2-*, or a fatal event *-pathway 3-*) or no event (*pathway 4*) among the 0–24 months old population in BC, before and after the implementation of the *PURPLE* program. An assumption was made that a child could only have a diagnosis of AHT once in a lifetime. Effects were expressed in decision tree models in terms of the probability of a child not having an AHT event.

2.4.1. Resource use and costs

The average lifetime health care and societal costs calculated for a least severe, severe and fatal case were applied to decision tree models. Projected lifetime health care and societal costs in 2014 Canadian dollars of $94,718.52 were assumed for children without AHT (Forget, Roos, Deber, & Walld, 2008). The expected costs per child 0–24 months old before and after the implementation of the *PURPLE* program were calculated by multiplying the costs associated with each AHT outcome by the probabilities of the occurrence of that outcome. The annual (2014) cost of administering the *PURPLE* program is approximately $200,000, including costs of supplies and educational materials, distribution, coordinators' salaries, and public education campaign. Estimating that 40,000 newborns and their parents are provided with the program annually, an average program cost of $5 per newborn was estimated, and added to the expected cost after the implementation of the *PURPLE* program. As maternity and public health nurses' costs for delivering the program represent in-kind costs, no monetary values were applied to these services for the purpose of this cost-effectiveness analysis.

2.5. Sensitivity analyses

Sensitivity analyses were conducted to estimate the lifetime healthcare and societal costs of least severe, severe and fatal AHT events using a discount rate of 0% and 3% (CADTH, 2017). Different program effectiveness estimates (percentage of AHT cases prevented) were used to determine the percentage at which costs invested and avoided would break even. Sensitivity analyses

Table 2
Average total and per child costs and Disability-Adjusted Life Years (DALYs) of abusive head trauma case by severity of brain injury, 2014 $CAD, BC 2002–2014.

	Severity of brain injury						
	Least severe		Severe		Fatal		Total cost
N (%)	9 (14)		50 (78)		5 (8)		
	All cases	Per case	All cases	Per case	All cases	Per case	
Death	–	–	–	–	39,358.15	7,871.63	39,358.15
Acute hospital services	85,687.66	9,520.85	2,971,069.12	59,421.38	45,272.84	9,054.57	3,102,029.63
Projected Lifetime Health services	4,713,446.76	523,716.31	23,570,216.59	471,404.33	–	–	28,283,663.35
Child protection services	159,634.71	17,737.19	2,312,187.31	46,243.75	35,111.10	7,022.22	2,506,933.12
Criminal investigation and trial	108,801.81	12,089.09	2,130,901.08	42,618.02	2,028,984.30	405,796.90	4,268,687.19
Punishment of offenders	113,288.23	12,587.58	3,184,962.81	63,699.26	1,454,550.40	290,910.10	4,752,801.44
Special education	0	0	918,167.34	18,363.35	0	0	918,167.34
Human capital suffering	0	0	8,942,371.88	178,847.44	0	0	8,942,371.88
Productivity Loss							
Victims	1,723,397.36	191,488.60	45,526,413.68	910,528.27	5,727,475.45	1,145,495.00	52,977,286.49
Caregivers' short-term loss	2,269.52	252.17	111,962.83	2,239.26	8,888.94	1,777.79	123,121.29
Caregivers' long-term loss	7,918,101.40	879,789.04	214,128,458.28	4,282,569.17	26,398,100.54	5,279,620.00	248,444,660.22
Total	14,824,627.45	1,675,099.15	303,796,710.92	6,057,760.94	35,737,741.73	7,147,548.35	354,359,080.10

combining different discount rates (0%, 1.5%, 3%) with the reported program effectiveness of 3% and the associated 95% confidence interval (1–57% effectiveness) (Barr et al., 2018), were also conducted.

3. Results

Sixty-four (64) children between 0–24 months old were diagnosed with definite AHT between 2002–2014 in BC, an average incidence of 11.2 AHT events per 100,000 population. Of these, 5 (8%) died within 30-days of the event, 50 (78%) were identified with non-fatal severe AHT, and 9 (14%) with non-fatal least severe AHT. The majority were males (66%), and the age range was 1–24 months (mean 7.7 months, median: 5.3, IQR: 7.3). Children with a non-fatal AHT were hospitalized for an average of 10-days, and none of the children with least severe AHT spent time at the Intensive Care Unit (ICU), while ICU days ranged between 1 and 13 days for children with a severe AHT event.

Table 2 details the average total and per-child lifetime costs by AHT category from a societal perspective. AHT events between 2002–2014 resulted in a total cost of $354,359,080 to society. The costs associated with fatal, severe and least severe AHT averaged $7,147,548, $6,057,761 and $1,675,099, respectively. When examining the costs incurred due to acute and projected lifetime health services only, the total cost to the healthcare system was $31,385,693 and the average costs per AHT affected child was $490,401 (fatal case: $9055; severe case: $530,826; least severe case: $533,237).

AHT outcomes, probabilities and expected costs, before and after the implementation of the *PURPLE* program, are presented in Figs. 1 and 2, and include both societal and a health services' perspectives. From a societal perspective, after distributing the costs incurred by AHT events and the PURPLE program, the expected lifetime cost per child was $95,201.76 with the *PURPLE* program and $95,475.28 with no program. Therefore, the investment of $5 per newborn to prevent AHT, resulted in a $273.52 per 0–24 months old child cost avoidance by society (Fig. 1). Similarly, from a health services perspective, the expected lifetime cost per child was $94,752.88 with the *PURPLE* program and $94,767.36 with no program, resulting in a $14.49 per child cost avoidance by the healthcare system (Fig. 2).

Fig. 3 illustrates costs avoided by the healthcare system and society, according to different percentages of the effectiveness of the *PURPLE* program to prevent AHT events, using the same costs of the program and of a fatal, severe and least severe AHT event per the decision tree models. A program preventing at least 2% of AHT events would demonstrate a positive return on investment to society, while program effectiveness of at least 7% would result in cost avoidance by the healthcare system.

Sensitivity analyses using a discount rate of 0% and 3% respectively, estimated total AHT lifetime costs to society of $421,074,262 and $321,118,751, while the lifetime costs per AHT affected child were $6,579,285 and $5,017,480, respectively. Table 3 shows sensitivity analyses of the cost-effectiveness of the *PURPLE* program from health services and societal perspectives, using discount rates of 0%, 1.5% and 3% and program effectiveness of 1% and 57% (95% confidence interval from the reported 35% program effectiveness) (Barr et al., 2018). Assuming the program prevented only 1% of AHT events and AHT-related lifetime costs were discounted to 3% (lower expected costs), the *PURPLE* program would cost $9.57 and $5.28 per child from a health services and societal perspective, respectively. On the contrary, assuming the program prevented 57% of AHT events and AHT-related lifetime costs were discounted to 0% (higher expected costs), the *PURPLE* program would cost -$52.17 and -$503.35 per child from a health services and societal perspective, respectively.

4. Discussion

This is the first study to assess the cost-effectiveness of the *PURPLE* program and to report the lifetime costs to society of AHT in

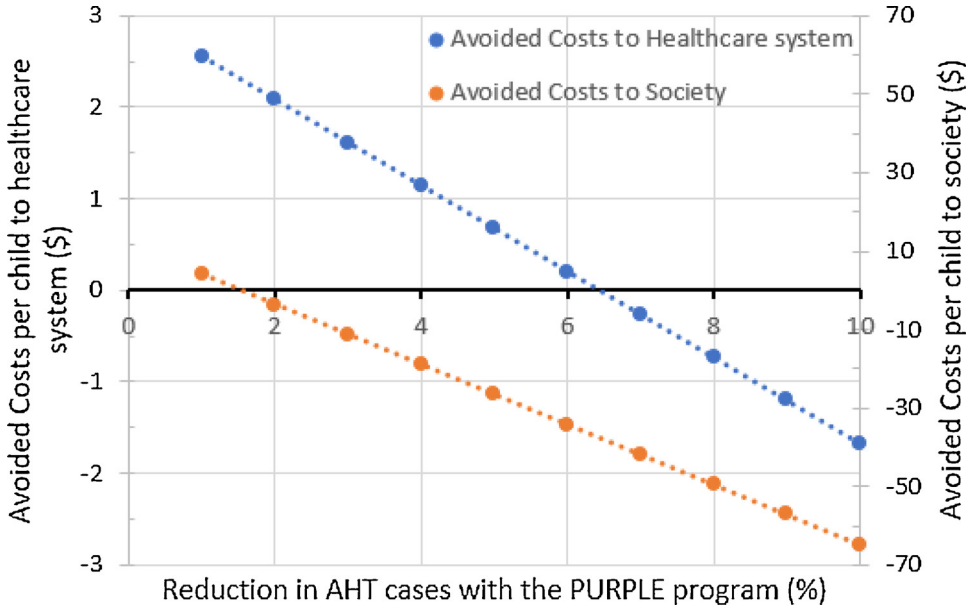

Fig. 3. Healthcare and societal costs avoided per child according to theoretical % reduction in AHT cases with the PURPLE program, 2014 $CAD, BC 2002–2014.

Table 3
Sensitivity analyses of the health services and societal cost per child spent or saved according to the program effectiveness and discount rates, 2014 $CAD, BC 2002–2014.

		Societal perspective ($)			*Health services perspective ($)*		
		Discount rate			Discount rate		
		0%	1.5%	3%	0%	1.5%	3%
Program effectiveness	1%	2.40	4.00	5.28	0.48	2.55	9.57
(% AHT cases prevented)	35%	−326.29	−273.51	−246.82	−33.70	−14.49	0.48
	57%	−503.35	−423.50	−383.07	−52.17	−23.69	−4.44

Canada. Our findings show that the acute and lifetime consequences of AHT resulted in costs to society ranging between $1.6 million per child for the least severe AHT events to more than $7 million per child for severe and fatal AHT events. The investment of $5 per newborn for the delivery of the *PURPLE* program province-wide, assuming its reported effectiveness to decrease AHT events by 35%, resulted in avoided costs of $273.52 per child to society and of $14.49 per child to the healthcare system, totalling annual positive return on investment to the healthcare system and society of more than $635,000 and $12 million respectively. Our results also emphasize that the benefits to society resulting from a minimal reduction of 2% of AHT events would still be sufficient to neutralize the costs invested in the *PURPLE* program annually. This new knowledge has significant implications for policymakers, practitioners and scholars, as it captures the significant human and economic burden of AHT to Canadian society and highlights the ability of well-developed AHT prevention programs to not only protect infants from preventable AHT events, but to also demonstrate positive returns on investment to society and the healthcare system. These findings resonate with the commentary of previous researchers, asking policymakers, hospital administrators and public health agencies about the Canadian system: “How can we NOT afford to introduce an effective strategy to prevent AHT?” (Ornstein & Dipenta, 2011).

AHT costs estimated in this present study aligned with those of previous studies from New Zealand (Friedman et al., 2012) and the US (Miller et al., 2017) despite different methods to generate hospitalization and medical care costs. While we used the methods from Friedman et al. (Friedman et al., 2012) to estimate costs related to Child Protection Services, criminal investigation and trials, punishment of offenders and special education, our findings regarding lifetime AHT costs to society were higher than those of New Zealand as we included the productivity loss of victims and of informal caregivers, like parents, as well as pain and suffering to our cost estimates. As opposed to Friedman et al. (Friedman et al., 2012), we did not use Quality-Adjusted Life Years (QALYs), which combine length of life and quality of life in a single index (Sassi, 2006), as an outcome measure given the absence of estimates of utility loss for children with AHT or traumatic brain injury in the literature. We used the estimates of DALYs for children with AHT provided by Miller et al. (Miller et al., 2014) to calculate long-term caregivers’ productivity losses, and used previously published Canadian data (Barr et al., 2018) to identify probabilities of AHT events as the outcome measure to be included in our cost-effectiveness analysis. Comparing our results to the US study by Miller et al. (Miller et al., 2017), most of our assumptions and methods

differed, except for our calculation of DALYs (Miller et al., 2014). As opposed to Miller et al., our costs included cost for pain and suffering from the severe consequences of AHT events and were based on Canadian and New Zealand references. Yet, our average lifetime AHT costs to society were, in the end, fairly similar to the US estimates (Miller et al., 2017), after converting our 2014 Canadian dollar costs to US 2010 dollars.

Although this is the first study to assess the cost-effectiveness of preventing AHT cases with the *PURPLE* program, our results can be compared to the cost-effectiveness of other child injury prevention programs. Our findings showed that for every dollar spent on the *PURPLE* program there was an associated saving by society of $54. This is higher than the cost-savings reported by the Zero Alcohol Tolerance for Driver under 21 ($25 saved per dollar spent), and Child Safety Seat Laws ($42 saved per dollar spent), which are both widely used public health interventions, given their unquestionable benefits (Injury Prevention: What Works? A Summary of Cost-Outcome Analysis for Injury Prevention Programs (2014 Update), 2014). Assuming the *PURPLE* program would have resulted in at least a 2% reduction in AHT events in BC, for each dollar spent on the *PURPLE* program, society would save $4, similar to the reported avoided costs from Poison Control Centres, implemented and operated as an essential service in all provinces and states of North America (Spiller & Griffith, 2009). Given the province of BC reportedly observes lower rates of AHT compared to other countries (Barlow & Minns, 2000; Barr et al., 2018; Keenan et al., 2003; Kelly & Farrant, 2008; Kesler et al., 2008), the avoided costs resulting from a 2% decrease in AHT cases could be expected to be higher in regions with higher AHT rates than the rate of 11.2 AHT cases per 100,000 population used in this study.

This study has some limitations. First, the average AHT costs presented in this study are likely an underestimate, as our methods are unlikely to have fully accounted for all costs, including those for capital (hospital building, equipment, etc.) and comprehensive physician services costs. Our findings were based mostly on average costs, obtained by dividing total costs from categories or departments by the number of patients who consumed the services. For example, hospitalization costs were in part derived from the costs of acute care hospital stays provided by CIHI, even though AHT cases likely necessitated more care and drugs compared to other diseases and age groups. Out-of-pocket expenses, including prescribed medications, transportation costs other than ambulances, and additional rehabilitation equipment and services, were also not captured by our methods. Although our methods included victim and caregivers' productivity losses (through absenteeism and household production loss), it did not consider presenteeism as a productivity loss, which acknowledges that caregivers of infants with AHT may continue to be at work, but not perform at full productivity, resulting in additional human and economic costs to society (Goetzel et al., 2004). Cost estimates were provided for definite AHT diagnoses only, underestimating the incidence and the costs resulting from AHT events, including those categorized as *probable, possible,* or misdiagnosed. Consequently, the results from the cost-effectiveness analysis likely underestimate the cost avoidance per child to society and health services. Another limit of the cost-effectiveness analysis is the impossibility to randomize children to either the treatment intervention (*PURPLE* program) or the control condition (no program), given that the *PURPLE* program was implemented universally in BC, which provides a less robust design and increases the likelihood of bias. The cost of the *PURPLE* program used in the cost-effectiveness analysis did not include in-kind costs of nurses who deliver the program, as these services don't require additional money from the healthcare system and society. The cost of the PURPLE program materials has increased in the past few years, which should be taken into account in the interpretation of the present findings. We acknowledge that part of the "savings" (cost avoidance) to the healthcare system and to society presented in our findings are in fact costs that will be reassigned to other activities. For example, hospitalization and police investigation costs 'avoided' by preventing AHT events will likely be reallocated to other patients or programs. Finally, limited sensitivity analyses were conducted for the AHT costs and the cost-effectiveness analysis, limiting our ability to assess the impact of some assumptions on the certainty around our estimates.

In conclusion, this study highlights the significant economic burden to society of AHT events in young children and provides evidence to policymakers, health practitioners and scholars that investing upstream in well-developed AHT prevention programs like the *Period of PURPLE Crying* program, not only promote child safety, health and well-being, but also translates into avoided costs and real dollars available for reallocation to other important health and societal issues.

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Declaration of Competing Interest

None.

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