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Blunt thoracic injury in older adults: application of Haddon's phase-factor matrix model.

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Activity Objectives

1. Identify the rate of hospitalization and death related to trauma for adults 65 and older.
2. Discuss factors in Haddon's Phase-Factor Matrix Model.
3. Describe the most common mechanisms of injury related to trauma in older adults.
4. Discuss age-related host factors that impact outcomes associated with traumatic injuries in older adults.
5. Describe post-event care considerations for older adults with traumatic injuries.

Author Disclosure Statement

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ABSTRACT

Blunt thoracic injury (BTI) in older adults can lead to grave illness, permanent disability, and even death. Using Haddon's phase-factor matrix model, this article examines the phenomenon of BTI in older adults. Preventive, diagnostic, and treatment interventions are discussed from the perspective of the pre-event, event, and post-event phases. Relevant physiological and pathophysiological changes regarding senescence and injury are reviewed, as are the common mechanisms of blunt trauma and anatomic injury patterns seen in older adults. Considerations for clinical interventions and future research are also presented.

Adults 65 and older are projected to account for 39% of all injury-related hospitalizations by the year 2050 (Mackenzie, Morris, Smith, & Fahey, 1990). In 2007, 12.6% of the U.S. population—37.9 million people—were 65 and older. By 2030, this number will grow to 72.1 million, or 19.3% of the U.S. population (U.S. Administration on Aging, 2008; Institute of Medicine [IOM], 2008). Those 85 and older are the fastest-growing subgroup of older adults; their number will double from 5 million in 2005 to 9 million in 2030 (IOM, 2008). Older adults are living longer and report improved physical functioning despite their chronic illnesses (Federal Interagency Forum on Aging Related Statistics, 2006; Freedman, Martin, & Schoeni, 2002; Manton, Corder, & Stallard, 1997). This improvement in overall health allows older adults to participate in activities that were traditionally limited to younger individuals (e.g., recreational sports, motorcycle riding, house maintenance), which exposes them to the possibility of blunt

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force trauma (BFT), including blunt thoracic injury (BTI).

Morbidity and mortality statistics on traumatic injury in older adults are staggering (Dellinger & Stevens, 2006; MacKenzie & Fowler, 2008). Adults 65 and older have the highest rate of hospitalization (30%) and death (25%) related to trauma of any age group (MacKenzie & Fowler, 2008). Older adults sustain BFT more often than younger people, their injuries are more severe, they develop more complications, and they incur more treatment costs than younger trauma patients (Newell et al., 2009). Injury is the sixth-leading cause of death for adults ages 65 to 74, and the seventh- and ninth-leading causes of death for those ages 75 to 84 and 85 and older, respectively (Dellinger & Stevens, 2006). The trauma-related death rate in those 65 and older is 113 per 100,000; for those 75 and older, it increases to 169 per 100,000, three times higher than the combined rate for all other age groups (MacKenzie & Fowler, 2008). Criddle (2009) found a relationship between injury in older adults and an increase in death rate up to 5 years post-injury, as well as a link between pre-injury patient characteristics (e.g., age, sex, comorbidities) and an increased death rate. Richmond, Kauder, Strumpf, and Meredith (2002) showed that besides the number and severity of injuries in older adults, their increasing age and the development of post-injury complications were significant predictors of mortality.

Past research on trauma in older adults has been primarily retrospective and descriptive (Jacobs et al., 2003). The limited amount of research that does exist is often contradictory and inconsistent due to its heterogeneity, lack of standardization among trauma registry data banks, under- and misreporting of data, and small samples.

Clinicians who care for older adults must gain knowledge about the causes and impact of BTI in this population. Treatment of BTI may be negatively affected by provider and/or institutional attitudes regarding the appropriateness of aggressive intervention for injured older adults (Callaway & Wolfe, 2007). Morbidity and mortality among this group could be greatly reduced if trauma care providers became more aware of the complex needs and responses of these patients and initiated appropriate assessments and timely interventions.

The purpose of this article is to describe a model of BTI and to summarize research on the causes and consequences of BTI in older adults. The three phases of Haddon's (1968) phase-factor matrix model of injury (i.e., pre-event, event, and post-event) are used as the framework for exploring the most common causes of injury known as mechanisms of injury (MOI) responsible for BTI in this age group. The article begins with definitions of terms that guided the review

TABLE 1

HADDON'S PHASE-FACTOR MATRIX MODEL

	Factors			
Phase	**Host (Human)**	**Agent (Vehicle)**	**Environment–Physical**	**Environment–Social**
Pre-event	Driver age, gender, driving experience, substance use, sensory deficits, fatigue, risk-taking behavior, medications, comorbidities	Vehicle size, speed, brakes, tire condition, road-holding ability, visibility (e.g., color, running lights)	Road design and traffic flow, road conditions, weather, traffic density, traffic control (e.g., lights, signals), visibility, time of day	Speed restrictions, impaired driving laws, licensing restrictions, road rage, seat belt laws
Event	Age, comorbidities, restraint use, distractions	Vehicle speed, size, crash-worthiness, type of restraints (e.g., lap/shoulder belts, air-bags), interior surface hazards	Guardrails, median dividers, break-away poles, road-side hazards	Enforcement of speed limits
Post-event	Age, comorbidities, specific injuries	Integrity of fuel system, extrication issues	Distance from emergency medical services (EMS), proximity to trauma center, extrication issues	EMS planning and delivery, bystander control/assistance, quality of trauma care, rehabilitation services, compensation practices, social support systems

Source. MacKenzie, E.J., & Fowler, C.J. (2004). Epidemiology. In E.E. Moore, D.V. Feliciano, & K.L. Mattox (Eds.), Trauma *(5th ed., pp. 21-39). San Francisco: McGraw-Hill. Reproduced with permission of The McGraw-Hill Companies.*

of current research findings on the occurrences and causes of these MOI in older adults, as well as a description of Haddon's model. The model is then used to present these various MOI, common injury patterns, consequences, and treatments of the resultant BTI in older adults. Recommendations for clinical practice are woven throughout the article, concluding with recommendations for future research.

DEFINITION OF TERMS

Haddon's Phase-Factor Matrix Model of Injury

William Haddon, Jr., a physician and epidemiologist, conducted much of the early work on factors that contributed to the cause of traumatic events (Haddon, 1963, 1968, 1972, 1973, 1980, 1995; Haddon, Valien, McCarroll, & Umberger, 1961; McCarroll & Haddon, 1962). These controlled studies of both fatal pedestrian versus vehicle crashes (PVCs) (Haddon et al., 1961) and motor vehicle crashes (MVCs) (McCarroll & Haddon, 1962) found that older adults were more likely to be involved in these MOI. Haddon served as the first director of the National Highway Traffic Safety Administration (NHTSA) and later, the Insurance Institute for Highway Safety. His leadership resulted in federal safety standards, including shoulder belts, helmet laws, and impaired driving legislation (O'Neill, 2002). As director of the NHTSA, he developed his conceptual model known as the "Haddon matrix" (Robertson, 2001), which was used to identify key factors involved in the occurrence of traumatic events (Runyan, 1998, 2003). His 1968 publication established three distinct phases of a MVC in two dimensions and was reprinted as an "injury classic" (Haddon, 1999). He later renamed the phases *pre-event*, *event*, and *post-event*, allowing the matrix to be applied to various mechanisms of injury (Haddon, 1980).

The pre-event phase addresses factors that predict and influence whether a traumatic event will occur at all. The event phase focuses on aspects that will determine whether and which specific injuries are likely to occur based on the event details. The post-event phase examines the issues that affect outcomes related to those injuries. In his revised model, Haddon (1980) more clearly identified factors that need to be considered in any evaluation of a traumatic occurrence, including the *host* (for purposes of this article, an older adult), an *agent* or mechanism that provides the energy to create an injury (e.g., vehicle, hard surface), and the *environment* (e.g., road, weather conditions). **Table 1** depicts this revised matrix as presented by MacKenzie and Fowler (2008).

Older Adult

The majority of research defines an older adult as one 65 and older. Therefore, for the purposes of this article, that definition will be used, as recommended by the U.S. Senate Special Committee on Aging, Ameri-

can Association of Retired Persons, Federal Council on Aging, and the U.S. Administration on Aging (1988).

Injury and Trauma

These terms are used synonymously and refer to physical injury to bodily tissues. More specifically, *injury* is defined by Horan and Little (1998) as physical damage that results from energy transfer when an external object, force, or agent acts on a physical being to create systemic responses that manifest as injury to specific body systems. Injuries are classified as either *penetrating* or *blunt*. Penetrating trauma is defined as injury produced by penetration of tissue by a foreign body (Weigelt & Klein, 2002). In contrast, blunt trauma is defined as injury incurred from forces applied and energy transmitted from a blunt object or stationary mass to body tissue, covering a wider body surface area, and having more complex and variable kinematics than isolated penetrating trauma (Hunt, Weintraub, Wang, & Buechter, 2004).

BTI in Older Adults

BTI refers to any bodily tissue injury (e.g., skin, muscle, bone, cardiac, pulmonary, vascular) to the anterior and posterior thorax from a blunt mechanism. Common MOIs affecting older adults include MVCs, PVCs, falls, and assaults with blunt objects (Dellinger & Stevens, 2006).

BTI may lead to rib fractures or contusions; fractures of the scapula or clavicle; cardiac or pulmonary contusions; pneumothorax, hemothorax, bronchial, and/or esophageal injury; or vascular/great vessel and diaphragmatic injuries. Common complications from these injuries are pneumonia and acute respiratory distress syndrome, which were found to account for 85% of complications in injured older adults (Carrillo, Richardson, Malias, Cryer, & Miller, 1993; Levy, Hanlon, & Townsend, 1993; Oreskovich, Howard, Copass, & Carrico, 1984). Other complications may include pulmonary atelectasis, respiratory failure, empyema, chylothorax, cardiac dysrhythmias, cardiac ischemia or infarction, sepsis, deep vein thrombosis, pulmonary embolism, acute lung injury, and/or multiple organ failure.

THE THREE PHASES OF HADDON'S PHASE-MATRIX MODEL

Pre-Event Phase

Pre-event factors that could influence the type and severity of BTI of older drivers in MVCs include their sex and distance from the steering column. Women tend to sit closer to the steering column than men; however, distance from the steering column may be related to body mass rather than sex (McFadden, Powers, Brown, & Walker, 2000; Parkin, Mackay, & Cooper, 1995). This decreased distance may result in more severe thoracic injuries related to the force exerted by the steering column or airbag deployment. Pre-event phase factors associated with a fall may include physiological loss of muscle mass and lower body strength as a result of inactivity (American Geriatrics Society, British Geriatrics Society, & American Academy of Orthopedic Surgeons Panel on Falls Prevention, 2001) or age-related changes in balance or gait. Likewise, a fall and associated hip fracture may be the result of osteoporosis, especially in older women (Greenspan et al., 1994; Melton, Chrischilles, Cooper, Lane, & Riggs, 1992). Unsafe living environments or a decrease in visual acuity at night can be considered pre-event causative factors. Significant age-related body system changes predispose older adults to injury and their negative sequelae. In addition, these age-related changes influence older adults' responses during the event and post-event phases of injury. Age-related changes in each of these systems are summarized below. These changes need to be evaluated as pre-event causative factors in BTI in older adults, as well as during the management of their traumatic event.

Musculoskeletal System. Age-related changes in the musculoskeletal system result in loss of muscle mass and strength, as well as bone loss. The loss of bone strength contributes to rib fractures, while muscle loss and weakness occur through loss of motor neurons and replacement of muscle with collagen and fat. Breakdown of cartilage and increased rigidity of ligaments are seen as early as age 30 (Kauder, Schwab, & Shapiro, 2004).

Respiratory System. Age-related changes in the respiratory system begin as early as the third decade of life and are influenced by structural and mechanical, as well as extrinsic factors (e.g., cigarette smoking). Chest wall stiffening can begin as early as age 20. After age 30, loss of bone mass, osteoporosis, loss of chest wall elasticity, and rib cartilage calcification contribute to decreased chest wall compliance (Kauder et al., 2004; Lyles, 1997). Other changes in lung function associated with aging include decreases in maximal inspiratory and expiratory flow, strength of respiratory muscles, respiratory drive, diffusing capacity resulting in decreased oxygen uptake, and respiratory response drive, as well as an increase in lung compliance and airway reactivity (Enright, 2009; Narang & Sikka, 2006). Older adults who sustain BTI may be at higher risk for aspiration because of decreased lung defense mechanisms, weaker cough and gag reflexes, swallowing disorders, esophageal sphincter malfunction, and age-related changes in the bacterial content of the oral cavity and upper airways (Allen & Schwab, 1985).

Cardiovascular System. Age-related changes in the cardiovascular system include stiffening of the heart walls due to fat and amyloid deposits and slowing of the conduction system. BTI, as well as resuscitation efforts to treat injuries, may expose the vulnerable cardiovascular system to physical damage and increased physiological demand (Kauder et al., 2004). Cardiac output decreases progressively with aging; a 50% decrease in cardiac output was noted between ages 20 and 80 (Boss & Seegmiller, 1981). Age-relat-

ed changes in the conduction system, loss of beta-adrenergic receptors, and catecholamine insensitivity can begin as early as age 40. These changes decrease the heart's ability to respond to the stress associated with BTI (e.g., reflex tachycardia, increased cardiac output) (Davies, 1992; Lye, 1992). The use of beta-blockers, calcium channel blockers, and pacemakers prevents the older adult's heart from increasing output in response to the stress of BTI (Kauder et al., 2004).

Renal System. Age-associated changes in renal function influence the susceptibility of older adults to the stress of BTI and usual resuscitation therapies. Older adults may have chronic dehydration due to a decrease in the sensation of thirst and the kidney's response to antidiuretic hormone (Kauder et al., 2004). Renal blood flow decreases by approximately 50% by age 90 (Wiggins & Patel (2009). In addition, a 40% loss of glomeruli may occur between ages 30 and 65 (McLachlan, Guthrie, Anderson, & Fulker, 1977). Alterations in renal sodium excretion and reabsorption, decreased renin production, and responses to angiotensin II and aldosterone may predispose an older adults to dehydration (Fish, Murphy, Elahi, & Minaker, 1995).

Neurological System. Structural and functional alterations occur in the nervous system as people age. Ten percent of brain mass is lost between ages 30 and 70 (Schwab & Kauder, 1990). The shrinkage of brain mass creates a space between the inner surface of the cranium and the brain surface, along with stretching of parasagittal veins, predisposing older adults to significant head injury and intracranial hemorrhage with minimal traumatic force (Schwab & Kauder, 1990). Intracellular protein and extracellular plaque deposits associated with dendritic breakdown and atherosclerotic intracranial vessel changes result in cognitive and sensory changes that may increase an older person's risk for BTI (Kauder et al., 2004). Sensory changes include decreases in visual acuity, depth, and color perception; decreased tolerance of glare and bright lights; loss of auditory capability; as well as a decrease in position sense (Kauder et al., 2004). These changes combine to increase the risk of falls and impair driving ability as well as complicate assessment of cognitive status.

Nutrition and Immune System. Older adults often have a decreased nutritional reserve (Robinson, 1995).

The...second-highest reason for hospitalizations, including those associated with blunt thoracic injury, is motor vehicle crashes and other road user-related incidents.

Protein-energy malnutrition is present in 30% to 60% of older adults on hospital admission (High, 2009) and is associated with decreased wound healing, formation of decubitus ulcers, and decreases in cytokine responses to activation of the immune system. While the catabolic response to BTI in older adults is similar to that of younger people, the decrease in pre-injury nutritional reserves and muscle mass often associated with aging heightens the importance of addressing protein losses and replacement in injured older adults once they are in the post-event phase (Frankenfield, Cooney, Smith, & Rowe, 2000).

Aging of the immune system involves both increased responses as well as impairments in function and is closely related to the older adult's nutritional status. Comorbidities predispose older adults to immune system weakness. Older adults have an enhanced inflammatory response, evidenced by elevated C-reactive protein and interleukin-6 levels (High, 2009). Despite this pre-injury enhancement, immune impairments occur, including a decrease in adaptive immune responses, cytokine and cellular surface receptors, and cytotoxic responses. Valente et al. (2009) showed that a delayed neutrophil response in older adults may occur as a response to blunt trauma. These changes contribute to older adults with BTI being predisposed to the development of and death from infection in the post-injury phase when compared with younger counterparts (Aucar & Mattox, 1998).

Comorbidities, Medications, and Alcohol Use. The presence of comorbidities has a significant influence on injury mechanisms, patterns, and recovery. Eighty-two percent of older adults have one or more comorbidities that require treatment, with hypertension, arthritis, and heart disease being the most common (Pleis & Lethbridge-Çejku, 2007). Chronic lung disease is significantly related to death in older adults with rib fractures (Elmistekawy & Hammad, 2007). In addition, both pre-existing cardiopulmonary disease (J.Q. Alexander et al., 2000) and diabetes contribute to complications in this population (Barnea, Kashtan, Shornick, & Werbin, 2002; Bergeron et al., 2003).

Increased medication use and frequent polypharmacy in older adults are important risk factors for BTI. More than 80% of patients ages 64 to 75 are taking medications that increase their risk for BTI (Nordell, Jarnlo, Jetsen, Nordstrom, & Thorngren, 2000), including antidepressant, neuroleptic, sedative, diuretic, antiepileptic, and

glaucoma medications; beta-blockers; and calcium channel blockers (Aschkenasy & Rothenhaus, 2006).

Often, the use of alcohol and other recreational substances is not assessed as a cause of BTI in older adults. In a 3-year study of trauma patients of which 32,382 (24%) were older adults, only 5% were tested for the presence of alcohol. However, 50% of those tested were positive, 72% of whom were intoxicated. The MOI for these individuals included falls (49.5%) and MVCs (36.7%) (Zautcke, Coker, Morris, & Stein-Spencer, 2002).

Influence of Sex, Ethnicity, and Culture on BTI in Older Adults. The influence of sex on the types of BTI and outcomes has not been assessed adequately in older adults. In terms of age, the highest rate of injuries for men (27 per 100 people) occurred in those age 15 to 24. In marked contrast, the highest rate of injuries for women (24 per 100 people) occurred in women 75 and older (Finkelstein, Corso, & Miller, 2006). In a study of fatalities from MVCs, sex differences were found in those 60 and older. Older men had a higher fatality rate than older women (Evans, 2001; Knudson, Lieberman, Morris, Cushing, & Stubbs, 1994). Female sex was identified as a major risk factor for falling (Aharon-Peretz et al., 1997).

Likewise, research on ethnic and cultural considerations associated with BTI in older adults is scant. Given the growing cultural and ethnic diversity of the United States, data should be collected and analyzed to identify differences that could maximize outcomes by highlighting preventive and treatment measures targeted to specific populations. For example, the Health, Aging and Body Composition study found that African American older adults of both sexes had healthier bones and were less susceptible to fractures than Caucasian older adults (Albert, 2007).

Event Phase

The leading cause of all-age traumatic death in the United States and the second-highest reason for hospitalizations, including those associated with BTI, is MVCs and other road user-related incidents. Falls are the leading cause of hospitalizations (Finkelstein et al., 2006). The three most common MOI seen in older adults are falls, MVCs, and PVCs.

Falls. Injuries sustained in a fall are directly related to the distance or height from which the person fell. Dispersion of the kinetic energy on landing depends on the type of surface struck (i.e., cement versus soft soil) and the proportion of the body making initial impact, which affects how the energy load is distributed (Hunt et al., 2004). In 2005, older adults were hospitalized for fall injuries at a rate of 1,177 per 100,000 (Centers for Disease Control and Prevention [CDC] & Merck Company Foundation, 2007). Differences in older subgroups are noted, in that those ages 65 to 69 had a hospitalization rate of 386 per 100,000 while those 85 and older had a rate of 3,370 per 100,000. In two studies (Hausdorff, Rios, & Edelberg, 2001; Hornbrook et al., 1994), it was noted that more than 30% of older adults fall yearly, and this number increases to 50% by age 80 (Tinetti, 1986). Older adults who fall will incur fractures 5% of the time, and between 5% and 10% of these individuals will incur serious injury. Twelve percent will die from injuries related to the fall itself or from a secondary cause (Baraff, Della Penna, Williams, & Sanders, 1997). Sampalis et al. (2009) showed that the mortality rate for older adults who fell was higher (25.3%) than those involved in MVCs (7.8%). Risk factors for falls include older age, history of previous falls, balance and gait abnormalities, arthritis, lower extremity weakness, use of psychotropic medications, and female sex (Aschkenasy & Rothenhaus, 2006). Older adults with four or more risk factors have a 78% chance of falling compared with an 8% chance in those with no risk factors (Tinetti, Speechley, & Ginter, 1988).

The most common blunt injuries sustained from a fall involve isolated extremity trauma (Schwab & Kauder, 1992). However, 25% of older adults sustain more significant injuries including pelvic, hip, and extremity fractures; head injuries; and rib fractures with concomitant pulmonary trauma (Scalea, 1995). Falls in older adults are generally not from great heights but from level surfaces. Most falls occur during daylight hours, with only 20% occurring at night (Cambell, Borrie, Spears, Jackson, Brown, & Fitzgerald, 1990). Colder weather has been shown to increase the risk of falls, especially in women (Campbell, Spears, Borrie, & Fitzgerald, 1988). Ten to twenty percent of all fractures in older adults are caused by falls (B.H. Alexander, Rivara, & Wolf, 1992), 85% of which occur in the home, while only 25% of those are caused by home environmental hazards (Campbell et al., 1997). Many falls in older adults are related to pre-event comorbid conditions such as dysrhythmias, postural hypotension, anemia, and hypoglycemia (Schwab & Kauder, 1992). Falls are often the sentinel event that leads to the discovery of ongoing, previously undetected cognitive decline (Aharon-Peretz et al., 1997). Any older adult who experiences a fall should have a complete medical examination to rule out an underlying medical cause, unless the mechanism was clearly mechanical and witnessed by another person. An environmental evaluation may be necessary if the fall was caused by conditions in the home or site of the fall.

MVCs. Older drivers were found to have a crash rate second only to drivers ages 16 to 25 (National Safety Council, 1991; Santora, Schinco, & Trooskin, 1994). In the 65-to-74 age group, MVCs are the leading cause of injury-related death and are second to falls as the leading cause of death in those 75 and older (Kauder et al., 2004). Deaths from MVCs in older adults are most often side-impact crashes and are found to be the result of driver error (Johnson & Johnson, 2001). MVCs are the primary MOI that results in older adults being taken

to a trauma center. Older adults are more likely to be involved in a MVC in good weather, close to their homes, during daylight, and often in intersections with another vehicle (Rehm & Ross, 1995). They are more likely to be involved in side-impact crashes (Austin & Faigin, 2003).

BTI associated with a MVC is dependent on the location of the person in the vehicle, the speed at which the vehicle is traveling, the use of restraint devices, the type of object struck, and the type of impact, such as frontal or head-on versus lateral or side. Initially in a frontal impact crash, the driver or passenger's upper body comes in contact with the steering column or dashboard, which causes the upper body to absorb the majority of the kinetic energy generated (Daffner, Deeb, Lupetin, & Rothfus, 1988; Mackay, 1992). Lateral or side-impact collisions result in even more significant injuries, as the space between the striking vehicle and the person is much less. The energy dissipation from this type of impact is seen in the lateral chest as well as in the abdomen and pelvis. Chest wall injuries are more prevalent in side-impact crashes than in frontal crashes (Dischinger, Cushing, & Kerns, 1993).

PVCs. Older adults are victims of PVCs more than any other age group (National Safety Council, 1992). In 2005, the crude rate of PVCs in those 65 and older was 10.5 per 100,000 (CDC & Merck Company Foundation, 2007). When divided into subgroups by age, the crude rate of PVCs for those ages 75 to 79 was 19.5 per 100,000, which is more than three times that of those ages 65 to 69 (crude rate of 5.7 per 100,000). Older victims of PVC injury have a death rate seven times higher than those older adults injured from other mechanisms (Loo & Tsui, 2009). Injuries associated with PVCs often involve the lower extremities. However, with the increase in the number of larger vehicles with a higher center of mass (e.g., sport utility vehicles and trucks), more chest and abdominal injuries are occurring (Hunt et al., 2004). As the person is struck in the lower portion of the body, the upper body makes contact with the car hood and windshield, resulting in thoracic injuries such as rib fractures, pneumothorax, hemothorax, and sternal fractures (Lane, McClafferty, & Nowak, 1994; Vestrup & Reid, 1989). Older PVC victims who sustained injury to the chest or abdomen incurred serious injury at a rate 35 times higher than those with lower extremity injuries (Loo & Tsui, 2009).

Fifty percent of all PVC deaths that occur in crosswalks involve older adults (Robbins & Courts, 1997), and 46% of all PVC fatalities in older adults occur in crosswalks (NHTSA, 1991). Pre-event mobility issues may impair an older adult's ability to cross the entire length of a street in the allotted time. This limitation is more apparent in metropolitan areas where streets are wider. Pedestrian crossing signals have a time allotment of 4 feet per second, which many older adults are unable to do (Kauder et al., 2004). Many of the same factors that precipitate MVCs are implicated in PVCs in older adults. The most common sites for blunt injuries are the head, chest, and lower extremities (Johnson & Johnson, 2001).

Specific BTIs in Older Adults. MVCs, falls, and assault with a blunt object are the primary mechanisms for BTIs in the general population (Livingston & Hauser, 2004). Injury severity can range from minimal chest wall contusions to life-threatening injuries with multiple rib fractures and lung tissue compromise requiring tube thoracostomy and mechanical ventilation. In the general population, one third of people hospitalized after MVCs have evidence of significant thoracic injury (Besson & Saegesser, 1983). Those 60 and older were found to have a higher rate of serious thoracic injury, defined as an Abbreviated Injury Scale score of 3 or greater in any one body region, following a MVC than younger trauma patients (Newgard, 2008). Morbidity and mortality rates related to BTI doubled (22%) in those older than 60 compared with younger patients (10%) (Bergeron et al., 2003; Sirmali et al., 2003). Injury to the thorax in older adults following a MVC more than doubled in those 70 and older compared with those ages 55 to 69 (Bauzá, LaMorte, Burke, & Hirsch, 2008), and those 80 and older had more serious thoracic injury, which outnumbered all other injury types (Newgard, 2008). Bergeron et al. (2003) found that falls were the cause of rib fractures in 75% of older adults.

Although mechanisms of BTI in older adults vary, the forces that act on body structures are similar and allow for the prediction of specific injury patterns (Hunt et al., 2004). In BTI, displacement of the chest wall inward due to compressive forces from sudden impact is the primary cause of injury regardless of mechanism, often resulting in sternal and rib fractures. Indirect rib fractures may be seen distant from the area of energy exchange, specifically with energy concentrated at the lateral and posterolateral rib cage areas (Hunt et al., 2004). Older adults have higher morbidity and mortality rates related to rib fractures and flail chest and have a higher susceptibility to fractures of the sternum (Bulger, Arneson, Mock, & Jurkovich, 2000). The blunt energy exchange may permeate deeper into the thorax, causing damage to lung parenchyma (e.g., pulmonary contusions) or may cause air-filled lungs to rupture, causing pneumothorax and/or hemothorax. Cardiac and great vessel injury may also occur from a combination of these forces.

Rib Fractures, Flail Chest, Pneumothorax, and Hemothorax. The incidence of traumatic rib fractures in the older population is approximately 60%, while in younger patients it is 10% (Victorino, Chong, & Pal, 2003). Older adults with three to four rib fractures had a 31% rate of pneumonia and a 19% mortality rate. When the number of ribs fractured increased to six, 51% developed pneumonia and 33% died (Bulger et al., 2000). Kieninger, Bair, Bendick, and Howells (2005) recommended hospital admission for older adults with more than two rib

TABLE 2

RESEARCH QUESTIONS PERTAINING TO OLDER ADULTS WITH BTI, ACCORDING TO PHASES OF HADDON'S PHASE-FACTOR MATRIX MODEL

Pre-Event Phase	Event Phase	Post-Event Phase
1. Is there a need for increased safety education (e.g., driver training, pedestrian safety) of older adults for specific physical and recreational activities that predispose them to BTI? 2. What role does specialized physical and endurance conditioning play in the prevention or minimization of BTI injury in this population? 3. Does education about and assessment of home safety risks decrease the occurrence of in-home, fall-related BTI injuries in older adults? 4. What changes could be made to municipal infrastructures (e.g., traffic signal and pedestrian crosswalk visibility and timing) that would decrease the number of injury events in the older population? 5. Does mandatory testing of older drivers by state agencies that issue drivers licenses decrease the rate of motor vehicle crashes and pedestrian versus vehicle crashes in this population? 6. Does education about pharmacological interactions and side-effects of common medications prescribed to older adults (e.g., opioid, anti-platelet, anticoagulant agents) decrease the occurrence of BTI in this population? 7. Does substance use (e.g., alcohol) treatment and prevention education for older adults help decrease their incidence of trauma resulting in BTI? 8. Does the position of an older passenger in a vehicle (e.g., back seat) influence the type and incidence of BTI in this population?	1. Do the redesign and/or reengineering of safety devices (e.g., passenger restraint systems, air bags) influence the type and severity of BTIs seen in older adults? 2. Does prevention and treatment of osteoporosis help decrease the types and incidence of BTI in older adults? 3. Does the position of an older passenger in a vehicle (e.g., back seat) influence the type and incidence of BTI in this population?	1. Does routine screening (e.g., x-rays, computed tomography scans) of asymptomatic older adults with BTI help identify specific, unsuspected injuries? 2. Does routine use of invasive monitoring (e.g., pulmonary artery catheterization, central venous pressure) to manage fluid resuscitation of older adults with BTI help decrease the development of adverse sequelae (e.g., atelectasis, acute respiratory distress syndrome, pneumonia)? 3. Do standardized orders, availability of practice guidelines, and/or education of care providers for and about acute pain management of older adults with BTI decrease the occurrence of adverse sequelae? 4. Does post-event safety education of the BTI patient and/or significant other affect the rate of re-injury in the older population? 5. Is there a relationship between presence of comorbidities, mechanism of injury, type and severity of BTI, acute pain management, and mortality rates in the older population?

Note. BTI = blunt thoracic injury.

fractures and intensive care unit (ICU) admission for those with more than six rib fractures. Seat belts were found to be the cause of rib fractures in older adults more frequently in low- and medium-speed crashes (Shimamura, Ohhashi, & Yamazaki, 2003).

Flail chest is defined as three or more contiguous ribs broken in more than one place (Livingston & Hauser, 2004). It occurs more frequently in the anterior and anterolateral chest wall areas and in the middle and lower areas of the rib cage. It is more common in thinner older adults, and mortality from flail chest increases with age (Albaugh et al., 2000). Mortality rates double if pulmonary contusions occur with flail chest (Clark, Schecter, & Trunkey, 1988). Flail chest causes dysfunction of the mechanics of ventilation, but the associated respiratory failure is attributed to the pulmonary contusions that underlie the flail segment (Craven, Oppenheimer, & Wood, 1979). Pulmonary contusions lead to decreased lung compliance and shunting of unoxygenated blood. The structural abnormalities in the chest wall and the pain caused by the numerous rib fractures contribute to impaired ventilation. Pneumothorax, which is collapse of lung tissue, is seen in 20% of patients who admitted to trauma centers following BTI (Di Bartolomeo et al., 2001). Both pneumothorax and hemothorax (blood in the pleural cavity) are frequently associated with rib fractures.

Post-Event Phase

The post-event phase of Haddon's model as it relates to older adults with BTI begins immediately after the cessation of the injuring force. It includes care rendered from the time of the event, through resuscitation, to outcomes that occur following discharge from the hospital. In addition, it includes outcomes that may influence the remaining life span of the older adult. Older drivers involved in a MVC who require hospitalization have increased mortality rates, longer lengths of stay, and are less likely to be discharged to home (Bauzá et al., 2008). Higher post-injury complication (e.g., pneumonia, sepsis) rates (33%) have been reported in older adults compared with a younger cohort (19%) (Knudson et al., 1994). Sixteen percent of older adults with BTI develop complications—most often pneumonia—in the post-event phase; those 85 and older, those with hemothorax, pneumothorax, or three or more rib fractures or pulmonary contusions were the subgroups most at risk (Lotfipour et al., 2009).

Older drivers involved in a motor vehicle crash who require hospitalization have increased mortality rates, longer lengths of stay, and are less likely to be discharged to home.

Deaths from trauma occurring in the post-event phase demonstrate a tri-modal distribution (American College of Surgeons, Committee on Trauma [ACSCT], 2008). The first peak occurs within seconds to minutes after the injury. The second peak occurs within minutes to hours, and the third peak occurs several days to weeks after the injury. Deaths that occur at the third peak are most often related to infections and multiple organ system failure (ACSCT, 2008). Death rates from trauma in the older population range from 15% to 30% compared with 4% to 8% in a younger trauma cohort (Schwab & Kauder, 1992). Data from regional and national trauma data banks indicate a significant increase in the all-injury death rate from MVCs in those 70 and older (Bauzá et al., 2008; Caterino, Valasek, & Werman, 2010). Initial work to predict mortality found that trauma patients older than 50 had a higher mortality rate than younger patients, despite their level of injury severity (Baker, O'Neill, Haddon, & Long, 1974). More recently, the overall mortality rate for older adults was found to be 89% higher than for younger patients regardless of the MOI or body regions involved (Finelli, Jonsson, Champion, Morelli, & Fouty, 1989). Caterino et al.'s (2010) study showed a significant trauma mortality increase in those ages 70 to 74 compared with any other age group. Age 65 and older was found to be a significant predictor of mortality within 24 hours of injury in those with multiple rib fractures following a MVC (Lien, Chen, & Lin, 2009).

Role of Emergency Medical Services (EMS). Injured older patients have the potential of being exposed to all services and departments within the hospital and trauma system. Their trauma care often begins in the pre-hospital setting with EMS and progresses to the emergency department (ED) or trauma resuscitation area. In fact, one third of all patients 65 and older who arrive at the ED do so by ambulance (Singal et al., 1992; Strange, Chen, & Sanders, 1992). Older patients often require more advanced life support procedures and more time for post-event stabilization at the scene before transport to the hospital (Dickinson, Verdile, Kostyun, & Salluzzo, 1996). Studies show that having a very low threshold for transporting injured older adults to a designated trauma center reduces morbidity and mortality (Finelli et al., 1989; Jacobs et al., 2003).

Often, EMS providers have the opportunity to examine the older adult's home environment. They can provide valuable information to the care team regarding the person's living conditions (e.g., possible hazardous living situations), which must be addressed prior to discharge (Aschkenzsy & Rothenhaus, 2006).

Goals of Initial Trauma Resuscitation and Clinical Implications Associated with the Care of Older Adults with BTI. The overall mortality rate from any blunt traumatic mechanism in older adults is approximately 44% (Scalea et al., 1990). This rate increased to 85% when they had the following risk factors: injury from PVCs, multiple traumatic injuries, an initial systolic blood pressure <130mm Hg, acidosis, multiple fractures, or head injuries. Approximately 65% of deaths occur late in the post-injury phase, usually from multiple organ failure (Scalea et al., 1990). Knudson et al. (1994) found that age 75 or older, systolic blood pressure of <90 mm Hg, respiratory rate of less than 10 breaths per minute, or a Glasgow Coma Scale score of 3 were all associated with increased mortality.

The ACSCT (2008) details very specific procedures for conducting the initial assessment and resuscitative management of trauma patients in their advanced trauma life support (ATLS) guidelines. ATLS guidelines currently teach clinicians to routinely insert two large-bore (14 to 16 g) intravenous catheters and to give adults an initial bolus of 1 to 2 liters of crystalloid fluid. Because of comorbidities and physiological changes in the cardiovascular and pulmonary systems, many older adults cannot manage this rapid infusion of a large amount of fluid. The monitoring of fluid status through measurement of central venous pressure (CVP) or intracardiac pressures could prevent accidental fluid overload and subsequent lung tissue injury and complications. While invasive central pressure monitoring is not standard of care for all patients, evidence suggests that, for older adults, preemptive insertion of a central venous catheter to guide fluid resuscitation may be warranted (Scalea et al., 1990). This study used early, invasive monitoring of cardiac outputs with pulmonary artery catheterization on a subset of older PVC victims and found that early mortality was reduced from 93% to 47% with more rapid initiation of monitoring in the ICU. If a pulmonary artery catheter cannot be inserted, the use of a CVP catheter to monitor fluid status and serial arterial blood gases to monitor base deficit are minimal recommendations for monitoring resuscitative endpoints (Tisherman et al., 2004).

Most BTI can be determined through radiological studies. The early and liberal use of both plain film chest radiographs (x-ray) and computed tomography (CT) identifies specific BTIs. However, aortic dissection and as many as 50% of rib fractures can be missed by chest x-ray (Palvanen, Kannus, Niemi, & Parkkari, 2004; Ziegler & Agarwal, 1994). Chest CT has been shown to be a more accurate tool for diagnosis of rib, scapular, and sternal fractures; pulmonary contusions; and pneumothoraces (Livingston, Shogan, John, & Lavery, 2008; Magu, Yadav, & Agarwal, 2009; Traub et al., 2007). Many radiological studies involve the use of contrast dye, which may cause damage to older adults' renal system, especially if it is already compromised by age-related changes. When contrast dye is used, the risk of developing nephropathy is more prevalent in those older than 75 and those with comorbidities (e.g., diabetes, renal insufficiency), dehydration, hypotension, and heart failure (Weisbord & Palevsky, 2005).

Early and continued assessment of renal function through assessments of blood urea nitrogen and creatinine are routine components of the resuscitation phase. In ICU patients who develop multiple organ dysfunction syndrome, a 50% or higher mortality rate occurs with the development of acute renal failure (Bartlett, 1996). Fluid resuscitation of injured older adults is paramount to preventing hypovolemia, hypoperfusion, and acute tubular necrosis (Kauder et al., 2004). Early assessment and management of pain is needed to conduct a thorough diagnostic evaluation as well as relieve discomfort and anxiety in older trauma patients. The inclusion of geriatric-trained care providers as part of the trauma team has been shown to aid in the identification of injured older adults with alcohol-related issues, delirium, and inappropriately prescribed medications, as well as assisting with disposition and advanced care decisions and acute pain management (Fallon et al., 2006).

Disposition and Clinical Outcomes of Hospitalized Older Adults with BTI. Post-event outcome measurements in older adults with BTI have included the development of complications, functional ability, and discharge disposition. Older trauma patients are more likely than younger trauma patients to develop multiple organ dysfunction syndrome and sepsis, leading to death (Kauder et al., 2004). The development of nosocomial infections not only increased ICU days and overall length of stay but also resulted in mortality rates more than five times higher for older adults (28%) versus younger patients (5%) ($p < 0.005$) (Bochicchio, Joshi, Knorr, & Scalea, 2001).

Injury can result in both long-term and permanent functional and cognitive disabilities, which are often more apparent in older trauma patients. One study that evaluated moderately injured blunt-trauma patients 65 and older—97% of whom were independent pre-injury—found that at discharge 33% were independent, 37% were dependent in their home, and 30% required nursing home placement (DeMaria, Kenney, Merriam, Casanova, & Gann, 1987). Follow-up data collected at 19 months post-hospital discharge found that 57% were independent, 32% remained dependent at home, and 11% remained in a nursing home. Another study that

KEYPOINTS

Hawk, M., Cataldo, J., Puntillo, K., & Miaskowski, C. (2012). **Blunt Thoracic Injury in Older Adults: Application of Haddon's Phase-Factor Matrix Model**. *Journal of Gerontological Nursing, 38*(2), 14-27.

1. Injury is the sixth-leading cause of death for adults ages 65 to 74 years, and the seventh- and ninth-leading causes of death for ages 75 to 84 and 85 and older, respectively.
2. Compared with the younger population, older adults have higher morbidity and mortality rates from rib fractures and flail chest, as well as a higher susceptibility to sternal fractures.
3. Hospital admission is recommended for older adults with more than two rib fractures and intensive care unit admission for those with more than six rib fractures.
4. Adults 85 and older and those with hemothorax, pneumothorax, three or more rib fractures, or pulmonary contusions are the subgroups most at risk for developing complications.

conducted follow-up evaluations of patients 65 and older at 3 years post-BTI found that 33% were independent, 51% had died, and 16% were dependent (van Aalst, Morris, Yates, Miller, & Bass, 1991). Patient age of 75 was a significant factor associated with death and dependency. Older adults who incurred injuries of any type were more likely to sustain repeated trauma, with two predictive factors being age older than 81 and the presence of comorbidities, especially mild liver disease (Gubler et al., 1996). Although the correlation of liver disease and alcohol use was not examined in this study, the known relationship should be addressed in preventing trauma recidivism in older adults.

IMPLICATIONS AND RECOMMENDATIONS

As the number of active, older adults increases, the predisposition for BTI intensifies the need for funding and support of research at each phase of the injury event (**Table 2**). Pre-event topics for BTI research with older adults include public policy, driver safety education, physical conditioning, home safety evaluations and education, as well as vehicle and equipment design. Data to support standardization of the definition of *older adult* are also needed. On the basis of their data, Caterino et al. (2010) suggested using an age of 70 and older as the definition of *older* for the purpose of trauma research. Safety device design and disease prevention are an example of event-phase research topics. Post-event topics include the influence of comorbidities and gender on injury patterns, as well as resuscitation protocols for older adults. Implications of not investigating these phenomena include not only the costs of extended and perhaps mismanaged care, but also worse outcomes; more costly dispositions from hospital, such as to skilled nursing facilities; and decreases in quality of life that may be permanent.

Implications for gerontological nurses include pre-event involvement in public health safety issues; injury prevention education to older adults, their families and caregivers; and home environment safety evaluations. Coordinating with local and state law enforcement agencies to provide safe driver evaluations for older adults, reporting to the proper licensing bodies those older adults who are no longer safe to drive, and ensuring that crosswalks are well timed and designated as highly concentrated older adult crossing areas. Acute care setting implications include being aware of the normal physiology of aging and how the effect of pathological processes caused by certain injury patterns can accelerate decline; knowing how to prevent complications by early mobilization; administering adequate and appropriate pain management; and providing the appropriate level of care that provides adequate physiological monitoring, such as telemetry and pulse oximetry.

CONCLUSION

The growing number of older adults who are physically more active while still experiencing the process of physical aging is forcing a need for education about the prevention, specific acute care treatment needs, and the importance of early rehabilitation. This article has explored the more common MOIs in this aging cohort, highlighted the need for additional research regarding injury and treatment in this rapidly growing segment of our society, and encouraged gerontological nurses to look at older adults from a new perspective when they are faced with the potential for injury or once injury has occurred.

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