1-1-2011

The Relationship Between Daily Snowfall Accumulation and Pattern and Severity of Traumatic Injuries at a U.S. Ski Resort

S. Jason Moore
Walden University

Walden University

COLLEGE OF HEALTH SCIENCES

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S. Jason Moore

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David Clinefelter, Ph.D.

Walden University
2011

Abstract

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by

S. Jason Moore

MS, Arizona School of Health Sciences, 2004

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Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

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Public Health

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Abstract

Throughout the relevant literature, research addressing the impact of a specific environmental factor, such as snowfall, on injury patterns or severity among alpine skiers and snowboarders is sparse. The foundation for inquiry into this relationship was developed based on principles of physics and traumatology coupled with findings in the available literature. Secondary analysis of trauma registry data coupled with daily snowfall measurements from one of the largest ski areas in North America illustrated a negative correlation between daily snowfall amount and injury severity (r = -.08). Concordant findings demonstrated an increased odds of sustaining an injury defined as severe or critical according to Injury Severity Score (ISS) classification when there was less than two inches of fresh snowfall (OR = 3.9; 95% CI[1.06, 16.69]). Additionally, utilizing the Abbreviated Injury Scale (AIS), a regional anatomical finding illustrated that in the absence of recent snowfall, there was an increased odds of sustaining a thoracic injury defined as severe in this patient population (OR = 10.4; 95% CI[1.62, 66.9]). Secondary research considerations detailed the variances in injury severity resulting from a collision when compared to a fall and the predilection for skiers to sustain increased lower extremity injuries when compared to snowboarders. Findings from this project may lead to positive social change as the increased understanding of predictive factors contributing to injury can be directly applied to further the current understanding of trauma care in this patient population. The benefits from this work may also extend to the public health arena through enhanced educational opportunities for skiers and snowboarders as well as enhanced resort safety initiatives tailored to the ambient conditions.

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Chapter 1: Introduction to the Study

The epidemiological study of traumatic injuries began with the authorization of the U.S. Department of Transportation by the U.S. Congress in 1985 to examine the existing areas of knowledge and determine areas in need of further research regarding the practice of trauma care (Jacobs & Jacobs, 1996). The mechanisms of injury, associated injury patterns, and the severity of injuries resulting from recreational trauma are potentially such areas. Personal observations from a critical access hospital in the central Rockies coupled with findings from the available literature have demonstrated that large snowfalls decrease the severity of traumatic injuries to the head, thorax, and abdomen leading to a relative decrease in severity scoring (Girardi, Braggion, Sacco, DeGiorgi, & Corra, 2010). This anatomical distribution seen with varied snowfall amounts is consistent with distinct differences in the severity and anatomical patterns of traumatic injuries sustained at a large Colorado ski resort. Until the true extent of the relationship between injury severity and the contribution of environmental factors is defined, the true degree of association is unknown.

Current literature on the topic of injuries sustained while alpine skiing or snowboarding and the effect of snowfall demonstrates a lack of research defining the relationship between these variables. A literature review provides numerous studies detailing snow sport injuries but lacks a definitive correlation between environmental conditions and injury. These works, although diverse, do not address the relationships between injuries and daily snowfall amounts. It is here where a gap in the literature and current understanding exists as this relationship, as it pertains to snow-sports, has yet to be defined. The paucity of research qualifying and quantifying the relationship between snow depth, injury patterns, and severity was likely multifactorial. The logistics of data collection and management are challenging as, after initial triage at a base clinic, many ski-resorts are serviced by multiple health-care facilities. This system spreads patients among facilities potentially utilizing variable trauma systems, documentation modalities, and auditing methods. Second, adequate population size is an additional challenge for a study of this sort as inclusion criteria as well as standardization of trauma admissions is challenging when spread among multiple facilities. Utilizing patients from a single healthcare facility that services one of the largest ski areas in North America provided ample trauma patients requiring hospital admission providing adequate power to the research as well as allowing for consistency in measures.

The Study: Resort, Hospital, and Relevant Components of the Trauma System

The resort, located in Colorado, is one of the largest ski resorts in North America and boasts over 5,000 skiable acres. The disciplines studied in this project included alpine skiing and snowboarding and are permitted on the resort with unlimited access to all resort areas. The resort proper contains (a) groomed ski runs, (b) terrain parks, and (c) open areas for skiing exemplified by numerous “bowls” of expansive terrain. The elevation of the base area and adjacent town is roughly 8,000 feet above sea-level while the highest point on the resort is over 11,500 feet above sea-level. The resort is serviced by a single medical facility located in the municipality at the base of the mountain.

The host medical facility has been in operation for over 40 years, is a Level III Trauma Center, and has an inpatient capability of nearly 60 beds. The facility provides medical services for both resort guests and a resident population of over 50,000 people. Relating to the resort in this research, this facility is the sole, initial provider of medical services for those injured while partaking in snow-sports activities on the host resort. Patients injured on the resort are transported from the mountain to the base area by ski patrol and occasionally by helicopter transport to the local facility or to tertiary care centers in neighboring urban areas. Infrequently, injured patients will bypass all available transportation options and present to the hospital as a walk-in. This modality, although infrequent, does not negate the possibility of serious injury obtained while on the resort. For the majority of patients, once at the base area, patients are transferred by ski patrol to a designated skier transport system, or if the suspicion for significant injury is high, to local emergency medical services (EMS) for transport to the hospital emergency department (ED). Both ski patrol and local EMS have the option of initiating a Trauma Team Activation (TTA) or Trauma Alert (TA) at any point in the transport process. A TA is based on suspicion of injury and notifies the emergency room physician of the possibility of a potentially seriously injured patient enroute, while a TTA is based on physiologic criteria and alerts the institution to mobilize resources to care for a seriously injured patient.

Trauma patients admitted to the host facility or who were transferred to a higher level of care were included in this study. Conversely, patients who were discharged from the ED or who sought medical care at alternative facilities were excluded from this work. After initial evaluation in the ED, specialty consultation was obtained and the determination for admission was made. Current standard operating procedure within the host facility dictates that all patients admitted with a traumatic injury are followed by the trauma registrars' office of the host facility to ensure appropriate consultations are obtained and to collect and manage data relevant to the care of the patient and the organization. The registrar's office then submits relevant data to the Colorado Department of Public Health for organizational surveillance and accreditation measures. As the principal researcher and an active member of the trauma team, personal observations have demonstrated that during periods of large snowfall, the clinical activity of the trauma service is diminished. Trauma consultation and management is required for all patients who present with significant injury, thus there was an apparent, inverse relationship between significant snowfall and injury severity at the host institution. It was in the wake of this observation that this study was developed and implemented in the hopes of adding clarity to the relationship between snowfall and the severity and patterns of traumatic injuries sustained at the host resort.

Statement of the Problem

The basic premise of this research was to define the correlation between daily snowfall depth and the severity and patterns of snow-sport related injuries from a major resort area. Personal observations demonstrated concordance with existing research and have shown that large snowfalls are associated with a relative decrease in Injury Severity Score (ISS) totals in trauma patients transported from the host resort (Girardi et al., 2010). It is unclear if this correlation is due to an increase in traumatic injuries to the appendicular skeleton with a decrease in axial skeletal, intracerebral, thoracic, and abdominal injuries leading to decreased overall injury severity, or to some other mechanism. In this work, daily snowfall amounts were recorded with the intent to correlate snowfall with the Abbreviated Injury Scale (AIS) as well as the ISS totals on all patients admitted with a traumatic injury sustained while skiing or snowboarding at the host resort. Analysis of the stated variables aided in the determination if this proposed, inverse relationship between daily snowfal and injury severity existed. Until the true extent of the relationship between snowfall and injury severity had been substantiated and defined, the correlation between snow depth and injury was unknown and personal observations and experience among providers and ski resort personnel remained unvalidated.

The Nature of the Study

The prompting for this research revolved around personal observations, consistencies in the available literature, the kinematics of trauma, and basic principles of physics. Personal evaluation and medical care provided for patients injured while skiing or snowboarding demonstrated consistencies between injuries and ambient outdoor conditions. This study employed a quantitative, observational design using archival data from the trauma database of the host hospital as well as snowfall data for the 2010-2011 ski and snowboard season from the host resort to address the following research questions. A more detailed discussion of statistical methodologies employed to test these hypotheses can be found in chapter 3.

Research Questions and Hypotheses

Question 1: Does snowfall depth affect the overall severity of injuries, based on the Injury Severity Score, sustained while alpine skiing or snowboarding at the host ski resort?

$H_0 1$: Daily snowfall amounts do not affect the severity of injuries, based on the Injury Severity Score, sustained while alpine skiing or snowboarding at the host ski resort.

H_a1: Daily snowfall amounts affect the severity of injuries, based on the Injury Severity Score, sustained while alpine skiing or snowboarding at the host ski resort.

Question 2: Does snowfall depth affect the severity of injuries relative to anatomical pattern(s), based on the Abbreviated Injury Scale, sustained while alpine skiing or snowboarding at the host ski resort?

H_02: Daily snowfall amounts do not affect the severity of injuries, relative to anatomical pattern(s), based on the Abbreviated Injury Scale, sustained while alpine skiing or snowboarding at the host ski resort.

H_a2: Daily snowfall amounts affect the severity of injuries, relative to anatomical pattern(s), based on the Abbreviated Injury Scale, sustained while alpine skiing or snowboarding at the host ski resort.

Question 3: Does snowfall depth affect the mortality of trauma patients who sustained injuries while alpine skiing or snowboarding at the host ski resort?

H_03: Daily snowfall amounts do not affect the mortality from traumatic injuries sustained while alpine skiing or snowboarding at the host ski resort.

H_a3: Daily snowfall amounts affect the mortality from traumatic injuries sustained while alpine skiing or snowboarding at the host ski resort.

Question 4: What are the statistical associations between snowfall depth and specific snow sport injuries sustained while alpine skiing or snowboarding at the host ski resort?

H_04: There is no relationship between snowfall depth and specific snow sport injuries sustained while alpine skiing or snowboarding at the host ski resort.

*H_a*4: There is a relationship between snowfall depth and specific snow sport injuries sustained while alpine skiing or snowboarding at the host ski resort.

Purpose of the Study

The purpose of this work was to define the relationship between daily snowfall amounts and the patterns and severity of traumatic injuries due to snow sport participation at one of the largest ski resorts in North America. Additional goals of this study were to correlate the daily snowfall depth with (a) the anatomical location of injury, (b) injury severity, and (c) patient mortality, in the hopes of increasing the understanding of predictive factors relating to traumatic injuries sustained while alpine skiing or snowboarding subsequently improving the care of the trauma patient in this setting.

Theoretical Framework of the Study

The current body of literature demonstrated a true paucity of works dedicated to an in-depth analysis of the correlation between environmental factors and injury severity in snow-sports. An appreciation for typical injury patterns and severity among skiers and snowboarders is well described in the available literature while a correlation between daily snowfall amounts and these injuries is more difficult to ascertain. A multiseason study in the South Tyrol region of the Italian Alps published in 2010 described a statistically significant negative correlation between ISS and snowfall (r = -0.05, CI = -0.01, -0.08), p = .009; Girardi et al., 2010). This work, although comprehensive, is confounded by the persistent utilization of man-made snow on the respective resorts that may have contributed to injury severity. Regardless, the authors found that the use of "daily produced…powder-like groomed artificial snow… [made] the slope *faster* and easier to ride" (Girardi et al., 2010, p. 1808). It was the conclusion of the researchers that small amounts of new snow “enhanced the possibility of high-speed accident[s]” (Girardi et al., 2010, p.1808). It is a consideration that small amounts of daily snowfall allow for increased skier speeds contributing to injury severity. A study by Bergstrom and Ekeland (2004), specifically addressing trail design, found that slope grooming (with subsequent snow compaction) increased the frequency of injuries as well as their respective severity (Bergstrom & Ekeland, 2004). Although infrequently discussed, the relevant, available literature on the topic of the contribution of snowfall to injury severity demonstrates consistency among researchers showing an inverse relationship between snowfall and injury severity (Girardi et al., 2010). It is the current ambiguity in regard to this relationship in the available literature that had prompted this research.

In conclusion, the theoretical framework for this research is multifactorial in nature. Personal observations in caring for trauma patients supplemented with established scientific principles from the disciplines of physics and traumatology as well as findings in the available literature formed the foundation for inquiry into the relationship between daily snowfall depth and the severity and patterns of traumatic injuries sustained while skiing or snowboarding.

Definition of Terms

Abbreviated Injury Scale (AIS): The AIS is an anatomic grading scale used to assign severity to injuries in anatomical regions. The AIS severity scale ranges from a minor injury with a score of 1, to a critical injury with a score of 6. The nine anatomical regions are as follows: head, face, neck, thorax, abdomen, spine, upper extremity, lower extremity, and skin/other (Genarelli & Wodzin, 2005).

Alpine skiing: This discipline involves planing down a snow-covered hill on two planks with fixed bindings.

Bowl: an open, sparsely treed, concave geographic feature of a ski area.

Facility: this refers to the hospital that is located in the town at the base of the resort. This hospital services guests injured on the resort with the exception of those who are airlifted directly from the resort to a higher level of care and those who choose to seek medical attention elsewhere or refuse to seek care. The facility is a 60-bed acute care facility with a Level III trauma designation.

Hospital: Traditional meaning of the word and used interchangeably with "facility" in this study.

Injury Severity Score (ISS): The ISS is an injury score that attempts to reflect overall bodily injury severity. The ISS is a calculated measure obtained from the sum of the highest AIS score in the three most severely injured distinct anatomical areas after they have been squared. The ISS range is from 1 to 75 (Pohlman et al, 2010).

Racecourse: a ski run (see definition), with a fixed start and end point where skiers compete with the goal of spanning the distance between points (by skiing) in the shortest time frame.

Resort: this refers to the ski resort utilized in this research. All traumatic injuries in this work were sustained while alpine skiing or snowboarding on the resort.

Ski Run: the area(s) within a ski resort boundary where: skiing is performed, grooming takes place, and skier assistance is available through the ski-patrol of the host resort.

Snowboarding: This discipline involves planing down a snow-covered hill on a single board with two bindings affixed to support the rider's feet.

Terrain Park: a demarcated zone within a ski area populated by man-made features used by both skiers and snowboarders.

Trauma Team Activation (TTA): an alert mechanism by which prehospital providers may alert the hospital to mobilize resources needed to care for a severely injured patient. This alert is based on physiologic criteria such as systolic blood pressure, heart rate, and respiratory rate, combined with physical examination findings. When activated, resources such as surgical teams, radiologists, laboratory personnel, respiratory therapists, operating room personnel are mobilized in anticipation of receiving a severely injured patient.

Trauma Alert (TA): this is an alert mechanism by which the emergency physician is notified of a potentially seriously injured patient prior to the arrival in the ED. It is the duty of the emergency physician to meet the patient upon arrival and determine if the clinical condition warrants escalation of the facility response to Trauma Team Activation. This alert is based on mechanism of injury and provider concern, without overt, objective physiologic criteria.

Assumptions of the Study

Assumptions made in this project include:

1. The diagnoses and radiographic findings found in the medical records were complete and accurate.
2. There was a completed medical record for all patients that fit the inclusion criteria for this project.

3. Hospital admission or transfer was directly related to the current, traumatic injury and not to concomitant medical issues.
4. Patients who sustained significant traumatic injuries while partaking in snow-sports on the host resort were evaluated at the resident healthcare facility.
5. All patients admitted with a traumatic diagnosis had been either: alpine skiing or snowboarding.

Scope and Delimitations of the Study

The following are deliberate inclusions and exclusions from the project that may limit the scope of the findings and subsequent conclusions of the research:

1. Data was collected from patients who had been admitted to the host facility or transferred for a higher level of care from the host facility. The goal of this work was to capture those patients with injuries severe enough to warrant admission for inpatient management, urgent operative intervention, or those with injuries serious enough to necessitate transfer to a tertiary care center. Those patients with relatively minor injuries who were evaluated in physician offices or the emergency department and discharged home do not undergo severity score tabulations, are not tracked as part of the hospital's trauma system, and subsequently were excluded from this work.
2. Patients who have concomitant medical and traumatic issues were treated as trauma patients for the purpose of this study. Although an infrequent occurrence, a medical issue that precipitates a traumatic event may falsely elevate the number of patients presenting with a traumatic injury as the primary etiology.

3. Although snowfall measurements were accounted for in this work, additional ambient conditions were not. Sunlight, new snowfall (since measurement), fog, wind, trail conditions, and other variables may affect participant's abilities to ski safely and were not addressed in this work.
4. Skier patient factors such as fatigue and intoxication, among others, were not addressed in this work although potentially contribute to injury severity.
5. The mountain location where the injuries occurred was variable. The host resort has quite varied terrain including: groomed runs, terrain parks, and racecourses. All of these options are open to the public on a regular basis, while weather or other variables may affect closings of certain areas at certain times. The specific geographic locations of the traumatic events were unknown.
6. Delays in final diagnosis with subsequent missed diagnosis may have occurred secondary to patients being transferred to another facility where follow-up data sharing was inadequate or absent.
7. There is the possibility of missed injuries, which were not available for scoring and interpretation purposes.
8. Resident status and the inherent familiarity with the host resort was not recorded although, admittedly, may influence skiing behavior and subsequent injury severity.

Limitations of the Study

The following are deliberate inclusions and exclusions from the project that may limit the interpretation or generalizability of the findings and subsequent conclusions of the research:

1. There was the potential for alternate snowfall characteristics (e.g. water content) to influence injury severity that could alter findings in geographical areas with different snow characteristics from the host resort, which was not analyzed in this work.
2. There was the potential for variable snow characteristics, terrain, skier ability levels, resort characteristics, personnel variances, and other factors to limit the generalizability of findings from this work to alternate ski areas and populations.
3. Due to the proprietary nature of figures regarding the number of skiers utilizing the resort on a given day, frequency calculations were not feasible for this work. Factors affecting the available skier population on a given day, week, or month includes: weather conditions, highway closures, holiday crowds, lift-ticket prices, community events, and the ambient economic environment, among others.
4. This work only included patients evaluated and treated in a single hospital over a single ski and snowboard season thus limiting the total number of participants in the research.

5. A major limitation of this study included the inherent limitations of the Injury Severity Score. These limitations are discussed by Pohlman, Bjerke, and Offner (2010):
    a. Due to the fact that the ISS calculation relies on the highest graded injury per anatomical region (from the AIS), only a single injury per region can be utilized in the calculation of the ISS. This does not allow multiple injuries in a single body region to be factored into the ISS.
    b. The total number of injuries utilized in the ISS calculation is three, regardless of the actual number of injuries or their severity. This fact is especially challenging when attempting to grade penetrating injuries, as the likelihood of multiple injuries is high.
    c. Although all anatomical areas are equally weighted when calculating the ISS, this fact does not account for anatomical areas with a propensity for increasing injury severity. An example of such an area is the head. Head injuries are a major component (30.5%) of all deaths due to traumatic causes in the United States; yet carry no additional weight in the calculation of the ISS (Faul, Xu, Wald, & Coronado, 2010).
    d. The utilization of the ISS as a predictive model is vague as a multitude of injury combinations can provide an identical ISS score (Pohlman, Bjerke, & Offner, 2010).

Significance of the Study

Characterizing the mechanism of injury, though not absolute, provides an index of suspicion for significant and possibly occult injuries based on the mechanism. An appreciation for the effect snowfall has on injury patterns and injury severity may change the diagnostic evaluation of patients injured while partaking in snow-sports in much the same way that high-speed motor vehicle collisions warrant a more aggressive diagnostic approach to the injured patient. Results of this work directly contribute to the body of medical knowledge in the field of traumatology as well as provide for increased educational opportunities for medical practitioners in mountain resorts. Lastly, the relationships identified between daily snowfall and injury severity provide for increased educational opportunities for skiers, snowboarders, as well as ski-resort personnel.

Statement for Social Change

The significance of this research from a social change perspective encompasses both the relationship between the resort and the general public in terms of safety, as well as the potential significance of the clinical applications in the medical arena. Mountain resorts may choose to alter signage and patroller placement emphasizing speed control when appropriate based on the ambient snow conditions. Additionally, findings from this work provide more accurate indices of injury suspicion for patrollers responding and transporting injured skiers or snowboarders from the host resort to definitive medical care. Lastly, findings from this study could aid medical practitioners in mountain resort clinics when faced with variable snow conditions by providing a narrowed differential diagnosis list based on probabilities determined from this study. Any research demonstrating correlation between environmental factors, mechanisms of injury, patterns of injury, and injury severity can be applied to further the current understanding of trauma care.

Summary

The impetus of this work came from personal experience caring for patients injured while partaking in snow-sports at a large Colorado ski resort. The amount of fresh snowfall and the injury severity score of the trauma patients presenting to the local facility appeared, anecdotally, to have an inverse relationship. An appreciation of the kinematics of trauma coupled with an understanding of basic principles of physics helps to explain this phenomenon. A possible explanation for the observations in traumatically injured skiers and snowboarders is that the increased friction found with deeper snow may cause a decrease in skier velocity potentially decreasing the severity of injuries sustained. Although much has been written about injury patterns related to skiing and snowboarding, an association between snowfall amounts and injury patterns and severity had yet to be addressed in a substantive manner in the literature. Defining the relationship between snowfall depth and traumatic injuries increases the current understanding of predictive factors leading up to injury and potentially improves both hospital resource utilization and the clinical management of these patients based on the ambient environmental factors present at the time of injury.

Chapter 2 presents an in-depth review of the literature related to the kinematics of trauma and the effects of ambient snow conditions on traumatic injuries while chapter 3 provides the details of the methodology that was utilized in this project. Chapters 4 and 5 present the results and conclusions, respectively.

Chapter 2: Review of the Literature

The goal of this work was to discern the impact of daily snowfall amounts on both the patterns and the severity of traumatic injuries obtained while alpine skiing or snowboarding on the host mountain ski resort. An attempt was made to obtain a working knowledge of all relevant literature with a specific emphasis placed on works detailing not only patterns and severity of traumatic injuries occurring while partaking in winter recreation sports, but also of previous works that detail factors directly or indirectly related to the injuries sustained. The effect of snowfall on the severity and patterns of traumatic injuries was not only the major factor analyzed in this work but also was the factor least discussed in the available literature. It was this association that I found to be the most compelling from a research perspective not only because of the sparseness of research describing the association but also due to the fact that it is a relevant consideration in the daily management of traumatic injuries sustained at the host resort.

The following review of the literature contains the following: the variances in injury patterns between snow-sport disciplines, the effects on ambient conditions on traumatic injuries, the kinematics of traumatic injuries as related to snow-sports, trauma scoring systems, and lastly, basic considerations of statistical methodologies found in the available literature.

Literature Search Strategy

For the purpose of literature acquisition, EBSCO research databases, Google Scholar, Pub Med, and CINAHL were queried utilizing search keywords: *skiing injury, snowboard injury, daily snowfall, injury severity score, abbreviated injury scale, traumatic injuries, patterns of injuries,* and *mortality.* The majority of the available peer reviewed literature details the differing injury patterns found between the disciplines of alpine skiing and snowboarding while there is a relative paucity of research investigating how snowfall may affect the pattern and severity of these traumatic injuries. Common accompanying variables in previous works include: participant ability level, the influence of intoxicants, injuries sustained during competition, and local or visitor status.

Differences in Injury Patterns between Snow-Sport Disciplines

From a historical perspective, Sacco, Sartorelli, and Vane (1998) described both demographic and injury pattern variances between alpine skiers and snowboarders studied in the early 1990s. Findings demonstrated that snowboarders were younger in age, demonstrated a lower ISS, and sustained more splenic injuries than skiers (13% vs. 2% respectively, $p = .01$; Sacco et al., 1998). Additionally, snowboarders had over 3 times the frequency of upper extremity injuries as compared to skiers (24% vs. 7%, $p < .003$), while skiers had a propensity toward lower extremity injuries compared to snowboarders (78% vs. 38%, $p < .001$; Sacco et al., 1998). As snowboarding increased in popularity throughout the late 1990s and early millennia, the number of research projects increased demonstrating persistence in the trends in injury patterns and severity found in previous works. Idzikowski, Janes, and Abbott (2000) focused solely on snowboard injuries and collected data from 47 facilities in Colorado that are in close proximity to ski resorts. Over 7,000 injuries were evaluated, demonstrating that snowboarding injuries are found in predominantly young men who are less than 30 years of age, with injuries to the upper extremity (wrist) demonstrating the highest frequency of snowboard injuries (Idzikowski et al., 2000).

The predominance of upper extremity injuries, youthful age, and increased incidence of splenic injuries in snowboarders is not a geographic phenomenon isolated solely to North America. Sutherland, Holmes, and Myers (1996) described injury patterns sustained as far back as the 1995 ski season in Scotland and demonstrated snowboarding injuries to have a male predominance, have a greater frequency in the upper extremities, and to be sustained by a younger population than found in ski injuries (Sutherland et al., 1996). The findings of a decreased ISS in snowboarders were echoed as Bergstrom, Askild, Jorgensen, and Ekeland (1999) reiterated the notion that skiers sustained more severe injuries and recommended the use of the AIS "as a tool in preventing skiing injuries" in a Norwegian study (Bergstrom et al., 1999, p.110). A decades worth of injuries sustained by alpine skiers and snowboarders formed the basis for a Swedish study that again demonstrated that young men sustain injuries to the upper extremity from snowboarding more frequently than other populations (e.g., skiers; Made & Elmqvist, 2004).

Pediatric Considerations

Although the majority of published works describe injuries in the adult population, it is worth mentioning that the injury patterns previously described extend to a certain degree to the pediatric population as well. Dohin and Kohler (2008) described an increased frequency of lower extremity injuries in skiers while upper extremity injuries (especially wrist fractures) were more prevalent in pediatric snowboarders (Dohin & Kohler, 2008). As an additional mention regarding the pediatric population, Hayes and Groner (2008) found that although not statistically significant, injuries to the spleen were, again, more common in snowboarders than skiers in the pediatric population

(14% vs. 4%; Hayes & Groner, 2008). Conveniently, the findings among the pediatric population are concordant with those found among the adult population regarding skiing and snowboarding injuries.

A generalization taken from studies addressing both the adult and pediatric populations is that skiers sustain injuries of increased severity and of different anatomical regions when compared to snowboarders. The anatomical variance of the injuries favors the lower extremities in skiers and the upper extremities and injuries to the spleen in snowboarders in both the adult and pediatric populations (Hayes & Groner, 2008). The effect of variable snowfall amounts on these injury patterns is not well elucidated from the available literature and was an area in need of increased inquiry.

Snowfall and Injury Severity

Although mention of characteristic injury patterns among skiers and snowboarders is found throughout the literature, discussions regarding the effects of snowfall on injury are sparse. Bergstrom and Ekeland (2004) described an inverse relationship between time spent on slope maintenance (grooming) and injuries over six ski seasons and demonstrated that in nearly half of the injuries studied, grooming was "rated poor" (Bergstrom & Ekeland, 2004, p. 264). Although intriguing, the effect of slope manicuring on injury patterns and severity is quite different than determining the effects of daily, natural snowfall on traumatic injuries.

Perhaps the most telling and proximal work to this current research occurred in the South Tyrol region of Italy from 2002 through 2005. Over 3,000 injured parties (skiers and snowboarders) were studied along with snowfall at the participating resorts. Injury severity was measured with the ISS and snowfall amount was recorded for the previous 24 hours. Findings demonstrated a negative correlation between 24-hour-snowfall and ISS (p = .034; Girardi et al., 2010). The authors described the daily use of artificial snow during low-snow periods, which is a variation from my research in which artificial snow is employed for early-season conditions only and is then covered by natural snow (Girardi et al., 2010). Although an interesting and likely contributory variable in other works, man-made snow does not represent a significant component of my research. In the current review of the literature, the mentioned works by Bergstrom and Ekeland (2004) and Girardi et al. (2010) are the only projects to incorporate trail grooming, snowfall, and trail design into a risk factor analysis regarding traumatic injuries obtained from skiing or snowboarding. It is this understanding of the relationship between the daily snowfall amount and the effect on traumatic injuries that is infrequently described in the literature and possesses the potential to alter the diagnostic approach to the trauma patient in this setting.

The Relationship between Weather and Traumatic Injuries

Although there is little research defining the relationship between daily snowfall and ski or snowboarding injuries, there is ample research discussing the effects of weather on traumatic injuries among the general population. A recent study evaluated all trauma patients who were admitted or transferred from 21 emergency departments in England and attempted to correlate admissions with observed weather variables. Findings demonstrated an increase in trauma admissions with either an increase or a decrease in daily temperature from the predetermined daily maximum or minimum respectively (Parsons, Odumenys, Edwards, Lecky, & Pattison, 2010). Additionally, through undescribed mechanisms, snowfall was determined to increase trauma admission rates in this work by 7.9% (Parsons et al., 2010). Although intriguing, this finding relating snowfall to increased trauma admissions demonstrates some variability when compared to the available literature.

Trauma Admissions and Daily Temperature

Bhattacharyya and Millham (2001) found no correlation between snowfall and trauma admissions although some of their findings did mirror those of Parsons et al. (2010) regarding higher maximum daily temperatures and increased admissions (Bhattacharyya & Millham, 2001). Rising, O'Daniel, and Roberts (2006) found, in contradiction to previously cited works, that precipitation in the previous 3 hours increased trauma admissions as much as 60% to 78% (Rising et al., 2006). Of note, this work also found an increased rate of admissions with increased daily temperatures, which demonstrates consistency across the literature (Rising et al., 2006). Maintaining consistency with previous works, Stomp, Fidler, ten-Duis, and Nijsten (2009) studied trauma admissions across the Netherlands over a 36-year period, and determined that, indeed, a positive relationship exists between the number of trauma admissions and positive weather conditions as reflected by increased daily temperatures (Stomp et al., 2009).

Trauma Admissions and Snowfall

Perhaps the most interesting and indirectly proximal to my research is a study by Eisenberg and Warner (2005), which described the effects of snowfall on motor vehicle accidents. This work analyzed 1.4 million fatal motor vehicle crashes from 1975 and 2000 and compared local weather data. Findings demonstrated that recent snowfall increased the incidence of crashes (nonfatal), while also demonstrating a decreased incidence of fatal crashes when compared to days with no precipitation (Eisenberg & Warner, 2005). It is this type of association that sparked my interest in this research. Personal and organizational observations from the host facility demonstrated that increased snowfall amounts increase the incidence of traumatic injuries with the caveat that these injuries demonstrate a lower severity score than those on “low-snow” days. It was this apparent inverse relationship between snowfall and injury severity that formed the cornerstone of this work.

Physics and the Kinematics of Trauma

The three basic principles of Newtonian physics state (a) objects will remain in motion (or at rest) unless an external force is applied to the object (or system), (b) the relationship of a force applied to change the momentum of an object to the mass and acceleration of the object or system is defined as: $F = ma$, and (c) for every action there is an equal reaction (Benson, 2010). If these three laws are followed, it can be deduced that when objects collide, each applies its respective, individual force to the other causing a change in momentum. It is this change in momentum that reflects the potential for significant injury in the setting of trauma. An additional applicable principle is that of kinetic energy. Kinetic energy (E_K) is defined by the equation $E_K = \frac{1}{2}mv^2$, where m = mass and v = velocity (Feliciano, Mattox, & Moore, 2008). Inherent in this principle is the understanding that a doubling of the mass equates to a doubling of the energy while a doubling of the velocity translates to a quadrupling of the energy. In short, velocity is the greater determinant of kinetic energy when compared to mass. Assuming that energy transfer is required for injury to occur, it can be stated that increased velocity with subsequent increased kinetic energy may equate to an increased potential for injury due to dramatic changes in momentum. Examples of this principle are evident in the significant injury seen with the rapid, deceleration type mechanism of motor-vehicle accidents. A last basic physical principle that should be grasped prior to a discussion of the relatively inelastic collisions of trauma is the principle of work (Feliciano et al., 2008). Work (W) is simply; force applied over distance and is represented by the equation $W = Fdx$ (Feliciano et al., 2008). An integrated understanding of these principles yields the following conclusion: increased velocity causes increased kinetic energy (E_K) translating to increased work which causes increased transfer of energy between colliding objects (to bring them to rest) resulting in potentially increased damage to the object(s) (e.g. a skier or snowboarder). It is the appreciation for the effect of velocity on the severity of traumatic injuries that formed the theoretical foundation for this work.

The Physics of Skiing and Snowboarding

Discussions regarding the physics of skiing and snowboarding start with an appreciation of the influence of thermal conductivity and friction. Although a comprehensive review of thermodynamics is beyond the scope of this research, it can be stated that the effective sliding over snow is the result of numerous factors. Hypothetically, with all snow being equal in consistency, water content, and temperature, it can be said that sliding over snow creates a water layer under the skier due to melting caused by kinetic friction that subsequently decreases friction over time and distance (Colbeck, 1988). In short, the greater the water layer, the less the friction on the ski and the greater the potential speed. An additional consideration is that all snow is not equal in nature, and variances in snow depth, temperature, and water content exist. This appreciation for the variances in the characteristics of snow and the effects of friction are well recognized and described in this example by Colbeck and Warren (1991), "distributions of frictional heating are sensitive to the…hardness of the snow surface" (Colbeck & Warren, 1991, p. 235). If the assumption is made that frictional heating is the result of ski-to-snow contact producing a melt-water layer that decreases friction, a logical deduction is that any variable that adversely affects the surface-to surface contact will adversely affect the production of the water layer with a subsequent increase in friction. In theory, it is this increased contact found in deeper snow that will lead to a decrease in skiing velocity translating to a decrease in kinetic energy with a subsequent decrease in injury severity. Rationale for increased friction in deep snowfall is discussed by Colbeck (1988) in the observation: "snowfall often consists of angular dendrites or needles which are "aggressive and increase the solid-to-solid component of the friction" (Colbeck, 1988, p. 78). Additional, although indirect, mention is made regarding the positive relationship between snow depth and friction by Colbeck, "as the snow becomes icy, the thickness of the water film increases" (Colbeck, 1988, p. 84).

Practical application of these physical principles can be seen in the world of ski racing. If the assumed goal of racing is to complete a designated course in as fast a timeframe as possible, then the course should, theoretically, be prepared to accommodate this goal. Reflections of this principle can be found in recommendations from the United States Ski and Snowboard Association (2011) regarding optimization of a skiing racecourse in the statement, "the surface of the racecourse should be made as firm and smooth as possible" (United States Ski and Snowboard Association, 2011, p. 9). The assumption is that a firmer course will translate to increased speeds while a softer course (e.g. fresh snowfall) will have an inverse relationship to velocity.

Anatomical Considerations

Injuries described in the available literature reflected that penetrating injuries resulting from snow-sports are exceedingly rare. The paucity of penetrating trauma mention in the literature relating to seriously injured patients in snow-sports is best illustrated in a study entailing 7 years worth of snow sport related injuries from the Oregon state trauma registry, which does not include a single penetrating event (Federiuk, Schlueter, & Adams, 2002). For the purposes of this work, discussions focused predominantly on the anatomic considerations and mechanics of blunt trauma. Feliciano et al. (2008) described five anatomical regions worthy of brief mention in this work.

Injuries to the head are worthy of mention if for no other reason than traumatic brain injury is described as, “the single most important factor contributing to death and disability after trauma” (Feliciano et al., 2008, p. 110). An appreciation for the basic anatomy is an important consideration when discussing brain injury. The rigid, bony cranium encases the gelatinous brain, vasculature, nerves, connective tissue, and cerebrospinal spinal fluid. The introduction of rapid deceleration forces cause the brain to impact the skull in the vector of impact and secondarily, strike the skull again in the opposite vector in recoil fashion (Feliciano et al., 2008). This “contrecoup” injury pattern predisposes the brain to separate impact sites with subsequent damage to multiple areas of the brain and to vascular structures in the calvarium such as bridging veins (Feliciano et al., 2008). Damage to brain tissue and vascular structures set the stage for increasing intracranial pressure due to intracranial hemorrhage and parenchymal edema resulting in potentially catastrophic consequences (Feliciano et al., 2008). A detailed description of the myriad of brain injuries are beyond the scope of this work, but an appreciation for the effect of increased velocity with subsequent rapid deceleration forces (e.g. contrecoup injury pattern) is paramount to the understanding of injury severity in this patient population.

The thorax represents the second anatomic area that warrants consideration. Blunt force to the thorax may affect the bones and musculature that comprise the thoracic cage, lung parenchyma, bronchioles, mediastinal structures, heart, and the great vessels (Feliciano et al., 2008). A multitude of injury patterns may result from the application of external forces causing shear forces acting upon the relatively pliable structures found in the thorax beyond the more obvious musculoskeletal damage commonly associated with blunt traumatic injuries. Additionally, due to the relevance of intrathoracic structures to patient hemodynamics, large energy transfers have the potential to cause catastrophic consequences in the setting of trauma.

A third anatomic consideration involves the relatively unprotected abdominal organs. Lacking bony protection, a combination of compressive and shear forces may work collectively or independently to cause significant injury in the setting of blunt abdominal trauma affecting both solid and hollow structures as well as the supporting vasculature (Feliciano et al., 2008). An example of the shear force phenomena as described by Feliciano et al., (2008) is that of renal artery avulsion after blunt abdominal trauma. In brief, rapid deceleration causes the renal artery to avulse from the relatively immobile abdominal aorta. This mechanism is thought to be due to the variance between the fixed aorta to the spine and the relatively unattached kidney in the retroperitoneum (Feliciano et al., 2008).

Injuries to the spine are varied and may be compressive, rotational, or due to flexion or extension forces (Feliciano et al., 2008). Injuries to the spine may include: bony damage, ligamentous or tendonous injury, and vascular, nerve, or soft tissue damage. Perhaps the most obvious and potentially serious anatomic consideration in spinal trauma is damage to the spinal cord, which is encased by the vertebrae (Feliciano et al., 2008).

The last anatomical consideration is that of musculoskeletal injuries as injuries to the appendicular skeleton represent the most commonly identified traumatic injuries (Feliciano et al., 2008). As previously stated, injury severity and pattern are directly related to the kinetic energy involved in the collision. Musculoskeletal injuries may be bony, tendonous, ligamentous, vascular, or cartilaginous in nature and are related to the compressive and tensile forces applied (Feliciano et al., 2008).

In summary, any condition that will increase kinetic friction (e.g., fresh snowfall) will have an inverse relationship with speed generation potentially decreasing the likelihood of severe injury. This relationship is constructed through an appreciation of concepts of traumatology and a basic understanding of physics. These principles taken collectively are paramount to this research as the relationship between daily snowfall depth and injury severity was a primary endpoint in this work.

Trauma Scoring Systems

A standardized approach for quantifying injury severity serves many purposes in the field of trauma care. Trauma epidemiology, resource allocation, and the possibility of prognostic indicators all are conceivable with a valid scoring system (Pohlman et al., 2010). There are three basic scoring modalities currently in use which include a (a) physiological score, (b) an anatomical score, and (c) a combined score system.

Physiological Severity Scores

The physiological score methodology utilizes vital signs, laboratory data, and/or physiological parameters from major body systems such as the cardiovascular and respiratory systems (Pohlman et al., 2010). Examples of scoring systems using the physiological model include: the Revised Trauma Score (RTS), the Systemic Inflammatory Response Syndrome Score (SIRS), and the Acute Physiology and Chronic Health Evaluation (APACHE) scoring systems. While the RTS uses the Glasgow Coma Score (GCS), systolic blood pressure (SBP), and respiratory rate (RR) to quantify injury severity, the APACHE model incorporates variables from the major systems combined with a chronic health assessment to reach a calculated value that theoretically correlates with mortality (Pohlman et al., 2010). Some limitations of the physiological scoring methods include: (a) the requirement for neurological assessment in patients who are often sedated, (b) lack of specificity regarding the anatomical location of traumatic injuries, and (c) poor predictive value in predicting mortality (Pohlman et al., 2010).

Anatomical Severity Scores

Scoring systems that use the anatomical score methodology grade injuries based on the anatomical location of injury. An AIS is determined through the grading of injury based on anatomical location with a 6-point scale spanning *minor injury* (1*) to injuries predisposing to a lethal outcome* (6; Pohlman et al., 2010). These values are tallied and subsequently used to calculate the ISS. The goal of the ISS is to provide a "summary view" of injury severity in a patient. Although the most commonly utilized scoring system in the available research regarding ski and snowboard trauma, there is a limitation in the sole use of the ISS for these purposes. In short, regional detail regarding specific injuries is lost in the interest of a “body-wide” severity score. The ISS demonstrates a progressive severity range from one to 75 with injury severity categorization as follows: mild injury (ISS 1-9), moderate injury (ISS 10-15), severe injury (ISS 16-24), and critical injury (ISS ≥25; Ashkenazi et al., 2006; Paladino et al., 2008).

Combined Severity Scores

The last injury severity score modality is that of the combined score. Combined injury scores are comprised of a combination of both physiological and anatomical variables. An example of this combined methodology is the combination of concepts found in the ISS and the RTS. Termed TRISS, the Trauma and ISS, although more inclusive and comprehensive than other scoring systems, still suffers from the limitations of its respective parts such as: (a) omission of comorbidities, (b) lack of applicability in sedated patients (due to requirement of neurological assessment), and (c) lack of anatomically specific identifiers (Pohlman et al., 2010).

In summary, none of the current injury scoring systems are generalizable to all potential patient populations. The limitations of each system must be appreciated and incorporated into epidemiologic conclusions and discussions when utilizing the various scoring systems. Although both the AIS and the ISS are utilized in this work, a large focus fell on the anatomically specific traits of the AIS in relation to the severity of injury in various anatomical regions with variable snowfall depths.

The Abbreviated Injury Scale and the Injury Severity Score

As described by Genarelli and Wodzin (2005), "the AIS is an anatomically-based, consensus-derived, global severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale" (Genarelli & Wodzin, 2005, p.2). The AIS was originally created in the early 1970s as a method to quantify the severity of injuries in distinct anatomical locations from motor vehicle collisions (MVCs). As new considerations in trauma care, injury diagnostics, and crash investigations progressed, the AIS has been revised to meet these changing needs. The latest revision (AIS, 2005) correlates directly with recognized organ and fracture injury scales allowing for increased user understanding and utilization (Appendix A). The objective of the AIS 2005, as in many severity scores, is to standardize injury descriptions allowing for utilization in mortality predictions, trauma epidemiology, and in conjunction with other scoring methodologies (Genarelli & Wodzin, 2005). Although demonstrating increased anatomic specificity in injury scoring, a very important drawback of the AIS is that multiple injuries in a single body region are not appreciated when tallying AIS scores for ISS calculations, as only the highest AIS score in a particular region is utilized (Pohlman et al., 2010). The lack of appreciation for multiple injuries in a single body region is further emphasized when utilizing the ISS. The squaring and summation of the AIS to generate the ISS further distances the appreciation for the contributions of multiple injuries when utilizing a single severity score.

The format of the AIS 2005 divides the human body into nine distinct regions: head, face, neck, thorax, abdomen, spine, upper extremity, lower extremity, and skin/other (Genarelli & Wodzin, 2005). The AIS 2005 severity code system relies on the grading of an injury in each anatomical region with severity coding as demonstrated in Table 1.

Table 1

Abbreviated Injury Scale and Injury Severity Description

AIS Code	Description
1	Minor injury
2	Moderate injury
3	Serious injury
4	Severe injury
5	Critical injury
6	Maximal injury (untreatable)

Note. Table reproduced from *Abbreviated Injury Scale, 2005* (p. 11) by T.A. Gennarelli and E. Wodzin, 2005, Barrington, IL: Association for the Advancement of Automotive Medicine. Copyright 2005, 2007.

Calculation of the Injury Severity Score

For the purpose of this research, injuries were coded according to the guidelines in *Abbreviated Injury Scale, 2005*, by the Association for the Advancement of Automotive Medicine. After the AIS have been coded, the ISS is calculated from the highest AIS code in the three most severely injured anatomical regions. These three numbers are individually squared and then summed to give the ISS. Of note and as previously discussed, there are some regional (anatomical) variances between the AIS and the ISS.

The ISS divides anatomical regions into six components as follows: “the head or neck, the face, the chest, the abdomen or pelvic contents, the extremities or pelvic girdle, and external or integument” (Genarelli & Wodzin, 2005, p. 29). The highest AIS scores from the highest three ISS regions are used in the calculation of the ISS. Note that ISS scores are varied from the more anatomically specific AIS scoring classifications. In this research, the ISS was calculated as a global indicator of severity while special attention and analysis was given to the more anatomically specific AIS. The AIS for each injury in each anatomical region for each patient was determined and analyzed. The importance of this analysis was to determine how snowfall affects the anatomical patterns of injuries in patients who sustain injury from snow-sports participation as opposed to solely addressing total-body severity. Detailed discussion of calculation of the AIS and ISS as relevant to this research is discussed in chapter 3.

Statistical Methods Found in the Literature

The utilization of the ISS in correlation analyses is ubiquitous in the trauma literature and has been used as "the benchmark of mortality risk in trauma centers for over 30 years" (Wong & Leung, 2008, p. 1). The ISS allows researchers a familiar tool for use in the analysis of body injury severity. This commonly employed methodology is reflected in a multitude of sources in the trauma literature and most proximally, in the work by Girardi et al. (2010), where descriptive and regression analyses on variables thought to affect the ISS were performed. Variables employed in the work by Girardi et al., (2010) include: age, sex, discipline (ski or snowboard), daily snowfall in centimeters, and mechanism of injury, among others. This current project also utilized many of the same variables with the addition of the AIS scores, and a listing of relevant injuries to the host institution in terms of resource allocation or transfer needs. As in the Girardi et al. (2010) work, the creation of dichotomous dependent variables relating to ISS thresholds for severity were used in logistic regression analyses with the aforementioned independent variables. Utilization of the ISS as a dependent variable along with predictor variables is a commonly used methodology in the literature and is applicable to a range of independent variables correlating to the ISS. Frederiuk et al. (2002) employed the ISS as a dichotomous, dependent variable and utilized it as inclusion criteria when analyzing the contribution of age, sex, and mechanism of injury to severely injured patients partaking in snow-sports in Oregon State (Federiuk, Schlueter, & Adams, 2002) In the work by Frederiuk et al. (2002), patients were only included in the analysis if they demonstrated severe injuries determined by a threshold ISS (Federiuk et al., 2002). Another, more unique application of the ISS was employed by Stomp et al. (2009) in research correlating injury severity and trauma admissions to the lunar cycle. In that work, ISS was correlated with numerous variables including the stage of the lunar cycle, utilizing a similar methodology centered on regression modeling (Stomp et al., 2009). Utilization of the ISS as an indicator of injury severity coupled with multiple independent variables is not a necessarily novel approach to determining the contribution of predictor variables to injury severity, though when applied to daily snowfall measurements it has the potential to reveal currently undefined associations. Use of the ISS coupled with predictor variables and categories is the commonly accepted methodology that was employed in this current research. Unique, additional components of the analysis in this project involved: daily snowfall, the AIS, and the anatomical patterns of injury in this population.

A consideration regarding utilization of the AIS is that although the AIS is more cumbersome to utilize from a statistical analysis perspective, it does provide a relative marker of injury severity with increased focus on anatomical region and organ system compared to the ISS. Detailed chart review was necessary not only to calculate the AIS, but also to categorize injury patterns by AIS scores thus causing logistical challenges from a data management and analysis perspective that is absent when utilizing the ISS alone. Although a requirement of ISS calculation, the AIS is infrequently mentioned in the available trauma literature. The etiology of this omission is unclear and this gap was addressed in this work, as the consideration for injury pattern in relation to snowfall was a vital component of this research.

Chapter 3: Research Methods

The stated goal of this observational study was to define the relationships between daily snowfall depths and the severity and patterns of associated injuries obtained while skiing or snowboarding. A benefit of conducting the research in the chosen location was that nearly all injured patients were admitted to a single healthcare facility, thereby streamlining the logistics of data collection. Patient data was securely collected by the researcher at the host institution through the established trauma registrar's department, de-identified, and entered into a spreadsheet format for analysis, while injury scoring was performed on all patients for use in subsequent analyses. Snowfall data was obtained in cooperation with the ski patrol of the host resort from daily snowfall logs kept by the resort weather department. A combination of descriptive and inferential statistical analyses was employed in this work to define the relationship between snowfall and injury severity. The following chapter provides details of: the design of the study, the study sample, data collection techniques, the statistical methodology, and the protection of patient information.

Design of the Study

The primary purpose of this work was to determine the association between daily snowfall amounts and the severity and patterns of traumatic injuries sustained while skiing or snowboarding at the host resort. This research included all patients admitted to the host institution with a traumatic injury sustained during the act of alpine skiing or snowboarding on the host resort during the 2010-2011 ski season. Due to the nature of the population and the existing data and the research questions, the study design was of the secondary analysis nature as I did not manipulate the study population but focused instead on assessing the individual and collective contributions of variables in relation to injury severity scores and injury patterns. The observational design is more in line with the objectives of this work in contrast to the experimental design as this work is designed to provide clinicians and ski areas a better understanding of how the ambient snow environment may portend certain injury patterns and associated injury severity. An understanding of this relationship may lead to improved diagnostic and therapeutic modalities in the clinical arena. As stated by Katz (2006), the recognized limitations of the observational study design such as confounding and bias were accepted and addressed through rigorous statistical methodology in favor of the inherent strengths of the observational study including: (a) increased generalizability, (b) lower cost, (c) shorter timetable for research, and (c) the potential for a broader understanding of the research problem potentially leading to the aforementioned improvements in diagnosis and treatment of injured patients (Katz, 2006).

Sample and Population

The timeframe for this research was from November 19, 2010 through April 24, 2011. This period encompassed the entirety of the 2010-2011 ski and snowboard season for the host resort. Only patients who presented to the healthcare facility between November 19, 2010 and April 24, 2010 with injuries sustained in the act of alpine skiing or snowboarding and who required hospital admission or transfer for specialty care were included as participants. This secondary analysis study included all patients admitted to the host facility with the aforementioned admission criteria while the population included those individuals admitted to the host facility and those who either refused to seek medical care, obtained care elsewhere, or were discharged from the healthcare facility’s emergency department. The host facility accommodates nearly all patients presenting from the host resort with traumatic injuries while a small number of patients are transferred by helicopter from the resort directly to specialized care. All patients included in the study had obtained an initial evaluation in the emergency department by an emergency physician, trauma surgeon, physician assistant, or subspecialist. Only patients who were admitted to the host facility and assigned inpatient or observational status or transferred to a tertiary care facility for specialty treatment were included in the research. The sampling design for this work embraced a single stage methodology as clustering was not feasible within the constraints of this research design.

Sample Size Justification

The primary endpoint of this research was to define the relationship between daily snowfall and injury severity among skiers and snowboarders at a large North American ski resort. The inclusion criteria for this research included all patients who were admitted to the healthcare facility or who were transferred from the emergency department of the host institution to a tertiary care center as a result of traumatic injuries sustained while skiing or snowboarding at the host resort for the 2010-2011 ski and snowboard season. Though manipulation of the sample size was not feasible within the constraints of this study design, justification of an adequate sample size was warranted. According to Katz (2009), estimation of an appropriate sample size can be accomplished through three mechanisms: (a) comparison from a relevant study that is comparable to the proposed work, (b) performing a pilot study to determine the appropriate number of subjects, and (c) determining the smallest meaningful difference and using this as a reference point for calculations (Katz, 2009). Although a pilot study was not feasible for this project, considerations regarding the assessment of proximal works and the determination of the smallest meaningful difference were viable options.

For the purposes of this work, the most proximal and relevant work in the literature is that by Girardi et al.(2010) in which injury severity and snowfall were analyzed over three consecutive ski seasons in the Italian Alps. The mean standard deviation (SD) of daily snowfall, in that research, was determined to be 2.2 inches with a mean ISS of 3.4 (SD 4.3; Girardi et al., 2010). Utilizing the standard deviation from this proximal study, the current research employed principles used for the comparison of means (ISS and snowfall) to calculate the sample population.

In this research, a level of significance of 0.05 and a power of 80% were embraced. After categorizing ISS into mild/moderate (1-15) and severe/critical (≥16), as described by Paladino et al. (2008), the detection of a mean difference in snowfall of one inch ideally required a sample size of 78 patients for each ISS group. When groups are combined for this study, the appropriate sample size required obtaining the desired power and significance for the complete work ideally required 157 patients. Compared to prior seasons, this sample size was a reasonable expectation and the increase in patient numbers (N= 297) provided a true mean difference in snowfall of less than the stated one inch to be appreciated in the analysis (D. Kluk, personal communication, March 21, 2011). Similar sample size calculations were applied to snowfall and AIS for each body region and for the purposes of this study, there was adequate power to detect a significant difference of less than two points in mean AIS scores for varied snowfall amounts when the standard deviation of AIS was between 2.5 and 3. If the standard deviation of AIS was between 3.5 and 4, there was enough power to detect a significant difference of less than three points in mean AIS scores for low versus high snowfall. Considering that AIS scores range from 1 to 7, standard deviations between 2.5 and 4 were reasonable estimates. From the clinical perspective, all that is required to escalate even a minor injury to serious or severe status in AIS scoring is 2 points on the injury score in a single anatomic area. Being able to detect a statistically significant difference of 2 or 3 points on the AIS scale allowed for the important distinction between minor and severe injuries to be elucidated in relation to snowfall depth and was feasible with the actual patient numbers.

Statistical Analyses

This work employed both descriptive and inferential statistical analyses. Basic components of descriptive statistics such as distribution, central tendency, dispersion, and correlation were addressed along with the regression tactics inherent in inferential statistical analysis. After the creation of categorical variables where applicable, correlation analyses and regression models were employed as determined by the nature of the variables in question. When addressing a dichotomous variable such as mechanism of injury for example, a logistic regression modality was employed. The determination of snowfall variance between high and low ISS was performed through a combination of parametric tests and nonparametric modalities. Additional analyses of the ISS were employed through the use of simple and multiple logistic regression models in order to allow for the consideration for the influence of additional covariates (e.g. sex, age, discipline, mechanism of injury, etc.). Similar to the ISS, the AIS is amenable to analysis using correlation analyses and logistic regression modalities with varied snowfall depths. Comparison of regression models and correlation analyses across anatomic regions illustrated both the strength of the relationship between snowfall and AIS in a particular anatomic area and the variance of that relationship across body regions. Correlation analyses and logistic regression methodologies were applied to the specific injury list where applicable to determine if daily snowfall depth was a predictor for a specific injury.

The specific injuries with subsequent anatomical grouping that were tracked in the study are as follows:

1. Shoulder Girdle Injuries
   a. Proximal humerus fracture (proximal to the anatomical neck)
   b. Clavicle fracture
   c. Scapula fracture
2. Thoracic Injuries
   a. Rib fractures
   b. Pneumothorax
   c. Hemothorax
3. Head Injuries
   a. Intracerebral contusion
   b. Intracerebral hemorrhage
   c. Concussion
   d. Skull fracture
4. Spine Injuries
   a. Cervical spine fracture/dislocation
   b. Thoracic spine fracture/dislocation

c. Lumber spine fracture/dislocation

5. Extremity Injuries

   a. Any long-bone, mid-shaft fracture

   b. Distal humerus fracture

   c. Ulna fracture

   d. Radius fracture

   e. Wrist fracture

   f. Hand fracture

   g. Femur fracture

   h. Tibia fracture

   i. Fibula fracture

   j. Foot fracture

6. Abdominal Injuries

   a. Liver laceration/hematoma

   b. Spleen laceration/hematoma

   c. Renal laceration/hematoma

7. Pelvic Fractures

   a. Ileum fracture

   b. Ischium fracture

   c. Pubis fracture

   d. Sacrum fracture

   e. Coccyx fracture

Discussion of Statistical Methodologies and Research Questions/Hypotheses

1. *Question 1*: Does snowfall depth affect the overall severity of injuries, based on the Injury Severity Score, sustained while alpine skiing or snowboarding at the host ski resort? H_0: Daily snowfall amounts do not affect the severity of injuries, based on the Injury Severity Score, obtained while alpine skiing or snowboarding at the host ski resort. H_a: Daily snowfall amounts affect the severity of injuries, based on the Injury Severity Score, obtained while alpine skiing or snowboarding at the host ski resort.
    a. The analysis of this research question and hypotheses involved the independent variable, daily snowfall (measured in inches) as well as the ISS, which is calculated from the AIS as, described in chapter 2. In this instance, a combination of correlation and univariate analysis was performed to determine the extent of the association between snow depth and injury severity.
2. *Question 2*: Does snowfall depth affect the severity of injuries relative to anatomical patterns, based on the Abbreviated Injury Scale, sustained while alpine skiing or snowboarding at the host ski resort? H_0: Daily snowfall amounts do not affect the severity of injuries, relative to anatomical patterns, based on the AIS, obtained while alpine skiing or snowboarding at the host ski resort. H_a: Daily snowfall amounts affect the severity of injuries, relative to anatomical patterns, based on the AIS, obtained while alpine skiing or snowboarding at the host ski resort.

a. The analysis of this research question and hypotheses involved the independent variable, daily snowfall (measured in inches) as well as the nine anatomical groupings of the AIS as distinct, dependent variables. In this instance, snowfall is an interval level variable while the AIS was measured directly. Statistical analysis in this instance was addressed through correlation and univariate analysis utilizing the Fisher's Exact Test, after the creation of dichotomous variables representing the independent and dependent variables respectively.

3. *Question 3:* Does snowfall depth affect the mortality of trauma patients who sustained injuries while alpine skiing or snowboarding at the host ski resort? H_0: Daily snowfall amounts do not affect the mortality from traumatic injuries obtained while alpine skiing or snowboarding at the host ski resort. H_a: Daily snowfall amounts affect the mortality from traumatic injuries obtained while alpine skiing or snowboarding at the host ski resort.

    a. The analysis of this research question and hypotheses involved the independent variable, daily snowfall (measured in inches) as well as the mortality data that was categorical in nature and was measured in a dichotomous fashion with the numbers 1 and 2 reflecting the presence of death from a traumatic injury or its absence, respectively. Statistical analysis in this instance was addressed through correlation analysis utilizing the Pearson's chi-square test or the Fisher's Exact Test when indicated, after the creation of dichotomous variables representing the independent and dependent variables respectively.

4. *Question 4*: What is the statistical association between snowfall depth and specific snow sport injuries sustained while alpine skiing or snowboarding at the host ski resort? H_0: There is not an association between snowfall depth and specific snow sport injuries sustained while alpine skiing or snowboarding at the host ski resort. H_a: There is an association between snowfall depth and specific snow sport injuries sustained while alpine skiing or snowboarding at the host ski resort.
    a. The analysis of this research question and hypotheses involved the independent variable, daily snowfall (measured in inches), as well as the individual injuries followed in the research. In this instance, snowfall was an interval level variable while the injury sustained was categorical in nature and was measured in a dichotomous fashion with the numbers 1 and 2 reflecting the presence of the injury or its absence, respectively. Statistical analysis in this instance was addressed through logistic regression models with correlation analysis utilizing the Pearson's chi-square test or the Fisher's Exact Test when indicated, after the creation of dichotomous variables representing the independent and dependent variables respectively.
    b. Additional secondary considerations that were examined include: how gender, helmet use, mechanism (e.g. falls or collisions), and discipline (ski or snowboard) affect injury severity in the studied population. Considering the dichotomous nature of these variables, logistic regression models were employed in the statistical analysis of these potential covariates.

Due to the numerous levels of measurement of the data in this research, numerous statistical methodologies were employed in the data analysis utilizing STATA/IC (11) statistical software.

Description and Coding of Patient Data

Categorical data such as: sex, snow sport discipline, helmet use, mortality, and mechanism of injury (fall vs. collision) were coded through a numeric system with the numbers 1 or 2 corresponding to pre-defined dichotomous variables (e.g. 1 = yes, 2 = no). The most common or relevant injuries observed at the host facility were coded in a binary system with a 1 reflecting a positive finding and a 0 demonstrating an absence of a particular injury. Ratio level data including: snowfall in inches (last 24 hours), and age, as well as the ordinal measures of the AIS and the ISS score did not require coding, and were input as an actual numeric amount without modification. The coding of the specific variables was as follows:

1. *Date*: calendar date with month, day, year expressed in mm/dd/year format
2. *Age*: expressed as numeric age in years
3. *Sex*: male or female gender, coded as: 1=male, 2=female
4. *Helmet Use*: coded as 1=yes helmet worn at time of injury, 2=no helmet worn at time of injury
5. *Discipline:* coded as: 1=alpine skiing, 2= snowboarding
6. *Mechanism*: 1= fall, 2=collision
7. *Mortality*: coded as: 1= patient died, 2= patient survived
8. *Snowfall*: expressed in inches, rounded to 1/10 decimal point
9. *Injury Severity Score (ISS):* the ISS will be expressed as a numeric score

10. *Abbreviated Injury Score (AIS):* the AIS will be expressed as a numeric score per specific anatomic region.
11. *Individual Injuries*: 0 = absence of listed injury, 1= presence of listed injury

Data Collection

The nature of the research required multiple steps in data management. Snowfall data was obtained from the weather department of the host resort while patient data was abstracted from medical records. To mitigate bias, strict adherence to measurement protocols for both data sets was established prior to data acquisition by the researcher. Both snowfall and patient data are measured and entered into their respective databases by personnel trained in the respective disciplines. In the case of snowfall data, professional ski patrollers with additional weather data training are responsible for the daily measurement and data entry. Regarding patient data, trauma nurses are responsible for creation of the abstracts of the patient data after physician diagnosis has been entered into the patient record.

Hospital Patient Data Management

Trauma patients from the host resort arrive to the host facility via multiple possible mechanisms and are transported to the hospital via a skier transport mechanism or local emergency medical services. Patients obtain appropriate initial management by board-certified ED physician or through subspecialty consultation. When consultation is complete, patients are admitted to the patient care unit (PCU), the intensive care unit (ICU), or directly to the pre-operative (PRE-OP) area for emergent operative intervention. After admission, all patients are followed throughout their course of stay by the trauma registrar's office consisting of nurses (RN) with specialty training in chart auditing and trauma care. The audit is performed on all trauma patients and records the following patient information: patient demographics, diagnoses, admission vital signs, triage data, operations, procedures, complications, mortality, consultations, and disposition with subsequent data submission to *Trauma Base: Version 7* statistical software. Additionally, AIS scoring is performed with subsequent ISS calculation on all patients.

Categorical data (e.g. demographic data, discipline) is assessed at time of patient presentation and is documented by the emergency department triage nurse in the patient's chart in the ED Snapshot portion of the electronic medical record (EMR). The patient diagnosis and disposition is determined by the emergency department physician or PA and input into the EMR in a similar fashion. After appropriate imaging and review by a board-certified radiologist, the radiology reports are also entered into the EMR. As an additional quality-control measure, randomized radiology images and reports are over read by a second, board-certified radiologist prior to finalization of the patient record. All triage nurses, technicians, and physicians are trained on components of patient documentation and data entry prior to the initiation of active work duty in the emergency department. Training on the use of the EMR is provided for all hospital employees using a systematic protocol prior to active duty in respective departments. Consistency in training and protocol help maintain the reliability of the system and subsequent research while peer-review serves as an aid to the validity of diagnoses in the current system. Current hospital protocol dictates that all data points are validated and then entered in to the EMR within 24 hours of hospital admission by appropriately trained personnel.

Patient Data Collection

Audits and chart review were performed in a consistent fashion to maintain the reliability of the patient data collection methodology. Data collection from the EMR was accomplished in a standardized fashion through access to the patient's EMR and radiology records as previously described.

In order to meet the needs of the research questions and hypotheses, the research and data collection involved multiple steps. First, audits from the trauma registry were created for the past ski season, specifically the dates of November 19, 2010 through April 24, 2011, inclusive. Audits were performed on all trauma patients admitted to the host facility and served as a primary source of data. Additional chart review was necessary to determine specific injuries and any additional data not readily available from the audit reports. These reports detailed each trauma admission at the host facility and included the following categorical data: sex, snow sport discipline, helmet use, mortality, mechanism of injury (fall or collision), and the most common or relevant injuries observed at the host facility. Ratio level data included: snowfall in inches (last 24 hours), and age, while the AIS score per anatomical region, and the ISS score were ordinal measures. Relevance of injuries to the host facility was defined by the need for: transfer for specialty consultation, emergent operative intervention, or additional resource utilization issues.

Data Abstraction

The previously described audit reports served as the primary source for data entry into a spreadsheet format for subsequent analysis. The audit reports were completed in entirety after consultation with the EMR, radiology reports, and any additional resources required completing the report. The audit report data coupled with the daily snowfall data was manually input into the aforementioned STATA statistical software package for subsequent analysis by the researcher. Patient information as well as snowfall data was input by date of injury. ISS and AIS scoring were performed if not already completed in the trauma audit report. In cases where the calculations were complete prior to evaluation of the report, I repeated the calculations in an effort to maintain consistency and accuracy in data entry.

Daily Snowfall Measurement Data Collection

Ski patrol members of the resort weather department perform daily snowfall measurement through a systematic protocol. The weather measurement department is composed of seven ski patrollers trained in snowfall measurement, measurement of snow water density, measurement of weather variables, and data entry. Daily (24 hour) weather reporting entails numerous measurements including: temperature, 24-hour snowfall, cumulative settled base, and the water content of the snow, among others. The measurement location is a stationary platform located within the westernmost boundary of the resort and is located at 10,200 feet above sea level. The settled-base measurement is based on a stationary device that is evaluated along with the new snowfall measurement at 0700 Mountain Time (MT) daily during the winter ski season. While the settled-base measurement device is not manipulated, the 24-hour snowfall measurement platform is cleaned after each measurement. After the new-snow measurement is taken from the platform, snow is placed in a *12-inch Tube Sampler (model T-1)* made by *Snowmetrics Corporation* and weighed on a calibrated scale for determination of water content. Data is recorded and subsequently entered using *Loggernet* software from *Campbell Scientific Incorporated*. After all daily measurements have been made the

Colorado Avalanche Information Center (CAIC) website is then referenced to complete the weather/avalanche report for the day (W. Mattison, personal communication, February 10, 2011). This data was subsequently entered into a spreadsheet format for integration with the patient data.

Injury Scoring

Injury scoring utilizing the AIS/ISS system was conducted in the accepted fashion as described by Pohlman et al. (2010) and Gennarelli and Wodzin (2005). The AIS score was assigned to a maximum of nine anatomical regions utilizing a numerical range of one through six. This numerical scale corresponds to injury severity in each anatomical region in a positive fashion. For example, an AIS score of one is consistent with minor injuries, while a score of six is relegated to those injuries at the current technological threshold of treatability. A comprehensive listing of anatomical injury descriptions with correlating AIS scoring can be found in numerous sources including the *Abbreviated Injury Scale, 2005* to aid in organ injury scoring. These organ injury scales were created by Moore et al. in the early 1990s over a series of works and are shown in Appendix A. Regardless of the number of injuries in a single anatomic region; only a single (highest) score is transferred for ISS calculation. Subsequent squaring of the highest scores followed by the summation of the resultant three highest AIS scores yielded the ISS for each patient. Of note, a maximum AIS score of six automatically translates to the maximum ISS score of 75.

Protection of Participants Rights/Patient Data Management

The consideration of participants' rights was a priority in this work and was protected throughout the entirety of the research project. Data was collected and stored in a database according to date of injury allowing for a retrospective correlation of daily snowfall amounts. Patient identifiers such as the patient name and medical record number (MRN) were removed prior to insertion into the database as patients were assigned a patient number which started with 1 and proceeded in an ascending numerical fashion. Data integrity and confidentiality was maintained through storage on a password-protected personal computer with an external hard-drive device, which served as a data storage device should the primary hardware had malfunctioned or had been destroyed. Once extracted from the trauma registry, the data was manually entered into a spreadsheet format for subsequent statistical analysis. Data management and cleaning was performed through statistical software employing both range and variable frequency checks to mitigate data entry and management inaccuracies.

Additionally, a “Letter of Cooperation from a Community Research Partner”, a “Data Use Agreement”, and Institutional Review Board approval was obtained from the host institution prior to the commencement of data acquisition. This study was conducted after approval by the Walden University Institutional Review Board (Approval # 07-27-11-0051184). Both the Walden University Research Office and the Dissertation Committee provided final approval of this project.

Conclusion

While addressing the stated research questions, the described methodology defined the relationship between snowfall and traumatic injuries as well as allowed for the identification of specific injury patterns that were subsequently correlated with alternate variables (e.g. discipline) as well as recent snowfall. The collection and utilization of the combination of ISS, AIS, and the listing of specific injuries facilitated an appreciation for global severity, specific body region severity, and specific injury patterns observed respectively in the setting of variable snow depths. This approach defined at what snowfall depth changes in injury patterns develop as well as the threshold for variance in injury severity scores.

Chapter 4: Results

The primary research objectives of this work were to define the relationship by which daily snowfall amounts contribute to the anatomical patterns as well as the severity of traumatic injuries occurring on one of North America's largest ski resorts. Secondary considerations explored the contributions of helmet use, mechanism of injury, and the varying disciplines of skiing and snowboarding towards the severity of traumatic injuries occurring in snow-sports. This chapter begins with the descriptive statistical analysis of the work and then proceeds through the inferential analysis with the last section discussing the secondary research considerations.

Descriptive Statistical Analysis

This study enrolled 297 patients from the host hospital who met the previously described inclusion criteria over the 2010-2011 ski and snowboard season. Frequency distribution analysis describing the patient population as well as injury severity scores, daily snowfall measurements, mechanism of injury, discipline, and specific injury frequencies are presented.

The Study Population

The mean age of the study participants was 41, with a range from eight to 84 years and a standard deviation (SD) of 17.2 years. Adults age 21 to 30 years were the largest group of patients, accounting for 20.5% of the study population, while children and teens (0 to 20 years) accounted for the smallest patient group (11.8%). Adults over the age of 40 accounted for 49.5% of the study population (Table 2).

From a gender perspective, males represented 65% of the sample while females made up the remaining 35% of injured patients. As shown in Table 2, the majority of patients were injured in the act of skiing (72.1%), while 27.9% of patients were injured in the act of snowboarding. Helmet use was tracked throughout the season as well with 64.3% of injured patients wearing a helmet at time of injury and 35.7% of patients being helmet-free at time of injury. From a mechanism of injury perspective, falls are far more common than collisions encompassing 90.6% of injuries with collisions making up the remaining 9.4% of the injury mechanisms in this patient population. Traumatic injuries did not contribute as the primary etiology of death on the host resort in this patient population over the course of the season, thus forcing the omission of the research question pertaining to mortality from the analysis.

Table 2

Frequency Distribution of Key Variables

Variable	Frequency (*n*)	%
Age		
0-20	35	11.8
21-30	61	20.5
31-40	54	18.2
41-50	49	16.5
51-60	52	17.5
Over 60	46	15.5
Gender		
Male	193	65.0
Female	104	35.0
Discipline		
Ski	214	72.1
Snowboard	83	27.9
Helmet		
Yes	191	64.3
No	106	35.7
Mechanism of injury		
Fall	269	90.6
Collision	28	9.4

Daily Snowfall

Snowfall was measured on a daily basis by the ski patrol of the host resort as described in Chapter 3. The daily snowfall amount demonstrated a range from zero to 17 inches over the course of the ski and snowboard season. The mean daily snowfall was 2.3 inches with a SD of 3.5 on the resort while the median snowfall was 0.5 inches over the 2010-2011 season. The frequency distribution of the daily snowfall amounts are presented in Table 3.

Table 3

Frequency Distribution of Daily Snowfall Amounts

Daily snowfall (inches)	Frequency (days)	%
1. [0-2.9]	217	73.1
2. [3-5.9]	35	11.8
3. [6-8.9]	20	6.7
4. [9-11.9]	19	6.4
5. [12-14.9]	1	0.3
6. [>15]	5	1.7

Injury Severity Scores

ISS demonstrated a mean of 6.3 over the study period with a range from 1 to 29 and a SD of 4.5. ISS frequency distributions based on severity are demonstrated in Table 4.

Abbreviated Injury Scales

As described in chapter 2, (AIS) are determined for each body region utilizing standardized injury scales and span an escalating severity range from one to six (Table 1). AIS frequency distributions specific to each anatomical region are demonstrated in

Appendix B with a comparison of means for anatomical regions found in Table 5. In this work, injuries to the thorax demonstrated the highest mean AIS (2.8), followed by injuries to the abdomen (2.5), spine (2.5), and head (2.4) in decreasing order of severity. Injuries to the integument demonstrated the lowest mean AIS (1.0; Table 5).

Table 4

Frequency Distribution of Injury Severity Score by Injury Severity

ISS	Frequency (patients)	%
Mild injury (1-9)	259	87.2
Moderate injury (10-15)	14	4.7
Severe injury (16-24)	21	7.1
Critical injury (>25)	3	1.0

Table 5

Mean Abbreviated Injury Scale by Anatomical Region

Anatomical region	Mean AIS
Head	2.4
Face	1.8
Neck	1.7
Thorax	2.8
Abdomen	2.5
Spine	2.5
Upper extremity	1.9
Lower extremity	2.2
Skin/other	1.0

Specific Injuries Used in the Research

Injuries that demonstrate either high frequencies (e.g. orthopedic injuries) or are resource intensive for the host facility (e.g. requiring transfer) were tracked over the course of the 2010-2011 season with frequency distributions shown in Table 6. In summary, extremity fractures accounted for the majority of injuries with upper extremity and lower extremity orthopedic injuries accounting for 32.8% and 38.3% of all injuries respectively. Thoracic injuries (9.9%), head injuries (8.3%), abdominal injuries (4.3%), spinal fractures (4.0%), and pelvis fractures (2.4%) represented the remainder of total injuries in this patient population. The contribution of discipline (ski or snowboard) on the frequency distribution of specific anatomical regions of injury demonstrated that, although skiers sustained the majority of injuries in each anatomical region, abdominal injuries, as well as upper extremity injuries were almost equally represented in both the skiing and snowboarding groups.

Inferential Statistical Analysis

Analysis of the relationship between daily snowfall accumulations and traumatic injuries utilized a combination of correlation analyses, univariate analyses, and logistic regression modeling. In instances where the cell count was low, appropriate statistical methodologies including Fisher's exact test (FET) and univariate analyses replaced traditional correlation analysis techniques and logistic regression modeling in an attempt to mitigate sparse-data bias and maintain meaningful inferences and generalizability (Greenland, Schwartzbaum, & Finkle, 2000).

Table 6

Frequency Distribution of Specific Injuries by Anatomical Area and Discipline

Injury	Frequency (*n*)	Percentage of total (%)	Skiing (%)	Snowboarding (%)
Head			76.9	23.1
Skull fracture	1	0.2		
Intracerebral	14	3.3		
Concussion	13	3.1		
Facial fracture	7	1.7		
Thorax			77.8	22.2
Rib fracture	23	5.4		
Pneumothorax	15	3.6		
Hemothorax	4	0.9		
Abdomen			56.2	43.8
Liver laceration	4	0.9		
Spleen	7	1.7		
Renal laceration	7	1.7		
Pelvis			80.0	20.0
Pelvis fracture	10	2.4		
Upper extremity			52.1	47.9
Shoulder girdle Fracture*	38	8.9		
Humerus	26	6.2		
Radius/ulna	38	8.9		
Wrist/hand Fracture**	29	6.9		
Vascular injury	1	0.2		
Elbow fracture	7	1.7		
Lower extremity			86.7	13.3
Femur fracture	29	6.9		
Knee	27	6.4		
Tibia/fibula	92	21.7		
Ankle fracture	14	3.3		
Spine			86.7	13.3
Cervical Fracture	3	0.7		
Thoracic Fracture	4	0.9		
Lumbar fracture	10	2.4		

Note. * Includes: humerus fractures proximal to the anatomical neck, clavicle fractures, and scapula fractures. ** Includes distal intraarticular radius or ulna fractures and any hand fracture.

Research Question 1: Examining the Relationship Between Daily Snowfall and Injury Severity Scores

Prior to statistical analysis, graphic representation of the relationship between daily snowfall and injury severity was performed. A negative correlation between the daily snowfall amount and the ISS can be appreciated from Figure 1 with a calculated correlation coefficient of -0.08.

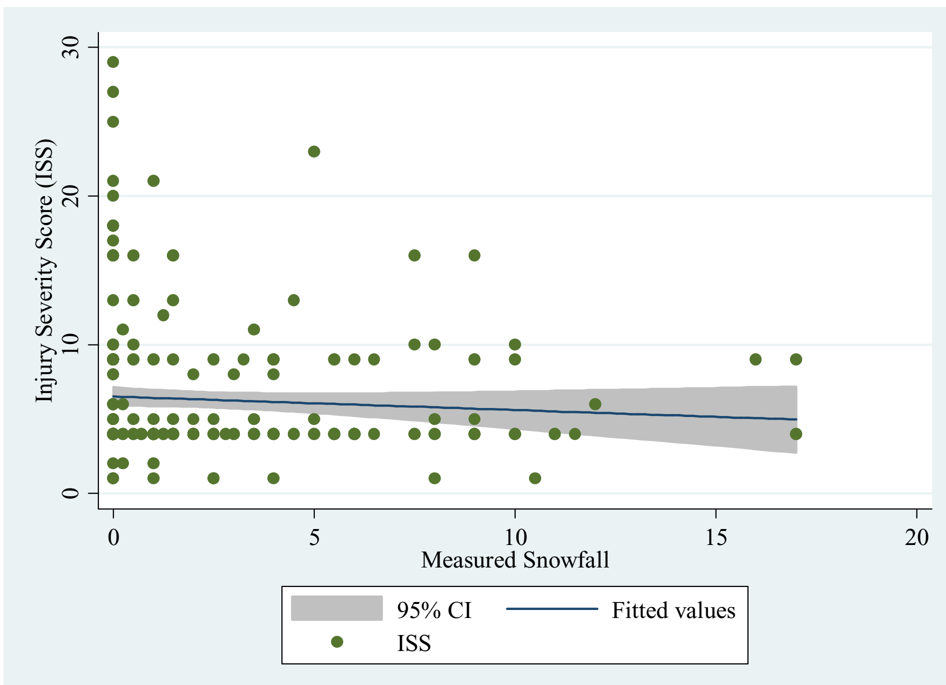

Figure 1. Scatter Plot Demonstrating Negative Correlation between Daily Snowfall and Injury Severity Score.

The determination of the precise amount of snowfall that may predict the variance in ISS from a moderate to a severe injury was tested utilizing correlation analysis, logistic regression, and univariate analyses. Initial regression analysis utilized the snowfall categories detailed in Table 3. Category 1 (0 to 2.9 inches) demonstrated the most significance and further development of categorical variables corresponding to snow depths within Category 1 were performed. The ISS score (≥16) served as the dependent variable while variable snowfall increments served as independent variables. To maintain consistency in the methodology, both the independent and dependent variables were assigned a value of 1 if the condition was present and a value of 2 if the condition was not met.

In this instance, the contingency table demonstrated at least one cell count that was less than or equal to 5 and FET was subsequently performed in place of chi-square analysis. Results of the analysis using FET confirmed that the odds of sustaining a severe or critical injury (ISS ≥16) is over 3 times more likely when the daily snowfall total is less than 2 inches (p = .024, Fisher's exact test). Due to low cell count, univariate analysis was performed and demonstrated an increased odds of sustaining a severe or critical injury when recent snowfall was less than two inches (OR = 3.86; 95%CI [1.06, 16.69]). Subsequent to these findings, the null hypothesis for Research Question 1 (daily snowfall does not affect the severity of traumatic injuries) was rejected.

Research Question 2: Examining the Relationship Between Daily Snowfall and the Anatomical Patterns of Injuries Based on the Abbreviated Injury Scale

The determination of the relationship between daily snowfall and the anatomical patterns of injury was performed utilizing a combination of logistic regression combined with correlation and univariate analyses. AIS scoring was divided into those with mild to moderate injuries (AIS≤2) and those with severe to critical injuries (AIS≥3) after elimination of those with an AIS score of zero, which is consistent with an absence of injury in a particular anatomical region. When addressing the relationship between daily snowfall amounts and the anatomical patterns of injuries, multiple categorical variables reflecting the anatomical distributions of injuries were created, as shown in Table 6. Patients were assigned a value of 1 if the respective AIS score was present and a value of 2 if the condition was not met.

After the creation of anatomical and AIS categories, daily snowfall measurement was cut at the median (0.5 inches), which evenly divided the population into two groups. Logistic regression analysis was performed on the daily snowfall categories detailed in Table 3 with the goal of determining where the snowfall threshold for a significant change in AIS resides. Snowfall was analyzed within each anatomical category to determine at what snow depth the likelihood of an injury to a particular anatomical region was significant.

Snowfall and the anatomical patterns of injury using the AIS. Although each of the anatomical regions utilized in the AIS calculations were analyzed, only AIS scores relating to thoracic injuries demonstrated statistical significance when using the aforementioned AIS breakpoint of three (p = .016, Fisher's exact test). Injuries to the upper extremity demonstrated a significant relationship only when the AIS threshold was decreased to a breakpoint of two signifying a variation between mild to moderate injuries (p = .028, Fisher's exact test).

Thoracic injuries, AIS, and daily snowfall. In the analysis between thoracic injuries and daily snowfall, the contingency table demonstrated at least one cell count that was less than or equal to 5 and FET was subsequently performed in place of chi-square analysis. Results of the analysis using FET confirmed that sustaining a serious injury (AIS $\geq$3) to the thorax is increased when the daily snowfall total is 0.0 inches (p = .016, Fisher's exact test). Further analysis demonstrated that a significant majority (72.2%) of severe or critical thoracic injuries occurred when there was no new snowfall in the previous 24 hours. Due to low cell count, univariate analysis was performed that demonstrated a 10 fold increased odds of sustaining a thoracic AIS defined as severe or critical when the daily snowfall accumulation was 0.0 inches (OR = 10.40; 95%CI [1.62, 66.90]).

Upper extremity injuries, AIS, and daily snowfall. When analyzing the remainder of the anatomical categories for a significant relationship between AIS and snowfall, injuries to the upper extremity demonstrated significance with snowfall using the previously discussed AIS cutoff of two, consistent with the difference between a mild and a moderate injury (p = .028). Although discordant with the previous thoracic AIS cut-off of three, nearly 95% of upper extremity injuries with an AIS greater than two occurred when there was less than nine inches of new snowfall.

In this instance, the contingency table demonstrated at least one cell count that was less than or equal to 5 and FET was subsequently performed in place of chi-square analysis. Results of the analysis using FET confirmed that sustaining a moderate to severe injury to the upper extremity, as defined by the AIS, is increased when the daily snowfall total is less than nine inches (p = .028, Fisher's exact test). Due to low cell count, univariate analysis was performed and demonstrated an increased odds of sustaining an injury to the upper extremity defined as moderate to severe by the AIS (OR = 7.63; 95%CI [1.50, 38.70]). Subsequent to these findings, the null hypothesis for Research Question 2 (daily snowfall does not affect the severity of traumatic injuries relative to anatomical patterns based on the AIS) was rejected.

Research Question 3: Examining the Relationship Between Daily Snowfall and Mortality

Over the course of the 2010-2011 ski and snowboard season there were no patients who died on the host resort with a traumatic injury listed as the primary etiology of death. Subsequent to this finding, Research Question 3 was omitted from further analysis.

Research Question 4: Examining the Statistical Relationship Between Daily Snowfall and Specific Snow-Sports Injuries

The testing of Hypothesis 4 was performed utilizing a combination of correlation analyses and logistic regression modeling. When addressing the relationship between daily snowfall amounts and specific injuries sustained while skiing or snowboarding, multiple categorical variables reflecting the specific injuries were created. Table 6 illustrates the specific injuries used for analysis as well as the anatomical groupings of each injury. Univariate analysis demonstrated a significant relationship between daily snowfall and both rib and lumbar spine fractures.

Lumbar spine fractures and daily snowfall. When addressing the relationships between lumbar spine fracture and the daily snowfall, multiple categorical variables were created dividing patients into those with a documented lumbar spine fracture and those without. Patients were assigned a value of 1 if the fracture was present and a value of 2 if the condition was not met. Determination of the precise amount of snowfall that may predict the likelihood of sustaining a lumbar spine fracture was tested utilizing simple logistic regression models using the presence of a lumbar spine fracture as the dependent variable and variable snowfall measurements within Snowfall Category 1 (Table 3), as previously described, as independent variables.

In this instance, the contingency table demonstrated at least one cell count that was less than or equal to 5 and FET was subsequently performed in place of chi-square analysis. Results of the analysis using FET confirmed that the risk of sustaining a lumbar spine fracture is increased when the daily snowfall total is less than or equal to 0.9 inches (p = .021, Fisher's exact test). Due to low cell count, univariate analysis was performed and demonstrated that the odds of sustaining a lumbar spine fracture are over 8 times more likely when the daily snowfall was less than one inch (OR = 8.45; 95% CI [1.08, 180.48]).

Rib fractures and daily snowfall. When addressing the relationships between rib fractures and daily snowfall, multiple categorical variables were created dividing patients into those with a documented rib fracture and those without. Patients were assigned a value of 1 if the fracture was present and a value of 2 if the condition was not met. In this instance, the contingency table demonstrated at least one cell count that was less than or equal to 5 and FET was subsequently performed in place of chi-square analysis. Results of the analysis using FET confirmed that rib fractures are over 3 times more likely when the daily snowfall is less than or equal to 0.5 inches (p = .009, Fisher's exact test).Univariate analysis was subsequently performed and demonstrated a 3-fold increased odds of sustaining a rib fracture when the daily snowfall is less than or equal to 0.5 inches (OR = 3.60; 95% CI [1.21, 11.43]).

Secondary Research Considerations

The primary research considerations of this project focused on the contribution of daily snowfall to injury severity and to the anatomical distribution of injuries. Additional considerations of potential relevance included the contributions of: mechanism of injury (fall or collision), discipline (ski or snowboard), helmet use, and gender as predictor variables for both injury severity and specific injuries. A combination of correlation analyses and simple logistic regression was utilized for the statistical analyses of the secondary research considerations, which demonstrated that although neither gender nor helmet use were significant predictor variables, both mechanism of injury and discipline demonstrate significance with both injuries and anatomical regions.

The Effect of Mechanism of Injury on Injury Severity

For the purposes of this research, the studied mechanisms of injury included falls or collisions with other skiers or snowboarders. The discipline of falls encompassed falls to the ground as well as a skier or snowboarder striking an inanimate object (e.g. tree). Analysis demonstrated that a collision with another individual increased the likelihood of an injury being defined as severe or critical by the ISS when compared to all types of falls.

Mechanism of injury and the ISS. The results of analysis between an ISS greater than or equal to 16 and mechanism of injury (fall or collision) demonstrated a χ^2 value (N = 297, df = 1) of 17.475. The chi-square statistic demonstrated a probability of $p < .001$, which is less than the stated alpha level of .05. Analysis reveals an increased percentage of collisions, when compared to falls, contributing to an injury with an ISS greater than or equal to 16 (28.6% vs. 5.9%). Simple logistic regression analysis demonstrated that the odds of a collision contributing to an ISS greater than 16 were over 6 times that of a fall in this study population (Table 7).

Table 7

Results of Simple Logistic Regression [Injury Severity Score≥16 and Mechanism of Injury]

ISS ≥ 16	OR	*p*	*df*	[95%CI]
Mechanism (collision)	6.325	0.000	1	[2.41, 16.57]
Constant		0.000	1	[-5.90, -3.30]

Note. OR represents the odds ratio; *p* is the *p*-value; df are the degrees of freedom for the variable; CI represents the 95% confidence interval.

Further comparisons between the mechanism of injury and the ISS were performed utilizing the categorical groupings outlined in Table 4. In this analysis, mechanism of injury (fall or collision) demonstrated significance with the ISS categories of mild injury (ISS 1-9). The results of analysis between a mild injury and the mechanism of injury demonstrated a χ^2 value (N = 297, $df = 1$) of 14.555. The chi-square statistic demonstrated a probability of $p < .001$, which is less than the stated alpha level of .05. Interpretation reveals that 93.1% of injuries that resulted in an ISS consistent with a mild or moderate injury (ISS 1-9) were the result of falls, while 6.9% of injuries with the same injury severity were the result of collisions.

Simple logistic regression analysis was performed using the mechanism of injury as the independent variable and the ISS (1-9) as a categorical, dependent variable. There was a significant relationship demonstrated between falls and a mild to moderate injury as defined by the Injury Severity Score ($p < .001$). The odds of a fall contributing to an

ISS score consistent with a mild to moderate injury was nearly 5 times that of a collision (OR = 4.78; 95% CI [2.01, 11.37]; Table 8).

Table 8

Results of Simple Logistic Regression [Injury Severity Score (1-9) and Mechanism of Injury (Falls)]

ISS (1-9)	OR	*p*	*df*	[95%CI]
Mechanism (falls)	4.78	0.000	1	[2.01, 11.37]
Constant		0.000	1	[-0.18, 1.36]

Note. OR represents the odds ratio; *p* is the p-value; *df* are the degrees of freedom for the variable; *CI* represents the 95% confidence interval.

Mechanism of Injury and Specific Injuries

Continued analysis was performed utilizing mechanism of injury (falls or collisions) and the specific injuries followed in the project. Statistical significance was found between the mechanism of injury (collisions) and the presence of rib fractures. The results of analysis between the presence of rib fractures and collisions demonstrated a χ^2 value (N = 297, *df* = 1) of 21.75. The chi-square statistic demonstrated a probability of $p < .001$, which is less than the stated alpha level of .05. Interpretation reveals an increased number of patients sustaining rib fractures secondary to a collision (28.6%) when compared to falls (5.6%).

Simple logistic regression analysis was performed using the mechanism of injury as the independent variable and the presence of rib fractures as a categorical, dependent variable. There was a significant relationship demonstrated between collisions and the presence of rib fractures ($p < .001$; Table 9). The odds ratio for this comparison was 6.8

indicating that the odds of a collision contributing to a rib fracture in this patient population is nearly 7 times that of falls (95% CI [2.56, 17.89]).

Table 9

Results of Simple Logistic Regression [Rib Fractures and Mechanism of Injury (Collision)]

Rib fractures	OR	*p*	*df*	[95%CI]
Mechanism (collision)	6.77	0.000	1	[2.56, 17.89]
Constant		0.000	1	[-6.07, -3.42]

Note. OR represents the odds ratio; *p* is the p-value; *df* are the degrees of freedom for the variable; *CI* represents the 95% confidence interval.

The Effect of Discipline on Injury

The two disciplines that were utilized in this project included alpine skiing and snowboarding. Correlation analysis and simple logistic regression were utilized to demonstrate statistical significance between discipline and the following: lower extremity injuries (collectively), ligamentous injuries to the knee, lower leg fractures, wrist or hand fractures, and forearm fractures.

Discipline and lower extremity injuries. Lower extremity injuries in this work collectively encompassed: femur fractures, ligamentous knee injuries, tibia/fibula fractures, and foot or ankle fractures. Simple logistic regression demonstrated that the discipline of skiing had a significant relationship to lower extremity injuries as an anatomical group.

The results of analysis of injuries to the lower extremity and discipline demonstrated a χ^2 value (N = 297, df = 1) of 24.025. The chi-square statistic demonstrated a probability of $p < .001$, which is less than the stated alpha level of .05. Analysis revealed an increased number of injuries to the lower extremity occurred when the patient had been skiing (51.9%) when compared to snowboarding (20.5%).

Simple logistic regression analysis was performed using the discipline of skiing as the independent variable and injury to the lower extremity as a categorical, dependent variable. There was a significant relationship demonstrated between the discipline of skiing and lower extremity injury ($p < .001$; Table 10). The odds ratio for this comparison was 4.18 indicating that the odds of skiing contributing to an injury of the lower extremity is increased in this patient population when compared to snowboarding by a factor of over 4 (95%CI [2.30, 7.59]).

Table 10

Results of Simple Logistic Regression [Injury to the Lower Extremity and Discipline]

Lower extremity injury	OR	*p*	*df*	[95%CI]
Skiing	4.18	0.000	1	[2.30, 7.59]
Constant		0.000	1	[-6.06, -3.41]

Note. OR represents the odds ratio; *p* is the p-value; *df* are the degrees of freedom for the variable; *CI* represents the 95% confidence interval.

Discipline and ligamentous injuries to the knee. In this instance, the contingency table analyzing ligamentous injuries to the knee and discipline demonstrated at least one cell count that was less than or equal to 5 and FET was subsequently performed in place of chi-square analysis. Results of the analysis using FET confirmed that ligamentous injuries to the knee are more likely when the discipline is skiing compared to snowboarding ($p = .001$, Fisher's exact test). Subsequent interpretation reveals an increased number of ligamentous injuries to the knee when the participant was skiing (12.5%) compared to snowboarding (1.2%). Due to low cell count, univariate analysis was performed demonstrating that the odds of a ligamentous injury being sustained from skiing are over 11 times that from snowboarding (OR = 11.34; 95% CI [1.60, 228.39]).

Discipline and wrist or hand fractures. The results of the analysis of wrist or hand fractures and discipline demonstrated a χ^2 value (N = 297, *df* = 1) of 18.58. The chi-square statistic demonstrated a probability of $p < .001$, which is less than the stated alpha level of .05. Interpretation reveals an increased percentage of wrist or hand fractures when the patient had been snowboarding (21.7%) compared to skiing (5.14%).

Simple logistic regression analysis was performed using discipline as the independent variable and a wrist or hand fracture as a categorical, dependent variable. There was a significant relationship demonstrated between snowboarding and wrist or hand fracture ($p < .001$) (Table 11). The odds ratio for this comparison was 5.1 indicating that the odds of snowboarding contributing to a wrist or hand fracture in this patient population is over 5 times that of skiing (95% CI [2.29, 11.37]).

Table 11

Results of Simple Logistic Regression [Wrist/Hand Fractures and Discipline]

Wrist or hand fracture	OR	*p*	*df*	[95% CI]
Discipline (snowboard)	5.11	0.000	1	[2.29, 11.37]
Constant		0.000	1	[-5.86, -3.22]

Note. OR represents the odds ratio; *p* is the p-value; *df* are the degrees of freedom for the variable; *CI* represents the 95% confidence interval.

Discipline and tibia or fibula fractures. The results of analysis of tibia/fibula fractures and discipline demonstrated a χ^2 value (N = 297, *df* = 1) of 19.30. The chi-square statistic demonstrated a probability of $p < .001$, which is less than the stated alpha level of .05. Subsequent interpretation revealed a disproportionate number of tibia or fibula fractures when the patient had been skiing (38.3%) compared to snowboarding (12.1%).

Simple logistic regression analysis was performed using the discipline of skiing as the independent variable and a tibia/fibula fracture as a categorical, dependent variable. There was a significant relationship demonstrated between the discipline of skiing and a tibia or fibula fracture ($p < .001$; Table 12). The odds ratio for this comparison was 4.53 indicating that the odds of skiing contributing to a tibia or fibula fracture are increased in this patient population over 4 fold when compared to snowboarding (95% CI [2.22, 9.28]).

Table 12

Results of Simple Logistic Regression [Tibia/Fibula Fractures and Discipline]

Tibia or fibula fractures	OR	*p*	*df*	[95%CI]
Discipline (skiing)	4.53	0.000	1	[2.22, 9.28]
Constant		0.000	1	[-2.65, -1.33]

Note. OR represents the odds ratio; *p* is the p-value; *df* are the degrees of freedom for the variable; *CI* represents the 95% confidence interval.

Discipline and radius or ulna fractures. The results of analysis of radius or ulna fractures and discipline demonstrated a χ^2 value (N = 297, *df* = 1) of 50.63. The chi-square statistic demonstrated a probability of $p < .001$, which is less than the stated alpha level of .05. Interpretation reveals a disproportionate number of radius or ulna fractures when the patient had been snowboarding (34.9%) compared to skiing (4.2%).

Simple logistic regression analysis was performed using the discipline of snowboarding as the independent variable and a radius or ulna fracture as a categorical, dependent variable. There was a significant relationship demonstrated between the discipline of snowboarding and a radius/ulna fracture ($p < .001$; Table 13). The odds ratio for this comparison was 12.23 indicating that the odds of snowboarding contributing to a fracture of the radius or ulna is over 12 times that of skiing in this patient population (95% CI[5.46, 27.38]).

Table 13

Results of Simple Logistic Regression [Radius/Ulna Fractures and Discipline (Snowboard)]

Radius or ulna fractures	OR	*p*	*df*	[95%CI]
Discipline(snowboard)	12.23	0.000	1	[5.46, 27.38]
Constant		0.000	1	[-7.03, -4.22]

Note. OR represents the odds ratio; *p* is the p-value; *df* are the degrees of freedom for the variable; *CI* represents the 95% confidence interval.

Discipline and upper extremity fractures. For the purposes of this comparison the upper extremity is comprised of the: humerus, radius, ulna, and bones of the wrist and hand. Previously discussed findings addressed components of the upper extremity while this portion of the analysis addressed the collective whole of upper extremity fractures. The results of analysis of upper extremity fractures and discipline demonstrated a χ^2 value (N = 297, $df = 1$) of 27.12. The chi-square statistic demonstrated a probability of p

< .001, which is less than the stated alpha level of .05. Analysis reveals over 2.5 times the number of upper extremity fractures when the patient had been snowboarding compared to skiing.

Simple logistic regression analysis was performed using the discipline of snowboarding as the independent variable and an upper extremity fracture as a categorical, dependent variable. There was a significant relationship demonstrated between the discipline of snowboarding and a fracture to the upper extremity (collectively; $p < .001$; Table 14). The odds ratio for this comparison was 3.99 indicating that the odds of snowboarding contributing to a fracture of the upper extremity is nearly 4 times that of skiing in this patient population (95% CI [2.33, 6.82]).

Table 14

Results of Simple Logistic Regression [Upper Extremity Fractures and Discipline (Snowboard)]

Upper extremity fractures	OR	*p*	*df*	[95%CI]
Discipline (snowboard)	3.99	0.000	1	[2.33, 6.82]
Constant		0.000	1	[-1.53, -0.89]

Note. OR represents the odds ratio; *p* is the p-value; *df* are the degrees of freedom for the variable; *CI* represents the 95% confidence interval.

Considering the aforementioned findings of increased upper extremity severity with higher levels of daily snowfall, and the increased odds of sustaining an upper extremity injury among snowboarders, additional analysis was warranted. Preliminary analysis utilized the snowfall categories detailed in Table 3 as previously described. Further development of categorical variables corresponding to snowfall depths within the stated snowfall categories was performed. The presence of an upper extremity injury served as the dependent variable while variable snowfall increments served as independent variables with the discipline of snowboarding was utilized as a covariate. To maintain consistency in the methodology, the independent and dependent variables as well as the covariate were assigned a value of 1 if the condition was present and a value of 2 if the condition was not met. Multiple logistic regression analysis demonstrated a significant relationship between an upper extremity fracture, the discipline of snowboarding, and a daily snowfall amount of greater than 1.7 inches ($p < .001$). Analysis demonstrated that the odds of a snowboarder sustaining an upper extremity fracture are increased over 4 times when there is more than 1.7 inches of fresh snowfall (OR = 4.3; 95% CI [2.49, 7.49]; Table 15).

Table 15

Results of Multiple Logistic Regression [Upper Extremity Fractures, Discipline (Snowboard), and Daily Snowfall >1.7 Inches]

Upper extremity fractures	OR	*p*	*df*	[95%CI]
Discipline (snowboard)	4.32	0.000	1	[2.49, 7.49]
Constant		0.000	1	[-3.27, -2.62]
Snowfall >1.7 inches				

Note. OR represents the odds ratio; *p* is the p-value; *df* are the degrees of freedom for the variable; *CI* represents the 95% confidence interval.

A similar methodology was employed analyzing the discipline of skiing, the aforementioned predisposition for lower extremity fractures, and daily snowfall. Multiple logistic regression analyses demonstrated that variable daily snowfall depths do not alter the odds of sustaining a lower extremity injury while skiing ($p < .05$).

Summary

Using a combination of correlation and univariate analyses coupled with simple logistic regression modalities, statistically significant relationships were demonstrated for Hypotheses 1, 2, and 4. Hypothesis 3 was omitted from analysis in a post-hoc fashion secondary to an absence of deaths from traumatic injuries on the host resort over the 2010-2011 ski and snowboard season.

Hypothesis 1 addressed the relationship between daily snowfall and ISS. The null hypothesis for Hypothesis 1 was rejected as patients who sustained injuries on the host resort had statistically significant increased odds of that injury being defined as severe or critical by ISS criteria when the daily snowfall amount was 1.9 inches or less. The negative correlation between daily snowfall and ISS demonstrated in this research (r = -0.08) is roughly concordant to that demonstrated by other researchers in the available literature, most notably by Girardi et al. (2010), which demonstrated a correlation coefficient of -0.05 (Girardi et al., 2010).

Hypothesis 2 addressed the relationship between daily snowfall amounts and regional injury severity in relation to the Abbreviated Injury Scale. The null hypothesis for Hypothesis 2 was rejected as daily snowfall amounts demonstrate a statistically significant relationship between the AIS in both, thoracic and upper extremity injuries. Analysis demonstrated an increased severity of thoracic injuries when there was no new daily snowfall and increased injury severity to the upper extremities when there was less than 9 inches of daily snowfall. A summary of findings related to the effects of snowfall on global and regional injury severity as well as specific injuries can be found in Table 16.

Table 16

Summary Table: The Effect of Snowfall on Specific Injuries and Injury Severity

Injury or severity score	Snowfall (inches)	OR	95% CI	*p*
ISS≥16	≤ 1.9	3.86	[1.06, 16.69]	.024
Thoracic AIS≥3	0.0	10.40	[1.62, 66.9]	.016
Upper extremity AIS≥2	< 9.0	7.63	[1.50, 38.70]	.028
Lumbar spine fractures	≤ 0.9	8.45	[1.08, 180.48]	.021
Rib fractures	≤0.5	3.60	[1.21, 11.43]	.009

Note. OR represents the odds ratio. *CI* represents the 95% confidence interval

Hypothesis 4 addressed the relationship between daily snowfall and specific snow-sports injuries sustained on the host resort. Of the injuries tracked during the 2010-2011 season, statistical significance was demonstrated between daily snowfall and lumbar spine fractures as well as rib fractures. Subsequent to these findings, the null hypothesis for Hypothesis 4 was rejected.

The secondary research considerations addressed the contribution of: mechanism of injury (fall or collision), discipline (ski or snowboard), helmet use, and gender on injury severity as well as on specific injuries. Analysis did not identify a statistically significant relationship when gender or helmet use was utilized, while both mechanism of injury and discipline were significant predictors of injury in this patient population.

Simple logistic regression modeling demonstrated a statistically significant relationship between mechanism of injury and an ISS consistent with severe or critical injuries (ISS≥16), rib fractures, and severity scores consistent with mild injuries (ISS 1-9). One of the more notable finding in this portion of the analysis was the relationship between mechanism of injury and sustaining an injury defined as severe by the ISS classification. Simple logistic regression demonstrated that collisions with other skiers are over 6 times more likely to contribute to a severity score consistent with a severe injury in this patient population when compared to falls (Table 17).

Table 17

Summary Table: The Effect of Mechanism of Injury on Injury Severity and Specific Injury

Injury severity and specific injury	Mechanism of injury	OR	95% CI	*p*
ISS ≥ 16	Collision	6.33	[2.41, 16.57]	< .001
Rib fractures	Collision	6.77	[2.56, 17.89]	< .001
Mild injury (ISS 1-9)	Fall	4.78	[2.01, 11.37]	< .001

Note. OR represents the odds ratio. *CI* represents the 95% confidence interval.

Continued analysis demonstrated statistical significance for the influence of discipline on traumatic injuries as well. The discipline of skiing demonstrated statistical significance with lower extremity injuries taken collectively, as well as specific injuries such as ligamentous injuries to the knee and tibia or fibula fractures. In this patient population, the odds of sustaining a lower leg fracture while skiing were over 4 times that of snowboarding (OR = 4.53; 95%CI [2.22, 9.28]). Additionally, the odds of sustaining a ligamentous injury to the knee were over 11 times greater when skiing (OR = 11.34; 95%CI [1.60, 228.39]). Of note, when daily snowfall was utilized as a covariate in the analysis regarding skiing and lower extremity injuries, snowfall depth did not affect the odds of sustaining an injury to the lower extremity. It seems that the act of skiing demonstrates the majority of influence on injuries to the lower extremity compared to the other measured variables in this research.

When the discipline of snowboarding was analyzed, upper extremity injuries taken collectively demonstrated a nearly 4 fold increase in odds of occurrence while wrist and hand fractures and lower arm injuries demonstrated and increased odds of 5.1 and 12.2 respectively (Table 18). As in the analyses regarding the discipline of skiing, daily snowfall was utilized as a covariate and did, in fact, demonstrate a significant effect on injury. Findings demonstrated that a daily snowfall amount of over 1.7 inches increased the odds of an upper extremity injury by a factor of over four when snowboarding was the discipline.

Table 18

Summary Table: The Effect of Discipline on Specific Injuries

Injury	Discipline	OR	95% CI	*P*
Upper extremity	Snowboard	3.99	[2.33, 6.82]	< .001
Upper extremity (snow > 1.7 inches)	Snowboard	4.33	[2.49, 7.49]	< .001
Wrist or hand fractures	Snowboard	5.11	[2.29, 11.38]	< .001
Radius or ulna fractures	Snowboard	12.23	[5.46, 27.38]	< .001
Tibia or fibula fractures	Ski	4.53	[2.22, 9.28]	< .001
Ligamentous injuries to the knee	Ski	11.34	[1.6, 228.39]	.001
Lower extremity injuries	Ski	4.18	[2.30, 7.59]	< .001

Note. OR represents the odds ratio. *CI* represents the 95% confidence interval.

These findings illustrating a predilection for upper extremity injuries in snowboarders and a predominance of lower extremity injuries in skiers is consistent with the findings of other researchers in the relevant literature (Idzikowski, et al., 2000; Sacco et al., 1998; Sutherland et al., 1996). A summary of findings regarding the effects of snow-sports discipline on injury can be found in Table 18. The final chapter will detail the interpretation of the findings from this work, the implications for social change, and recommendations for further study.

Chapter 5: Discussion, Conclusions, and Recommendations

Overview

A review of the literature demonstrates that snow sport-related injuries represent a significant source of morbidity and hospitalization while the details of the relationship between daily snowfall amounts and associated injuries in skiers and snowboarders are ill defined. This work focused on the contribution daily snowfall has on both the type and severity of traumatic injuries sustained at one of North America's largest ski resorts through the measurement of daily snowfall coupled with analyses of: Injury Severity Scores, Abbreviated Injury Scales, and specific snow sport injuries sustained while skiing or snowboarding over the 2010-2011 season.

Findings from this study demonstrated that increased amounts of daily snowfall are protective for severe injury whereas relatively small amounts of daily snowfall increased the likelihood of sustaining an injury defined as severe or critical by the ISS classification. This relationship between snowfall and global injury severity also applies to the specific anatomical regions of the thorax and the upper extremity, as variable snowfall amounts increased the odds of sustaining injuries to these anatomical regions as defined by the AIS classification. Additionally, daily snowfall demonstrated a statistically significant association with specific orthopedic injuries as well as injury patterns in this patient population. Lastly, both the mechanism of injury (fall or collision) and discipline (ski or snowboard) were demonstrated to be factors that contribute to an increased likelihood of injury in both skiers and snowboarders over the 2010-2011 ski season.

Interpretation of the Findings: Frequency Distribution of Key Variables

This project enrolled 297 participants over the 2010-2011-ski season. The age distribution in this project is consistent with previous works detailing ski or snowboard traumatic injuries and ranged from eight to 84, with adults aged 21 to 30 representing over 20% of the study population while children and teens up to age 20 represented the smallest patient group (11.8%). Consistencies with the prior research by Girardi et al. (2010), include a male predominance (65%), and an increased percentage of skier-related injury (72.1%) when compared to the discipline of snowboarding (27.9%; Girardi et al., 2010). The mean daily snowfall was 2.3 inches over the course of the 2010-2011 ski season which is roughly concordant with a mean of 3.0 inches stated in the work by Girardi et al. (2010). Comparatively speaking, the previous work by Girardi et al. (2010) reported a mean ISS of 3.4 while the mean ISS in this current project was 6.3. It is unclear if this variance is due to potential confounders or an actual increased severity in this current patient population.

Interpretation of the Findings: Research Questions 1, 2, 3, and 4

Analysis of the research questions required the utilization of correlation analysis, logistic regression methodologies, and univariate analysis. In instances where a predictive relationship between variables was not feasible due to small patient numbers regarding a particular variable, regression methodologies were abandoned in favor of univariate analysis. The aim of this approach was to mitigate the overestimation of effect found with sparse-data bias and provide sound descriptions of the relationships between predictor variables and outcomes.

Research Question 1: Examining the Relationship Between Daily Snowfall and the Injury Severity Score

In the analysis of Research Question 1, correlation analyses coupled with univariate analysis demonstrated that a daily snowfall amount of 1.9 inches or less is associated with increased odds of an injury being defined as severe or critical by ISS criteria. Correlation analysis showed that over 3 times as many severe or critical injuries were sustained when the daily snowfall totaled less than two inches in the previous 24 hours. In must be stated that although sustaining an injury with an ISS greater than 15 was a relatively infrequent occurrence, encompassing only 8.1% of patients in this research, its importance should not be limited by its prevalence. As described by Feliciano et al. (2008), "the ISS correlates well with mortality and remains the most widely used anatomical scoring system" (Feliciano et al., 2008, p.84). The significance of this relationship between daily snowfall and the ISS forced the rejection of the null hypothesis for Research Question 1. Of note, these findings are concordant with findings from one of the more proximal works in the literature by Girardi et al. (2010), in which the highest ISS points were observed when daily snowfall measurements were less than 3 centimeters or 1.2 inches (Girardi et al., 2010).

The association between increased injury severity and small amounts of fresh snowfall is a prominent finding of this work, a consistency in the literature, and concordant with the assumptions detailed in chapter 2 regarding the physics of skiing and the kinematics of trauma. From a kinematics perspective, velocity demonstrates the majority of the influence on kinetic energy, which directly relates to energy transfer and subsequent injury (Feliciano et al., 2008). Regarding the physics of skiing and snowboarding, it is has been demonstrated experimentally that increased snow depth will decrease the water layer present between the ski and the snow causing an increase in friction and a subsequent decrease in velocity (Colbeck, 1988). It is the positive relationship between velocity and injury severity combined with the physics of skiing that likely serves as the foundation for the findings of this work as well as those in the available literature.

In summary, snowfall depths demonstrate an inverse relationship to the kinetic energy generated by the skier or snowboarder subsequently affecting the severity of injury in an inverse manner. It is this general principle that is applicable to nearly all of the findings from this research and may serve as the foundation etiology of traumatic injuries in this patient population.

Research Question 2: Examining the Relationship Between Daily Snowfall and the Anatomical Patterns of Injuries Based on the Abbreviated Injury Scale

As previously described, the AIS provides a measure of injury severity relative to specific anatomical regions. Findings demonstrated that not only does daily snowfall depth contribute to overall injury severity but also maintains a significant relationship with regional anatomical injury scoring as well. Statistically significant relationships were demonstrated with daily snowfall amounts and the severity of injury scoring in multiple anatomical regions based on the AIS. Although not previously described in other works, findings from this current research demonstrated a significant association between daily snowfall and AIS scoring in the anatomical regions of the thorax as well as the upper extremities.

When analyzed, a thoracic AIS breakpoint of three was used defining a difference in moderate to severe injuries according to AIS classification. It was demonstrated that when there was no new snowfall, there was an increased odds of sustaining a thoracic injury having an AIS greater than or equal to three. Correlation of this relationship demonstrated that 72.2% of thoracic injuries with an AIS greater than or equal to three occurred when there was no new daily snowfall. This finding is consistent with previous works in which periods of minimal snowfall are associated with an increase in injury severity due to the presumed increased speeds generated by the riders (Girardi et al., 2010).

A similar methodology was employed when analyzing the upper extremities as an anatomical region. Findings demonstrated a statistically significant relationship between an AIS breakpoint of two in the upper extremity region, signifying the divergence between a mild to a moderate injury, and a daily snowfall measurement of less than nine inches. Correlation analysis demonstrated that 94.7% of upper extremity injuries that earned an AIS scoring of greater than or equal to two occurred when there was less than nine inches of fresh snowfall in the previous 24 hours. This is a unique finding from this project as all other associations regarding daily snowfall and injury in this research reflect snow depths of less than one inch. This finding may be comprised of a multifactorial etiology. As described by Sacco et al. (1998), increased snow depth increases torsional forces on the lower extremities increasing the odds for injury while skiing (Sacco et al., 1998). This mechanism may be the etiology of the upper extremity injuries as a result of the initial fall. When viewed as a result of disruption of lower extremity congruence, injuries to the upper extremity may be associated with increased snowfall as demonstrated in this research. Another consideration regarding the relationship between upper extremity injuries is that of the effect of discipline on injury patterns. As previously detailed, discipline, specifically snowboarding, is associated with injuries to both the upper and lower arm. Although discipline did not demonstrate statistical significance with AIS scores in this research, it is conceivable that increased snow depth contributes to falls, which in turn, affect snowboarders disproportionately due to the relative immobility of the lower extremities while attached to the snowboard. This upper extremity vulnerability may lead to an increase in regional injury severity in this population that could be exacerbated by situations that potentially contribute to falls such as increased snowfall. Further analysis regarding this association can be found in the discussion regarding Secondary Research Considerations.

Research Question 3: Daily Snowfall Amounts Affect the Mortality Rates from Traumatic Injuries Sustained at the Host Resort

Over the course of the 2010-2011 ski and snowboard season there were no patients who died on the host resort with a traumatic injury listed as the primary etiology of death. Subsequent to this finding, Research Question 3 was omitted from further analysis. Due to the relative infrequency of traumatic deaths in his patient population, additional research may require a larger sample size for analyses before an association between snowfall and mortality can be determined.

Research Question 4: Examining the Statistical Relationship between Daily Snowfall and Specific Snow-Sports Injuries

The relationships between daily snowfall and specific injuries were explored through a combination of correlation analyses and simple logistic regression models.

Daily snowfall was demonstrated to have a statistically significant relationship with rib and lumbar spine fractures. In this work, the odds of sustaining a lumbar spine fracture are increased over eight times when there is less than an inch of fresh snowfall. Additionally, deeper snow is relatively protective against rib fractures as the likelihood of sustaining a rib fracture increases when there is less than 0.5 inches of daily snowfall. The finding that a decreased daily snowfall is associated with multiple specific injuries and anatomical regions should not be surprising when taken in light of other findings from this research, as low snowfall amounts have been demonstrated to contribute to increased injury severity in this patient population.

Secondary Research Considerations: The Effects of Mechanism of Injury and Discipline on Injury.

The mechanisms of injury and disciple were analyzed to determine their contributions to injuries and injury severity. Through a combination of correlation analyses and logistic regression modeling, both, mechanism of injury and discipline were determined to have statistically significant relationships to multiple injury patterns.

The Effect of Mechanism of Injury

Regarding the mechanisms of injury in this patient population, while falls demonstrated a significant association with mild injuries as defined by ISS criteria, collisions maintained a significant association with more severe injuries as illustrated in Table 16. Although not commonly utilized as a variable in the related research, falling while skiing or snowboarding was quoted by Girardi et al. (2010), as a factor contributing to an increased ISS (n.s.; Girardi et al., 2010). This current project demonstrated concordance with that finding but only regarding ISS scores consistent with a mild to moderate injury (ISS≤9). Continued analysis in this current project demonstrated that collisions are predictive of an ISS consistent with a severe or critical injury (ISS≥16) and increase the odds of sustaining a severe or critical injury by a factor of over six in this patient population.

The Effect of Discipline

The last consideration of this research addressed the relevance of discipline (skiing or snowboarding) on injuries in this patient population. The influence of discipline on the anatomical patterns of traumatic injuries is demonstrated throughout the available literature, and cannot be overstated. Common findings in previous works demonstrated an increased propensity for snowboarders to sustain upper extremity injuries when compared to skiers (Girardi et al., 2010; Hayes & Groner, 2008; Sacco et al., 1998). Findings from this current project are concordant with those in the available literature regarding the anatomical injury patterns of skiers and snowboarders.

In this research, snowboarding injuries were predominately of the upper extremity and specifically increased the odds of sustaining either a wrist or hand fracture, or a radius or ulna fracture by a significant margin. Generally speaking, snowboarders sustained injuries to the upper extremities at a rate of over twice that of other anatomical regions during the 2010-2011 season. In much the same manner as skiing predisposes an individual to lower extremity trauma; the discipline of snowboarding increased the odds of sustaining injuries to the upper extremity. Further analysis incorporating snowfall demonstrated that this relationship was amplified when there was over 1.7 inches of snowfall. As previously discussed, a potential etiology for this injury pattern could be that increased snow depth predisposes the snowboarder to instability and subsequent falls which translate to the utilization of the arms in a supportive fashion, increasing upper extremity exposure, and ultimately leading to increased injuries. Although yet to be defined in the literature, the fact that snowboarding restricts independent movement of the legs through the use of attachments to a single board may contribute to a decreased ability to compensate for imbalance with the lower extremities thus relying on the upper extremities to provide support in a fall.

Findings from this research demonstrated that the discipline of skiing is significantly associated with injuries to the lower extremities. The finding of increased lower extremity fractures in skiers demonstrates concordance within the literature while illustrating a potential theory on mechanism of injury in this patient population (Dohin & Kohler, 2008; Sacco et al., 1998). A potential explanation for this phenomenon entails an appreciation for the mechanism of injury in skiers. While the lower extremities are fixed to a single board in snowboarding, balance and recovery while skiing rely on the utilization of the lower extremities acting in an independent yet coordinated fashion. It is possible that this reliance on the lower extremities places them in a potentially vulnerable position thus increasing the likelihood of injury. Although not conclusively defined in this research, this vulnerability may be exacerbated when conditions exist that combine with the momentum of the rider to exert torsional forces on the lower extremities such as those found with deep snow (Sacco et al., 1998).

Summary

Many findings from this work are consistent with the existing research while some results are truly novel such as defining the influence of daily snowfall on both global and regional anatomical injury severity. Generalizations regarding the findings of this study demonstrate that low levels of daily snowfall contribute to an increased: (a) global injury severity, (b) regional injury severity, and (c) the odds of specific injuries. Conversely, increased snowfall is a significant contributor towards injuries of the upper extremities while being seemingly protective in regard to global injury severity. The finding that collisions demonstrated increased odds of contributing to more severe injury patterns when compared to falls is best explained through the kinematics of trauma. While falls to the ground are potential sources of severe injury, the energy transfer between two independently moving bodies is greater, predisposing the skiers to more severe injury as discussed in chapter 2. Possible etiologies for these findings revolve around both, the physics of skiing and snowboarding as well as the specific mechanics of a fall within the respective disciplines.

Implications for Social Change

Findings from this research may be found to be applicable to (a) the existing body of medical knowledge, (b) health care providers in resort settings, and (c) to ski resorts through enhanced understanding of the effect of environmental factors on injury severity. Although numerous works can be found addressing traumatic injuries in skiers and snowboarders, there is a relative paucity of research regarding the effects of daily snowfall on injuries. This work directly contributes research findings in an attempt to mitigate this void in the available body of knowledge. From a healthcare perspective, an appreciation of the effects of variable snowfall amounts may be utilized to enhance the index of suspicion on the part of clinicians when serving resort communities. Although not absolute, the understanding that trace amounts of daily snowfall increase the odds of sustaining a significant injury can be used to increase diligence regarding (a) pre-hospital care, (b) triage procedures, (c) resource management, and (d) staffing concerns in mountain hospitals.

Possibly the most proximal beneficiaries of these findings may be the ski resorts, as speed-control signage, personnel placement, and patroller stationing can be adjusted to better serve the public based on snowfall measurements that are an already established, daily component of mountain operations. An appreciation for the results of this work may influence the skier traffic on the resort allowing for resort personnel to mitigate skier speeds through direction and signage appropriately tailored to the ambient snow conditions.

Lastly, the findings from this work directly contribute to the epidemiological aspects of trauma care. Previously, the relationship between daily snowfall and the severity and patterns of traumatic injuries had not been well defined. The results of this research provide data that can be analyzed and used to identify areas of opportunity for injury mitigation. Once viable areas are identified, public health professionals in conjunction with resort officials may be able to collaborate and devise mechanisms for not only injury mitigation, but for improved responder: suspicion, recognition, and disposition of injured patients in the mountain resort setting.

Epidemiological Applications of Research Findings

Although not directly mentioned in the available literature regarding ski or snowboard injuries, findings from this research are applicable to an epidemiological assessment tool termed a Haddon Matrix. Developed in 1970 by Dr. William Haddon Jr., the matrix fractionates an injury or disease into rows and columns reflective of factors and phases that comprise the event (Haddon, 1980). In the instance of an injury, the component factors would include: human, vehicle, and the environment while the complimentary phases include the pre-event, the event itself, and the post-event (Haddon, 1980). Once the researcher appreciates that an injury does not occur independently of contributing factors, the utilization of this type of matrix allows for the careful analysis of the factors that contribute to the injury in each phase of development. The goal of this assessment is to identify factors that are amenable to mitigation thus allowing for interventions to decrease either the incidence or severity of injury. Specific applications of the findings from this research would allow for objective data, such as snowfall depth, to be used in detailing the environment column of the matrix, as ambient snow conditions are a component of the resort environment potentially contributing to injury. An example of the Haddon Matrix is shown in Table 19 with considerations from this work instilled in the matrix as an example of a possible application using epidemiological research to directly affect social change.

Table 19

Haddon Matrix for Skier/Snowboarder Injury on the Host Resort

	Factors		
Phases	Human	Vehicle	Environment
Pre-event	1	2	3
Event	4	5	6
Post-event	7	8	9

Possibilities for the reduction of injuries sustained while skiing or snowboarding on the host resort are examined. The following numbers correspond to the appropriate phases and factors in the matrix respectively:

1. Is the individual physically prepared for activity (skiing/snowboarding) and educated/informed of ambient snow conditions?
2. Is the ski or snowboard appropriate for the rider and adequately prepared for use?
3. Is there appreciation for ambient snow conditions/depth with resort information/signage appropriate for conditions readily available to the general public?
4. Are the participants adequately prepared and informed of conditions.
5. Are there appropriate bindings in place to disengage the rider after a fall and mitigate further injury?
6. Is there appropriate placement of resort personnel to respond to accidents in a timely fashion with appropriate equipment for: stabilization, communication, and transfer?
7. Has there been appropriate education to the patient on post-injury care and concerns as well as resort staff on tactics to prevent similar events during periods of relevant snow conditions.
8. Is there a quality control mechanism in place to ensure binding release mechanisms are intact and calibrated appropriately for rider experience and ambient conditions?
9. Has there been a formal investigation of the injury site for potential signage/personnel adjustments to mitigate recurrences during periods of relevant snowfall in the future?

Utilization of structured tools such as the Haddon Matrix require the determination of contributing variables to injury (e.g. daily snowfall), allowing for efficacy analysis of past, present, and future interventions in a cell by cell manner, dictating possible novel implications for change based on the identification of susceptible components (Haddon, 1980). It is the identification of contributing factors to injury coupled with an appreciation for mitigation measures that allow for injury prevention strategies to come to fruition and truly affect social change.

Recommendations for Action

Prior to this work, the true relationship between snowfall and injury severity and patterns of injury had yet to be defined in a substantive manner. Findings from this research can now be used in the development of injury mitigation plans for health care practitioners, hospitals, and mountain resorts.

A recommendation for action includes increased diligence on the part of mountain resorts during times of low snowfall. From the resort perspective, ski patrol and mountain safety personnel can work in conjunction to development mountain maintenance as well as patrol protocols based on daily snowfall amounts. A possible source of benefit from this work is the education of ski patrollers, which can reflect findings precipitating increased appreciation for causative factors in skier injury. At times of low snowfall it would seem prudent to alter signage on the resort to keep skier speeds down in the hopes of mitigating injury severity. Patroller placement on the resort is an additional consideration for potential change. On days of low snowfall, patrollers can be stationed in areas of increased skier velocity, further mitigating skier speeds. From a logistics perspective, the placement of rescue equipment in areas of increased skier speeds during periods of low snowfall seems prudent based on the findings from this work.

From the community perspective, increased educational directives aimed toward snow-sports enthusiasts detailing the potential dangers of low snow days would seem prudent. Considerations regarding helmet use and an appreciation for skier speeds are additional areas of potential injury mitigation amenable to public education in resort settings. Local resort television and print media could be enhanced to reflect the importance of speed control especially during periods of low daily snowfall while educating the public on skier safety tactics while on the resort.

Lastly, if this type of research is deemed beneficial from an epidemiological perspective, it may be worthwhile to construct data collection tools that facilitate injury analysis with existing or novel software instead of involving multiple steps in collection, data entry and analysis. The creation of a comprehensive database that can abstract data directly from the electronic medical record would prove timely, facilitate research opportunities, and allow for rapid interventions in regards to injury mitigation as needed. As a last consideration, electronically streamlining the daily snowfall data to the research department of the host facility will ease the transfer of data and potentially mitigate data collection errors while providing real-time analysis facilitating injury prevention opportunities and resource management measures.

Recommendations for Further Study

Although the primary research questions addressing the effects of snowfall on injury severity and patterns could be addressed in a meaningful manner, inadequate patient numbers forced the omission of mortality analysis from this work. In previous works, mortality has been associated with various snow-sports disciplines (e.g. sledding) as in the work by Federiuk, Schleuter, and Adams (2002), but is yet to demonstrate an association with daily snowfall measurements in a substantive manner in the literature. Due to the relative infrequency of occurrence compared to nonfatal injuries, it is likely that the association between mortality and daily snowfall would require analyses over numerous seasons, from multiple resorts, or embracing a meta-analysis methodology in order to obtain an adequate sample size for meaningful analysis.

An additional consideration for further research is that of other environmental factors that may contribute to skier or snowboarder injury. Ambient light, active snowfall, wind speeds, snow density, and terrain features could potentially contribute to accidents on ski resorts as independent entities or in a collective fashion. Research involving these potential factors would likely require the coordinated efforts of numerous researchers combined with appropriate technological components for measurement purposes.

Lastly, a similar methodology could be employed as was utilized in this research encompassing multiple ski seasons in the hopes of increasing the sample size to determine if there are significant associations between other Abbreviated Injury Scale regions and daily snowfall. Anatomical regions such as the face and integument are infrequently involved in skier trauma, thus mandating a larger sample size in the hopes of further defining the potential relationship between daily snowfall and these variables. Continued inclusion of anatomical considerations in future research addressing skier or snowboarder trauma may provide further understanding into the effects of snowfall on traumatic injuries in this patient population.

Conclusion

The sports of skiing and snowboarding are both popular and also possess the potential for serious traumatic injuries leading to a significant source of morbidity for snow-sports enthusiasts (Deady, 2010; McBeth, Ball, Mulloy, & Kirkpatrick, 2009). While ample research has been devoted to describing injury prevalence among the disciplines of skiing or snowboarding, little has been established in regards to defining the contribution of the ambient environmental condition to injury pattern and severity (Idzikowski et al., 2000; Sutherland et al., 1996; Torjussen & Bahr, 2006; Warme, Feagin, King, Lambert, & Cunningham, 1995). The goal of this study was to supplement the available body of knowledge with specifics regarding the relative contribution that variable snowfall amounts have on injury severity, anatomical patterns of injury, and specific injuries common among skiers and snowboarders.

The findings from this research validate the consideration that snowfall demonstrates an inverse relationship with global injury severity while variable amounts of daily snowfall are associated with predictable injury patterns among the disciplines of skiing and snowboarding respectively. A potential beneficiary of this work includes medical practitioners in mountain resort settings who may employ a heightened suspicion of injury based on ambient snow conditions allowing for a narrowed differential diagnosis when treating injured skiers and snowboarders. Lastly, the results of this research may be utilized to enhance educational opportunities among resort personnel, medical providers, and the general public regarding increased skier or snowboarder safety based on the daily snowfall amount.

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Appendix A: Organ Injury Scales

Cervical Vascular Organ Injury Scale

Grade	Description of injury	ICD-9	AIS-90
I	Thyroid vein	900.8	
	Common facial vein	900.8	
	External jugular vein	900.81	1-3
	Non-named arterial/venous branches	900.9	
II	External carotid arterial branches (ascending pharyngeal, superior thyroid, ingual, facial maxillary, occipital, posterior auricular)	900.8	
	Thyrocervical trunk or primary branches		
	Internal jugular vein	900.8	
	External carotid artery	900.1	1-3
III	Subclavian vein	900.02	2-3
	Vertebral artery	901.3	3-4
	Common carotid artery	900.8	2-4
IV	Subclavian artery	900.01	3-5
	Internal carotid artery (extracranial)	901.1	3-4
V		900.03	3-5

Note. Increase one grade for multiple grade III or IV injuries involving more than 50% vessel circumference. Decrease one grade for less than 25% vessel circumference disruption for grade IV or V. From "Organ Injury Scaling VII: cervical vascular, peripheral vascular, adrenal, penis, testis, and scrotum," by E.E. Moore, 1996, *Journal of Trauma, Volume 41*, p. 524. Copyright 1995 by EE. Moore, MD. Adapted with permission.

Chest Wall Injury Scale

Grade	Injury type	Description of injury	ICD-9	AIS-90
I	Contusion	Any size	911.0/922.1	1
	Laceration	Skin & subcutaneous	875.0	1
	Fracture	< 3 ribs, closed; nondisplaced clavicle closed	807.01	1-2
			807/02	
			810.00/810.03	2
II	Laceration	Skin, subcutaneous and muscle	875.1	1
	Fracture	>3 adjacent ribs, closed	807.03/807.09	2-3
		Open or displaced clavicle	810.10/810.13	2
		Nondisplaced sternum, closed	807.2	2
		Scapular body, open or closed	811.00/811.18	2
III	Laceration	Full thickness including pleural penetration	862.29	2
	Fracture	Open or displaced sternum	807.2	2
		Flail sternum	807.3	
		Unilateral flail segment (<3 ribs)	807.4	3-4
	Laceration	Avulsion of chest wall tissues with underlying rib fractures	807.10/807.19	4
		Unilateral flail chest (>3 ribs)		
	Fracture	Bilateral flail chest (>3 ribs on both sides)	807.4	3-4
V	Fracture		807.4	5

Note. This scale is confined to the chest wall alone and does not reflect associated internal or abdominal injuries. Therefore, further delineation of upper versus lower or anterior versus posterior chest wall was not considered, and a grade VI was warranted. Specifically, thoracic crush was not used as a descriptive term; instead, the geography and extent of fractures and soft tissue injury were used to define the grade. From “Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra,” by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

Heart Injury Scale

Grade	Description of injury	ICD-9	AIS-90
I	Blunt cardiac injury with minor ECG abnormality (nonspecific ST or T wave changes, premature arterial or ventricular contraction or persistent sinus tachycardia)	861.01	3
	Blunt or penetrating pericardial wound without cardiac injury, cardiac tamponade, or cardiac herniation		
II	Blunt cardiac injury with heart block (right or left bundle branch, left anterior fascicular, or atrioventricular) or ischemic changes (ST depression or T wave inversion) without cardiac failure	861.01	3
	Penetrating tangential myocardial wound up to, but not extending through endocardium, without tamponade	861.12	3
III	Blunt cardiac injury with sustained (>6 beats/min) or multilocal ventricular contractions	861.01	3-4
	Blunt or penetrating cardiac injury with septal rupture, pulmonary or tricuspid valvular incompetence, papillary muscle dysfunction, or distal coronary arterial occlusion without cardiac failure	861.01	3-4
	Blunt pericardial laceration with cardiac herniation		
	Blunt cardiac injury with cardiac failure		
IV	Penetrating tangential myocardial wound up to, but extending through,	861.01	3-4
	endocardium, with tamponade	861.12	3
	Blunt or penetrating cardiac injury with septal rupture, pulmonary or tricuspid		
	valvular incompetence, papillary muscle dysfunction, or distal coronary arterial occlusion producing cardiac failure	861.12	3
	Blunt or penetrating cardiac injury with aortic mitral valve incompetence		
	Blunt or penetrating cardiac injury of the right ventricle, right atrium, or left atrium		
	Blunt or penetrating cardiac injury with proximal coronary arterial occlusion		
	Blunt or penetrating left ventricular perforation		
	Stellate wound with < 50% tissue loss of the right	861.03	5

Grade	Description of injury	ICD-9	AIS-90
	ventricle, right atrium, or of left atrium		
V	Blunt avulsion of the heart; penetrating wound producing > 50% tissue loss of a chamber	861.03	
		861.13	5
		861.03	5
VI		861.13	6

Note. Advance one grade for multiple wounds to a single chamber or multiple chamber involvement. From “Organ Injury Scaling IV: thoracic, vascular, lung, cardiac, and diaphragm,” by E.E. Moore, 1994, *Journal of Trauma, Volume 68*, p. 524. Copyright 1994 by EE. Moore, MD. Adapted with permission.

Lung Injury Scale

Grade[a]	Injury Type	Description of Injury	ICD-9	AIS-90
I	Contusion	Unilateral, <1 lobe	861.12	3
			861.31	
II	Contusion	Unilateral, single lobe	861.20	3
			861.30	
	Laceration	Simple pneumothorax	860.0/1	3
III	Contusion	Unilateral, > 1 lobe	861.20	3
			861.30	
	Laceration	Persistent (> 72 hrs) air leak from distal airway	860.0/1	3-4
			860.4/5	
			862.0	
	Hematoma	Nonexpanding intraparenchymal	861.30	
IV	Laceration	Major (segmental or lobar) air leak	862.21	4-5
			861.31	
	Hematoma	Expanding intraparenchymal		
	Vascular	Primary branch intrapulmonary vessel disruption	901.40	3-5
V	Vascular	Hilar vessel disruption	901.41	4
			901.42	
VI	Vascular	Total uncontained transection of pulmonary hilum	901.41	4
			901.42	

Note. From "Organ Injury Scaling IV: thoracic, vascular, lung, cardiac, and diaphragm," by E.E. Moore, 1994, *Journal of Trauma, Volume 68*, p. 524. Copyright 1994 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for bilateral injuries up to grade III. Hemothorax is scored under thoracic vascular injury scale.

Thoracic Vascular Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Intercostal artery/vein	901.81	2-3
	Internal mammary artery/vein	901.82	2-3
	Bronchial artery/vein	901.89	2-3
	Esophageal artery/vein	901.9	2-3
	Hemizygous vein	901.89	2-3
	Unnamed artery/vein	901.9	2-3
II	Azygos vein	901.89	2-3
	Internal jugular vein	900.1	2-3
	Subclavian vein	901.3	3-4
	Innominate vein	901.3	3-4
III	Carotid artery	900.01	3-5
	Innominate artery	901.1	3-4
	Subclavian artery	901.1	3-4
IV	Thoracic aorta, descending	901.0	4-5
	Inferior vena cava (intrathoracic)	902.10	3-4
	Pulmonary artery, primary intraparenchymal branch	901.41	3
	Pulmonary vein, primary intraparenchymal branch	901.42	3
V	Thoracic aorta, ascending and arch	901.0	5
	Superior vena cava	901.2	3-4
	Pulmonary artery, main trunk	901.41	4
	Pulmonary vein, main trunk	901.42	4
VI	Uncontained total transection of thoracic aorta or pulmonary hilum	901.0 901.41 901.42	5 4

Note. From "Organ Injury Scaling IV: thoracic, vascular, lung, cardiac, and diaphragm," by E.E. Moore, 1994, *Journal of Trauma, Volume 68*, p. 524. Copyright 1994 by EE. Moore, MD. Adapted with permission.

[a]Increase one grade for multiple grade III or IV injuries if more than 50% circumference; decrease one grade for grade IV injuries if less than 25% circumference.

Diaphragm Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion	862.0	2
II	Laceration <2cm	862.1	3
III	Laceration 2-10cm	862.1	3
IV	Laceration >10 cm with tissue loss < 25 cm2	862.1	3
V	Laceration with tissue loss > 25 cm2	862.1	3

Note. From "Organ Injury Scaling IV: thoracic, vascular, lung, cardiac, and diaphragm," by E.E. Moore, 1994, *Journal of Trauma, Volume 68*, p. 524. Copyright 1994 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for bilateral injuries up to grade III.

Spleen Injury Scale (1994 Revision)

Grade[a]	Injury type	Description of injury	ICD-9	AIS-90
I	Hematoma	Subcapsular, <10% surface area	865-01	2
			865.11	
	Laceration	Capsular tear, <1cm	865.02	2
		parenchymal depth	865.12	2
II	Hematoma	Subcapsular, 10%-50% surface area	865.01	
		intraparenchymal, <5 cm in diameter	865.11	
				2
	Laceration	Capsular tear, 1-3cm parenchymal depth that does not	865.02	
		involve a trabecular vessel	865.12	
				3
III	Hematoma	Subcapsular, >50% surface area or expanding; ruptured subcapsular or parecymal hematoma; intraparenchymal hematoma > 5 cm or expanding		
	Laceration	>3 cm parenchymal depth or involving trabecular vessels	865.03	3
			865.13	
IV	Laceration	Laceration involving segmental or hilar vessels producing major devascularization (>25% of spleen)		4
V	Laceration	Completely shattered spleen	865.04	5
	Vascular	Hilar vascular injury with devascularizes spleen	865.14	5

Note. From “Organ Injury Scaling: Spleen and Liver (1994 Revision,)” by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 324. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III.

Liver Injury Scale (1994 Revision)

Grade[a]	Type of Injury	Description of injury	ICD-9	AIS-90
I	Hematoma	Subcapsular, <10% surface area	864.01 864.11	2
	Laceration	Capsular tear, <1cm parenchymal depth	864.02 864.12	2
II	Hematoma	Subcapsular, 10% to 50% surface area intraparenchymal <10 cm in diameter	864.01 864.11	2
	Laceration	Capsular tear 1-3 parenchymal depth, <10 cm in length	864.03 864.13	2
III	Hematoma	Subcapsular, >50% surface area of ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma > 10 cm or expanding		3
	Laceration	>3 cm parenchymal depth	864.04 864.14	3
IV	Laceration	Parenchymal disruption involving 25% to 75% hepatic lobe or 1-3 Couinaud's segments	864.04 864.14	4
V	Laceration	Parenchymal disruption involving >75% of hepatic lobe or >3 Couinaud's segments within a single lobe		5
	Vascular	Juxtahepatic venous injuries; ie, retrohepatic vena cava/central major hepatic veins		5
VI	Vascular	Hepatic avulsion		6

Note. From "Organ Injury Scaling: Spleen and Liver (1994 Revision,)" by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 324. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III.

Extrahepatic Biliary Tree Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Gallbladder contusion/hematoma	868.02	2
	Portal triad contusion	868.02	2
II	Partial gallbladder avulsion from liver bed; cystic duct intact	868.02	2
	Laceration or perforation of the gallbladder	868.12	2
III	Complete gallbladder avulsion from liver bed	868.02	3
	Cystic duct laceration	868.12	3
IV	Partial or complete right hepatic duct laceration	868.12	3
	Partial or complete left hepatic duct laceration	868.12	3
	Partial common hepatic duct laceration (<50%)	868.12	3
	Partial common bile duct laceration (<50%)	868.12	3
V	>50% transection of common hepatic duct	868.12	3-4
	>50% transection of common bile duct	868.12	3-4
	Combined right and left hepatic duct injuries	868.12	3-4
	Intraduodenal or intrapancreatic bile duct injuries	868.12	3-4

Note. From "Organ Injury Scaling VI: extrehepatic biliary, esophagus, stomach, vulva, vagina, uterus(nonpregnant), uterus(pregnant), fallopian tube, and ovary," by E.E. Moore, 1995, *Journal of Trauma, Volume 39*, p. 1070. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III.

Pancreas Injury Scale

Grade[a]	Type of Injury	Description of Injury	ICD-9	AIS-90
I	Hematoma	Minor contusion without duct injury	863.81-863.84	2
	Laceration	Superficial laceration without duct injury		2
II	Hematoma	Major contusion without duct injury or tissue loss	863.81-863.84	2
	Laceration	Major laceration without duct injury or tissue loss		3
III	Laceration	Distal transection or parenchymal injury with duct injury	863.92/863.94	3
IV	Laceration	Proximal? transection or parenchymal injury involving ampulla	863.91	4
V	Laceration	Massive disruption of pancreatic head	863.91	5

Note. From "Organ Injury Scaling II: pancreas, duodenum, small bowel, colon, and rectum," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 1427. Copyright 1990 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III. *863.51,863.91 - head; 863.99,862.92-body;863.83,863.93-tail. aProximal pancreas is to the patients' right of the superior mesenteric vein.

Esophagus Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion/hematoma	862.22/.32	2
	Partial thickness laceration	862.22/.32	3
II	Laceration <50% circumference	862.22/.32	4
III	Laceration >50% circumference	862.22/.32	4
IV	Segmental loss or devascularization <2cm	862.22/.32	5
V	Segmental loss or devascularization >2cm	862.22/.32	5

Note. From "Organ Injury Scaling VI: extrehepatic biliary, esophagus, stomach, vulva, vagina, uterus(nonpregnant), uterus(pregnant), fallopian tube, and ovary," by E.E. Moore, 1995, *Journal of Trauma, Volume 39*, p. 1070. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple lesions up to grade III.

Stomach Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion/hematoma	863.0/.1	2
	Partial thickness laceration	863.0/.1	2
II	Laceration <2cm in GE junction or pylorus	863.0/.1	3
	<5cm in proximal 1/3 stomach	863.0/.1	3
	<10cm in distal 2/3 stomach	863.0/.1	3
III	Laceration >2cm in GE junction or pylorus	863.0/.1	3
	>5cm in proximal 1/3 stomach	863.0/.1	3
	>10cm in distal 2/3 stomach	863.0/.1	3
IV	Tissue loss or devascularization <2/3 stomach	863.0/.1	4
V	Tissue loss or devascularization >2/3 stomach	863.0/.1	4

Note. From "Organ Injury Scaling VI: extrehepatic biliary, esophagus, stomach, vulva, vagina, uterus(nonpregnant), uterus(pregnant), fallopian tube, and ovary," by E.E. Moore, 1995, *Journal of Trauma, Volume 39*, p. 1070. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple lesions up to grade III. GE-gastroesophageal.

Duodenum Injury Scale

Grade[a]	Type of injury	Description of injury	ICD-9	AIS-90
I	Hematoma	Involving single portion of duodenum	863.21	2
	Laceration	Partial thickness, no perforation	863.21	3
II	Hematoma	Involving more than one portion	863.21	2
	Laceration	Disruption <50% of circumference	863.31	4
III	Laceration	Disruption 50%-75% of circumference of D2	863.31	4
		Disruption 50%-100% of circumference of D1,D3,D4	863.31	4
IV	Laceration	Disruption >75% of circumference of D2	863.31	5
		Involving ampulla or distal common bile duct		5
V	Laceration	Massive disruption of duodenopancreatic complex	863.31	5
	Vascular	Devascularization of duodenum	863.31	5

Note. From "Organ Injury Scaling II: pancreas, duodenum, small bowel, colon, and rectum," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 1427. Copyright 1990 by EE. Moore, MD. Adapted with permission

[a]Advance one grade for multiple injuries up to grade III. D1-first position of duodenum; D2-second portion of duodenum; D3-third portion of duodenum; D4-fourth portion of duodenum.

Small Bowel Injury Scale

Grade[a]	Type of injury	Description of injury	ICD-9	AIS-90
I	Hematoma	Contusion or hematoma without devascularization	863.20	2
	Laceration	Partial thickness, no perforation	863.20	2
II	Laceration	Laceration <50% of circumference	863.30	3
III	Laceration	Laceration > 50% of circumference without transection	863.30	3
IV	Laceration	Transection of the small bowel	863.30	4
V	Laceration	Transection of the small bowel with segmental tissue loss	863.30	4
	Vascular	Devascularized segment	863.30	4

Note. From "Organ Injury Scaling II: pancreas, duodenum, small bowel, colon, and rectum," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 1427. Copyright 1990 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III.

Colon Injury Scale

Grade[a]	Type of injury	Description of injury	ICD-9	AIS -90
I	Hematoma	Contusion or hematoma without devascularization	863.40-863.44	2
	Laceration	Partial thickness, no perforation	863.40-863.44	2
II	Laceration	Laceration <50% of circumference	863.50-863.54	3
III	Laceration	Laceration > 50% of circumference without transection	863.50-863.54	3
IV	Laceration	Transection of the colon	863.50-863.54	4
V	Laceration	Transection of the colon with segmental tissue loss	863.50-863.54	4
	Vascular	Devascularized segment	863.50-863.54	4

Note. From "Organ Injury Scaling II: pancreas, duodenum, small bowel, colon, and rectum," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 1427. Copyright 1990 by EE. Moore, MD. Adapted with permission

[a]Advance one grade for multiple injuries up to grade III. *863.41,863.51-ascending;863.42, 863.52-transverse;863.45,863.53-descending; 863.44,863.54-rectum.

Rectum Injury Scale

Grade[a]	Type of injury	Description of injury	ICD-9	AIS-90
I	Hematoma	Contusion or hematoma without devascularization	863.45	2
	Laceration	Partial-thickness laceration	863.45	2
II	Laceration	Laceration < 50% of circumference	863.55	3
III	Laceration	Laceration > 50% of circumference	863.55	4
IV	Laceration	Full-thickness laceration with extension into the perineum	863.55	5
V	Vascular	Devascularized segment	863.55	5

Note. From “Organ Injury Scaling II: pancreas, duodenum, small bowel, colon, and rectum,” by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 1427. Copyright 1990 by EE. Moore, MD. Adapted with permission

[a]Advance one grade for multiple injuries up to grade III.

Abdominal Vascular Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Non-named superior mesenteric artery or superior mesenteric vein branches	902.20/.39	NS
	Non-named inferior mesenteric artery or inferior mesenteric vein branches	902.27/.32	NS
	Phrenic artery or vein	902.89	NS
	Lumbar artery or vein	902.89	NS
	Gonadal artery or vein	902.89	NS
	Ovarian artery or vein	902.81/.82	NS
	Other non-named small arterial or venous structures requiring ligation	902.90	NS
II	Right, left, or common hepatic artery	902.22	3
	Splenic artery or vein	902.23/.34	3
	Right or left gastric arteries	902.21	3
	Gastroduodenal artery	902.24	3
	Inferior mesenteric artery, or inferior mesenteric vein, trunk	902.27/.32	3
	Primary named branches of messenteric artery (e.g., ileocolic artery) or messenteric vein	902.26/.31	3
	Other names abdominal vessels requiring ligation or repair	902.89	3
III	Superior mesenteric vein, trunk	902.31	3
	Renal artery or vein	902.41/.42	3
	Illiac artery or vein	902.53/.54	3
	Hypogastric artery or vein	902.51/.52	3
	Vena cava, infrarenal	902.10	3
IV	Superior mesenteric artery, trunk	902.25	3
	Celiac axis proper	902.24	3
	Vena cava, suprarenal and infrahepatic	902.10	3
	Aorta, infrarenal	902.00	4
V	Portal vein Extraparenchymal hepatic vein	902.33	3
		902.11	3(hepatic vein) 5 (liver + veins)
	Vena cava, retrohepatic or suprahepatic	902.19	5
	Aorta suprarenal, subdiaphragmatic	902.00	4

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

[a]This classification system is applicable to extraparenchymal vascular injuries. If the vessel injury is within 2 cm of the organ parenchyma, refer to specific organ injury scale. Increase one grade for multiple grade III or IV injuries involving > 50% vessel circumference. Downgrade one grade if <25% vessel circumference laceration for grades IV or V. NS-not scored.

Adrenal Organ Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion	868.01/.11	1
II	Laceration involving only cortex (<2 cm)	868.01/.11	1
III	Laceration extending into medulla (> 2 cm)	868.01/.11	2
IV	>50% parenchymal destruction	868.01/.11	2
V	Total parenchymal destruction (including massive intraparenchymal hemorrhage) Avulsion from blood supply	868.01/.11	3

Note. From "Organ Injury Scaling VII: cervical vascular, peripheral vascular, adrenal, penis, testis, and scrotum," by E.E. Moore, 1996, *Journal of Trauma, Volume 41*, p. 524. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for bilateral lesions up to grade V

Kidney Injury Scale

Grade[a]	Type of injury	Description of injury	ICD-9	AIS-90
I	Contusion	Microscopic or gross hematuria, urologic studies normal	866.01	2
	Hematoma	Subcapsular, nonexpanding without parenchymal laceration	866.11	2
II	Hematoma	Nonexpanding perirenal hematma confirmed to renal retroperitoneum	866.01 866.11	2
	Laceration	<1.0 cm parenchymal depth of renal cortex without urinary extravagation	866.02 866.12	2
III	Laceration	<1.0 cm parenchymal depth of renal cortex without collecting system rupture or urinary extravagation	866.02	3
IV	Laceration	Parenchymal laceration extending through renal cortex, medulla, and collecting system	866.12	4
	Vascular	Main renal artery or vein injury with contained hemorrhage		4
V	Laceration	Completely shattered kidney	866.03	5
	Vascular	Avulsion of renal hilum which devascularizes kidney	866.13	5

Note. From "Organ Injury Scaling: Spleen, Liver, and Kidney," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 1664. Copyright 1989 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for bilateral injuries up to grade III

Ureter Injury Scale

Grade[a]	Type of injury	Description of injury	ICD-9	AIS-90
I	Hematoma	Contusion or hematoma without devascularization	867.2/867.3	2
II	Laceration	< 50% transection	867.2/867.3	2
III	Laceration	> 50% transection	867.2/867.3	3
IV	Laceration	Complete transection with < 2cm devascularization	867.2/867.3	3
V	Laceration	Avulsion with > 2cm of devascularization	867.2/867.3	3

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for bilateral up to grade III.

Bladder Injury Scale

Grade[a]	Injury type	Description of injury	ICD-9	AIS-90
I	Hematoma	Contusion, intramural hematoma	867.0/867.1	2
	Laceration	Partial thickness		3
II	Laceration	Extraperitoneal bladder wall laceration <2 cm	867.0/867.1	4
III	Laceration	Extraperitoneal (>2cm) or intraperitoneal (<2cm) bladder wall laceration	867.0/867.1	4
IV	Laceration	Intraperitoneal bladder wall laceration >2cm	867.0/867.1	4
V	Laceration	Intraperitoneal or extraperitoneal bladder wall laceration extending into the bladder neck or ureteral orifice (trigone)	867.0/867.1	4

Note. From “Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra,” by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple lesions up to grade III

Urethra Injury Scale

Grade[a]	Injury type	Description of injury	ICD-9	AIS-90
I	Contusion	Blood at urethral meatus; retrography normal	867.0/867.1	2
II	Stretch injury	Elongation of urethra without extravasation on urethrography	867.0/867.1	2
III	Partial disruption	Extravasation of urethrography contrast at injury site with visualization in the bladder	867.0/867.1	2
IV	Complete disruption	Extravasation of urethrography contrast at injury site without visualization in the bladder; <2cm of urethra separation	867.0/867.1	3
V	Complete disruption	Complete transaction with >2 cm urethral separation, or extension into the prostate or vagina	867.0/867.1	4

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission

[a]Advance one grade for bilateral injuries up to grade III

.

Uterus (Nonpregnant) Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion/hematoma	867.4/.5	2
II	Superficial laceration (<1 cm)	867.4/.5	2
III	Deep laceration (> 1 cm)	867.4/.5	3
IV	Laceration involving uterine artery	902.55	3
V	Avulsion/devascularization	867.4/.5	3

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III

Uterus (Pregnant) Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion or hematoma (without placental abruption)	867.4/.5	2
II	Superficial laceration (<1cm) or partial placental abruption <25%	867.4/.5	3
	Deep laceration (>1cm) occurring in second trimester or placental abruption >25%		
III	but <50%	867.4/.5	3
	Deep laceration (>1cm) in third trimester		
	Laceration involving uterine artery	867.4/.5	4
IV	Deep laceration (>1cm) with >50% placental abruption	902.55	4
	Uterine rupture	867.4/.5	4
V	Second trimester		
	Third trimester	867.4/.5	4
	Complete placental abruption	867.4/.5	5
		867.4/.5	4-5

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III

Fallopian Tube Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Hematoma or contusion	867.6/.7	2
II	Laceration <50% circumference	867.6/.7	2
III	Laceration >50% circumference	867.6/.7	2
IV	Transection	867.6/.7	2
V	Vascular injury; devascularized segment	902.89	2

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for bilateral injuries up to grade III

Ovary Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion or hematoma	867.6/.7	1
II	Superficial laceration (depth <0.5 cm)	867.6/.7	2
III	Deep laceration (depth > 0.5 cm)	867.8/.7	3
IV	Partial disruption or blood supply	902.81	3
V	Avulsion or complete parenchymal destruction	902.81	3

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for bilateral injuries up to grade III

Vagina Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion or hematoma	922.4	1
II	Laceration, superficial (mucosa only)	878.6	1
III	Laceration, deep into fat or muscle	878.6	2
IV	Laceration, complex, into cervix or peritoneum	868.7	3
V	Injury into adjacent organs (anus, rectum, urethra, bladder)	878.7	3

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III

Vulva Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion or hematoma	922.4	1
II	Laceration, superficial (skin only)	878.4	1
III	Laceration, deep (into fat or muscle)	878.4	2
IV	Avulsion; skin, fat or muscle	878.5	3
V	Injury into adjacent organs (anus, rectum, urethra, bladder)	878.5	3

Note. From "Organ Injury Scaling III: chest wall, abdominal vascular, ureter, bladder, and urethra," by E.E. Moore, 1995, *Journal of Trauma, Volume 38*, p. 337. Copyright 1992 by EE. Moore, MD. Adapted with permission.

*Advance one grade for multiple injuries up to grade III

Testis Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Contusion/hematoma	911.0/922.4	1
II	Subclinical laceration of tunica albuginea	922.4	1
III	Laceration of tunica albuginea with <50% parenchymal loss	878.2	2
IV	Major laceration of tunica albuginea with >50% parenchymal loss	878.3	2
V	Total testicular destruction or avulsion	878.3	2

Note. From "Organ Injury Scaling VII: cervical vascular, peripheral vascular, adrenal, penis, testis, and scrotum," by E.E. Moore, 1996, *Journal of Trauma, Volume 41*, p. 524. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for bilateral lesions up to grade V

Scrotum Injury Scale

Grade	Description of injury	ICD-9	AIS-90
I	Contusion	922.4	1
II	Laceration <25% of scortal diameter	878.2	1
III	Laceration >25% of scrotal diameter	878.3	2
IV	Avulsion <50%	878.3	2
V	Avulsion >50%	878.3	2

Note. From "Organ Injury Scaling VII: cervical vascular, peripheral vascular, adrenal, penis, testis, and scrotum," by E.E. Moore, 1996, *Journal of Trauma, Volume 41*, p. 524. Copyright 1995 by EE. Moore, MD. Adapted with permission.

Penis Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Cutaneous laceration/contusion	911.0-922.4	1
II	Buck's fascia (cavernosum) laceration without tissue loss	878.0	1
III	Cutaneous avulsion Laceration through glans/meatus Cavemosal or urethral defect <2cm	878.1	3
IV	Partial penectomy Cavarnosal or urethral defect > 2 cm	878.1	3
V	Total penectomy	876.1	3

Note. From "Organ Injury Scaling VII: cervical vascular, peripheral vascular, adrenal, penis, testis, and scrotum," by E.E. Moore, 1996, *Journal of Trauma, Volume 41*, p. 524. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Advance one grade for multiple injuries up to grade III

Peripheral Vascular Organ Injury Scale

Grade[a]	Description of injury	ICD-9	AIS-90
I	Digital artery/vein	903.5	1-3
	Palmar artery/vein	903.4	1-3
	Deep palmar artery/vein	904.6	1-3
	Dorsalla pedia artery	904.7	1-3
	Plantar artery/vein	904.5	1-3
	Non-named arterial/venous branches	903.8/904.7	1-3
II	Basilic/cephalic vein	903.8	1-3
	Saphenous vein	904.3	1-3
	Radial artery	903.2	1-3
	Ulnar artery	903.3	1-3
III	Axillary vein	903.02	2-3
	Superficial/deep femoral vein	903.02	2-3
	Popliteal vein	904.42	2-3
	Brachial artery	903.1	2-3
	Anterior tibial artery	904.51/904.52	1-3
	Posterior tibial artery	904.53/904.54	1-3
	Peroneal artery	904.7	1-3
	Tibioperoneal trunk	904.7	2-3
IV	Superficial/deep femoral artery	904.1/904.7	3-4
	Popliteal artery	904.41	2-3
V	Axillary artery	903.01	2-3
	Common femoral artery	904.0	3-4

Note. From “Organ Injury Scaling VII: cervical vascular, peripheral vascular, adrenal, penis, testis, and scrotum,” by E.E. Moore, 1996, *Journal of Trauma, Volume 41*, p. 524. Copyright 1995 by EE. Moore, MD. Adapted with permission.

[a]Increase one grade for multiple grade III or IV injuries involving >50% vessel circumference. Decrease one grade for < 25% vessel circumference disruption for grades IV or V

Appendix B: Frequency Distributions of Abbreviated Injury Scales for Anatomical Regions

Table B1

Frequency Distribution: Abbreviated Injury Scale-Head

AIS score	Frequency	%
1	6	20.7
2	13	44.8
3	4	13.8
4	5	17.2
5	1	3.5
6	0	0

Table B2

Frequency Distribution: Abbreviated Injury Scale-Neck

AIS score (neck)	Frequency (patients)	%
1	4	66.6
2	0	0
3	1	16.7
4	1	16.7
5	0	0
6	0	0

Table B3

Frequency Distribution: Abbreviated Injury Scale-Face

AIS score (face)	Frequency (patients)	%
1	5	55.6
2	2	22.2
3	2	22.2
4	0	0
5	0	0
6	0	0

Table B4

Frequency Distribution: Abbreviated Injury Scale-Thorax

AIS score (thorax)	Frequency (patients)	%
1	3	10.7
2	7	25.0
3	14	50.0
4	4	14.3
5	0	0
6	0	0

Table B5

Frequency Distribution: Abbreviated Injury Scale-Abdomen

AIS score (abdomen)	Frequency (patients)	%
1	5	21.7
2	7	30.4
3	6	26.2
4	5	21.7
5	0	0
6	0	0

Table B6

Frequency Distribution: Abbreviated Injury Scale-Spine

AIS score (spine)	Frequency (patients)	%
1	0	0
2	9	60.0
3	4	26.7
4	2	13.3
5	0	0
6	0	0

Table B7

Frequency Distribution: Abbreviated Injury Scale-Upper Extremity

AIS score (upper extremity)	Frequency (patients)	%
1	10	9.7
2	93	89.4
3	1	0.9
4	0	0
5	0	0
6	0	0

Table B8

Frequency Distribution: Abbreviated Injury Scale-Lower Extremity

AIS score (lower extremity)	Frequency (patients)	%
1	7	4.8
2	103	71.0
3	34	23.5
4	1	0.7
5	0	0
6	0	0

Table B9

Frequency Distribution: Abbreviated Injury Scale-Skin/Other

AIS score (skin)	Frequency (patients)	%
1	27	100.0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0

Curriculum Vitae

S. Jason Moore PA-C, M.S.

Current Position

PA-C, Trauma/General Surgery, Critical Care Medicine

2004-Present

Professional Experience

[redacted] Medical Center:

Trauma Committee Member

Quality Committee of the Board Member

Medical Staff Credentialing Board Member

Director of Hospital Epidemiology and Infection Control Department

- Co-Founder Antimicrobial Stewardship Program
- Influenza (H_1N_1) Committee Member
- Clostridium difficile Outbreak Team Member
- Methicillin-Resistant S. Aureus (MRSA) Surveillance Committee Member
- Mandatory Influenza Vaccination Project

Quality Department Special Projects Team Member:

- Medication Reconciliation Project (JHACO Compliance Initiative)
- Central Venous Catheter Policy
- Statistical Analysis-Risk Management
- LEAN Event: Oxygen Therapy Policy Development
- CPOE/EMR Implementation Clinical Advisory Team

Clinical Advisor to Administration

Interim Clinic Manager/Mountain Surgical Associates (2007)

Chief Medical Officer-Upper Yangtze Expedition, Eastern Tibet, 2009

Chief Medical Officer-First Descent of the Salween River, Eastern Tibet, 2008

Western Eagle County Ambulance District, Eagle, CO
Paramedic/Field Training Officer, Wilderness Paramedic 1999-2002

Nova Guides, Vail, CO

Trip Leader/Trainer/Paramedic
River Expeditions, Backcountry Guide, 1996-2002

Copper Mountain Ski Patrol, Copper Mt., CO

Paramedic Patroller/Educator, 1999-2000

Vail Valley Medical Center, Vail, CO

Emergency Department EMT, 1998-1999

Eagle County Ambulance District, Vail, CO

Emergency Medical Technician, 1996-1998

Professional Affiliations/Certifications

Certified Physician Assistant, National Commission on Certification of Physician Assistants (NCCPA)

State of Colorado Certified Physician Assistant

AASPA- American Association of Surgical Physician Assistants

AAPA- American Association of Physician Assistants

NCCPA Surgical Certification

Society of Critical Care Medicine Member

ATLS – Advanced Trauma Life Support

ACLS – Advanced Cardiac Life Support

PALS-Pediatric Advanced Life Support

Education

2006-Present	Ph.D. Epidemiology/Public Health-Walden University
2002-2004	Physician Assistant. Arizona School of Health Sciences, Phoenix, Arizona
2002-2004	Master of Science. Arizona School of Health Sciences, Phoenix, Arizona
2003	Emergency Medicine/Critical Care Rotation; Maryvale Hospital/Maricopa County Medical Center, Phoenix, Arizona
1998-1999	Paramedic/Wilderness Paramedic/Colorado Mountain College/St. Anthony's Hospital, Breckenridge/Denver, Colorado
1996-1997	EMT, Colorado Mountain College, Vail, Colorado
1993-1994	Post Baccalaureate Medical Program, West Chester University, Pennsylvania
1988-1992	B.A. Advertising/Communications, Loyola College, Baltimore, Maryland

Teaching Experience/Presentations

2010-Present	[redacted] Clinic Trauma Lecture Series for Athletic Trainer Fellowship Program
2008-Present	[redacted] Center Diagnosis and Management of Severe Sepsis & Septic Shock.
2007-Present	[redacted] Center Cardiology Lecture Series
2006-Present	United States Ski-Team

	Trauma Management in Ski and Snowboard Sport
2004-Present	[redacted] Annual Lectures on Management of Trauma in Wilderness Situations
2004- Present	Beaver Creek Ski Patrol Annual Lectures on Management of Trauma in Wilderness Situations
2004-Present	Colorado Mountain College Paramedic Program Trauma Management, Cardiology, Endocrine Emergencies
2004-Present	State of Colorado State EMS Conference Advanced-Procedure Cadaver Lab.
2004-Present	[redacted] Center Critical Care Lecture Series.
2004-Present	Western Eagle County Ambulance District Trauma Lecture Series.
2005, 2010	Eagle County Ambulance District Trauma, Infectious Disease Lectures.
2003	Arizona School of Health Sciences PA Program Advanced Cardiac Life Support.
1999-2000	Copper Mountain Ski-Patrol Wilderness/Environmental Emergencies Lecture Series.
1996-2001	Nova Guides Medical Trainer, Protocol Development.

Publications/Research

2005	Abernathy's Emergency Medicine Secrets, 4thEd. Abdominal Trauma. Co-Authored, E.E. Moore M.D.
2005-Present	[redacted] Center, Protocol Development:

- Management of Blunt Abdominal Trauma/Splenic Injuries
- Management of Septic Shock
- Prevention of Ventilator Associated Pneumonia
- Inpatient Management of Alcohol Withdrawal

- MRSA Surveillance Policy
- Management of Heparin-Induced Thrombocytopenia
- Diagnosis and Management of Clostridium Difficile Associated Diarrhea
- Antimicrobial Stewardship Program
- Oxygen/Respiratory Therapy Protocol Development

2009-Present	Journal of the American Association of Physician Assistants (JAAPA) Peer-Reviewer (journal articles/abstracts)
2010- Present	Severe Sepsis and Septic Shock Prospective Study Evaluating Compliance with the Society of Critical Care Medicine/ Institute for Healthcare Improvement Quality, and Internal Indicators. [redacted]
2011	The Effects of Daily Snowfall Accumulation on the Pattern and Severity of Traumatic Injuries at a U.S. Ski Resort, [redacted]