A META-ANALYSIS OF REPORTED CROSS-COUNTRY SKIING INJURIES

By

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Abstract

The purpose of this study was to conduct a comprehensive quantitative meta-analysis including a qualitative assessment of studies reporting cross-country skiing injuries. To date there have been three comprehensive review articles on cross-country skiing injuries, yet these studies neglected to demonstrate the importance or statistical significance of specific epidemiological factors. In addition, there has not been a consistent approach to the design of studies that have attempted to describe the type and prevalence of the observed injuries.

This meta-analysis considered three epidemiological parameters (body part injured, injury types, and mechanisms of injury) in assessing cross-country skiing. More than 200 articles on cross-country skiing injuries were initially collected and 53 were retained for the meta-analysis. The qualitative analysis of the cross-country skiing injury articles allows us to conclude that the overall quality of the articles collected was adequate but identified some areas of the research as lacking critical information, especially in the description of the skiing conditions, the interacting role of other activities/cross-training with cross-country skiing injuries and the mechanisms of injury involved in this sport. The quantitative meta-analysis was used to summarize the results of the studies and to determine to significance of the proportional estimates of injury types, body part injuries, and the mechanisms of injuries in cross-country skiing. Nearly every injury category demonstrated a significant prevalence. This study may provide the framework for future consideration on research design, training and equipment development that underlie injury prevalence in this sport.

Key words: cross-country skiing injuries, sport specific injuries, meta-analysis, qualitative analysis, biomechanics of cross-country skiing.

Chapter 1

Introduction

Although acute injury risk is relatively low among cross-country skiers, there has been a noticeable increase in the frequency of both acute and chronic injuries reported over the past two decades. The increased rate of injuries has been attributed to such factors as the introduction of ski-skating which led to an increase in skiing speed, significant differences in equipment design, the use of more challenging courses, and rigorous training schedules for elite competitors (Renstrom & Johnson, 1989; Smith, Matheson & Meeuwise, 1996; Eriksson, Nemeth & Eriksson 1996; and Smith, 1990). The greater prevalence of injuries can also be attributed to an increase in overall participation rates. However, there is a problem in determining the exact prevalence rates for cross-country skiing injuries in that an accurate denominator representing the true population at risk does not exist. Therefore, most cross-country skiing injury studies are descriptive and heavily weighted to the numerator, the number of cases observed. As such, comparisons between studies of injury frequency are difficult.

Another problem that makes it difficult to compare studies is that there has not been a consistent approach to the design of investigations on cross-country ski injuries. Soma, Mandelbaum, Watanake & Hanft (1996) used an ancestral approach in their epidemiological study, with much of the data for their study coming from case series, hospital records or retrospective surveys collected from ski patrols. The critical analysis by Smith et al. (1996) into cross-country skiing injuries revealed that most studies used one of the following four designs: (a) prospective cohort studies; (b) case series studies; (c) single case reports; and, (d) mixed studies which combined the design of case series and cohort studies. Smith et al. (1996) also found that comparing results was meaningless unless the internal and external validity of the studies were also reported. Although 38 research projects, 15 case studies and 3 review articles have been published since 1975, there are very few general conclusions that can be drawn from their results.

There is a need to establish a base of comparison for cross-country skiing injuries. Furthermore, there is a need to examine and make recommendations on the methods that are used to report and analyze the prevalence of cross-country skiing injuries.

Purpose

The purpose of this study was to conduct a comprehensive meta-analysis of studies reporting cross-country skiing injuries. A preliminary step to the meta-analysis consisted of examining the design of the experiments included in this study. The quantitative meta-analysis was used to summarize the results of the articles available and determine the significance of the proportional estimates of injury types, body part injured and the mechanisms of injury in cross-country skiing.

Rationale for the study

This study provided a unique classification of cross-country skiing injuries by body part, type of injury, and mechanism of injury, which is currently not available in the relevant literature. The results of the meta-analysis on reported cross-country skiing injuries will be a useful resource for cross-country skiing researchers. The cross-country skiing injury model may also serve as an education tool for health care providers and coaches.

Limitations

Most research into cross-country skiing injuries is reported for case studies, with the result that the accuracy of the estimate of effect size may be compromised. Given the lack of a representative denominator for participation rates (population at risk), a comparison of prevalence may not be possible. Also, the studies included required coding in order to undergo qualitative evaluation and only one researcher performed this task. Strict evaluation guidelines were used to avoid researcher bias. The information gathered was also limited by the translation of original text. Although many efforts were made to confirm the validity of the translations and major discrepancies where reviewed, minor interpretational errors may be present.

Delimitations

Etiology, frequency, site distribution and types of injuries were delimited by the guidelines set in Renstrom & Johnson (1989), Smith et al. (1996); and Soma et al. (1996). These guidelines have been commonly accepted in the critical assessment of cross-country skiing injury epidemiology. Initially, all categories of cross-country injuries were included in the survey. Because of the lack of standards in sport specific injury reports, many injury categories had to be collapsed in order to be evaluated statistically. The inclusion and exclusion criteria; mainly the language of the published article, the content of new data and a relatively recent date of publishing also delimited the data gathering.

Definition of Terms

General

Epidemiological factor: A factor describing a sample related to the larger population; in this study it will apply to proportions of events relative to a sample of cross-country skiing injuries.

Cross-country skiing

Cycle length: The distance traveled in one cycle, including the glide phase.

Cycle rate: Cycle rate is defined as the amount of cycles completed per unit of time. One full stride with each leg makes up one cycle.

Diagonal stride technique: Technique performed when the skier's forward movement is obtained by leaning slightly forward with the upper part of the body and by straightening the pushing leg at the hip, knee and ankle joints at the same time as the opposite ski pole is applied for propulsion. The diagonal stride technique involves a glide and kick phase alternating from both legs.

Double poling: A stride in which both arms are brought forward, as in a single stride of the diagonal technique, and then used to push simultaneously (Ekstrom, 1985).

One-Skate (V-2): A method of skating on skies where both legs alternately become the gliding and the push leg, with a double symmetrical pole plant occurring for each leg stride. This method is used for flat to slightly uphill terrain (Silleta & Sheier, 1995).

Offset (V-1): A non-symmetrical leg stride with asynchronous pole plants where the dominant side pole plant and the non-dominant side skate stride allows the arms to recover. This technique is used for ascending hills from moderate slopes to steep hills (Silleta & Sheier, 1995).

Two-Skate (V-2 alternate): The two skate involves similar mechanics to one-skate except for the use of a double symmetrical pole plant for two leg strides. It is a technique used when the track varies from slightly downhill to slightly uphill. The two-skate technique is a little more relaxing than the one-skate (Silleta & Sheier, 1995).

Injury definitions

Acute injury: Injury with rapid onset due to a traumatic episode, with a short duration (Anderson & Hall, 1995).

Bursitis: An inflammation of a bursa; the fibrous sac usually found between bones and tendons that acts to decrease friction during motion (Anderson & Hall, 1995).

Catastrophic injury: An injury that is either fatal or has extreme consequences; for example: paralysis, loss of mental or sensory functions or loss of the use of a limb.

Chronic injury: An injury with long onset and duration (Anderson & Hall, 1995).

Environmental Injury: Injury caused by environmental conditions.

Injury: A physical impairment due to an accident or repeated motion during skiing, including wounds, of short or long term duration.

Injury characteristics: The injury onset and type.

Injury severity: The time loss in training or competing, or the duration of restriction from athletic performance (functional definition adapted from Pigman, 1990).

Injury types: The nature of injury for example: stress fractures, sprains, strains, and dislocations.

Sprains: The injury to ligamentous tissue, a stretching or slight tear (Anderson & Hall, 1995).

Strains: The injury to muscle tissue, over-stretching or tear (Anderson & Hall, 1995).

Stress fractures: The fracture resulting from the repeated load of low forces (Anderson & Hall, 1995).

Tendinitis: The inflammation of a tendon; the attachment from muscle to bone (Anderson & Hall, 1995).

Chapter 2

Review of Literature

An Introduction to Cross-country Skiing

It is fairly well accepted that cross-country skiing puts an extremely high demand on the cardiovascular and musculoskeletal systems. Elite cross-country skiers are known to have some of the highest oxygen uptake capacities among athletes (McArdle, Katch & Katch, 1994; Karlson, 1984; Lyons, 1980), with VO_2 max values recorded as high as 80 ml/Kg/min. Sheier (1987) published guidelines in the National Coaching Certification Program - Cross Country Canada (NCCP-CCC) recommending upwards of 800 hours of training per year for national and international level cross country athletes. Karvonen, Ryszard, Kalli, Boguslaw & Krasicki (1987), in their physiological comparison of the skating and diagonal technique, recorded maximal intensity velocities averaging 7 m/s from their junior national-level Polish athletes using the skating technique. Bilodeau, Boulay & Roy (1992) reported velocities upwards of 8.6 m/s from their national-level Canadian athletes. In comparison, a runner's four-minute mile is equivalent to 6.5 m/s. Furthermore, elite level cross-country ski races range from 10 Km to 50 Km marathons. The end result is that the extremely high levels of performance observed and expected of elite cross-country skiing athletes can lead to injuries.

Known Mechanisms of Injury

Injuries in cross-country skiing are often divided into three categories according to their nature: Acute, chronic/overuse and environmental. Acute injuries resulting from trauma usually include lacerations, concussions, bursitis, impact injuries such as crushed muscles and impact fractures; most sprains and ligament ruptures such as shoulder dislocations and acromioclavicular separation. Frequently, skiers suffering from these injuries fell with a twisting motion, often "catching an edge" or crossing the tips of their skis while attempting to snowplow on a downhill portion of the course (Renstrom & Johnson, 1989). In addition, skiers described either hitting a tree, another skier or attempting to avoid an obstacle. Soma et al. (1996) reported that their review analysis suggested that acute injuries are often prevalent in the upper extremities while chronic injuries are more common in the lower extremities.

In the existing injury literature, both chronic and overuse terminology is used to identify non-traumatic painful condition affecting the locomotor system (Kannus et al. 1988). In this study, the term overuse is more appropriate since it points to the mechanism of injury and not the duration. Overuse injuries are present in the form of tendinitis, for example: Achilles tendon problems, medial tibial stress syndrome (MTSS), patelofemoral pain syndrome (PFPS), strains - especially in the groin group, anterior compartment syndrome, ulnar collateral ligament problems, shoulder laxity/muscle strains and lower back pain. Renstrom & Johnson (1989) listed mechanisms of injury such as training errors (poor periodization, overtraining, not enough recovery), improper equipment and poor technique. Soma et al. (1996) indicated that cross-training during the pre-season was the probable cause of the insult creating an injury and that continuing to cross-country ski repeatedly aggravates it so that healing is delayed and painful. Running during the pre-season was given as an example. Brody (1980) and Clements et al. (1981) believe that overuse injuries are more directly related to endurance sports and to elite-level endurance participants. Orava (1980) categorized cross-country skiing as a pure endurance sports and unlike the acute injuries and their "accidental" nature, Orava et al. (1985) attributed overuse injuries directly to cross-country skiing. Many authors (Butcher, 1996; Eriksson et al., 1996; Kanuus et al., 1988; Lindsay et al., 1993; Mahlamaki et al., 1987; Mahlamaki et al., 1988; Orava et al., 1985) have identified a special interest in overuse injuries, especially in elite level cross-country skiing athletes.

Environmental injuries and illnesses are common among all outdoor winter sports enthusiasts. Frostnip, frostbite and hypothermia are all concerns and are compounded by the athlete's perspiration during intense physical activity, putting skiers at risk of suffering such injuries (Soma et al., 1996). Other related factors such as wind-chill and certain body part exposures decrease the blood flow to the working muscles and can possibly lead to a higher risk of traumatic and overuse injuries. In addition, some recreational skiers do not use the appropriate clothing/layering system thus exacerbating the probability of injury. However, Schelkun (1992) gives credit to manufacturers for boots becoming more comfortable and better adapted for dealing with the cold. Along with the complications listed above, Renstrom & Johnson (1989) identified respiratory problems as a source of concern with respiratory infections and exercise/cold induced asthma causing the most concern. Awareness and education for the athletes are necessary to combat environmental illnesses.

Factors Suspected to Increase Injury Rates

In the last 50 years, cross-country skiing has gained popularity as a recreational sport with great training benefits. As a result, more than 16 million people are estimated to participate in cross country skiing activities worldwide with 5.5 million Canadians having tried the sport. With a proportional increase in participants, more injuries are to be expected (Schelkum, 1992).

Equipment

The objective of the development of cross-country skiing equipment has been to improve the quality of performance, achieve higher velocities and develop better techniques. The use of fiberglass revolutionized the process of ski constructions in 1973. Skis no longer weighed 2 Kg, but rather they are closer to 1 Kg in weight. Even more impressive, modern skis made of graphite weigh less than 500 g and are 4-6 cm wide. This forces skiers to balance on their skis, as if they were on skates (Paclet, 1990). Skis designed with a glide, kick sections and a camber result increased velocities during the performance of the classic technique and even better performance.

Renstrom & Johnson (1989) reported that up to the mid 1980's, popular bindings used in cross-country skiing incorporated ridged heel plates/peg systems that allowed no lateral heel movement during weight bearing. During a fall or a bad twist, it is suspected that the skier suffered the full extent of the force generated by the extended levers of the skis at the knee. Around the same time, soft leather boots were developed to allow the full dorsi and plantar flexion required for the diagonal stride, thus rendering the ankle more vulnerable to sprains. Modem skate skiing techniques stress the ankle joint, and as a result, much more support is needed. Newer boots come up higher above the ankle and are much stiffer. This offers control over extreme eversion and inversion but also transfers the torsional stress up the limb to the tibia and the knee. Injuries once seen at the ankle are now transferred to the knee. The older bindings (three pegs) that anchored the toes into the binding only allowed motion at the metatarsophalyngeal joint, which caused skier's toe, an osteoarthritis condition of the joint (Losh, 1981). The new binding types "NNN and Salomon Profile" isolate motion at the tip of the boot, taking the flexion stress away from this joint. Unfortunately, many recreational cross-country skiers are still using the three peg bindings, and therefore exposing themselves to foot/ankle injuries.

Sheier (1987) recommended that skiers use ski poles 90% of body height. Some athletes have been experimenting with poles 10-25 cm longer than the recommended height and have suffered shoulder complications, which may be attributed to the extremes in the range of motion demanded at the shoulder. In addition, pole straps were developed to attach the pole to the hand so that the grip on the pole could be released during the poling action allowing a full extension at the end of the push phase in poling (Street, 1992). Inappropriate straps or poorly adjusted straps are suspected to greatly increase the tension on the ulnar collateral ligament in the elbow and some of the metacarpals, leading to painful tendinitis, joint inflammation and stress fractures. In an attempt to give more leverage during the push phase of poling, lateral shelves have been added to the grips of some models of ski poles. These grip shelves, in addition to stiff recoil from modern poles made of graphite or carbon mix, are now suspected of creating a force fulcrum that possibly leads to injuries to the lateral metacarpals (Bovard, 1994). To ward off such injury, pole manufacturers recommend adjusting pole straps properly so that the hand does not rest continuously on the shelf.

Clothing

Along with the cold temperatures usually associated with cross-country skiing, the clothing that athletes choose is very important. Recent trends in design attempt to reduce air drag through the use of tight-fitting "lycra" type outfits. These, however, are suspected to contribute to frostbite and infection injuries (Smith et al., 1996), since the clothing does not offer enough protection against the cold at the very surface of the skin. The skier's core temperature remains constant from the heat generated by the working muscles during exercise but the skin is vulnerable to the cold. Urinary tract infections have also been attributed to the clothing worn during a race. In addition, form-fitting cross-country skiing outerwear offers very little padding as seen in contact sports. However, when a skier suffers a collision, the full force of the impact is directly transmitted to the body instead of being distributed over a larger surface area. Of course no cross-country skier wishes to be encumbered by bulky padding but skiers should be advised to dress appropriately for various conditions.

Physiology

The physiological demands placed on the cross-country skier need to be considered, including oxygen level uptake, quantity of training necessary to achieve high aerobic physical fitness, muscle development and body composition, and systems of homeostasis including liquids, electrolytes, lactate levels, thermoregulation and endocrine function. The energy systems in cross-country athletes are adapted to obtain exceptionally high outputs as a result of years of demanding training (Saltin & Astrand, 1967; Karlsson, 1984). Even so, in long distance events such as the American Birkebeiner (55 km), the

Canadian Cross-Country Ski Marathon (160 Km over two days) and the Swedish Vasaloppet (89 Km) medical conditions such as dehydration and exhaustion are very common. They accounted for 15% of all injuries in the 1984 American Birkebeiner (Gannon, Derse, Bronkema & Primley, 1985) and 20% of the injuries during the 1983-1984 Vasaloppet (Hallmarker & Aronsson, 1985). By 1995, the exhaustion/dehydration injury rate of the American Birkenbeiner grew to include 60% of all race withdrawals (Butcher, 1996).

Speed of Skiing Performance

One of the major contributors to acute injuries in cross-country skiers is the increased speed presently achieved by well-equipped skiers on well-maintained tracks. Moreover, the mechanical and physiological demands such as the maintaining of velocities upwards of 25 Km/H must be considered important factors in cross-country skiing overuse injuries. In addition, new skate skiing techniques are recognized for generating speeds 23% greater (Street, 1988) than the classic technique. Bilodeau, Roy & Boulay (1991) stated that skate skiing generates greater velocities because: (a) there is no kick wax with skate skis, creating less drag; (b) the ability of the skier to use the arms and the trunk more thoroughly complements the work accomplished by the legs; (c) the lower trunk position creates less air resistance; (d) longer poles produce a longer push period with the result that more force is being applied to propel the body forward; and, (e) biomechanically, the propulsion phase is almost double the length of a typical diagonal stride, which again applies more force to advance. The kinetic energy of a skier is directly related to velocity:

$$[\text{Kinetic Energy} = 2 \text{ mass X velocity}^2]$$

Therefore, the faster a skier travels, the more destructive will be the energy release upon impact if collision results. Impacts that once allowed the skier to walk away with bruises may now result in sprains, fractures or concussions. Increased velocities may affect both the injury rates and injury severity in modern cross-country skiing research.

Biomechanics of Injury and Cross-Country skiing

Many of the injuries occurring in cross-country skiing are mechanical in nature, for example: impacts and twisting motion in acute injuries; and repetitive stress and improper technique in overuse injuries. A number of injuries have been specifically identified and analysized mechanically. One such example is the action during the diagonal stride. Renstrom & Johnson (1989) observed that when the kick wax did not offer proper footing, a violent slide back motion of one leg often occurred. They described this mechanism as a cause of cumulative insults to the lumbar vertebrae and suggested that it could possibly lead to herniated discs, which in turn puts pressure on the spinal cord. Eriksson, Nemeth & Eriksson (1996) added that the load on the lower back (the erector spinae muscles) is static at the same time as it is dynamic for the hip flexors (the iliopsoas muscles) and suggested that this action could be a cause of lower back pain; in a similar fashion, so could the action of deep double poling.

Certain kinematic variables are often measured in cross country skiing, for example: Cycle length, cycle rates, velocity, angles at specific body joints, percentage of time spent in different phases of the ski cycle and the path of the centre of mass displacement. Renstrom & Johnson (1989), Smith & Heagy (1994), Smith (1998) and Rundell & McCarthy (1996) all identified that an increase in the cycle length was critical in order to maximize velocity. Unfortunately, a poorly advised athlete may compensate for a short cycle length by increasing the cycle rate. In doing so, the athlete submits his body to more repetitions in order to accomplish the desired work, causing a condition similar to the swimmer's shoulder. Hunter's et al., (1982) instructional package: *The Common Orthopaedic Problems of Female Athletes* explains that swimmer's shoulder is more prevalent in the female swimmer that the male. They attribute this to the female body's generally shorter length with the result that women must take more swim strokes to travel the same distance as a man. In the case of the skier, a short cycle length will increase the number of repetitions necessary to cover the same distance, and thus the extra repetitions are a possible factor contributing to overuse injury.

Force outputs generated by the limbs to maintain certain velocities may be too exigent on some structures and repeated stress injuries may result. Poling forces are estimated to push 40-50% of body weight values, while skating produces forces peaking at around twice the body weight. Different conditions affect body segments differently for example, in the case of on-snow versus dry land roller ski training. Gervais & Wronko, (1988) found that ski pole plants were 3-6% longer on snow than on roller skiers. Thus, they suggest that the upper body, contributes more to on-snow skiing propulsion, whereas the kicking action of the legs are a greater source of propulsion on dry land. The force generated by the body to sustain propulsion of the skier likely stresses some structures to the point of injury (Street, 1988). Frymoyer et al., (1982) explained that the properties of the anatomical structures might play a significant role in spinal injury while skiing, for example: osteoporosis, state of muscle contraction at the time of injury, abdominal tone and body posture.

Biomechanics of Skate Skiing

When skate skiing was first developed, many assumed that the increased work load generated by the biomechanics of the skate skiing motion would lead to an increase in injuries. This was probably the case until techniques were refined and coaching knowledge caught up to the new practice. Notwithstanding this, some of the velocity generating advantages of skate skiing are suspected to have contributed to skate skiing specific injuries. Mechanically, more force is being applied from the upper body in skate skiing, which is suspected to create more stress through the shoulder joint. Also, the action of skating including forceful edging, push off by extension, eversion and external rotation isolate the hip extensors and groin muscles used in recovery. Lindsay's et al. (1993) study of lumbosacral dysfunctions in elite cross-country skiers compared skate skiers to a control, non-skier population. They concluded that the asymmetrical ski-skating technique played an influential role in the pathogenesis of sacroiliac joint dysfunctions in elite cross-country skiers. Gertsch et al. (1987) stated that the use of skate skiing techniques and preexisting conditions had to have been present in order to precipitate the appearance of bilateral anterior compartment syndrome in an elite level cross-country skier. On the other hand, Butcher & Brannen (1998) found that there was no significant difference in injuries between classic and skate skiing techniques, whereas Eriksson et al. (1996) found that classic style skiing induced most of the back pain in his retrospective epidemiological study of 87 elite cross-country skiers.

Specific Biomechanical Concerns in the Female Cross-Country Skier

In an article summarizing sports injuries of female athletes, Rubin (1991) concluded that female athletes had similar injury rates to their male counterparts and that injuries were specific to sports, not gender. During a 30-month, 227 patient survey of basketball players, Gray et al. (1985) demonstrated that female basketball players were more prone to anterior cruciate ligament (ACL) and lower extremity stress injuries than male players. Hunter et al. (1982), explained those biomechanical factors such as increased varus position at the hip and valgus stress at the knee as seen in people with greater than 15 degrees Q-angles was likely to lead to overuse syndrome. They reported the following commonly seen overuse injuries in female athletes: Patellofemoral disorders, spondylosis, stress fractures in the lower limgs, MTSS, bunions, swimmer's shoulder and breast trauma. Some of the injuries listed above are also very common in cross-country skiing. The fact that women are more prone to these injuries and that cross-country skiing has also had those injuries identified for being significantly prevalent may put female cross-country skiers in double jeopardy.

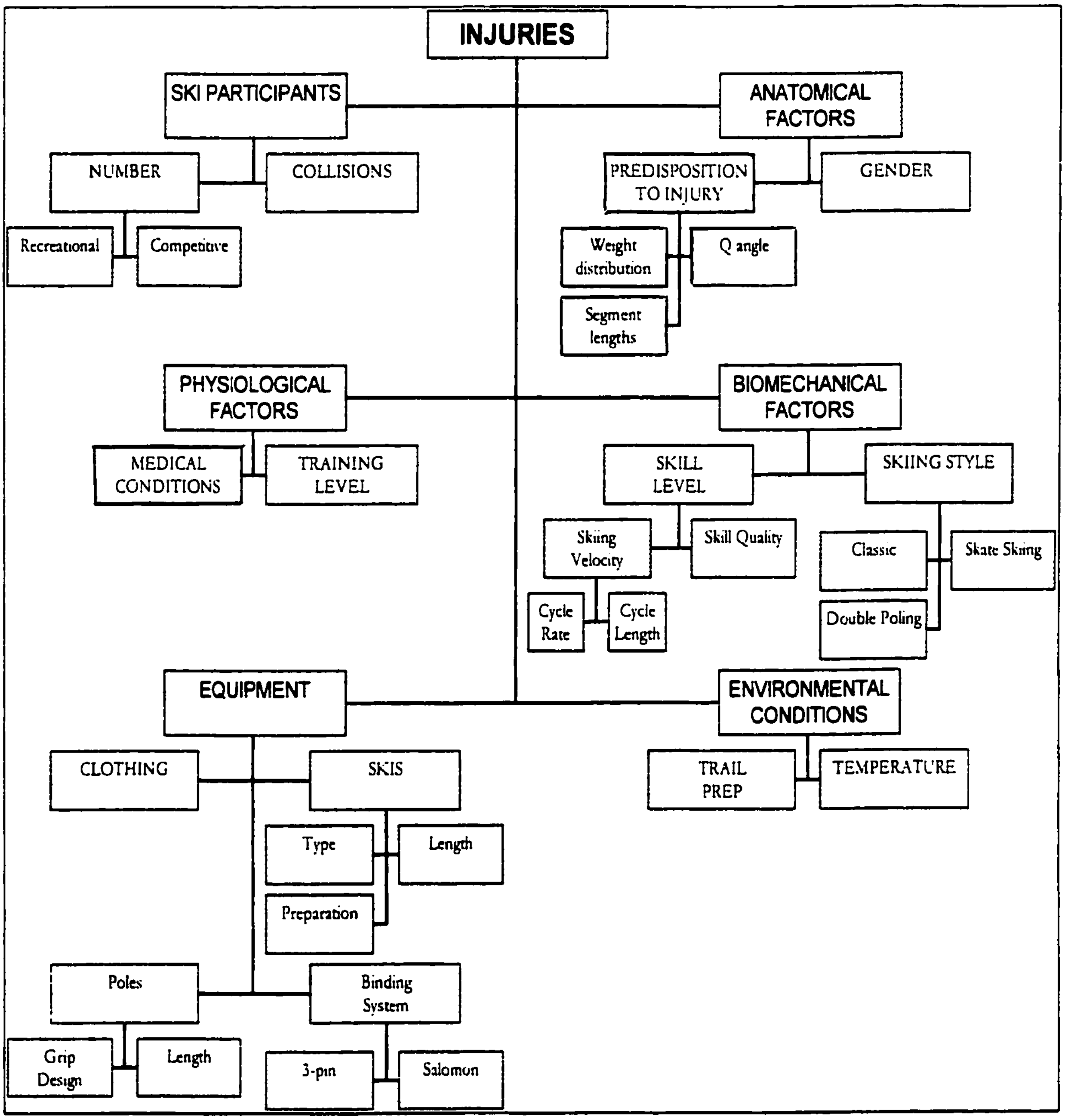
In her article, Arendt (1994) listed many of the changes that occurred at puberty between males and females. She stated that females had characteristically wider hips and narrower shoulders, and that females did not demonstrate as significant a muscle mass gain as did the males. Arendt also noted a gender difference in upper body strength and limb length. She went on to postulate that wider hips produced a varus position leading to a femoral angle of less than 125°, which was a contributing factor for overuse syndromes in hips and knees in women. In support of Rubin (1991), Arendt went on to explain that there were greater similarities in sport specific injuries than there were differences between genders. She also attributed injuries to ligamentous laxity as being due to hormonal cycles, whereas lesser performance in events like running and jumping was due to women's lower centre of mass and shorter limb length.

In her follow-up article, Arendt (1996) said that the relationship between wider Q-angles and overuse injuries was not clearly established. Micheli however, author of the ASport Medicine Bible -1995", describes that a Q-angle greater than 20 degrees is likely to pull the kneecap laterally and cause patellofemoral pain and subluxation. The biomechanical implications of Q-angles are unclear. There are citations in the literature that identify Q-angles as a possible factor leading to lower body injuries but no causal effect has been measured.

In his study of 488 patients admitted at Ringerike Hospital in Norway, Paus et al. (1982) found that women were at a higher risk of injury, particularly the population of female cross-country skiers above the age of 40. Moreover, they showed that women tended to suffer more ligamentous injuries during cross-country skiing, mainly at the knee. Paus et al. (1982) pointed to the pronounced valgus position of the female knee as a possible source of trauma to the medial compartment of the knee. Eriksson et al. (1996) on the other hand, cited muscular weakness and fatigue as likely factors for their results that showed women suffered twice as much from back pain compared to men when using double poling.

In summary, a review of the literature that has focused on cross-country skiing has demonstrated the complex nature of the characteristics, which underlie the knowledge and understanding of cross-country skiing injuries. The following Figure 1, presents a model of the factors and characteristics of cross-country skiing injuries which emerged from this review of literature. The psychological factors that may also relate to the injuries in cross-country skiing were not considered.

Figure 1 - Cross-country skiing injury factor model



Meta-analysis

In the traditional summary analyses of research, the review is dependent on the author's subjective selection of inclusion criterion, review methods and interpretation. In addition, researchers face immense difficulties in summarizing large numbers of studies. On certain topics, hundreds of articles have been published and analyzing results by summarizing would be an enormous task. Meta-Analysis is a method of observational research designed to address the two main disadvantages of literature analysis. Glass (1976, 1977) developed the meta-analysis as a statistical approach for summarizing the results of numerous studies investigating the same problem in educational research (disadvantage # 1). To combat the main source of author bias in the selection criterion of studies (disadvantage #2), Glass also specified that the review must be as inclusive as possible. He argued that this exposed the truest summary of all the available studies reporting on a given topic. The application of meta-analysis has spread, and is now also used in medical research to provide guidance for clinicians in treating future patients. At the same time, it offers direction for future research (Halvorsen, 1986).

Hedge (1981, 1982) and Hedge and Olkin (1983, 1985) made considerable advances in developing the statistical methods of meta-analysis by addressing the problems faced by the Glass (1976) method (difficulty in establishing effect size differences, which often yielded null-effect results). In these papers, the authors developed new techniques for treating and analyzing the effect sizes. Thomas and French, (1986) published a tutorial overview of those methods, which specifically addressed exercise and sports research.

In one of the first meta-analyses used to study a problem in exercise science, Sparling (1980) summarized the results of 13 studies on the differences between men's and women's maximal oxygen uptake (VO_2 max). As expected, he found great differences between the two genders. Sparling was able to correct for body weight differences between men and women and found that 66% of the variance in VO_2 max was explained by knowing the subject's gender. He then corrected for body composition, using Free Fat Weight (FFW) as the denominator (ml/minute*Kg of FFW) for VO_2 max, knowing that women typically have higher percentage body fat. The result was that the variance in VO_2 max accounted for by gender was now reduced to 35%. Even though he hypothesized about the possible effects of hemoglobin concentration and activity level differences between men and women as factors in VO_2 max, Sparling's (1980) meta-analysis led him to conclude that the advantage of males over females in VO_2 max was dramatically reduced when it was corrected for body weight and composition. Thus, the gender differences in VO_2 max appear to be mostly accounted for by differences in body composition.

In a more recent meta-analysis, Cordova, Ingersoll & LeBlanc (2000) studied the influence of ankle support on joint range of motion, using a "before and after" exercise model. Cordova et al. (2000) had three testing conditions, a control group and a pre and post test. The dependent variables used in their analysis were standardized effect sizes differences in range of motion during (a) inversion; (b) eversion; (c) dorsi-flexion; and, (d) plantar-flexion. They were able to conclude that the semi-rigid brace condition offered the greatest inversion restraint, followed by the lace up condition. Ottenbacher (2000) wrote a commentary on the study and identified some points of concern. He stated that there was a lack of background information on meta-analysis in the study and that the existing reviews on ankle joint support articles were not discussed adequately. He also questioned the limited literature search, in that Cordova et al. (2000) had only accepted articles presented in peer-review periodicals. In addition, Ottenbacher evaluated the coding criterion and deemed it unclear. This included the evaluation of research design, which he considered most important. Finally he pointed to the new meta-analysis methods outlined in Cooper (1998), which Cordova et al. (2000) did not use.

In rebuttal, Cordova et al. (2000) addressed Ottenbacher's issues. They used peer-review articles since they were the only ones considered of high quality, and they decided that the added range of generalization that would be afforded by a wider inclusion criterion did not outweigh the disadvantages of including "poor quality" studies. They also assured the reader that both the inclusion/exclusion criterion and the coding had been done following strict guidelines to limit bias. Cordova et al. (2000) went on to explain that they had used the most appropriate methodology for their study, given that they had a small sample. The criterion of homogeneity of effect sizes was not violated since the researchers expected dependencies among the effect sizes.

Many of Ottenbacher's concerns could also be addressed using a qualitative assessment in conjunction with the quantitative analysis outlined by Cordova et al., (2000). In this case, a meta-analysis is used to assess the quality of the literature/research, not to summarize the results of articles. Conclusions drawn from qualitative meta-analysis speak to the validity and reliability of an article and to the strength of design and distribution of results. Jenicek (1989) identified three purposes to qualitative meta-analysis: (1) to determine the prevalence, homogeneity and distribution of the quality attributes of articles included; (2) expand the knowledge of missing or imperfect data; and (3) evaluate and interpret the outliers from the expected distribution. Jenicek (1989) established some guidelines for conducting a qualitative meta-analysis and a logical sequence to integrate this procedure in a complete meta-analysis. He explained that the qualitative assessment must take place before the quantitative meta-analysis. Unacceptable studies must be rejected according to pre-set inclusion/exclusion criteria. Some weight may be assigned to studies to establish a quality score and an effect size is calculated. Halvorsen (1986) also explained some aspects of qualitative assessment but did not present a formal method for qualitative meta-analysis.

Thomas & French (1986), discussed the characteristics of the results on which evaluations should take place, for example: Internal validity, method of measurement, scale of measure, publication, as well as the age and gender of the subjects. More recently, Thomas & Nelson (1996) developed two important procedures not seen before in other types of literature review that applied to meta-analysis: (a) A decision regarding the literature analysis; and, (b) a standard metric against which the results of the different studies could be quantified and compared. They described the decisions involved in the literature analysis to be of a certain character, including "thoroughness of the literature search... the basis for inclusion or exclusion of certain studies," and "an evaluation of how the conclusions were drawn." By enforcing strict demands on the extent of the literature search and the near-all inclusion criterion, Thomas and Nelson (1996) increased the generalization factor of the meta-analysis procedure, thereby increasing its external validity.

Jenicek (1987) described the meta-analysis method as one of the best possible means of synthesizing information on a topic, especially befitting medical research problems. Not only did Jenicek encourage the use of meta-analysis in health studies but he also guided its ongoing development, which enabled meta-analysis to answer broad questions about health policies and programmes.

Using Meta-Analysis to Examine Cross-Country Skiing Injuries

Many of the studies involving cross-country skiing injuries are done in a report format, with case studies, surveys and retrospective studies being some examples. Renstrom's & Johnson's (1989) review article of cross-country skiing injuries and Smith's et al., (1996) critical appraisal of the literature on the biomechanics of cross-country skiing injuries both condensed the results of cross-country skiing injury articles as published up to that point. However they lacked the structure to allow for a thorough statistical examination.

Renstrom & Johnson (1989) discussed cross-country skiing techniques, equipment, injury factors and types of injuries and they concluded that cross-country skiing is a relatively safe sport for people of all ages as well as being appropriate for physical rehabilitation. They observed a trend, which suggested that the growth of prevalence in serious cross-country skiing injuries be due to increased velocities and aggressiveness in the sport. Smith et al. (1996) made many recommendations that addressed cross-country skiing safety including: the development of safer ski bindings; the need for speed control; and, the development of a skier's endurance, strength and flexibility. The authors described the methodology of their literature search but summarize their article by arguing that future recommendations will only be valid if they are based on studies that have developed a greater degree of methodological rigor. Thus, they acknowledged the limitations of their work. In spite of these thorough literature reviews, neither research team was able to offer significant meaning for their conclusions nor were they able to generalize their findings for a broader population outside the limitation of each article. A meta-analysis, however, can be used to summarize the findings of the many cross-country skiing injury articles. In addition, it can add confidence to the findings by offering statistical power and population generalizability (Cordova, Ingersoll & LeBlanc, 2000).

Using modern methodology appropriate to study sport-specific injuries, a meta-analysis was used to study three features of cross-country skiing injuries, including the interdependence of injury factors. The features studied were the body parts susceptible to injury during cross-country skiing, the mechanisms of injury and types of injury frequently seen in this sport.

Chapter 3

Methodology

A meta-analytical study was conducted to evaluate the statistical significance of cross-country skiing injuries summarised from the results of articles and sources found in the comprehensive review of literature. A meta-analysis approach was used to determine the significance of the proportional estimates of injury types, body parts injured and the mechanisms of injury in cross-country skiing. Three quantitative statistical analyses were performed to address the epidemiological factors included in this study.

This study was conducted based on the recommendations made by a number of researchers (Jenicek, 1989; Fleiss, 1982; Matt, 1989; Thomas & French, 1986, Thomas & Nelson, 1996). The steps used to conduct the meta-analysis are listed below and are addressed in detail in the following sections:

(1) a comprehensive review of the literature;

(2) establishment of the inclusion and exclusion criteria;

(3) translation of articles not available in English or French

(4) a qualitative assessment;

- i) coding of the qualitative characteristics
- ii) statistical assessment of the qualitative analysis

(5) a quantitative meta-analysis

- i) establishing effect size
- ii) statistical analysis of the effect size

(6) interpretation of results; and

(7) reporting summary of results.

Comprehensive Review of the Literature

An initial literature search using the key words: cross-country, skiing, injuries, medical problems/concerns, sport specific injuries, mechanisms of injury, chronic/acute injuries and biomechanics of cross-country skiing was completed in order to gather the literature relevant to the question of injuries in cross-country skiing. It was apparent from an initial analysis that there was no clear direction in the general trends or tendencies for the number or types of injuries reported in cross-country skiing. From a meta-analytic perspective, Matt (1989) has referred to this stage as establishing the domain of relevance, from which the guiding research question emerges. A comprehensive review of the literature including all relevant studies and all review papers that could be accessed through MedLine and Sports Discus was conducted. The data search yielded more than 200 possible sources of cross-country skiing injury results.

A secondary search was completed using references from the initial review of literature. In this second stage the "relevant sample of research studies" was declared. However, in order to identify the relevant sample, the initial set of studies was filtered through a series of inclusion and exclusion criteria established by the researcher apriori.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were set to limit the information gathered within the scope of the study. Studies published in French, English, Norwegian, German, Finnish and Swedish were accepted. Articles had to contain new data, compiled from original research. In addition, reviews (Renstrom & Johnsons, 1989; Soma et al., 1996; Smith et al. 1996) of cross-country skiing injuries were used to complete the literature research and to compare results but were excluded from the meta-analysis. Both retrospective and prospective research was accepted, as were case-series and case studies. Case specific articles were accepted even if they were of the type published in medical journals in which reported "odd", "weird" or "exceptional" cases were presented. Articles publishing data from 1973 onward were accepted. Also, articles had to specifically identify cross-country skiing, and no article lacking this specificity was included. Often, articles grouped all forms of skiing or did not distinguish between downhill, telemark or ski jumping.

Translation Procedure

In this study, a specific procedure was used for translations. During the article collection phase, all articles matching the description of the search were accepted, including articles published in languages other than English. Since cross-country skiing has a strong cultural history in Scandinavian Countries, it was important to include all articles found from those countries in the initial search and make every effort to include their results. To exclude articles published in Finnish, Norwegian, Swedish or German would have lessened the validity of a meta-analysis on cross-country skiing injuries. Articles in a language other than English or French were translated in order to be include in the qualitative assessment and the meta-analysis.

Student translators attending Canadian universities during the school term of

1999-2000 did the translations. They were contacted through the Lakehead University International Student Association, with students whose primary language was not English being recruited. Candidates with a background in sports or physical activity and functional written English were selected.

A translation guide and a list of expected English terms were provided. The guideline explained the inclusion criteria and the purpose of the task. The list of specific terms was provided to help the translators with medical and technical terminology in cross-country skiing and injury mechanism. Refer to appendix for English list of terms. The content of the articles was translated to answer the specific qualitative assessment questions and discuss the quantitative results. The translators were then interviewed to complete any section lacking information and to confirm the content of the translations.

Qualitative Assessment

The procedure of meta-analysis has historically been applied to a quantitative assessment of a pool of results reported across the literature on a specific topic. In this study, a preliminary step used a qualitative analysis to assess articles and provide an index of quality. Using the qualitative assessment, the researcher can discuss the overall quality of an article in respect to the inclusion or exclusion of information that could support the internal or external validity and assist in the interpretation of the meta-analysis results in order to report discrepancies.

The qualitative assessment served as an evaluation of the overall thoroughness of the published articles on cross-country skiing injuries. The results of the qualitative assessment identified areas requiring further attention in the future study of cross-country skiing injuries.

Coding Qualitative Characteristics

A qualitative assessment of the articles included in the meta-analysis was developed as follows. Initially a list of 13 questions was created to determine the acceptability and appropriateness of the research methodology and reported outcomes. The questions were then applied to each research study that met the previously stated inclusion criteria. The questions were written so that the individual responses could be scored in binary terms (1=yes and 0=no). The questions used for this stage of the qualitative assessment are listed in Table 1, below

Table 1 - Qualitative Assessment Questions.

Question Number	Question
1	Was the study design cohort or experimental?
2	Was the study design case series or report?
3	Were the participants described and grouped according to age?
4	Were the participants described and grouped according to gender?
5	Were the participants described and grouped according to skill level?
6	Were the participants described and grouped according to training volume?
7	Were the participants described and grouped according to interaction to other sports or activities?
8	Was there a differentiation between the equipment used by skiers? Ex: 3 pins or Salomon
9	Were the skiing conditions identified?
10	Was the method of cross-country skiing identified? Ex: skating technique, classic technique, double polling

11	Was the injury information specific? Included location & degree
12	Were the diagnosis criteria justified/appropriate?
13	Was the mechanism of injury identified?

This process was repeated so that each research study was assigned a "qualitative score" which was the result of the sum of binary scores for the set of questions. A middle-score test was used to evaluate the total group of research studies. In this study, the middle-score test used a "passing grade" of 7, based on the potential scoring range from 0 to 13. A frequency distribution was computed for the qualitative score.

Justification of the Questions Used in Qualitative Assessment

Howe & Johnson (1985) explained that many variables could be attributed to observed injury rates for cross-country skiing. For example: gender, age, skiing ability, type and function of ski equipment, fatigue and snow conditions each have been reported as possible factors for injury (Howe & Johnson, 1985). Renstrom & Johnson (1989) listed "Factors of Importance in Sustaining Injuries During Cross-Country Skiing," such as:

(1) ski materials;

(2) increased speed on machine groomed tracks;

(3) falls during attempts to snow-plough, particularly while descending steep hills;

(4) training several hours daily such as with top level athletes who are then at

risk for overuse injuries.

In addition, some studies of top-level athletes have identified problems associated with training, faulty technique, and inadequate equipment (Renstrom & Johnson, 1989).

Smith et al. (1996) wrote about injury prevention and named the following considerations:

(1) equipment and technique of cross-country skiing;

(2) avoiding downhill portions;

(3) skier awareness; and

(4) conditioning.

Furthermore, Kannus et al. (1988) stated "There is a clear change in the frequency of overuse injuries in connection with the change in cross-country skiing technique". These recommendations were followed in the establishment of the qualitative assessment questions.

Summary of the Qualitative Assessment

Each selected article was assessed according to the qualitative assessment criteria and a total score for a measure of quality was obtained. Dichotomously scored nominal scale variables, were used. The results of the qualitative evaluations were then charted using a frequency distribution. A middle-score test was used to differentiate between articles on the basis of their assessed thoroughness. The middle-score test identified those articles that either "passed" or "failed" the qualitative assessment. Since 13 questions were used in the qualitative assessment, a score of 7 and above was considered a pass while a score of 6 or less was a fail.

A Quantitative Meta-Analysis

Establishing the effect size

The quantitative meta-analysis combined all the proportions of injuries reported in each selected article. A chi-square for proportions was used to determine if an effect size existed within the total distribution of selected research papers. Rather than compare the mean scores, as in a traditional effect size calculation, the present research compared each article's proportion of injuries to the expected distribution, and then analysed the results with a chi-square test for proportions. A significant chi-square value indicated that an effect size existed, thus demonstrating that there was an inconsistency in the distribution of results reported by the articles.

The design of the present study followed that of Crump, Krewski & Van Landingham (1999). In their study of the carcinogenic effects of different chemicals in liver bioassays, Crump et al. (1999) used this method to examine the distribution of p-values from the statistical tests used in original research. The authors postulated that if there were no carcinogens present, then the p-values would be uniformly distributed between zero and one. If there were carcinogens present however, then they would observe a deviation from the norm. This procedure allowed Crump et al. (1999) to re-evaluate certain chemicals that had previously been declared non-carcinogenic and thus reverse the classification of these chemicals.

Statistical analysis of effect size

An effect size for proportions was used since the purpose was to compare proportions of injuries reported. Since the design of this research has multiple proportions, the chi-square analysis followed the technique of Fleiss (1982) "chi-square for proportions." This established the significance of the frequency in injury sites, types of injury and mechanisms of injury. The formula by Fleiss (1982):

$$\chi^2 = \frac{1}{\overline{pq}} \sum_{i=1}^{m} n_{i.} \quad (p_i - \overline{p})^2$$

The chi-square analyses were applied to each aspect of cross-country skiing injury included in this research. While studying the body parts injured in cross-country skiing, the first set of chi-square analyses compared the proportions of injuries reported across the studies for a given body part. The chi-square determined the extent to which articles differ in the reporting of injury proportions (i.e. effect size), and was based on all studies selected from the qualitative stage of the meta-analysis. If significant differences existed in the proportion of injuries reported for a given body part across the articles of the study, the researcher would conclude that one or more articles are causing the significant difference in the overall chi-square. The next step was to perform pair-wise comparisons to identify those article(s), which caused the overall significant chi-square results.

This second stage chi-square analyses compared, on a pair-wise basis, the proportions of injuries to body parts from the results of all selected studies. The formula for the pair-wise comparison was as follows (Fleiss, 1982).

$$\chi^2 = \frac{1}{pq} * \frac{n_{(1)} n_{(2)}}{n..} (\bar{p}_1 - \bar{p}_2)^2$$

The significant results from this second stage chi-square were intended to illustrate which research studies were reporting proportions of injuries that were inconsistent within the general pool of research articles. A re-evaluation of those articles that were shown to contribute to the overall significant difference(s) in the chi-squares provided information about which specific studies had a higher injury prevalence.

This four-stage analytic process was repeated for the study of injury types, and mechanisms of injury. Each stage of the process was used to identify which article's results were significantly different from the distribution and which specific types of injuries or mechanisms of injuries were most prevalent.

Chapter 4

Results and Discussion

From the comprehensive review of literature, 158 articles met the initial search parameters. Of this number, 153 were collected and 5 were unavailable at the time of writing. The inclusion and exclusion criteria were applied to the articles published in either French or English, while articles published in other languages were translated according to the translation procedures. Of the initial 153 articles, 53 were retained as having met the inclusion criteria. From the selected articles, two were translated from Swedish, one from Finnish, one from Norwegian and six from German. In total, 15 articles were classified as either case series or single case studies, while 38 were either cohort or experimental designs.

In this study the epidemiological research on cross-country skiing injuries was evaluated from both a qualitative and quantitative perspective. As part of the evaluation, a qualitative scoring method was developed and used to assess the inclusion or exclusion of information that could support the internal and external validity. This in turn assisted with the interpretation of the reported results. The results of the quantitative meta-analysis indicated that rates, types, and mechanisms of injuries were significantly different across injury reports. These results also support the need for a comprehensive investigation of the incidence and cause of skiing injuries.

Qualitative Assessment Results

Each article was assessed for its qualitative characteristics according to the qualitative analysis questions (Table 1 - Methodology). As a result of this process, each article was assigned a "qualitative score," which was the sum of the positive answers each article collected. The score range was from 1 to 11, with 13 being the highest possible score. Tables 2a and 2b contain the individual qualitative assessment scores for each article.

Table 2a - Individual Scores of Case Studies or Case Series Articles

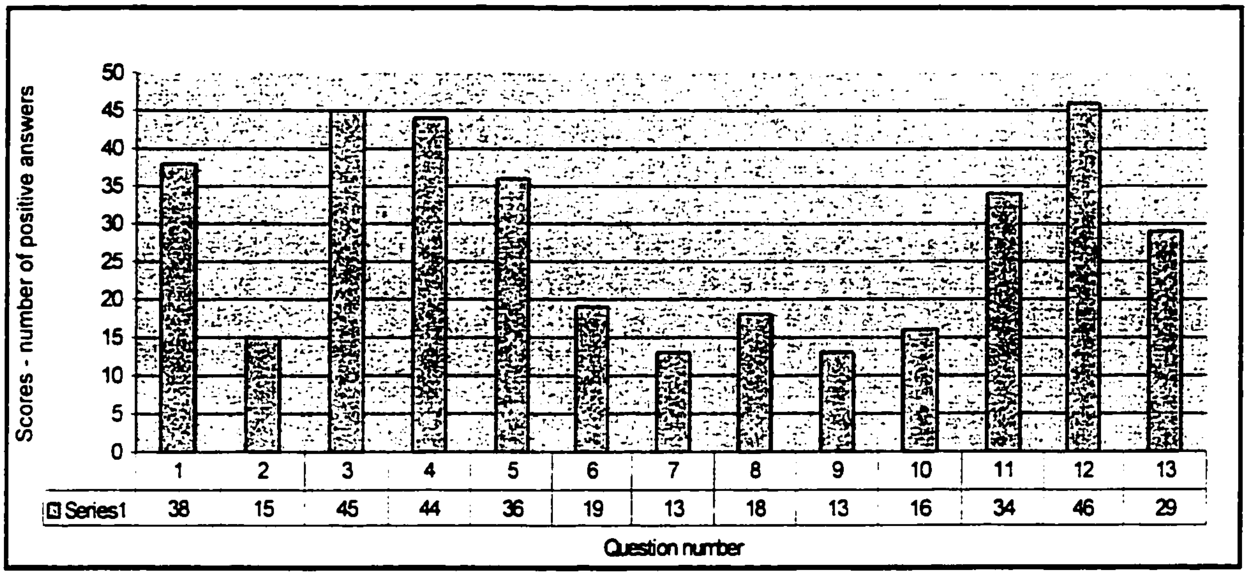
Articles with either case series or case report designs	Article Code	Scores	Articles with either case series or case report designs	Article Code	Scores
Aitchison,S. & McNabb,J.(1983)	342	8	Losh,D.L. (1981)	349	6
Bovard,R. (1994)	343	9	Lyons,J.W. & Porter,R.E. (1978)	350	7
Fenner,A. (1976)	355	5	Sherry,E. & Henderson,A. (1987)	351	9
Frost,A. & Bauer,M. (1991)	344	6	Stamm,F. & Brunner,U.V. (1982)	356	9
Fulkerson,J.P. (1980)	345	7	Stuart,M.J. (1992)	352	6
Gertsch.P. Borgeat,A. & Walli,T. (1987)	346	8	Turbelin,J.M. (1986)	353	6
Husson,J.L. Certain,J.L. Blouet,J.M. & Masse,A. (1985)	347	11	Williams,J.S. Jr & Williams,J.S. Sr (1994)	354	7
Husson,J.L. Certain,J.L., Rochcongar,P. & Masse,A. (1983)	348	8			

The designs of the articles were evaluated by questions 1 and 2 of Table 1 - Methodology. When comparing table 2a to table 2b, articles with case study designs generally achieved a higher qualitative score than cohort studies with a mean score of 7.46 versus 6.68. Most articles described the participants adequately (refer to graph 1 - Qualitative Analysis, questions 3 - 7), with training volume and other sport or activity interaction the least reported factors. The nature of the medical reports included in the articles reflected the high standard of the medical assessment of injuries. The articles evaluated as lacking an appropriate diagnosis criterion were those that used a survey filled out by the patient, and without the involvement of any medical staff in the diagnosis or follow-up. These articles were in the minority (7/53).

Table 2b - Individual Scores of Cohort or Experimental design Articles

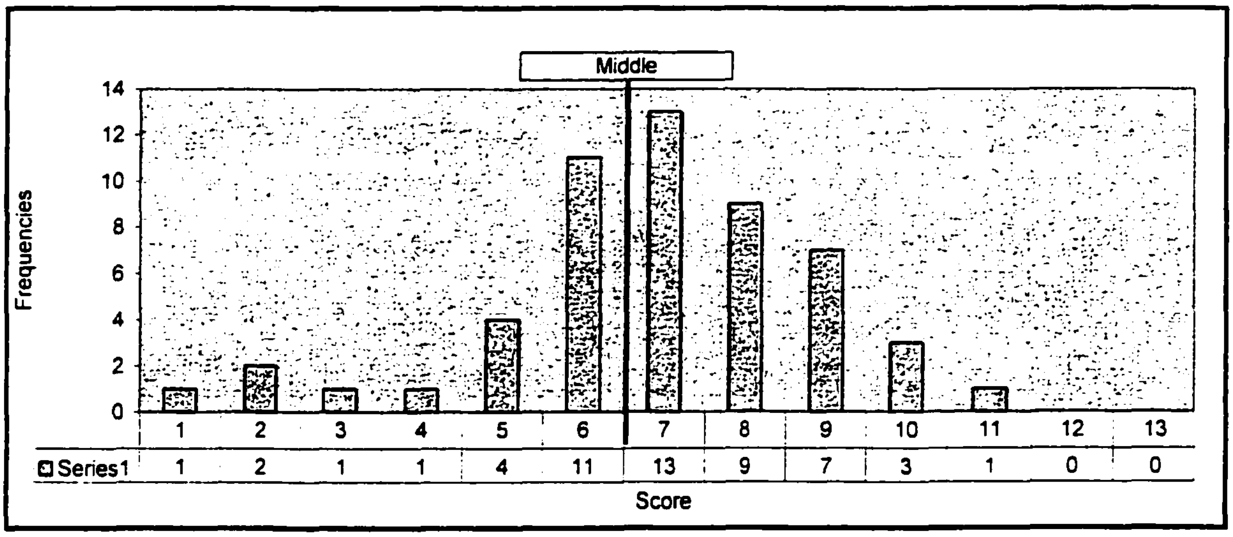
Articles with either cohort or experimental designs	Article Code	Scores	Articles with either cohort or experimental designs	Article Code	Scores
Alt,M., Ostentag,A.,Ashert,R. & Lechner,F. (1982)	230	10	Lindsay,D.M., Meeuwisse,W.H., Vyse,A., Mooney,M.E. & Summerside,J. (1993)	115	8
Boyle,J.J., Johnson,R.J. & Pope,M.H. (1982)	103	10	Mahlamaki,S.T. Michelsson,J.E. & Pekkarinen,H. (1985)	237	9
Boyle,J.J., Johnson,R.J., Pope,M.H. Pierce,J.C. & Brady,M.M. (1985)	104	8	Mahlamaki,S.T., Pekkarinen,H. Haenninen,O. & Michelsson,J.E (1987)	116	5
Burger,H. & Ott,W. (1984)	231	6	Mahlamaki,S.T., Soimakallio,S. & Michelsson,J.E. (1988)	117	7
Butcher,J.D. (1996)	105	1	Markov,L.N. (1987)	238	8
Butcher,J.D. & Brannen,S.J. (1998)	106	7	Orava,S., Jaroma,H. & Hulkko,A. (1985)	118	9
Cote,J.P.,Saint-Cyr,Y. & L'Heureux,G. (1977)	107	9	Paus,A., Tuveng,J.M., Nilssen,A. & Holter,I. (1982)	101	7
Daljord,O.A., Maehlun,S. (1986)	232	7	Pigman,E.C. & Karakla,D.W. (1990)	119	6
Edlund,G. Gedda,S. & Hemborg,A. (1980)	108	6	Pigman,E.C., Volcheck,G.W. & Grice,G.P. (1990)	120	7
Eriksson,E. (1976)	109	8	Sandelin,J., Kiviluoto,O. & Santivirta,S. (1980)	121	5
Eriksson,E. & Danielsson,K. (1977)	110	8	Shealy,J.E. (1985)	122	5
Eriksson,E., Nemeth,G. & Ericksson,E. (1996)	111	6	Shealy,J.E. & Miller,D.A. (1991)	102	4
Frank,B.C. (1995)	233	6	Sherry,E. & Asquith,J. (1987)	123	2
Gannon,D.M., Derse,A.M., Bonkema,P.J. & Primley,D.M. (1985)	112	6	Steinberg,L. (1981)	124	7
Hallmarker,U. & Aronsson,D. (1985)	234	7	Steinbruck,K. (1987)	125	7
Heuman,R., Sten,J. & Tidermark,J. (1985)	236	2	Sutter,P.M. & Matter,P. (1983)	239	3
Hintermann,B. (1983)	235	8	Ueland,O. & Kopjar,B. (1998)	126	7
Kannus,P. & Jarvinen,M. (1986)	113	8	Vacelet,J.L. (1981)	127	10
Kannus,P., Niitymaki,S. & Jarvinen,M. (1988)	114	9	Westlin,N.E. (1976)	128	6

Graph 1 – Qualitative Scores per Question of Each Article



Questions numbers 8-10 (Graph 1), as a group, were the least well addressed. These questions reported information on the "type of equipment used," "the skiing conditions" and the "cross-country skiing technique" used by the participants. Graph 2 - Frequency Distribution, illustrates that 62%, or 33 out of the initial 53 articles, achieved a score above the middle score, thus "passing" the qualitative assessment.

Graph 2 - Frequency Distribution of the Qualitative Scores.



<u>Qualitative Assessment Discussion</u>

Previous literature was used to establish the critical areas of evaluation throughout the process of quality assessment. Questions used in the assessment identified the types of research, including the methods used to study the prevalence and /or incidence of injuries as well as whether or not the researchers included critical information regarding the specific cross-country skiing injuries. These critical details assisted in the overall evaluation of each article used in the meta-analysis.

The first set of questions used in the qualitative assessment of the papers focused on the description of the participants. In each case the description of the sample that was used in the report was thorough and provided the reader with enough information to adequately delimit the sample. However, the injuries reported in cross-country skiing may have been influenced by concurrent participation in other sports.

This information was rarely reported in the studies examined. Thirteen articles reported screening for prior injuries, but only three published results reflecting consideration the interaction between participation in other activities and the recorded injuries. The importance of reporting such interaction effects was brought to light in Orava et al.(1985). In this case, the authors studied 194 overuse injuries sustained by 187 cross-country skiers, where forms of training or exercise other than skiing itself caused 60% of the injuries.

The qualitative assessment included a number of questions, which focused on the reporting of "skiing conditions," including the "type of equipment used," "snow conditions" and "individual cross-country skiing technique." In most cases this information was poorly reported. According to Howe & Johnson (1985); and Renstrom & Johnson (1989); this information is important and it is unfortunate that these aspects of cross-country skiing injuries are not often included in reports since equipment selection/design and skill development are areas that can be modified by research and education. Similarly, general skiing conditions are one of the factors that skiers should evaluate when deciding to train or race. The researchers addressed this criterion in only 13 of the 53 articles. If authors were to commonly record and report this information, skiers and coaches would have access to potentially valuable injury prevention information.

In general, the results of the present research demonstrated that case studies achieved a higher qualitative score than cohort studies. It is suspected that this result is due to the characteristics of case studies, which imply that such studies do not attempt to establish statistical significance. Further, it is possible that the investigators put less emphasis on the consideration of the threats to internal and external validity. Although case studies do not meet the stringent requirements of scientific research using an experimental design, they are still considered good quality articles since particularly in this case they usually present a thorough history of the injury, the diagnosis, the skiing conditions and the participant. Moreover, case studies are used to describe rare but important incidents that would not be statistically significant if analysed using other research methods. An example is Sherry & Henderson's (1987) cautionary tale of an accidental death while cross-country skiing. Epidemiologically, case studies are useful in identifying the specific trends and patterns of injuries for selected conditions within an event that can later be expanded to cohort evaluations.

Each selected article was assessed according to the qualitative assessment criteria. A middle score test was used to differentiate between articles which were found to be lacking in substantive information, and those that provided adequate information to support internal and external validity. This process was deemed to be important in a study that set out to conduct a meta-analysis of the epidemiological characteristic of cross-country skiing injuries. The assessment resulted in 33 of the 53 studies achieving a score above the middle qualitative score. Only 9 of the 53 were below a score of 6 and these were clearly lacking the information necessary in a study attempting to make comparisons between rates and proportions of injuries. While the difficulty in attempting to assess a measure of "quality" in research is recognized, these results lend support to the need to establish some objective measure of the characteristics, which may impact on the development of an epidemiological description of injury trends and interpretation. In this study, the results of the qualitative assessment were considered in the interpretation of the final analysis.

Quantitative Meta-Analysis – General Results

All of the data on proportions of injuries, collected from the selected articles, was organized into spreadsheet tables. Data from the tables was then used to calculate the chi-square analysis of effect size. Each aspect of the cross-country skiing injuries was individually measured and assessed using chi-square calculations for proportion based on Fleiss's technique (1982). For example: within the "Body Parts Injured" epidemiological parameter, the proportion of injury data for the head, face, shoulder, arm, hand and wrist, back, pelvis/hip and thigh, knee, ankle and foot were statistically analyzed separately in order to establish the presence of effect sizes within each body part category.

Meta-analysis – General Discussion

In this study, the injury reports were organized according to the following epidemiological factors: body parts injured, injury types, and mechanisms of injury. These categories formed the basis for the subsequent comparisons using chi-square analyses. However, one important restriction of the chi-square analysis is that all cells used in the comparison process must have at least N=5 cases in order to yield reliable results. To this end, several cells within the original data tables were collapsed to enable appropriate statistical evaluation, for example: hand with wrist; pelvis with hip and thigh; crossing tips with catching an edge in "accidents." This was particularly necessary for the "Mechanism of Injury" category, since several cells were under-represented across the total group of studies available for the analyses.

Epidemiological Factor 1 (Body Parts Injured) – Results:

The significant chi-squares of Table 3 - Summary comparison of body parts injured as reported in cross-country skiing injury articles, demonstrated that the proportions of injury reported are significantly different from an expected distribution. Once significant differences were found, multiple pair-wise comparisons using the variance of the full model were performed to identify differences between any two-research studies. This second step was completed in order to identify the articles that caused the significant differences resulting from the initial chi-square. The face injury proportion was the only one of the body parts reported that did not yield a significant difference from the expected results. The article codes used to identify each article are provided in Tables 2a and 2b.

Table 3 - Summary Comparison of Body Parts Injured across the Selected Articles

Body part	Total injury reported	Number of injuries of this type	Chi-Square	p values	Significant pairwise comparisons between articles chi-square value of df=1, p<0.05 (3.841)
Head	13201	865	493.980525	p<0.05	article 122 vs article 126
face	3261	96	7.746890	**p>0.05**	
Shoulder	12631	1369	100.345977	p<0.05	
Arm upper limb	11533	1077	1497.282391	p<0.05	101 vs 122; 121 vs 122; 101 vs 232; 122 vs 128; 122 vs 232; 122 vs 233; 122 vs 236; 122 vs 239; 231 vs 233; 232 vs 233; 232 vs 239; 233 vs 236; 236 vs 239
Hand & wrist	12742	2280	416.247359	p<0.05	122 vs 123; 122 vs 231; 126 vs 231
Back	13801	998	624.587168	p<0.05	106 vs 111; 111 vs 118; 111 vs 122; 111 vs 126; 111 vs 128; 111 vs 233; 111 vs 239; 115 vs 121; 115 vs 126; 122 vs 235
Internal organs	1852	138	69.229405	p<0.05	
Pelvis, hip & thigh	11133	773	185.767902	p<0.05	122 vs 238; 122 vs 300 (Case studies)
Knee	15158	2962	794.332837	p<0.05	101 vs 122; 101 vs 126; 101 vs 232; 101 vs 239; 113 vs 122; 122 vs 124; 122 vs 126; 122 vs 235; 122 vs 239; 126 vs 231
Ankle & foot	12560	2132	588.118787	p<0.05	118 vs 122; 118 vs 126; 122 vs 124; 122 vs 126; 122 vs 235; 122 vs 239

The third step of the quantitative meta-analysis was to measure the significant difference across the range of injuries to answer one question: Is there a significant prevalence of reported cross-country skiing injuries for specific body parts? Once this was determined, injury comparisons that caused the significant chi-square; were identified. The chi-square analysis indicated the presence of a significant prevalence of certain body parts injury (chi-square=2838.1, $p<0.05$). Pair-wise comparisons were performed to identify which report of body parts injuries caused the significant results. The injury prevalence of every body part was significantly different from the knee and the ankle/foot category, including the prevalence of facial injuries that did not have a significant presence in the overall reported cross-country skiing injury rates. In addition, the head and arm/upper limb injury prevalence differed from the hand/wrist injury prevalence; and the hand/wrist injury prevalence also differed from the back and the pelvis/hip/thigh.

Discussion:

The statistical evaluations of the rates of injuries for body parts injured produced statistically significant results across the studies included, with the exception of the rates of injuries reported for facial injuries. This result may be attributed to the relatively low number of injuries reported for facial injuries across all studies. The significant chi-square values for specific body parts indicate that there is a distinctly larger proportion of injuries reported for the selected body part studied than would be expected. In particular, the injury rates reported for the "shoulder" and "internal organs" produced significant chi-square statistics across studies, although post-hoc pair-wise analyses were unable to identify the significant differences.

Research by Shealy (1985) on the similarity of cross-country and downhill skiing injuries, especially in lower extremity torsion injuries, yielded the greatest significant results across the studies included. This research record scored a low "5" on the qualitative assessment scale (below the middle score), and the results indicate that rates of head injuries and of pelvis/hip and thigh injuries were greater than similar reported studies. In this case, not only did Shealy's (1985) article score low on the qualitative scale but his results are also considered to be skewed as evidence from their over-representation in the pair-wise comparisons of Table 3. This contrasts with the results of Ericksson's (1996) study, which was the greatest contributor to significant rates of back injuries. This latter article also scored low on the qualitative scale but three other "good" quality articles supported it in pair-wise comparisons.

Comparisons of studies reporting the "arm and upper limb," "the knee," and the "ankle and foot," yielded significant results across the various studies included in the combined set analysis. Such results indicate that although the proportions of injuries in the larger group was significant, some studies contributed to the overall injury rates more than others.

Most important, the results of the chi-square analyses of the rates of injuries across body parts shows that injuries to the "knee" and injuries to the "ankle-foot" were identified most often among studies of cross-country skiing related injuries. This finding supports the need for continued research on equipment design as well as training protocols in order to diminish the prevalence of injuries to these body parts.

Epidemiological Factor 2 (Injury Types) - Results:

The significant chi-squares of Table 4 - Summary Comparison of Injury Types as Reported in Cross-Country Skiing Injury Articles, demonstrates that once again, the proportions of injuries reported are significantly different from an expected distribution. Significant differences were found and multiple pair-wise comparisons were performed in order to identify differences between any two research studies. However for this epidemiological factor, every injury category yielded significantly different results.

Table 4 - Summary Comparison of Injury Types as Reported in Cross-Country Skiing Injury Articles

Injury Type	Total injury reported	Number of injuries of this type	Chi-Square	p values	Significant pair-wise comparions between articles Chi-Square value of df=1, p<0.05 (3.841)
Sprains	14689	4857	1650.369853	$p<0.05$	article 102 vs article 124; 102 vs 126; 102 vs 231; 102 vs 232; 102 vs 239; 108 vs 122; 112 vs 122; 122 vs 124; 122 vs 231; 122 vs 232; 122 vs 233; 122 vs 239; 124 vs 126; 124 vs 233; 126 vs 233; 126 vs 239; 232 vs 233; 233 vs 239
Strains	3050	476	143.9010693	$p<0.05$	124 vs 234
Tendonitis & Bursitis	1603	69	28.43125413	$p<0.05$	
Fractures	14853	3687	999.6481401	$p<0.05$	101 vs 126; 107 vs 122
Dislocations	11635	579	78.03967671	$p<0.05$	
Lacerations and Abrasions	11915	995	1162.214676	$p<0.05$	102 vs 112; 112 vs 122; 112 vs 123; 112 vs 126; 112 vs 232; 112 vs 233; 112 vs 239
Contusions	13355	1883	414.1196338	$p<0.05$	122 vs 233
Concussion	3369	43	34.61357029	$p<0.05$	

Again, the third step of the quantitative meta-analysis was applied to measure the significant difference across the reports of injuries in order to answer the question: Is there a significant prevalence of reported cross-country skiing injuries of specific injury types?

The chi-square analysis identified the presence of a significant prevalence of certain injury types (chi-square=6038.63, $p<0.05$) and the pair-wise comparisons identified the following injury comparisons as the cause of the significant results. The prevalence of sprains and fractures was significantly different from every other type of injury recorded in this study. Also important to note, contusion prevalence differed from injury prevalence of sprains, fractures, dislocations and lacerations/abrasions.

Discussion:

In each chi-square analysis of injury type, the observed injury rate was significantly different than the expected injury rate. However, there were no significant pair-wise comparisons in the reports of tendinitis-bursitis, dislocations, or concussions, across the studies reviewed here. As noted earlier, the lack of significant pair-wise comparisons does not contradict the significant chi-square results. It does indicate, however, that the significant chi-square emerged from the combined effects of the differences from the expected results, rather than being caused by any two article pair-wise comparisons. Significant differences were reported for injury rates across studies for sprains, fractures, and lacerations-abrasions.

Finally, although there were significant differences in the reports of observed versus expected injuries in a general sense; the reports of specific injuries by various researchers were identified as the greatest contributors to the significant differences. For example, reports of "contusions" by Shealy (1985) were significantly higher than other injury reports, and reports of lacerations and abrasions by Gannon et al (1985) were higher than all other studies reporting injury rates; this despite the low score of both the articles on the qualitative assessment analysis. Epidemiologists should therefore remain critical of published results.

Injury reporting research often refers to the results from injury surveillance of a single event, as was the case of Gannon's (1985) article. This application of injury monitoring works in conjunction with an "emergency care network" (ECN) designed to treat injuries during a single event. While such systems may provide only a cross-section or event-specific injury information, the data should be considered extremely valuable. For example, the ECN data can provide the injury epidemiology researcher with information about climate, course and competition conditions, which are assumed to be consistent for all participants. Likewise, since the event is typically constant, both in length, duration and location from year to year, the data from the ECN can be combined to form an accurate homogenous description of injuries related to a "controlled" event. In the present study, ECN data was available for the American Berkebeiner from two different researchers (Butcher, 1989; Gannon, 1985), while Steinberg (1981) described ECN injury data over a five year period for the Canadian Ski Marathon. While the direct control of the "exposure" conditions in these studies is limited, these studies provide extremely comprehensive descriptions of the event. Researchers should, therefore, combine data from such studies in order to provide an accurate picture of cross-country skiing injuries under known conditions.

Epidemiological Factor 3 (Injury Mechanism) - Results:

The significant chi-squares of Table 5 - Summary Comparison of Injury Mechanism as Reported in Cross-Country Skiing Injury Articles, demonstrated that the proportions of injuries reported are significantly different from an expected distribution. Significant differences were found and multiple pair-wise comparisons were completed in order to identify differences between any two research studies. Every factor of injury mechanism yielded significantly different results.

Due to the nature of cross-country skiing injury articles, very few injury mechanisms could be compared. Most articles did not publish data on mechanisms of injury and the articles that did discuss it did not use matching factors. For example: five articles discussed the skill level as a mechanism of injury, but only three specified information about twisting motion versus falling due to a bare spot or collision. As a result of the lack of information in the cross-country skiing injury articles available, many highly specific mechanisms of injury could not be assessed in this study. There seams to be confusion as to the definition of "Injury Mechanism", unfortunately the words "cause", "mechanism" and "mechanics" are not well defined and are often misused by many researchers.

Table 5 - Summary Comparison of Injury Mechanisms as Reported in Cross-Country Skiing Injury Articles

Injury mechanism	Total injury reported	Number of injuries of this type	Chi-Square	p value	Significant pair-wise comparions between articles Chi-Square value of df=1, p<0.05 (3.841)
Level - Novice	587	119	59.10987225	p<0.05	article 101 vs article 119; 105 vs 119; 119 vs 230
Level - Intermediate	587	324	54.57355748	p<0.05	101 vs 230
Level - Expert	542	115	55.19165123	p<0.05	101 vs 105
Falls	307	218	184.0229037	p<0.05	103 vs 127; 103 vs 230; 104 vs 127; 104 vs 230; 127 vs 300; 230 vs 300 (case studies)
Accidents	236	70	139.0313851	p<0.05	103 vs 104; 104 vs 300 (case studies)

The third step of the quantitative meta-analysis was once again applied to measure the significant difference across the injuries to answer the question: Is there a significant prevalence of reported cross-country skiing injuries of specific injury mechanisms? The chi-square analysis identified the presence of a significant prevalence of certain injury mechanisms (chi-square=1720.06, $p<0.05$) and the pair-wise comparisons identified which injury prevalence comparisons caused the significant results. The injuries caused by falls showed the highest level of prevalence, which differed, from the three skill-level categories and the accidental injury prevalence. In addition, the prevalence of injuries reported for each skill-level differed from the other skill-level categories.

Discussion:

Results of the chi-square analyses for the category "mechanism of injury" were significant across all categories, indicating that the rates of injuries reported according to specific mechanisms were greater than one should expect for these data. In other words, the observed rate of injuries reported for the "skill level" was higher than the expected, as was the rate of injuries reported for "falls and accidents." It is interesting to note the role of "mechanism of injury" in the reporting of the epidemiology of cross-country skiing injuries. This epidemiological characteristic seems to be considered less important in cross-country skiing injury research since it was poorly identified and seldom researched in the articles gathered for this study. For example, during the initial literature search for this research, 36 articles were found that focused on certain mechanisms of injury in football (including American football and soccer); 20 articles on downhill skiing; 8 on hockey; and 10 on running. In comparison, only 4 articles were found to focus specifically on the mechanisms of injury found in cross-country skiing.

The category of "accident as a cause of injury," which includes falls, contributed to the greatest proportion of injury reports. For example, of the 846 injury reports included under the mechanism of injury category, 288 injuries were attributed to the accident/fall sub-classification. These findings are important in that they highlight the prevalence of injuries not directly attributed to training or over-use. This is a departure from Hemmingsson's and Ohlsen's (1987) results that attributed 75% of the injuries sustained by members of the Swedish National Cross-Country Ski Team during the 1983-84 season to overuse injuries and only 25 % of the injuries to trauma. Considering these specific findings one might expect that as the participation rates increase in planned "race" events, where steeper pitches, faster speeds, and uncertain conditions are combined with competitive performance, cross-country skiing injury reports may begin to resemble injury reports for downhill skiing. No doubt skiing experience (especially skill level) will also be a critical precursor to injury incidence, as shown by Pigman and Karakla's (1990) report of higher injury rates among novice skilled Marine Corps soldiers.

It is also important to note that few articles exist reporting biomechanical analysis of cross-country skiing injuries while at least 25 articles are available on downhill skiing, especially regarding knee injuries. And, even though "back" related injuries are prevalent among the reported injury rates, only Mahlamaki et al. (1988) and Orava et al. (1985) for example described the injuries with specificity. The lack of explanations or biomechanical descriptions of overuse injuries is obvious from the literature, and suggests a need for further research in this area.

Nature of Injuries - Acute versus Overuse.

Both acute injuries (e.g. trauma resulting from falls) and overuse injuries are prevalent in cross-country skiing. Anderson & Hall (1995) include sprains, dislocations and lacerations as acute injuries, while strains, tendinitis, and stress fractures are considered to be overuse related injuries. While some researchers reported these typical injury types, they often alluded to long-term injuries such as spinal problems, respiratory difficulties, nerve injuries, and arthritic or fatigue problems in their descriptions of cross-country skiing related injuries. There are no significant differences between the rates of acute and overuse injuries observed in this research.

The extreme physiological demands of cross-country skiing are well documented (Renstrom and Johnson, 1989). However, few authors published data on the consequences of such physical stress as a precursor to injuries or conditions. Yet this is not so anomalous as it may seem in injury research typically reports only serious injuries or conditions in which the participant lost time for a future event (Soma et al, 1996). Physiological stress on the body may be attributed to decreased performance in cross-country skiing and may contribute to injuries, but by itself may not be a cause of lost time for training or competing.

Chapter 5

Summary, Conclusions and Recommendations

Summary

The purpose of this study was to conduct a comprehensive quantitative meta-analysis including a qualitative assessment of studies reporting cross-country skiing injuries. To date there have been three comprehensive review articles on cross-country skiing injuries yet these studies neglected to demonstrate the importance or statistical significance of specific epidemiological factors. In addition, there has not been a consistent approach to the design of studies that have attempted to describe the type and prevalence of the observed injuries.

This meta-analysis considered three epidemiological parameters (body part injured, injury types, and mechanisms of injury) in assessing cross-country skiing in articles published since 1975. More than 200 articles on cross-country skiing injuries were initially collected and 53 were retained for the meta-analysis. Jenicek (1989), Thomas & French (1986) and Thomas & Nelson (1996) established a basic requirement for qualitative evaluation, and based on this study a structured qualitative assessment was developed. The qualitative analysis of cross-country skiing injury articles allowed us to conclude that the overall quality of the articles collected with respect to the inclusion or exclusion of information essential to the internai and external validity, was adequate but identified some areas of the research left incomplete. Critical information was especially lacking in the description of the skiing conditions, the activities/cross-training with cross-country skiing injuries and the mechanisms of injury involved in this sport.

The quantitative meta-analysis was used to summarize the results of the studies and to determine to significance of the proportional estimates of injury types, body part injuries, and the mechanisms of injuries in cross-country skiing. Almost every injury category was found to be significantly prevalent.

Conclusions and Recommendations

1. The assessment that was used to examine the inclusion or exclusion of information related to the internal and external validity of the research articles proved to be a valuable approach. The format used for this assessment should be further refined and applied to future epidemiology meta-analysis studies.

2. The majority of the articles (62%) that were assessed provided adequate details regarding the methodology, the participants and the conditions under which the data was collected to score above the middle score of qualitative assessment.

3. Historically, skiing conditions and other activity interaction/training have been poorly monitored in cross-country skiing injury research. Only three of the published articles that reported screening for prior injury also addressed the potential interaction between participation in other activities and the recorded injuries. This greatly affects the ability to thoroughly understand the reported results and to generalize. Future studies should consider accessing this information.

4. With respect to injury type, injury prevalence and body part injured, cross-country skiing injuries were reported across all standard injury types and with similar proportions as those reported for alpine skiing. Likewise, cross-country skiing injuries included all body parts reported for alpine skiing.

5. Although cross-country skiing differs from alpine skiing in several regards, the research investigated in this study indicates that cross-country skiing injuries have similar characteristics to those reported in alpine skiing, for example: rates of injury and location of injuries. While cross-country skiing is performed at lower speeds than alpine skiing, the reported injuries are often less severe.

6. Research needs to be conducted on the mechanisms of injury in cross-country skiing. A biomechanical analysis of the segmental movements that result in the loading of vulnerable joints and limbs should be completed. Recommendations for modifications to training, racing and equipment design should be a result of this research.

7. Finally, there needs to be a gender and skill-level specific analysis completed.

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