UNIVERSITY OF CALGARY

Risk Factors for Groin and Abdominal Strain Injury in the National Hockey League

by

Carolyn A. Emery

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ABSTRACT

Objective: To determine the level of off-season sport specific activity, peak isometric adductor torque and hip abduction flexibility that are predictive of groin or abdominal strain injury in the National Hockey League in the 1998 training camp period of play.

Setting: The National Hockey League (NHL).

Participants: The NHL participants were 1292 consenting players who attended one of 23 NHL training camps in September 1998.

Main Outcome Measures: The injury definition for groin or abdominal strain injury included any injury recorded in training camp as a muscle strain injury involving a muscle in any of the abdominal, hip flexor or hip adductor muscle groups. Estimated relative risks of injury are reported based on stratified analysis using the following exposures; 1. Level of sport specific training in the off-season. 2. Peak isometric adductor torque. 3. Total hip abduction flexibility. 4. Previous injury. 5. Years NHL experience. 6. Skate blade hollow measurement. Estimates of probability of groin or abdominal strain injury are predicted for various levels of exposures based on logistic regression analysis.

Results: Based on a stratified analysis, those players who reported less than 18 sessions (6 weeks/ 3 times per week) sport specific training in the off-season were at greater than three times the risk of groin or abdominal strain injury than those players reporting at least 18 sessions. Those players who reported previous history of groin or abdominal strain injury were at greater than two times the risk of injury than those with no previous history. Veterans were at six times the risk of injury than were rookies. Peak isometric adductor torque, total abduction flexibility and skate blade hollow measurement were not predictive of groin or abdominal strain injury in training camp. The predicted probability of injury was greatest for veterans with a previous history of injury, who did no off-season sport specific training. There is evidence of a dose response gradient as predicted probability of injury decreases with increasing levels of sport specific training.

Conclusions: Low levels of off-season sport specific training and previous injury are clearly risks for groin and abdominal strain injury at an elite level of hockey. The group of players who would potentially benefit most from increasing their level of off-season sport specific training are NHL veterans. This study likely has implications for prevention of groin and abdominal strain injury in hockey at all levels. Future research is required to investigate prevention strategies for groin and abdominal strain injury in hockey.

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I would like to acknowledge that funding for this project was received from the National Hockey League.

DEDICATION

I would like to dedicate this thesis to my parents, Jim and Peggy Stitt, who taught me to pursue my dreams but never lose site of what is truly important. As such, I also dedicate this thesis to my family; Herb, Charlie and Jamie. Without them, my work would have no meaning.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE : INTRODUCTION

1.1 Study Purpose

The purpose of this study is to examine risk factors associated with groin and abdominal strain injury in hockey; specifically, to determine if levels of off-season sport specific training, isometric adductor peak strength, and hip abduction flexibility are predictive of groin and abdominal strain injury in hockey. Ultimately, the goal of this study is to determine if it is advisable to proceed to a clinical trial to examine prevention strategies for groin and abdominal strain injury in hockey.

1.2 Study Rationale

There is a significant incidence of groin and abdominal strain injury in hockey at the elite level as demonstrated by data from the National Hockey League (NHL) over the previous 6 seasons of play (see Chapter 2) and other relevant literature (6,22,35,40,45). The incidence of groin and abdominal strain injury has increased yearly in the NHL over the past 6 seasons of play (see Chapter 2). There is also a significant incidence of muscle strain injury (non-specific) reported at a recreational level of hockey (59). There has been no research in the literature which focuses directly on intrinsic risk factors (ie. muscle strength, flexibility, and level of off-season sport-specific training) for groin and abdominal strain injury in hockey. It is these factors which may be modifiable with pre-season training intervention to potentially prevent groin and abdominal strain injury in hockey. There is, however, basic science evidence in the literature demonstrating that muscle strain injury is likely to occur during a strong eccentric contraction in a stretched muscle (20,55). There is also epidemiological evidence to support decreased muscle strength as a risk factor for hamstring muscle strain injury in track and Australian rules football athletes (11,13,23,25,38,61,62). Liemohn (29) provides epidemiological evidence demonstrating an association between decreased hamstring flexibility and hamstring strain injury in track athletes. There are animal studies to support the theories that both muscle fatiguability and previous injury are also associated with muscle strain injury (30,49,57).

The focus of this study is to examine intrinsic and potentially modifiable risk factors (muscle strength, flexibility, and level of off-season sport specific training) associated with groin and abdominal strain injury in hockey.

Ideally, a pre-season assessment of peak eccentric muscle strength and endurance is necessary to establish muscle group specific strength and endurance as potential predictors of groin and abdominal strain injury in hockey. Emery et al. (16) have established excellent reliability (ICC= 0.85) of peak eccentric adductor strength measured on a Cybex Norm™ isokinetic dynamometer. This testing protocol however, resulted in significant post-test muscle soreness. As a result, this testing protocol was not deemed appropriate for testing in the elite hockey population, prior to an intensive training camp period. As a result, another method to measure strength was developed for use in this study. We have established excellent reliability (ICC=0.95) of peak isometric hip adductor torque as measured using an adapted Nicholas Manual Muscle Tester (see Chapter 4). In addition, there was no evidence of post-test muscle soreness associated with the peak isometric adductor torque measurement using the adapted Nicholas Manual Muscle

Tester. As such, peak isometric adductor torque was chosen to be assessed as a potential predictor of groin and abdominal strain injury in this study.

Flexibility was measured by total hip abduction range of motion as reliability tested by Balmer and Brosseau (4) using a validated Universal Goniometer.

The rationale for assessing levels of off-season sport specific activity is to determine the impact of specificity of off-season training as a potential predictor of groin and abdominal strain injury in hockey. It is well documented that specific muscle strength training will lead to increases in muscle specific strength (50,53). There are very few sporting activities, other than skating, which address specifically the eccentric activity of the hip adductor and flexor muscle groups, particularly towards the end of range of movement where muscle strain injury is likely to occur. Information collected through interviews with National Hockey League (NHL) professional staff (coaches, players, physicians, team therapists, strength and conditioning coaches) resulted in the following anecdotal evidence. In off-season strength training programs recommended to players in the NHL, the groin muscle groups are not always specifically addressed. When they are addressed, it is not always in a sport-specific eccentric fashion. In addition, some players in the NHL do not train on-ice in the off-season. Some players do participate in power skating camps, regular organized hockey games, acceleration programs (skate training on an off-ice treadmill), slider board training and in-line skating. If level of off-season sport specific training is predictive of groin injury in hockey, there will be significant implications for further research to assess training interventions off-season to prevent injury. As the incidence of muscle strain injury in recreational hockey is also significant

(59), this study also has implications for players at a recreational level of play.

1.3 Specific Research Questions and Hypotheses

The purpose of this study is to determine the level of off-season sport specific activity, peak isometric adductor strength and hip abduction flexibility that are predictive of groin or abdominal strain injury in the National Hockey League in the 1998 training camp period of play. There are three a-priori hypotheses: 1. The first is that players with less than 6 weeks of on-ice or other sport specific training in the off-season preceding training camp (minimum of three sessions per week) will be at greater risk for groin strain injury during the 1998 training camp period. 2. The second is that players with peak isometric strength measuring more than one standard deviation below the mean, will be at greater risk of groin strain injury in the 1998 training camp period. 3. The third is that players with hip abduction range of motion measuring more than one standard deviation below the mean, will be at greater risk of groin strain injury in the 1998 training camp period.

Secondary exploratory analysis using logistic regression models will be done to determine the level at which off-season sport-specific training, abduction flexibility, and peak isometric strength become significant risk factors for groin strain injury in hockey. Logistic regression analysis will also be used to determine if increasing levels of off-season sport specific activity and decreasing levels of peak isometric adductor strength and total hip abduction flexibility will reduce the risk of groin strain injury in hockey.

Other potential risk factors such as skate blade hollow measurement, previous injury, age, and level of NHL experience will be controlled for in the analysis of predictors of groin strain injury.

1.4 Summary of Thesis Format

This thesis is organized in such a fashion that the background studies and review of the literature are presented in four separate manuscripts (Chapters 2 through 5) prior to the Methods, Results, Discussion, and Conclusions sections of the thesis (Chapters 6 through 9). The background chapters will include a review of groin and abdominal strain injury in the NHL through a case series study (Chapter 2), a critical appraisal of the literature addressing risk factors for muscle strain injury in sport (Chapter 3), a test-retest reliability study using the adapted Nicholas Manual Muscle Tester for measurement of peak isometric adductor torque (Chapter 4), and development, validation and reliability testing of an off-season sport specific training questionnaire (Chapter 5).

CHAPTER TWO: GROIN AND ABDOMINAL STRAIN INJURY IN THE NATIONAL HOCKEY LEAGUE (1991-1997): A RETROSPECTIVE CASE SERIES

2.1 Structured Abstract

Objective: To analyze groin and abdominal strain injuries retrospectively among elite male hockey players in the National Hockey League (NHL) over 6 seasons of play (1991/92-1996/97).

Design: Retrospective case series design.

Setting: The National Hockey League.

Participants: The NHL participants were an inclusive sample 7050 NHL hockey players who played in the NHL from 1991/92 to 1996/97 seasons. A subset of 2600 NHL hockey players who played from 1995/96 to 1996/97 seasons were further analyzed.

Main Outcome Measures: The injury definition for groin/abdominal strain injury included any injury recorded as a muscle strain injury involving a muscle in any of the abdominal, hip flexor or hip adductor muscle groups. Abdominal and inguinal hernias were also included. Cumulative incidence rates over 6 seasons of play in the NHL and incidence densities over 2 seasons of play in the NHL are reported. Specific injury parameters examined included muscle region, time in season, type of session, re-injury, time period in session, position of play, player's experience, mechanism of injury, and time loss.

Results: A total of 617 groin/abdominal strain injuries were reported in the NHL over 6 seasons of play. The cumulative incidence rate in the NHL increased over 6 years of play from 12.99 injuries/100 players/year in the 1991/92 season to 19.87 injuries/100 players/year in the 1996/97 season. The rate of increase (95% CI) was 1.32 (-0.58,3.21) injuries/100 players/year. The incidence density of groin/abdominal injury during NHL training camp was 5 times the incidence during regular season and 20 times the incidence during post season. The incidence density in the NHL during games was 6 times that during practice. The majority of injuries reported were adductor groin muscle strains. The proportion of injuries reported which were recurrent was 23.5%. The mechanism of injury recorded was non-contact in nature in over 90% of injuries reported. Mean time loss due to injury was significantly greater for abdominal injuries (10.59 sessions) than for groin injuries (6.59 sessions). A conservative estimate of the impact of groin/abdominal injury on each NHL team is a game loss of 25 player games per year.

Conclusions: The impact of groin and abdominal strain injury at an elite level of play in hockey is significant and increasing. Future research in this area is needed to identify risk factors and potentially implement prevention strategies to reduce groin and abdominal strain injury at all levels of play.

Key words: Hockey, injury, groin, abdominal, risk factors, epidemiology.

2.2 Introduction

Groin injury is clearly a significant problem in hockey at the elite level of play. Review of the literature reveals significant incidences of groin injury between 6 and 15 injuries/100 players/year in elite hockey league play (6,22,35,40,45). Voaklander et al (59) examined the incidence of injury in recreational and old-timer (over age 30) ice hockey players. In this sample, 35% of the players sustained injury in both groups. Of these injuries, 35% were sprain/strain injuries in the recreational group and 47% in the old-timer group. Though there was no specific information on groin strains in this study, we can speculate that muscle strain injury continues to be a concern at a recreational level of hockey as well as the elite level.

Soft-tissue injury is the most common cause of groin pain in athletes (17,45,64). The most common are muscle-tendon injuries involving adductor longus, rectus femoris, rectus abdominus and ileopsoas (17,45,64). Injury to the adductor longus most frequently occur at the proximal musculotendinous junction. Tidball et al (58) demonstrated that experimental strain caused failure most commonly at or near the proximal musculotendinous junction. Injury, however, could also occur within the tendon or at the tendon-bone junction (17). Muscle strain injuries occur when a muscle is either stretched passively or a contraction occurs as a muscle lengthens (eccentric contraction) resulting in disruption of the muscle-tendon unit (20,55) and resultant blood vessel rupture and bleeding (17). This may occur in a groin or abdominal muscle in ice hockey during a quick acceleration or change of direction.

There is epidemiological evidence to support decreased muscle strength as a risk factor for muscle strain injury in sport (11,13,23,25,38,62,63). Groin and abdominal strain injuries are of particular interest in hockey as they are one of the few types of injuries that clinicians speculate may occur independent of contact in the game of hockey. This is supported by unpublished varsity level hockey injury data (15) in which 91.4% of the groin/abdominal strain injuries reported over 3 years of Canada West University Athletic Association (CWUAA) play occurred without direct contact with another player, equipment or the boards. As such, one can study potential intrinsic risk factors (ie. muscle strength, flexibility, and level of sport-specific training off-season) more clearly than for those injuries more frequently occurring as a result of contact. There has been no research in the literature which focuses directly on intrinsic risk factors affecting groin injury in hockey. It is these factors which may be modifiable with pre-season training intervention to potentially prevent groin injury in hockey.

The purpose of analyzing groin and abdominal strain injuries retrospectively among elite male hockey players is to clearly define the problem by determining the incidence of groin/abdominal injury and associated factors, prior to developing a study to investigate risk factors for injury. The future goal is to establish prevention strategies based on associated risk factors for groin/abdominal injury in hockey.

There is evidence from the Canadian Fitness and Lifestyle Research Institute (12) and the Alberta General Recreation Survey (43) that hockey is clearly a sport with high participation rates in Canada for all age groups. There is an increasing trend of participation for both males and females in Canada. Prevention strategies for injury in hockey will ultimately benefit not only elite hockey players but also men, women and children at all levels of play.

2.3 Methods

2.3.1 Design

A retrospective case series design is used to determine the incidence of groin and abdominal strain injury and associated factors in the National Hockey League (NHL).

2.3.2 Participants

The NHL participants were an inclusive sample of 7050 NHL hockey players who played in the NHL (including players attending training camp only) from 1991/92 to 1996/97 seasons. A subset of 2600 NHL hockey players who played from 1995/96 to 1996/97 seasons (including players attending training camp only) were further analyzed.

2.3.3 Procedures

The data analysis which will be reported on groin strain injuries in the NHL comes from data collected through the National Hockey League Injury Surveillance System (NHLISS) (42). The injury data has been collected by each NHL team athletic trainer and recorded directly on computer through the NHLISS. Incidence data will be reported for the 6 previous NHL seasons, 1991/92 through to 1996/97. Complete data analysis will include injury data for the last two seasons only (1995/96 and 1996/97). These two seasons were chosen because the 1994/95 season was considerably shortened due to an NHL/NHL Players' Association work stoppage. In addition, it was felt that the reporting details of the NHLISS would be similar in the two most recent seasons of play. The total yearly NHL roster was included in calculations; therefore a participant would be included more than once if they played more than one season in the NHL.

For the purpose of this data analysis it would be appropriate to define some terms and variables of interest:

Groin strain injury - any injury recorded as a muscle strain injury involving a muscle in any of the hip flexor or hip adductor muscle groups. Inguinal hernias were also included in this group. A direct blow to a muscle resulting in a muscle contusion was not considered to be a muscle strain injury as the mechanism of injury differs significantly. An injury was reportable if a player was removed from the current practice or game or the player missed the next day's session.

Abdominal strain injury - any injury recorded as a muscle strain injury involving a muscle in the abdominal muscle group. Abdominal hernias were also included in this group. A direct blow to a muscle resulting in a muscle contusion was not considered to be a muscle strain injury. An injury was reportable if a player was removed from the current practice or game or the player missed the next day's session.

Cumulative Incidence Rate - the number of injuries per 100 players per year.

Incidence Density - the number of injuries per 1000 athlete exposures per defined period of play.

Athlete Exposure - a measure of the opportunity for an injury to occur (1 athlete exposure = 1 game or 1 practice).

NHL Training camp - pre-season play including practice sessions and exhibition games up until but excluding the first regular season game (generally early September until early October).

NHL Regular season - includes all practice sessions and regular season games (generally early October until mid April).

NHL Post-season - includes all play-off games up to and including Stanley Cup Final (generally mid April until the beginning of June).

Contact/No contact injuries - in the NHLISS the trainer has the opportunity of coding a reported injury to be a result of direct contact with another player, the boards, and/or equipment or not the result of direct contact.

Mechanism of Injury - in the NHLISS the trainer has the opportunity of recording the primary mechanism of injury to be direct impact, indirect force, torsion, stretch, impingement, overuse, shearing, spontaneous, or insidious onset. Impingement and shearing were not recorded as the mechanism of injury in any groin strain injury reported. For the purpose of this data analysis, mechanisms including direct impact and indirect force were considered contact injuries and mechanisms including torsion, stretch, overuse, spontaneous, and insidious were considered non-contact injuries.

Sessions missed - recorded number of games and/or practices missed due to reported injury (could record 0 sessions missed).

2.4 Results

A total of 617 groin/abdominal injuries were reported over 6 NHL seasons of play (1991/92-1996/97). Cumulative Incidence Rates were calculated over these 6 seasons of play. The cumulative incidence rate has increased, over the past 6 seasons of play, from 12.99 injuries/100 players/year in 1991 to 19.87 injuries/100 players/year in 1996 (Figure 2.1). The increasing trend from season to season does not hold for the 1994/95 season likely due to the significantly shortened season as a result of the NHL/NHL Players' Association work stoppage. A simple linear regression was done with year as the independent variable and cumulative incidence rate as the dependent variable (ignoring the 1994 season due to the shortened season of play). This revealed an increase in cumulative incidence rate (95% CI) per year of 1.32 (-0.58,3.21) injuries/100 players/year. Based on the point estimate, this demonstrates an increasing trend. The increasing trend is greater from 1993 to 1996 seasons, based on the point estimate, which revealed an increase in cumulative incidence rate per year of 2.57 (-10.79,15.94) injuries/100 players/year. In terms of number of groin/abdominal injuries reported each season, this represents an increase of 16 injuries in the NHL per year.

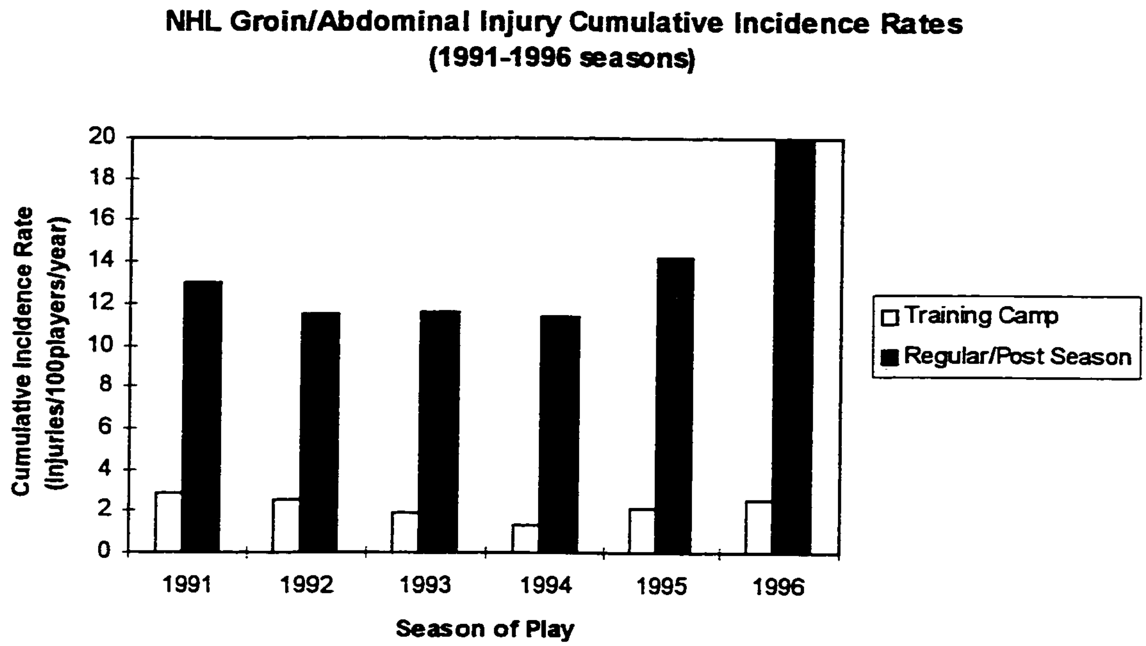

Figure 2.1: Cumulative Incidence Rate for Groin Injury in the NHL over 6 seasons of play (1994 season shortened due to NHL players Association work stoppage)

Incidence densities for groin/abdominal strain injury were examined over 2 seasons of NHL play (1995/96 and 1996/97 seasons). A total of 272 groin injuries were reported over these two seasons of play. Incidence density has clearly increased from the 1995/96 to the 1996/97 season (Table 2.1). A two sample test of proportions was used to examine this difference in incidence density between the 1995/96 and 1996/97 seasons. The change was found to be statistically significant (p=0.0058).

Table 2.1: Incidence Density Rates in the NHL:

Season of play	Total number of injuries	Total number of Athlete Exposures (AE)	Incidence density (#injuries/1000AE/ year) (95%CI)
1995-1996	117	144,884	0.8075 (.6679, 0.9677)
1996-1997	155	137,129	1.1303 (.9595, 1.3228)
Total	272	282,013	0.9645 (.8533, 1.0681)

Groin muscle strain injuries (95% CI) accounted for 76.84% (71.36,81.72) and abdominal muscle strain injuries accounted for 23.16% (18.28,28.64) of the total groin/abdominal muscle strain injuries in the NHL in the combined 1995 and 1996 seasons. Adductor strain injuries specifically accounted for 68.3% (65.1,71.3) of all groin/abdominal injuries reported over 2 seasons of NHL play.

Incidence density was calculated for training camp, regular and post-season (Figure 2.2). The incidence density for groin/abdominal injury is clearly significantly greater during training camp than the remainder of the season. The incidence density in training camp was 5 times that in the regular season and 20 times that in the post season. In addition, the incidence density for groin injury during games was 6 times that during practice (Figure 2.3).

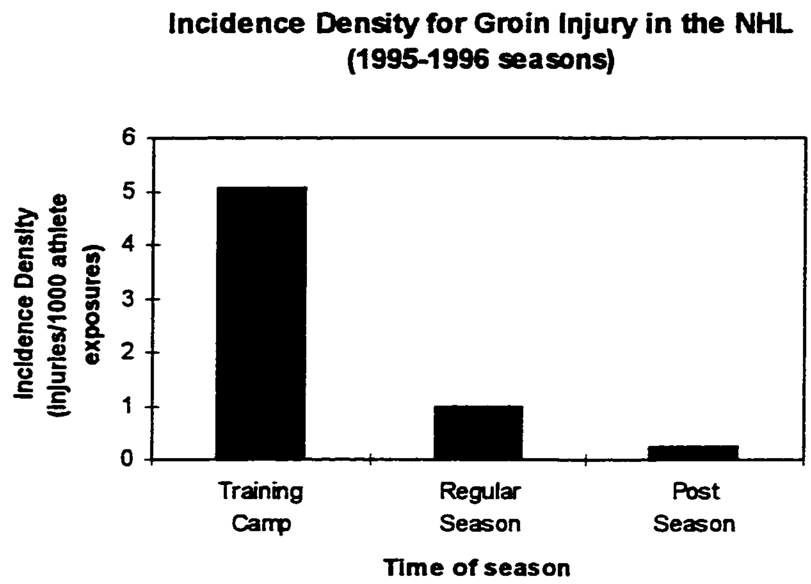

Figure 2.2: Incidence Density for Groin Injury in the NHL by time in the season (combined 1995 -1996 seasons)

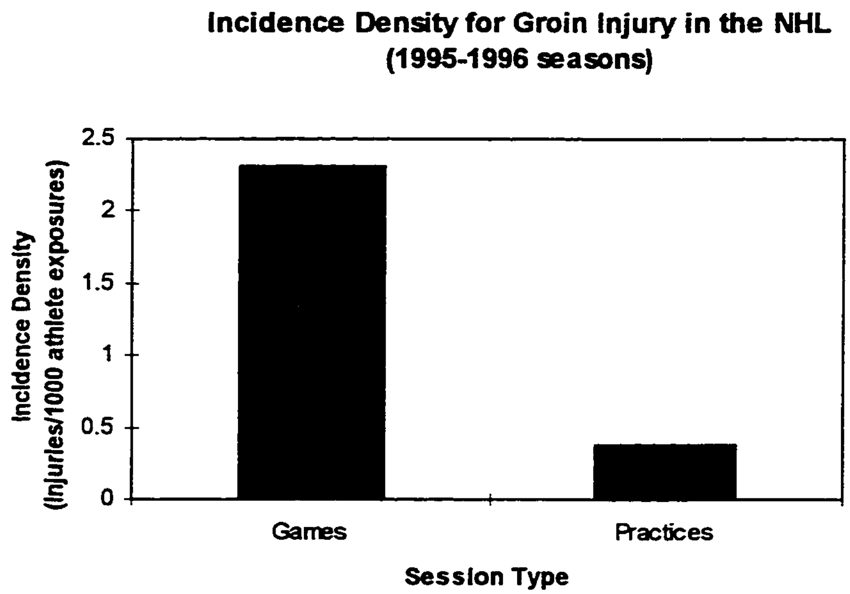

Figure 2.3: Incidence Density for Groin Injury in the NHL by session type (combined 1995 -1996 seasons)

Of all the groin/abdominal strain injuries occurring in the 1995/96 and 1996/97 seasons, 23.52% (18.62, 29.03) were reported as re-injuries. To further categorize into re-injury in the same season and re-injury from the previous season, 13.24% (9.45, 17.85) were re-injuries with the same diagnosis in the same season and 10.29% (6.95, 14.53) were re-injuries of the same muscle group injured in the previous season.

When we examined the proportion of injuries occurring during different time periods within a session, there was no significant difference in the proportion of injuries occurring during the 3 periods in a game session or the 4 quarters of a practice session.

Investigation of injury by position reveals that 60.6% (55.1, 66.0) of the groin/abdominal strain injuries occurred in offensive players, 28.9% (24.1, 34.2) in defensive players and 5.5 % (3.3, 8.6) in goalies. Position was not recorded in 4.9% (2.8, 7.9) of the injuries reported. In assessing adductor strain injuries alone, the proportion of injuries incurred by offensive players was 55% (46.9, 62.5). This is not significantly different from the proportion of all groin injuries incurred by offensive players. Given the distribution of player position on each team, one would expect 50% of the injuries to be incurred by offensive players by chance alone.

In attempting to determine what proportion of groin injuries occurred as a result of direct contact we can examine two reporting fields in the NHLISS. Firstly, we looked at the contact/no contact field and find that 34.56% (28.91, 40.54) of the injuries reportedly occurred with contact, 30.88% (25.44, 36.74) with no contact, and 34.56% (28.91, 40.54) with unknown contact status (either recorded unknown or no entry made in this field). If, however, we examine the mechanism of injury field, 91.18% (87.16, 94.26) of these injuries are recorded as secondary to the following mechanisms; torsion, stretch, overuse, spontaneous or insidious onset (implying no contact) and the remaining 8.82 % (5.74, 12.84) are recorded as direct impact, indirect force, or unknown.

The mean number of sessions lost in the NHL due to groin/abdominal strain injury was 14.46 (11.69, 17.23). However, as this is a right skewed distribution the median is a more appropriate parameter to describe central tendency. The median time loss due to groin injury was 7 sessions. The minimum was 0 sessions lost and the maximum was 180 sessions lost. As time loss due to injury was a skewed distribution, a natural log transformation was done to achieve a more normal distribution of the data and to calculate arithmetic means and 95% CI's by back-transforming. We calculate a more meaningful arithmetic mean session loss of 7.32 (6.35,8.43), similar to the median. If we group by muscle group injured, the arithmetic mean time loss for groin strains was 6.59 (5.65, 7.68) sessions and for abdominal strains was 10.59 (7.67,14.82) sessions.

Another useful interpretation of time loss due to groin/abdominal injury can be made from a survival analysis technique using a Kaplan Meier Survival Function (Figure 2.4). From the NHL data we can conclude that 25% of the injured players returned to play after 3 sessions lost, 50% after 6 sessions lost, 75% after 13 sessions lost, 90% after 33 sessions lost and 95% after 47 sessions lost and 100% after 180 sessions lost.

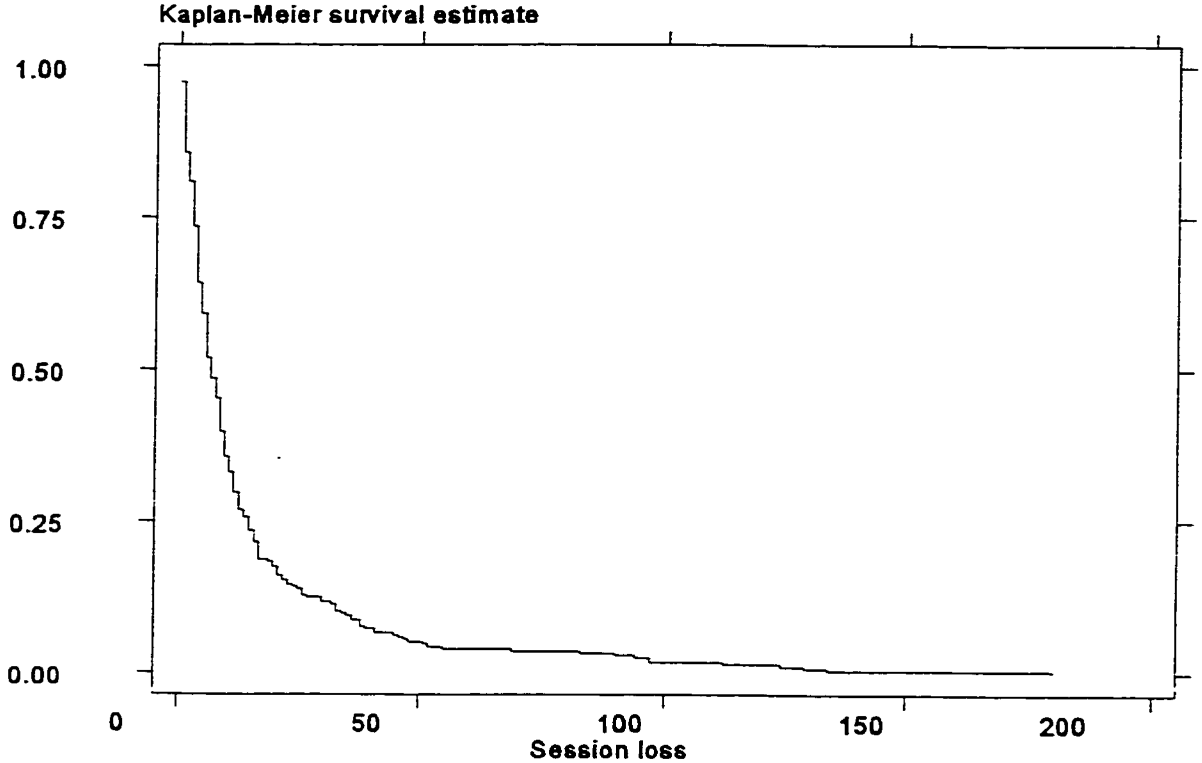

Figure 2.4: Kaplan Meier Survival Function representing sessions lost due to injury

2.5 Discussion

Studies examining the incidence of groin injury in hockey are relatively few. Overall, our study has demonstrated a cumulative incidence rate of groin/abdominal injury in the NHL over 6 seasons of play similar to that found at the varsity level of play in the CWUAA (15) and in other relevant studies (6,22,35,40,45). However, the cumulative incidence rate in the most recent 1996/97 NHL season was significantly greater than those reported in other studies. There also appears to be some indication of an increasing trend of cumulative incidence rates over 6 years of NHL play, however, due to the small number of seasons reported, the power of the simple linear regression is low and confidence intervals are wide. Incidence density, however, has not been examined for groin injury in any of these relevant studies.

Adductor muscle strains were the most frequently occurring groin/abdominal muscle strain injury in the NHL. This is consistent with the findings in the CWUAA (15) and other relevant literature (17,45,56). This consistency may be related to the mechanics of the sport of ice hockey. In a quick deceleration or acceleration or change of direction during a skating motion, the adductors are often under considerable tension during a strong contraction. It is also this muscle group which works, often eccentrically, in a sport specific fashion during hockey play and may not be addressed in non-sport-specific off-season training.

Of particular interest is that the incidence density during training camp in the NHL was 5 times that during regular season and 20 times that during post season. This finding is consistent with that found in the CWUAA (15) where 75% of the groin injuries occurred in the first half of the season. This may exist because the players are in better physical condition (strength/flexibility/endurance) toward mid season, with respect to these sport specific muscle groups. In addition, during pre-season play, sessions are more frequent and players are being continually assessed by coaching staff and hence fatigue may be a significant factor resulting in increased muscle strain injuries. Also, entering training camp, players are often changing from impact training to on-ice intense training sessions.

The increased incidence density of groin/abdominal injury in the NHL during a game situation (5 times that in practice sessions) is not surprising given the increased speed and intensity of play in a game situation.

In addressing re-injury rates, we found that almost one quarter of all groin/abdominal injuries reported in the NHL were recurrent injuries. In the CWUAA (15), 47% of injuries were reported as re-injury (from that season or a previous season). This is consistent with animal studies in the literature which demonstrated that following minor strain to a muscle, the load required to complete rupture and the stretch at complete rupture were significantly reduced (20,57).

It was interesting that there was no significant difference in groin/abdominal strain injury rates between time periods in game or practice sessions in the NHL. One might regard this as evidence against the theory demonstrated in an animal study by Mair et al (30), that fatigued muscle is less able to absorb energy and a reduction in force was required to produce muscle strain. However, it must be considered that at an elite level of play, a player may withhold reporting a minor groin strain injury until the end of a session due to the potential importance of playing through a game or practice. An elite player is continually being reassessed by coaching staff for potential player trades and increased ice time.

A majority of the groin/abdominal injuries reported in the NHL were incurred by offensive players. This is consistent with the findings in the CWUAA (15). It appears, however, that offensive players were not more frequently injured than would be expected by chance alone, assuming that 50% of the players are offensive players.

In analyzing mechanism of injury there was some discrepancy in our findings based on the NHLISS reporting field assessed. The contact/no contact field was incomplete or unknown in over 1/3 of the injuries reported and of the injuries for which this field was complete there was no significant difference between the proportion of injuries reported as secondary to contact and secondary to no contact. The mechanism of injury field, which was completed in 99% of injury reports, demonstrated that only 8% of injuries recorded were as a result of direct impact or indirect force. This is consistent with the findings in the CWUAA (15) where 91% of groin injuries reported occurred independent of contact. In a sport in which the majority of injuries occur as a result of contact, it is very interesting to note that the majority of these injuries are non-contact in nature. Stuart and Smith (56) report 79% of all injuries over a 3 year period on a US Junior A team occurred secondary to contact with another player, boards, puck or other equipment. To compare with a study which described the injuries over a one year period in 21 Canadian college and universities and 9 US colleges, Hayes (22) reports 66% of total injuries occur secondary to contact (other players, puck and boards). This information is important from the perspective of investigating intrinsic risk factors for groin strain injuries by providing a unique opportunity in hockey to investigate an injury that occurs most often without associated contact.

Time loss due to groin/abdominal strain injury is significant. Only 25% of players who sustain these injuries miss 3 sessions or less following an injury. Mean session loss for players sustaining abdominal strains is also significantly greater than those sustaining groin strain injuries. This implies a relatively increased severity factor for abdominal versus groin strain injuries. It is possible that surgery is more prevalent in abdominal strain injuries. The role of surgery and rehabilitation warrants investigation in future. The impact of time loss following groin and abdominal strain injury in the NHL is clinically significant. Not only does it impact significantly on an NHL player's career but it also has a significant impact on the league. A conservative estimate of the impact on each of 26 NHL teams (1995/96 and 1996/97 seasons) is a game loss of 25 player games/team/year. In addition, groin and abdominal strain injury also has potential implications regarding health care costs (physician visits, physiotherapy, and surgical costs).

Limitations of this study include the inability to determine individual exposure status through the NHLISS. Exposure status for the purpose of incidence density calculations was estimated based on the average number of players participating in any given game or practice. This does not take into consideration movement of players in the NHL between teams and leagues throughout the season. In addition, not all players will have the same exposure status due to injuries and sitting out of games and/or practices. This limitation would likely result in an underestimation of incidence densities due to an overestimation of player exposure. In addition, many players at these elite levels of play may fail to report an injury as they may feel it will affect their ice time and future hockey career. This would result in an underestimation of incidence of injury.

In addition, there was potentially a heightened awareness of groin/abdominal strain injury by NHL trainers which may have contributed to some of the increase in reported injury over the last two seasons of play. The decreased awareness in earlier seasons may have lead to an underestimation of groin/abdominal injury in the earlier seasons reported. Other limitations of the NHLISS are that formal testing of it's validityt and reliability have not been completed.

2.6 Conclusions

This study demonstrates a significant and potentially increasing incidence of groin/abdominal strain injury in hockey at an elite level of play. The impact on both the players and the league are significant due to time loss and potential for re-injury. The high incidence density of groin/abdominal strain injury early in the season has significant implications for further investigation of risk factors such as off-season sport specific training. The high proportion of groin/abdominal strain injuries occurring without direct contact of another player, equipment or the boards also has important implications for assessment of intrinsic risk factors such as strength, flexibility and off-season sport specific training.

Future study investigating potential risk factors for groin and abdominal strain injury in hockey will be the next step toward prevention of these injuries both at the elite and recreational level of play. Specifically, an observational prospective cohort study could be done to investigate potential risk factors for groin/abdominal strain injury in hockey. Ultimately, a clinical trial following this type of observational study may help to determine prevention strategies for groin/abdominal strain injury in hockey at both the elite and recreational level of play.

CHAPTER THREE: RISK FACTORS FOR MUSCLE STRAIN INJURY IN SPORT. DOES DECREASED MUSCLE STRENGTH CAUSE ACUTE MUSCLE STRAIN INJURY IN SPORT? A REVIEW OF THE EVIDENCE.

3.1 Structured Abstract

Objective: To determine if decreased muscle strength is a cause of acute muscle strain injury in sport, by critical appraisal of the literature.

Data sources: A computerized MEDLINE search was the initial search conducted to identify the maximum number of articles published from 1966 to 1997. A combination of Medical Subject Headings (MeSH) and text words (tw) were used in this search. Medical subject headings included; "sprains & strains", "risk factors", "physical fitness", "muscle, skeletal". Text words used included; "muscle strain" and "strength". No limitations were put on articles searched under these Medical Subject Headings or text words. Similar strategies were used to search SPORT DISCUS, a CDROM data base which includes references to many Sport Science journals (1980-1997) and CARL UNCOVER (1997-1998).

Study selection: Ten observational epidemiological studies met the inclusion criteria: human population, outcome measure included some measure of acute muscle strain injury, exposure measure included some objective measurement of muscle strength and/or an intervention including a specific strengthening program, study design included an attempt to create a comparison group, and original data studies only.

Data extraction: The data extracted from each of these 10 studies included; a definition of the study design, a description of the study population, a description of the exposure(s) of interest measured, a description of the outcome measure, and conclusions. Each study was assessed for the quality of it's evidence. Appropriate measures of association (relative risk for cohort data and odds ratio for case-control data) and population impact (attributable risk percent or preventive fraction) were calculated where data were appropriate. Sensitivity, specificity, positive and negative predictive values were calculated where predictive tests for injury were constructed.

Data synthesis: Most studies reported some association between decreased muscle strength and acute hamstring strain injury in sport. Most studies had limitations regarding internal validity. All studies had limitations precluding generalizability to a wider athlete population.

Conclusions: Despite an apparent association between decreased muscle strength and specific hamstring strain injury in elite male athletes in sport, the evidence for decreased muscle strength as a risk factor for or cause of muscle strain injury in sport is inconclusive. Further research is required to confirm this relationship.

Keywords: muscle (skeletal), sprains & strains, risk factors, strength

3.2 Introduction

Acute muscle strain injury is frequently cited as the most frequently occurring injury in sport (20). It is characterized by a disruption of the muscle-tendon unit (20). Many clinicians would agree that muscle strain injuries occur when a muscle is either stretched passively or a contraction occurs during a stretch (20). The latter is an eccentric contraction. An eccentric muscle contraction involves lengthening of the muscle fibers where the origin and insertion of the muscle separate. This is an important factor because muscle forces can be greater during lengthening (55). Acute muscle strain injuries are characterized clinically by a sudden onset of localized pain and varying degrees of muscle weakness of the specific muscle injured and decreased function (20,37). These injuries often recur and can become chronic (20). Although acute muscle strain injury is one of the most common injuries seen in sport, there is relatively little known about prevention of this injury. The cause of acute muscle strain injury in sport has been attributed to: improper warm-up, poor flexibility, overuse, muscle weakness, muscle imbalance, and fatigue by many authors (61). Most of the evidence to support these potential causal factors, however, appears to be based on animal studies and anecdotal evidence.

In animal studies, Safran et al (49) demonstrated that increased temperature in a muscle following a warm-up activity led to a muscle capable of increased force production and increased stretch was required before failure. Garrett (20) demonstrated that repeated cyclic stretch to a muscle (to 50% of failure force) resulted in increased muscle stretch at failure. Garrett (20) and Taylor et al (57) demonstrated that following minor strain to a muscle the load required to complete rupture and the stretch at complete rupture were significantly reduced. Mair et al (30) demonstrated that fatigued muscle is less able to absorb energy and a reduction in force was required to produce muscle strain.

Supporting epidemiologic evidence to assess potential intrinsic risk factors for acute muscle strain injury in sport needs to be reviewed in order to determine potential causal associations between risk factor and injury. A critical appraisal of the literature to investigate specifically decreased muscle strength as a risk factor for acute muscle strain injury in sport has not been done. It was felt that critical appraisal of relevant epidemiological studies would assist in identification of the need for future epidemiological research in this area.

3.3 Objective

The research question to be addressed in this critical appraisal of the literature is: Does decreased muscle strength cause acute muscle strain injury in sport? Studies that have examined an association between muscle strength and acute muscle strain injury in sport will be reviewed and assessed regarding their strength of scientific evidence.

3.4 Methods

3.4.1 Data sources

A computerized MEDLINE search was the initial search conducted to identify articles published from 1966 to 1998. A combination of Medical Subject Headings (MeSH) and text words (tw) were used in this search. Medical subject headings included; “sprains & strains”, “risk factors”, “physical fitness”, and “muscle, skeletal”. Text words used included; “muscle strain” and “strength”. No limitations were put on articles searched under these Medical Subject Headings or text words. If 500 articles or less were identified by a given search strategy, the study title and abstract were reviewed to identify potentially relevant articles to subject area. The methods section of these articles were then reviewed to identify those studies that met selection criteria for inclusion in this critical appraisal.

Other computerized searches completed to identify further relevant articles to subject area included SPORT DISCUS, a CDROM data base which includes references to many Sport Science journals (1980-1998). This search is based on key words. Key words identified included; “muscle strain”and “muscle strength”.

A final strategy was used in CARL UNCOVER, another computerized data base on-line, in an attempt to identify more recent (1997-1998) relevant articles. The strategy used was identical to that used in MEDLINE search.

3.4.2 Study Selection

A study was identified by the author as potentially relevant to the subject area based on review of the abstract. There were no limitations regarding methodological considerations. Review articles and descriptive articles were included. This was considered an important step to give the author potential background information regarding acute muscle strain injury, groin injury, relevant incidence of injury in sport, sport training strategies and prevention strategies.

Studies were included in the critical appraisal only after reviewing the methods section of the study in question. The inclusion criteria were identified as follows:

1. Human epidemiological studies attempting to assess the association between muscle strength and acute muscle strain injury in sport.

2. Outcome measure included a measure of acute muscle strain injury.

3. Exposure measure included some objective measurement of muscle strength and/or an intervention including a specific strengthening program.

4. Study design included a comparison group.

5. Original data studies only were included.

6. English language studies only.

The rationale for selecting these inclusion criteria was to review original epidemiological research addressing the relevant research question of a causal association between decreased muscle strength and acute muscle strain injury in sport. As there were limited epidemiological studies identified, all types of study design were considered. There were some descriptive case studies and review studies identified (n=59) which were based significantly on anecdotal evidence and clinical impression which were excluded. In addition, there were 3 animal studies excluded which reported experimental evidence addressing physiological risk factors for muscle strain injury (30,49,57).

3.4.3 Data extraction

The data extracted included; a description of the study design, a description of the study population, a description of the exposure(s) of interest measured, a description of the outcome measure, and results (including relevant methods of analysis). Each study was assessed for the quality of it's evidence based on criteria regarding internal validity, power, external validity, and causal association.

Internal validity of each study was assessed based on the following criteria:

1. Strength of study design.
2. Presence of selection bias.
3. Presence of information bias (measurement and misclassification). This included an appraisal of reliability and validity of measurements (exposure and outcome).
4. Control of potential confounding.

In addition, an assessment was made of external validity of each study as well as analysis of power as appropriate.

Criteria used for assessment of causal association are those summarized by Rothman (48) as a commonly used set of standards advanced by Hill in 1965. These criteria include; strength of association, consistency of results, specificity, temporality of exposure, biological gradient (dose-response), biologic plausibility, coherence with natural history and biology of disease, experimental evidence, and analogy.

3.4.4 Data synthesis

Characteristics of the studies are summarized: study design, study subjects, outcome measured, exposure measured and conclusions. An estimate of association (relative risk or odds ratio) in addition to attributable risk or preventive fraction was be calculated and presented in this review where adequate data were included in the report. These estimates were calculated using Stata statistical software package (54). The attributable risk percent (AR%) is defined by Hennekens and Buring (24) as an estimate of the proportion of disease (injury) among the exposed that could be prevented by eliminating the exposure. The preventive fraction as defined in Last (28) is the proportion of disease (injury) in the population which can be prevented by exposure to the factor. It is important to consider the predictive nature of muscle strength for acute muscle strain injury in assessing the causal association. Those studies which establish a critical point for a strength parameter to predict injury will be assessed with respect to sensitivity, specificity, positive predictive value and negative predictive value of the test for prediction of injury. The sensitivity of a test is a measure of the probability of correctly identifying a diseased person with that test (24). The specificity of a test is a measure of the probability of correctly identifying a non-diseased person with that test (24). The positive predictive value (PPV) of a test is the probability that a person with a positive test will have the disease (24). The negative predictive value (NPV) of a test is the probability that a person with a negative test will not have the disease (24).

Assessment of each study with respect to internal validity, external validity, power and causal association were summarized. Findings of each study in addition to relative strengths and weaknesses were compared and contrasted. Specific recommendations were made for future research.

3.5 Results

The findings of the MEDLINE search are described in Table 3.1. There were a total of 63 articles appraised by the author as potentially relevant to the subject matter.

However, only seven of these studies were included in the critical appraisal based on inclusion criteria. The findings of the SPORT DISCUS SEARCH are identified in Table 3.2. An additional 5 articles from this search were considered potentially relevant to the subject matter. However, only two of these studies were included in the critical appraisal based on inclusion criteria. One further article was identified in the CARL UNCOVER search. There were 5 repeats to those identified as potentially relevant to subject area in MEDLINE search above. None of these met the inclusion criteria for critical appraisal. In total, ten studies were chosen to be included in this critical appraisal.

Table 3.1: MEDLINE strategy and findings

Medical Subject Heading (MeSH) or textword (tw)	MeSH or tw defined	Number of articles identified*	Number of articles determined as potentially relevant** (n/a = not assessed > 500)	Number of articles included in critical appraisal***
MeSH 1	sprains & strains	2025	n/a	n/a
MeSH 2	risk factors	113242	n/a	n/a
MeSH 3	physical fitness	3926	n/a	n/a
MeSH 4	muscle, skeletal	57644	n/a	n/a
1 and 2		206	13	2
1 and 3		14	14	0
3 and 4		111	10	1
tw 1	muscle strain	96	23	2
tw 2	strength	5942	n/a	n/a
MeSH 1 and tw 2		52	3	2

*Number of articles identified by given strategy in MEDLINE search
** Number of articles identified by author as potentially relevant to subject area based on abstract
*** Number of articles identified, following review of methods section in article, as relevant for critical appraisal based on inclusion criteria

Table 3.2: SPORTDISCUS search strategy and findings

Key word	Key word defined	Number of articles identified*	Number of articles determined as potentially relevant**	Number of articles included in critical appraisal***
1	muscle strain	141	6	2
2	muscle strength	292	2	0

*Number of articles identified by given strategy in SPORT DISCUS search
** Number of articles identified by author as potentially relevant to subject area based on abstract
*** Number of articles identified, following review of methods section in article, as relevant for critical appraisal based on inclusion criteria

One of the fundamental difficulties in reviewing and comparing research in this area is the variability in research design and measurements used to assess exposure. In the studies reviewed, the outcome measure was always defined as "acute hamstring muscle strain injury in sport", with some variability in how this outcome was defined (5,11,13,23,25,29,38,39,62,63). All of the identified studies assessed the association between muscle strength and hamstring muscle strain. Some also assessed the association between flexibility and hamstring muscle strain (29,62). Others also assessed the implications of previous history of hamstring muscle strain injury as a risk factor for hamstring muscle strain injury (15,23,38). No other muscle groups have been identified in any of the studies in this review. A summary of research design, subjects, outcome measure, exposure measures and results for all ten studies reviewed can be found in Table 3.3.

The research designs used to address the association between muscle strength and acute hamstring muscle strain injury in sport are all observational designs. The designs used include cross-sectional (11,25,39,62), prospective case-control (5,11,29,38,63), and cohort (13,23) designs. A significant weakness shared by the cross-sectional studies (11,25,39,62) to assess this association is that measurements of muscle strength were assessed following injury. Regardless of significant associations found in two of these four studies, one cannot examine decreased strength as a risk factor for muscle strain injury ignoring the temporal association between exposure (muscle strength) and outcome (injury). Jonhagen et al's (25), Paton et al's (39) and Worrell et al's (62) study objectives were to compare strength parameters between injured and uninjured athletes following acute hamstring strain injury. Regardless of the potential strengths of their findings, these studies are not useful in assessing decreased muscle strength as a predictor or risk factor or muscle strain injury. These three studies are not considered to be appropriate for further analysis in this review. Burkett (11) uses a combination of cross-sectional and prospective case-control designs with two different study groups. This study will be included for further analysis in this review. The other study designs used, including prospective case-control and cohort, are both appropriate to assess decreased muscle strength as a potential risk factor for acute muscle strain injury. Five of these remaining studies under review, yield evidence to support the hypothesis that decreased hamstring muscle strength is a risk factor for acute hamstring muscle strain injury. Bennell et al (5) and Liemohn (29) do not support this hypothesis. It should be noted that exposure (strength) measurement strategies and athlete populations differ for each study and cannot be compared directly.

Yamamoto (63) provided descriptive statistics which demonstrated a significant decrease in mean hamstring maximal voluntary contraction per unit body weight as well as decreased mean hamstring to quadricep ratios in injured legs in track athletes. A critical point was not determined in this study to define exposure. Only mean values for the two groups are presented. A measure of association cannot be calculated based on this data and predictions of injury are not made. Burkett (11) not only demonstrated a significant increase in hamstring strength imbalance (between sides) in injured football players, but also correctly predicted 4/6 injured and 31/33 non-injured athletes based on a critical point of strength imbalance greater than 10%. He defined strength imbalance as the difference in hamstring strength between sides divided by hamstring strength on the strongest side, expressed as a percentage. In Bukett's (11) study AR% can be calculated to be 100%. A measure of association (odds ratio) cannot be calculated as there were no injuries in the non-exposed group. In addition, the sensitivity of the critical point for hamstring muscle imbalance to predict an injury is 1.0 and the specificity is 0.94. The PPV is 0.67 and the NPV is 1.0.

In Christensen et al's (13) study the critical point chosen to predict injury was based on means for hamstring to quadricep ratios in all athletes at two different knee angles for measurement. The AR% in this study is also 100%.The sensitivity of this critical point to predict injury is 1.0 and the specificity is 0.57. The PPV is 0.4 and the NPV is 1.0. The relative risk of injury in the exposed group compared to the unexposed group in this study cannot be calculated as there are no injured athletes in the unexposed group.

In Orchard et al's (38) study a significant decrease in mean peak torque hamstring strength (at 60^0/second) and hamstring/quadricep ratios was demonstrated in hamstring injured legs. In addition, a significant decrease in mean hamstring ratio (weak hamstring/strong hamstring strength) was demonstrated in injured football players. A cohort analysis based on a discriminant function analysis was used to predict hamstring injury. Last (28) defines a discriminant analysis as a statistical technique used to determine a function by which individuals from two or more discrete populations (ie. exposure groups) can be allocated to a correct population group (ie. outcome group) with minimal misclassification. The discriminant function used in Orchard et al's (38) study was based on weak to strong hamstring strength ratio and hamstring to quadricep strength ratio. The sensitivity of prediction is 0.83 and the specificity is 0.77. The PPV 0.28 and NPV 0.98 demonstrates a function which will overpredict injury (a large number of false positives will result). The calculated odds ratio in this study (based on the discriminant function to define exposure) is 16.54 (2.27, 97.42). The AR% is 93.95% (55.90, 99.0).

Heiser et al (23) demonstrated a significant decrease in hamstring muscle strain injury rates and recurrence rates between two groups of football players with significant differences in strength training, running, stretching, and rehabilitation programs. Strength measurements for each group were unfortunately not reported. The relative risk of "first time" injury (95% CI) in the group exposed to a more stringent strengthening, running and flexibility program (1978-1982) compared to the less stringent regime (1973-1977) can be calculated from data available in the study to be 0.138 (0.059, 0.324). The preventive fraction (95% CI) in Heiser's (23) study can be calculated to be 0.861 (0.676, 0.941). The relative risk of injury and preventive fraction (first time or recurrent injury) can also be calculated. The relative risk is 0.105 (0.046, 0.243). The preventive fraction is 0.895 (0.758, 0.954). The impact of the more stringent rehabilitation program had a significant impact on recurrence rate.

Both Bennell et al (5) and Liemohn (29) demonstrated no significant difference in hamstring/quadricep strength ratios between injured and non-injured players. Bennell et al (5) reported ratios based on pre-season concentric and eccentric isokinetic peak torque measurements at varying speeds using a KinCom isokinetic dynamometer. Liemohn (29) reported ratios based on maximal voluntary isometric torque measurements using a cable tensiometer.

The study subjects in all of the studies are male athletes competing at an elite level in their sport. The target population of interest in four of the studies was football players (5,11,23,38) and in four of the studies was track athletes (13,25,39). An attempt was made in all of these studies to identify a comparison group to study an association between strength and muscle strain injury. Although randomization into study groups was not done in any of these studies, five of these studies used a non-random but complete athlete population and inferences from study results can be made for the study population in question. Burkett (11) used one complete college football team reporting to training camp for the case-control portion of his study. In doing so, external validity may be in question, however, selection bias is not as all team members are included in the study and their inclusion does not depend on exposure (strength measurements). Christensen et al (13) included all members of a varsity track team. Heiser et al (23) included all members of a university football program (1973-1982). Orchard et al (38) included all players on an

Australian professional football team. Yamamato (63) included all players from the Japan intercollegiate championship track team. As in Burkett's (11) study, selection bias is not of concern as a complete "athlete population" is included. One could argue that this will lead to issues regarding external validity which will be discussed later in this review.

Measurement bias is of significant concern in many of these studies. Misclassification of outcome (injury status) is not of significant concern in Orchard et al's (38) and Bennell et al's (5) studies, as well defined clinical criteria were provided and diagnosis was made by physician blinded to exposure measurements. In Heiser et al's (23) study, injury status was based on well defined clinical criteria for diagnosis and sessions lost due to injury, however, classification of injury is dependent on an adequate and consistent injury reporting system over a 10 year period. Considering these records were likely kept by numerous athletic trainers and physicians, consistency is of concern. In the remaining studies (11,13,29,39,63) injury status and method of collection of injury status are not well defined. There is no indication of blinding to exposure status and differential misclassification may result in an overestimation of association between decreased strength and injury. This is due to the potential of being more likely to classify an athlete with a mild injury as "injured" if he demonstrated significant muscle weakness pre-season or classifying an athlete with a mild injury as "non-injured" if he demonstrated no muscle weakness pre-season.

Hennekens et al (24) refer to non-differential measurement bias resulting when inaccuracies exist in the measurement of exposure or disease status but these inaccuracies occur in similar proportions in each of the study groups. This source of bias will lead to an underestimation of study effect. This source of bias may be present in the classification of injury status in all of the studies as misdiagnosis of sudden onset posterior thigh pain may occur (ie. sciatic pain or referred pain). In addition, measurement of exposure status (strength measurements) are subject to non-differential measurement bias. Burkett (11), Christensen et al (13) and Liemohn (29) used a cable tensiometer and Yamamoto (63) a strain gauge for strength measurements, however, there is no referenced literature pertaining to validity or reliability of these instruments. Heiser et al (23) and Orchard et al (38) used a Cybex II (340) isokinetic dynamometer for strength measurements. Bennell et al (5) used a KinCom isokinetic dynamometer. The reliability and validity of Cybex II (340) and KinCom isokinetic dynamometers have been examined to investigate the accurate assessment of muscle function (27). Excellent test-retest reliability has been shown in quadracep and hamstring peak torque strength measurements (Intraclass correlation coefficient > 0.87) (21). In the studies that demonstrated a significant association between hamstring strength and injury (23,29), potential sources of non-differential measurement bias which result in underestimation of this association are not of significant concern.

One of the most critical shortcomings in many of the studies identified is the lack of control for potential confounding variables. Most studies have controlled for age, sport, and level of competition by matching techniques or by virtue of inclusion of all athletes in a particular subject population of interest. However, previous injury is likely a significant confounding variable in the relationship between strength and muscle strain injury. Though mentioned by Bennell et al (5), Heiser et al (23) and Orchard et al (38) it is not measured or controlled for in most of these studies. Based on the study by Jonhagen et al (25) which demonstrated reduced quadricep and hamstring strength (concentric and eccentric) post hamstring strain injury, previous injury may be of considerable concern as a potential confounder. Ignoring confounding from previous injury may result in an overestimate of association between decreased strength and hamstring injury. Bennell et al (5) assess previous history of injury and flexibility. They demonstrated a 2.1 times increased risk of injury in players with a past history of injury, however past history of injury was not related to muscle strength or imbalance. They demonstrated no evidence of decreased strength or flexibility related to injury. Orchard et al (38) do assess previous history, hamstring flexibility, speed and other fitness parameters and find no significant difference in these parameters between injured and non-injured athletes. In addition, they find no correlation between previous history of hamstring strain injury and strength parameters tested in this population. Liemohn (29) examined hip joint flexibility and found decreased flexibility in the injured group. Other potential confounding variables which have not been considered are improper warm-up and fatigue. None of these potential confounding variables have been considered in the other studies. In Heiser et al's (23) study where two groups with different fundamental training programs demonstrate significant differences in injury rates, these differences cannot be attributable to strengthening program alone. Athletes are not randomized to exposure groups and there are multiple other differences in training to be considered between the two groups including stretching program, running program, potentially different coaching strategies and changes in league rules (ie. penalties) over a period of 10 years.

Most of the relevant studies demonstrated a significant association between some decreased strength parameter(s), or in Heiser's (23) study decreased mandatory strength training program, and acute hamstring strain injury. Bennell at al (5) and Liemohn (29) demonstrated no association between strength and injury.

In terms of assessing a potential causal association of decreased strength for hamstring strain injury, the focus was on Bennell et al's (5) and Orchard et al's (38) studies as these are the only studies without significant concerns regarding internal validity. Orchard et al's (38) study reveals an odds ratio of 16.54 (2.27, 97.42). This demonstrates a significant association between decreased hamstring muscle strength and injury and estimates an increased risk of injury in the exposed to be at least 2.27 times the risk of injury in the non-exposed (based on Orchard et al's (38) discriminant function of prediction). In this study there is clearly a temporal association between muscle strength measurement and injury occurrence. Even though the evidence from many of the other studies in this review may be weak, there is certainly consistency between findings supporting an association between muscle weakness and hamstring muscle strain injury. There are certainly animal studies to confirm the biological plausibility of this association (30, 57). There is no data however, to provide evidence of a dose-response relationship in this study. Bennell et al (5) demonstrated no association between muscle strength and hamstring strain injury. Perhaps Bennell et al's (5) and Orchard et al's (38) cohorts, however, are not directly comparable as Orchard et al (38) used an entire elite team of Australian footballers and Bennell et al (5) a sample of senior male Australian footballers. In addition, the two studies used different testing protocols pre-season and time lag between testing pre-season and injury likely differed.

3.6 Discussion

There is evidence to support the hypothesis that decreased hamstring muscle strength is a risk factor for acute hamstring strain injury in sport. There is evidence from Orchard et al's study (38) to support this hypothesis as demonstrated by a significant increased risk of injury for football players with decreased hamstring side to side ratios and decreased hamstring to quadricep ratios. Burkett (11), Christensen et al (13) and Yamamoto (63) provide somewhat weaker evidence consistent with that found by Orchard et al (38). Though Heiser et al (23) demonstrate a significantly decreased risk of hamstring injury in a group of football players who have increased strength training regimes, there are too many other variables that may be responsible for this diminished risk of hamstring strain injury. The more significant finding in this study is the significantly decreased risk of recurrent injury in the second group. In this group, rehabilitation following injury included a specific isokinetic strengthening regime and attainment of a minimal hamstring strength deficit prior to returning to play. Both Bennell et al (5) and Liemohn (29) demonstrated no significant difference in hamstring/quadracep strength ratios between injured and non-injured players. Perhaps the differences in findings are due to examination of differing athlete populations.

Burkett (11), Christensen et al (13) and Orchard et al (38) provide exploratory cohort analysis to predict injury based on hamstring muscle strength parameters. Burkett (11) bases predictions on hamstring strength imbalance between sides, Christensen et al

(13) on hamstring to quadricep ratios and Orchard et al (38) on both. All of these measures would decrease with diminished hamstring strength on one side. All three studies provide a prediction strategy that yields a very high sensitivity (0.83, 1.0). The lower positive predictive values yielded (0.28, 0.67) indicate an overestimation of injury prediction. In injury prevention the sensitivity of a predictive test is most important as the ability to predict injury will assist trainers and coaches in developing appropriate training programs. Individual, team and health care costs of injury due to failure to address weakness pre-season likely outweigh the costs of encouraging strength training in athletes not at risk of injury.

Selection bias is not a significant concern in most of these studies as entire populations of athletes are studied in each case (ie. team). It could be of concern in Bennell et al's (5) study as subject selection was not random. Players who had not rehabilitated adequately following a previous injury or players who were not doing a strength training program in the off-season may have been less likely to volunteer. As a result, an underestimation of the association between strength and injury may have been reported. Measurement bias due to lack of reliability and validity of measuring apparatus for exposure and reporting system for outcome in many of these studies is of concern. However, these sources will bias the estimate of association toward the null. As significant differences are reported in most of these studies, this source of bias is not as significant a concern as other sources. Differential misclassification of outcome is of concern in all but Bennell et al (5), Orchard et al (38) and Heiser et al's (23) studies as examiners defining outcome status are not blinded to exposure status. This bias may result in an overestimate of association.

The most significant source of bias in all but Bennell et al (5) and Orchard et al's (38) studies is the lack of measurement and control for other potential confounding variables. Flexibility, muscle endurance, and previous injury are likely of most significant concern as there is biological evidence from animal studies that these factors may be related to acute muscle strain injury. Fatigue and inadequate warm-up activity are also potential confounding variables, but these factors are likely to be similar between athletes in the same athletic program with identical coaching strategies and training schedules.

There is no strong evidence of a causal association between decreased muscle strength and hamstring strain injury. In Orchard's (38) study, cut-points for muscle strength were not explored in an attempt to establish a dose-response relationship. In addition, there is no sound experimental evidence to assess the implications of preventative intervention in reducing acute hamstring muscle strain injury in sport

External validity or generalizability of these studies is certainly poor. It could be argued, that with the exception of Bennell et al (5) and Orchard et al's (38) studies, there are significant concerns regarding internal validity which preclude the assessment of potential external validity of these studies. The main concerns which would result in an overestimate of association are lack of control for confounding variables and differential misclassification of injury status when examiner is not blinded to the strength measurement results. In Orchard et al's (38) study the study population is an elite professional Australian football team at risk of acute hamstring strain injury. Bennell et al (5) examine both professional and amateur senior Australian footballers which may differ from a single professional elite team studied by Orchard et al (38). The hamstring injury rate in both of these populations of athletes is likely to be different than the hamstring injury rate in another football team (ie. Canadian) with different league rules and team training regime. The injury rate in football is also likely to be significantly different in entirely different athlete populations. However, one may infer from these results that if hamstring strain injury can be adequately predicted by strength measurements in the elite male athlete, then perhaps there are significant implications to be explored for prediction and prevention of hamstring injury in the female, adolescent or recreational athlete. There are potentially implications regarding other muscle groups arising from this evidence, however, these need to be assessed in future epidemiological research.

Limitations of this review include the limitations of the electronic databases utilized which do not likely cover all of the potential sources of studies of strength/training as related to acute muscle strain injury in sport. In addition, this review is clearly muscle group specific including only studies assessing hamstring muscle strain injury in sport.

3.7 Conclusions

Based on the observational epidemiologic studies reviewed, there is some evidence of an association between decreased hamstring muscle strength and acute hamstring strain injury in elite male athletes in sport. There is, however, no strong evidence to support a causal association. There is also not adequate evidence to support decreased muscle strength to be a risk factor for acute muscle strain injury in sport as all evidence provided pertains to hamstring injury only.

Clearly, future research is required to obtain convincing evidence of decreased muscle strength as a risk factor for acute muscle strain injury in sport. Implications for future research include: the necessity for valid and reliable injury reporting systems to quantify outcome measures, the necessity for reliable and valid measurement tools to assess exposures such as strength, the necessity of randomized selection of subjects and the importance of controlling for all potential confounding variables (particularly history of previous injury). Future research is necessary to establish decreased muscle strength as a risk factor for muscle strain injury in other muscle groups, other sports and other athlete populations (ie. female, adolescent and recreational). Eccentric muscle strength is a hypothesized factor of importance in muscle strain injury based on animal studies (30,49,57). Now that computerized isokinetic dynamometry is equipped to assess eccentric muscle strength, this is potentially a tool which should be utilized in the assessment of muscle function in future research in this area.

With respect to the study of specific muscle strain injury in specific sports, a research initiative will be required to establish an association between decreased muscle strength in appropriate muscle groups and acute muscle strain injury.

Table 3.3. Studies investigating the association between muscle strength and acute muscle strain injury.

Study	Study Design	Sample	Exposure	Outcome	Conclusions
Bennell K et al, 1998 (5)	Prospective case-control	102 male Austral-ian rules football players (12 cases, 90 controls)	Maximum voluntary concentric + eccentric hamstring/ quadricep peak torque ratio (KinCom)	Acute hamstring strain (requiring >= 1 game loss), diagnosed by physician blinded to exposure measure	No association between hamstring/ quadracep ratio and injury. Players with previous injury at 2.1X risk of injury.

Burkett LN, 1970 (11)	Cross-sectional and prospective case-control	30 male varsity track athletes (12 cases and 18 matched controls) and 37 male varsity football players (5 cases, 32 controls)	Maximum voluntary isometric hamstring/ quadricep peak torque ratio and weak/strong hamstring peak torque ratio (Cable tensiometer)	Acute hamstring strain (1st or 2nd degree)	Significantly decreased hamstring/ quadricep ratio and increased hamstring imbalance in injured group. Correctly predicted 4/6 injuries in football group.
Christensen CS et al, 1972 (13)	Prospective cohort	9 male varsity track athletes (5 exposed, 4 not exposed)	Maximum voluntary isometric hamstring/ quadricep peak torque ratio (Cable tensiometer) Exposed= below mean ratio	Acute hamstring strain	Predicted correctly 4/4 not exposed with no injury and 2/5 exposed with injury.

Heiser TM et al, 1984 (23)	**Historical cohort**	**Group 1- 534 varsity football players (1973-1977) and Group2- 564 of same (1978-1982)**	**Group 1- non-specific stretching, training, and return to activity post injury Group 2- specific mandatory stretching, training, and rehab-ilitation (return to sport when hamstring strength discrepancy <=10% between sides)**	**Acute hamstring strain (session loss>=1 week + required >= 10 physio-therapy sessions)**	**Group 1 - 41 players (7.7%) sustained injury of which 13 (31.7%) had recurrence Group 2- 6 players (1.1%) sustained injury no recurrences.**

Jonhagen S et al, 1994 (25)	**Cross-sectional**	**20 male sprinters (11 cases, 9 matched controls)**	**Maximum voluntary concentric + eccentric hamstring/ quadricep peak torque (KinCom)**	**Previous history (within 2 seasons) of acute hamstring strain (minimum training/ competit-ion loss 1 week)**	**Significant-ly decreased concentric and eccentric peak torque for hamstrings and quadriceps in injured legs (30 degrees /second) and significantly decreased eccentric peak torque for hamstrings only (180 and 230 degrees/ second).**

Liemohn W, 1978 (29)	**Prospective case-control**	**27 varsity track and field athletes (7 cases, 20 controls)**	**Hip flexion flexibility (standard goniometer) and maximum voluntary isometric hamstring/ quadricep peak torque ratio (Cable tensiometer)**	**Mild-moderate acute hamstring strain**	**Significant-ly decreased hip flexion in injured players and no difference between injured and non-injured players hamstring/ quadricep ratio.**

Orchard J et al, 1997 (38)	**Prospective case-control (cohort analysis)**	**37 profes-sional Austral-ian rules football players**	**Maximum voluntary concentric + eccentric hamstring/ quadricep peak torque ratio + weak/strong hamstring ratio (Cybex 340)**	**Acute hamstring strain diagnosed by physician blinded to exposure measure-ments**	**Significant-ly decreased hamsting/ quadricep, weak/strong hamstring ratios and peak hamstring torque in injured legs. Discrimin-ant function analysis correctly predicted injury/no injury for 77.4% of players.**
Paton RW et al, 1989 (39)	**Cross-sectional**	**14 profes-sional soccer players (7 cases, 7 controls)**	**Maximum voluntary concentric hamstring/ quadricep peak torque ratio (Cybex 340)**	**Acute hamstring strain injury previous season (mild-moderate)**	**No difference in hamstring/ quadricep ratio in injured and non-injured players.**

Worrell TW et al, 1991 (62)	**Cross-sectional**	**32 highly skilled male athletes (football, track, soccer, lacrosse) (16 cases, 16 matched controls)**	**Maximum voluntary concentric hamstring and quadricep peak torque (Kinetic Com-municator isokinetic dynamo-meter) Flexibility measure-ment (popliteal angle at 90 degrees hip flexion)**	**Acute hamstring strain injury previous season (>=1 week training loss)**	**No difference in peak torque measure-ments between injured and non-injured legs or players. Significant-ly decreased flexibility in injured group.**

Yamamato T, 1993 (63)	Prospective case-control	65 Japanese male varsity track athletes (2 year follow-up) (26 cases, 38 controls, 1 lost to follow-up)	Maximum voluntary isometric peak torque quadriceps, hamstrings and hip flexors (strain gauge) Reported were: peak torque/body weight ratio, hamstring/ quadricep ratio and Index(%)= peak torque (strong-weak)/ peak torque (strong) X 100	Acute hamstring strain	Significantly decreased peak torque/body weight and hamstring/ quadricep ratios in injured legs. Indexes for hip flexors and quadriceps significantly higher in injured legs.

CHAPTER FOUR: TEST-RETEST RELIABILITY OF ISOMETRIC HIP ADDUCTOR MUSCLE STRENGTH USING AN ADAPTED NICHOLAS MANUAL MUSCLE TESTER.

4.1 Structured Abstract

Objectives: The purpose of this study is to determine the test-retest reliability of peak isometric hip adductor torque using an adapted Nicholas manual muscle tester and to determine whether peak isometric adductor torque is a good predictor of peak eccentric adductor torque as measured on a Cybex Norm™ isokinetic dynamometer. In addition, to evaluate post exercise muscle soreness as a result of the testing procedure.

Design: Prospective test-retest reliability study.

Participants: A total of 22 male volunteers between the ages of 19 and 49 were the subjects for this study. Of these, 9 subjects had participated in a test-retest reliability study examining peak eccentric torque measurement of hip flexors and adductors using a Cybex Norm™ isokinetic dynamometer.

Intervention: Peak hip adductor isometric torque was measured using an adapted Nicholas manual muscle tester. Subjects were tested on 2 occasions at a 1 week interval.

Main Outcome Measures: Repeated measures analysis of variance was performed. An intraclass correlation coefficient (ICC) was used to compare the data between sessions. Simple linear regression analysis was completed to determine the relationship between session 1 and session 2 measurements. In addition, simple linear regression analysis was done to determine peak isometric strength as a predictor of peak eccentric adductor torque measurement as previously measured on a Cybex Norm™ isokinetic dynamometer.

Results: The main findings of this study are that peak isometric hip adductor torque was reliably measured on an adapted Nicholas manual muscle tester (ICC=0.95). Based on a small sample of 9 subjects, there was inadequate evidence that peak isometric adductor torque was a predictor of peak eccentric adductor torque (at a velocity of 60 degrees per second). There was no post-test muscle soreness reported following such an isometric

protocol.

Conclusions: The results from this test-retest reliability study confirm the reliability of peak isometric hip adductor torque measurements using an adapted Nicholas manual muscle tester for use in future research. In addition, it is confirmed that there is no concern regarding post-test muscle soreness following such an isometric protocol.

Key words: Hip, muscle strength, dynamometry, reliability, isometric contractions, post exercise muscle soreness.

4.2 Introduction

Published studies suggest that muscle strength may be a risk factor for hamstring muscle strain injury (30,49,57). There is evidence, based on several epidemiological studies, of an association between decreased hamstring muscle strength and acute hamstring strain injury in elite male athletes in sport (11,13,23,25,38,62,63). There are implications arising from this evidence, regarding other muscle groups (such as non-contact groin injuries) which need to be assessed in future research.

The purpose of this study was to determine the test-retest reliability of isometric hip adductor peak torque using an adapted Nicholas manual muscle tester (Appendix A1) and to determine whether it is a good predictor of peak eccentric adductor torque (velocity 60 degrees per second) as measured on a Cybex Norm™ isokinetic dynamometer. It is felt that the assessment of peak isometric hip adductor torque using an adapted Nicholas manual muscle tester may be a suitable alternative to eccentric peak torque strength measurement as it is quick, simple, and may not result in post-test muscle soreness (as did eccentric testing on an isokinetic dynamometer). Determination of reliability of such measurements is essential prior to their use in future studies; for example, to assess strength specifically as a predictor of groin muscle strain injury in sport.

It has been established in a previous test-retest reliability study (16) that peak eccentric adductor torque measurement on a Cybex Norm™ isokinetic dynamometer is extremely reliable (ICC=0.84). Post-test muscle soreness, however, was a significant problem following this test-retest reliability protocol. It is of particular importance to identify when asking for informed consent prior to testing using any strength testing protocol. Post-test muscle soreness may have a significant impact on an athlete's subsequent training bouts. For these reasons, it is essential to assess post-test soreness following sessions of muscle strength testing bouts in a test-retest reliability study.

Last (28) defines reliability as the degree of stability exhibited when a measurement is repeated under identical conditions or the degree to which the results obtained by a measurement procedure can be replicated. Test-retest reliability of a measurement using an adapted manual muscle tester would refer to the reproducibility of a test result upon repetition under identical conditions. Muscle strength can be measured isometrically, concentrically or eccentrically. A concentric muscle contraction involves shortening of the muscle fibers where the origin and insertion of the muscle approximate. An eccentric muscle contraction involves lengthening of the muscle fibers where the origin and insertion of the muscle separate. An isometric muscle contraction involves no change in length of the muscle fibres (14). Hand held dynamometers, such as the Nicholas Manual Muscle Tester provide a simple, quick, portable, noninvasive, and relatively inexpensive way of measuring isometric strength objectively and accurately (2).

There are numerous studies which report good to excellent intrarater reliability (Intraclass Correlation Coefficients reported 0.71-0.99) using hand held dynamometers (7,10,34,46). The interrater reliability, however, has not been strong in some studies (1,45). Agre et al (1) found high interrater reliability for upper extremity muscle groups but poor interrater reliability for lower extremity muscle groups tested. Perhaps this is due to the limitation of the tester's ability to resist an isometric contraction in a powerful lower extremity muscle group with their upper extremity strength. In studies in which testers are experienced with use of the instrumentation and testing techniques, interrater reliability tends to be higher (2).

Previously, Nicholas (36) established population norms for peak isometric adductor force using a Nicholas manual muscle tester in a hand-held fashion by the examiner. The norms were established using 1002 normal subjects ages 10 to 82 and reported as 95% confidence limits. The norms reported for males ages 18-34 were 21 to 23 kilograms (kg) force and for males ages 35-54 were 18 to 21 kg force. The intrarater reliability, specifically, has not been determined previously for hip adductor muscles.

Muscle strain injury is characterized by a disruption of the muscle-tendon unit (20). Many clinicians would agree that muscle strain injuries occur when a muscle is either stretched passively or a contraction occurs during a stretch (20). The latter occurs during an eccentric contraction. This is an important factor because muscle forces can be greater during lengthening (55). Mair et al (30) demonstrated for the extensor digitorum muscle of rabbits, that a reduction in force was required to produce muscle strain in a fatigued muscle. This is consistent with Garrett's (20) findings which suggest that muscle strain injuries occur late in the training or competitive setting.

Kannus (26) described peak torque measurement as the single highest torque output of the joint produced by muscular contraction. Peak torque has become a gold standard and reference point in isokinetic measurements against which accuracy, precision and clinical relevance of all other parameters have been compared. During a concentric contraction, peak torque stays relatively constant for angular velocities between 0 and 60 degrees/second and thereafter declines with increasing velocity. It is well documented that at a given angular velocity the eccentric torque is greater than the corresponding concentric torque (27). Westing (60) demonstrated that for knee extensors and flexors eccentric torque is greater than the corresponding concentric torque at the same angular speed.

Pincevero et al (41) found that increasing the number of maximal contractions from 3 to 5, improved the chance of producing peak torque strength after the third contraction. This concept was tested by Mawdsley and Knapik (31) in their comparison of isokinetic measurements with test repetitions and they found that 5 repetitions was ideal to capture the greatest peak torque measurement. In a previous study, Emery et al (16) found excellent reliability of peak eccentric hip adductor torque using a similar concentric followed by eccentric contraction protocol with five repetitions.

The most common method of statistical analysis to describe test-retest reliability of dynamometry measures is intraclass correlation coefficients (ICC) as described by Shrout and Fleiss (52). Authors vary in their definitions of good and excellent reliability. There is no gold standard definition for quality of reliability defined in the literature. According to Fleiss (18) excellent reliability is demonstrated by an ICC>0.75.

4.3 Methods

4.3.1. Subjects

Twenty-two male volunteers, in some way associated with the University of Calgary, between the ages of 19 and 49 were the subjects in this study. Nine of these subjects were subjects in the previous test-retest reliability study measuring peak eccentric and concentric torque of hip adductors using a Cybex Norm™ isokinetic dynamometer (16).

There was no remuneration for subject participation in this study. The sample size required was calculated based on the a priori hypothesis that there would be a difference of <10% on peak isometric strength test between measurements. Based on alpha=0.05 and Power=0.80 a minimum sample size of 16 was required. Exclusion criteria were; previous history of serious low back, hip, or knee injury, and any history of problems or pain in any of these joints in the year prior to testing. Serious disorder includes fracture, rheumatological disease, systemic disease and surgery. An informed consent form, as approved by the Faculty of Kinesiology at University of Calgary, Ethics Panel, was signed by all study participants prior to testing.

4.3.2 Measurement Apparatus

All peak isometric hip adductor strength measurements were done using an adapted Nicholas manual muscle tester (Appendix A1). The adaptation included securing a metal brace and carved wood force test support to the front side of the Nicholas manual muscle tester. This wood force test support was constructed to match the circumference of the existing force test support on the back of the Nicholas manual muscle tester. In addition, a low temperature polymer material was molded and attached to each force test supports using a thin layer of silicone. These were to increase comfort during a maximal isometric contraction. Silicone was chosen such that these adaptations could be easily removed to use the Nicholas manual muscle tester as a hand-held dynamometer.

The adaptation was done to remove any tester variability which may occur using the Nicholas manual muscle tester in the standard fashion. It was also felt that the upper extremity strength of some individual testers may be the limiting factor in measurement of peak isometric hip adductor torque measurement.

4.3.3 Procedures

Each subject was tested with this identical protocol on two separate occasions approximately one week apart.

At the first session subjects were required to complete a questionnaire regarding age, weight, activity level and prior injury status. Leg dominance was determined by asking subject which leg they prefer to kick a soccer ball with. Warm-up prior to testing included five minutes on a stationary bicycle.

The subject's position at the time of testing was supine with hips and knees flexed and feet flat on the examining table (Appendix A2). Knee flexion of 90 degrees was measured using a universal goniometer and maintained throughout testing repetitions. Feet were aligned with the anterior superior iliac spine on each side. The force test supports were placed over the vastus medialis muscle as distally as was comfortable for the subject. The subject was asked to produce a maximal effort hip adductor contraction by closing their thighs on the Nicholas manual muscle tester. The peak isometric force (kg) was recorded following each of 5 repetitions. The subject was given a 10 second rest period between contractions. The Nicholas manual muscle tester was reset to zero between measures.

This position was chosen for testing as it was felt to be most stable non-weightbearing position with hips and knees in a close to functional skating position. In addition, it was felt this position would be easily reproducible between testers. Due to the width of the Nicholas manual muscle tester, hip abduction angle may vary between subjects due to variable lengths of each subject's femur. Distance between distal femur will of course be constant between subjects as width of Nicholas manual muscle tester will remain constant.

Peak torque calculation required the length of the lever arm to be measured (Appendix A3). This measurement was done with a measuring tape and recorded in meters. The measurement was done with the subject in supine with hips and knees in a neutral position. Measurement was from the midpoint of the inguinal ligament (approximating the position of the hip joint underlying) to the superior border of the patella. An assumption of equal femoral length bilaterally was made and the measurement was always done on the right side. The peak torque (Newton meters) was calculated by multiplying the peak force produced over 5 repetitions (kilograms) by the lever arm length (meters) by 9.807. The peak torque measured of course will be equivalent to the peak torque produced by the weakest of the two sides.

Specific variables to be analyzed included: 1. Peak isometric torque produced using Nicholas manual muscle tester at each of two testing sessions.2. Peak torque produced during eccentric contraction of hip adductors at angular velocity of 60 degrees per second using a Cybex Norm™ isokinetic dynamometer.

A post-exercise muscle soreness questionnaire was completed by each participant following each of the two sessions (Appendix B1). This questionnaire asked questions regarding post-test exercise soreness up to 2 days following each test session. Participants were instructed to refrain from any high intensity sporting activity for the duration of any post-test muscle soreness.

4.3.4 Data analysis

Peak isometric torque (greatest of 5 measurements recorded at each of 2 sessions) as produced using the Nicholas manual muscle tester were recorded for each subject. The peak eccentric torque over three sessions as previously recorded using the Cybex Norm™ computer and dedicated Cybex Norm™ software for 9 subjects were used for comparison. All data analysis was done using the Stata (54) statistical software package. Peak isometric torque is the greatest torque produced at 0 degrees/second angular velocity, measured in Newton-meters. Peak eccentric torque was defined as the greatest torque achieved through maximal effort contraction at 60 degrees/second velocity, measured in Newton-meters. The peak eccentric torque chosen for comparison was the lesser of the right and left side measurements.

Repeated measures analysis of variance was performed to compare the means of the two tests for peak isometric torque. Intraclass correlation coefficients (ICC's) as described by Shrout and Fleiss (52) was used to measure test-retest reliability following repeated measures analysis of variance for peak isometric torque.

The one-way analysis of variance intraclass correlation coefficient (ICC) described by Shrout and Fleiss (52) was used to estimate the reliability of peak hip adductor isometric torque measurement. ICC is defined by:

$$ICC = (MSB - MSW) / [MSB + (k - 1) MSW]$$

where, MSB = mean square between (between subject variance), MSW = mean square within (within subject variance), and k = number of tests. The 95% confidence interval for values of ICC were estimated according to Shrout and Fleiss (51).

Simple linear regression analysis was completed to determine the association of measurements between 2 sessions in addition to the association between peak isometric torque and peak eccentric torque produced. The coefficients of interest included the slope which represents the change in one session measurement per unit change in the previous session measurement and the intercept which represents the current session measurement predicted by previous measurement equal to 0. A perfect correlation between session measurements would of course yield a slope=1 and an intercept=0.

Descriptive statistics were used to describe post-test muscle soreness. This will include survey results following each of two test sessions.

4.4 Results

The mean age (standard deviation) of the 22 subjects was 32.09 (8.33) years. All subjects were right leg dominant. Eight of the 22 subjects played hockey on a regular basis. Three of these subjects considered their level of play to be competitive. All 22 subjects participated in recreational or competitive sport a minimum of three times per week.

The mean peak isometric force (kg) and torque (Nm) with standard deviation, minimum and maximum are presented in Table 4.1.

Table 4.1: Peak isometric hip adductor force and torque produced over two trials by 22 subjects.

Trial	Peak Force (kg)		Peak torque (Nm)	
	Mean (sd)	Min. - Max.	Mean (sd)	Min.-Max.
Trial 1	42.87 (8.27)	24.3 - 57.4	175.56 (37.51)	96.52 - 247.69
Trial 2	43.74 (8.56)	25.1 - 58.1	179.16 (39.08)	99.69 - 243.37

The reliability estimate (ICC and 95% confidence interval) for test-retest reliability of peak isometric hip adductor torque measurement using the adapted Nicholas manual muscle tester was 0.95 (0.89, 0.98).

Simple linear regression analysis was done between sessions 1 and 2 for peak isometric adductor torque (Figure 4.1). The slope coefficient and 95% confidence interval was 1.02 (0.93, 1.11) and the intercept coefficient and 95% confidence interval was -0.11 (-16.38, 16.17).

Simple linear regression was done between peak isometric torque (the highest torque achieved over 2 sessions) and peak eccentric torque (the lowest of the left and right peak torque measurements) (Figure 4.2). The slope coefficient and 95% confidence interval was 0.51 (-1.20, 2.21) and the intercept coefficient and 95% confidence interval was 139.15 (-143.18, 421.47).

There was no reported post-test muscle soreness associated with the peak isometric adductor strength measurement using the adapted Nicholas Manual Muscle Tester.

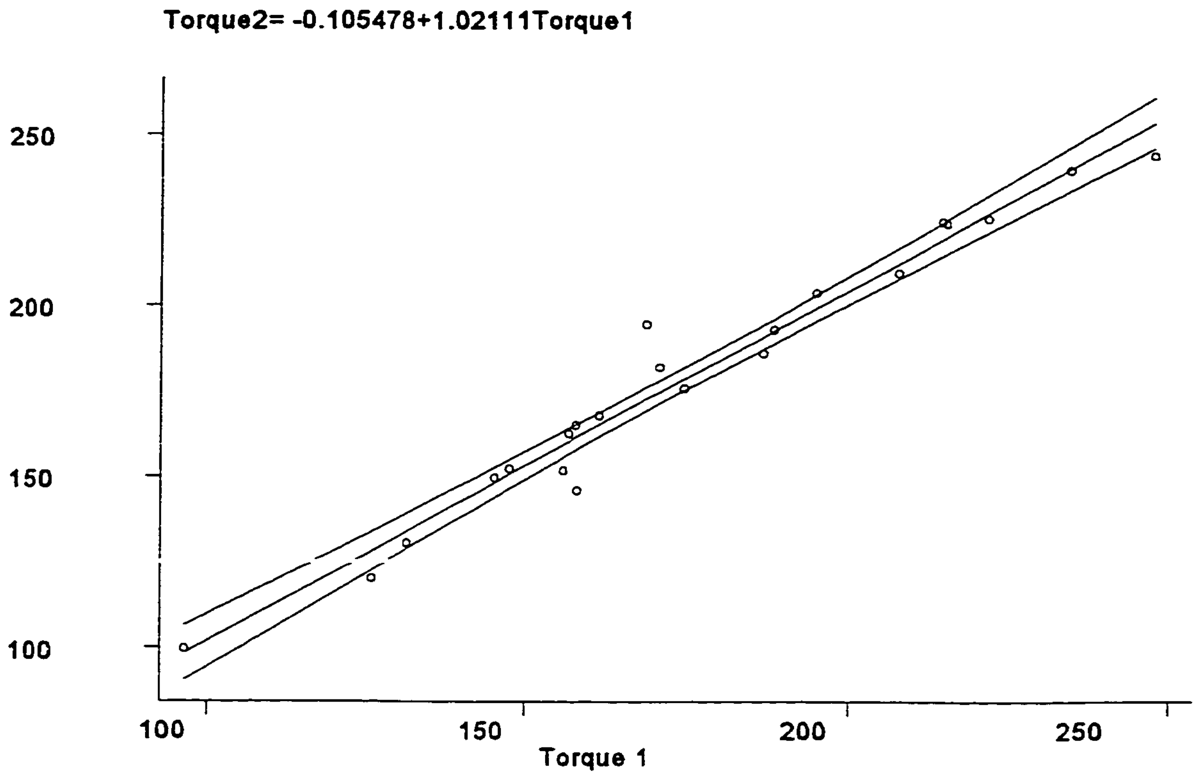

Figure 4.1: Simple linear regression of Peak isometric hip adductor torque in Nm (Trial 2) on Peak isometric adductor torque in Nm (Trial 1).

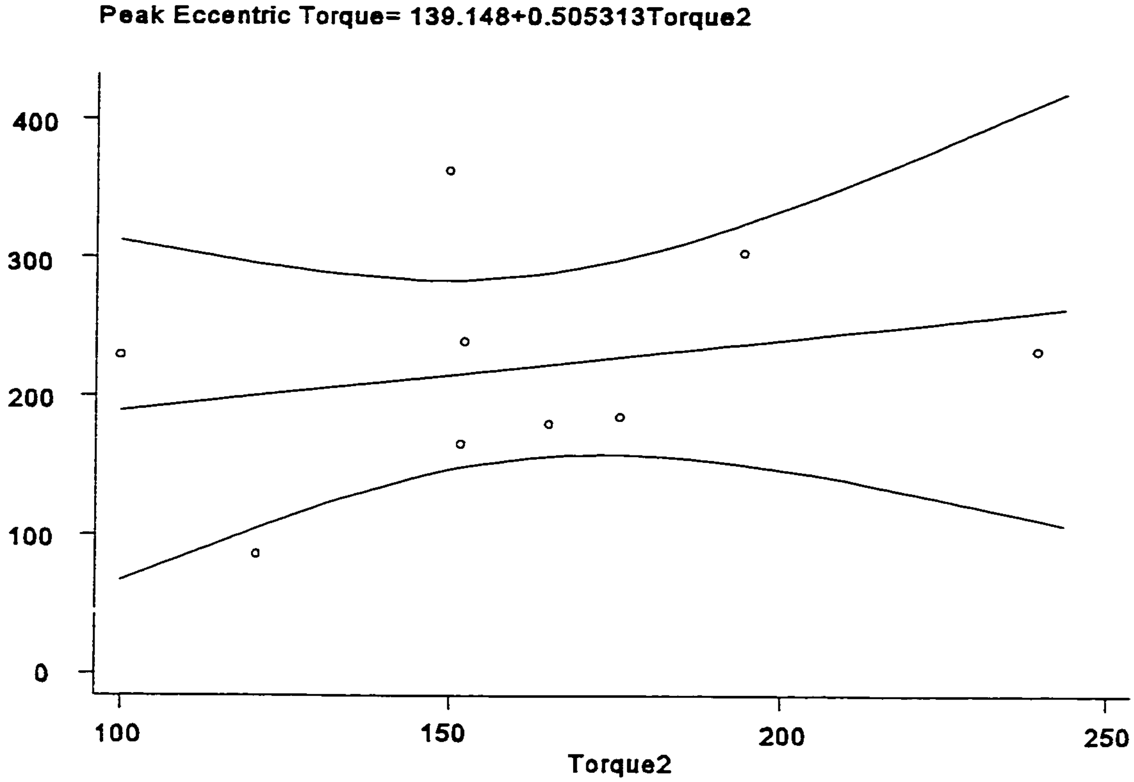

Figure 4.2: Simple linear regression of Peak eccentric adductor torque in Nm (Cybex Norm™ isokinetic dynamometer) on Peak isometric adductor torque in Nm (adapted Nicholas manual muscle tester = Torque2)

4.5 Discussion

This study shows that it is possible to reliably measure isometric peak adductor torque on an adapted Nicholas manual muscle tester. This test measurement demonstrated excellent test-retest reliability over 2 sessions tested based on Fleiss' (18) definition of excellent reliability (ICC>0.75). The reliability found in this study were ICC=0.95. These findings are similar to those found in other test-retest reliability studies using hand held dynamometry where ICC's range from 0.71 to 0.99 (34.7, 10.46). In addition, the element of examiner variance present in hand-held dynamometry is removed by using the Nicholas manual muscle tester with the stated adaptations.

The simple linear regression analysis was provided to confirm reliability between measures which were demonstrated to be reliable by ICC estimates. Excellent reliability between session one and two was confirmed. This conclusion was based on presence of one in the 95% confidence interval for the slope coefficient (ie. estimate of predicted change in session two peak torque per unit change in session one peak torque) and 0 in the 95% confidence interval for the intercept coefficient (ie. estimate of predicted peak torque in session two given peak torque = 0 in session one). The other simple linear regression (using peak isometric adductor torque and peak eccentric adductor torque) does not provide significant evidence to demonstrate peak isometric adductor torque as a predictor of peak eccentric adductor torque based on this small sample of 9 subjects. Though the confidence interval for slope does indeed contain one and the confidence interval for the intercept does contain zero, it would be possible to predict a regression line which was horizontal with zero slope which would fall within the confidence bounds. Such a line would demonstrate no relationship between peak isometric torque and peak eccentric torque.

The actual peak isometric force measurements found in this study using an adapted Nicholas manual muscle tester are significantly greater than those reported by Nicholas et al (36) to be population norms. Nicholas et al (36) report mean 95% confidence intervals to include measurements between 18 and 23 kg of force using the Nicholas manual muscle tester in a traditional hand held fashion for men between the ages of 18 and 54. In our sample of men ages 19 to 49, using an adapted Nicholas manual muscle tester, the range of measurements fell between 24 and 58 kg of force. Perhaps this gives us an indication that peak hip adductor torque measurements are limited by the examiners ability to resist with upper extremity force using a hand-held dynamometer.

4.6 Conclusions

The main findings of this study are peak isometric hip adductor torque can be reliably measured on an adapted Nicholas manual muscle tester. There is inadequate evidence based on this study, however, to suggest that peak isometric adductor torque as measured on an adapted Nicholas manual muscle tester is predictive of peak eccentric torque as measured on a Cybex Norm™ isokinetic dynamometer.

The clinical relevance of this study is to confirm the reliability of peak isometric adductor torque measurements, using an adapted Nicholas manual muscle tester, for use in future research. Post-test muscle soreness is clearly of no concern in normal subjects following peak isometric adductor torque measurements using an adapted Nicholas manual muscle tester. As such, this measurement may be more suitable alternative to peak eccentric hip adductor torque measured isokinetically for the measurement of strength in epidemiologic studies.

In addition, there is some evidence that a measurement of hip adductor peak isometric torque may be greater when measured independent of an examiner as in hand-held dynamometry. If measured in the standard fashion the strength measured may be dependent on the relative strength of the examiner.

CHAPTER FIVE: DEVELOPMENT, VALIDATION AND RELIABILITY TESTING OF A SPORT SPECIFIC TRAINING QUESTIONNAIRE.

5.1 Structured Abstract

Objective: To develop a questionnaire to assess level of self reported off-season sport specific training activity in a population of National Hockey League (NHL) players. In addition, to validate and reliability test the questionnaire.

Methods: Face and content validity were assessed by interviewing 5 professionals in the field (team physician, team therapist, team strength and conditioning trainer, elite hockey player and coach) both prior to and following development of an initial questionnaire. Test-retest reliability was investigated using a sample of 24 varsity level hockey players who completed and returned two questionnaires two weeks apart.

Results: There was no discrepancy in the two questionnaires completed by each player regarding reported position of play, number of years varsity experience, and previous injury status. The reliability estimate (ICC and 95% confidence interval) for test-retest reliability of total number of sport specific training sessions reported was 0.915 (0.814 - 0.962).This was confirmed using simple linear regression.

Discussion: The sport specific training questionnaire developed for use in a cohort study with the NHL population was extremely reliable when tested by varsity hockey players.

Conclusions: This questionnaire was thought to be both valid and reliable and will be used in the pre-season evaluation of NHL player's off-season sport specific training. The number of sessions off-season sport specific training will be used in a prospective cohort study to determine whether it is a predictor for groin/abdominal strain injury in the NHL.

Key words: Specificity, muscle strength, training, questionnaire, validity, reliability

5.2 Introduction

It is well documented that specific muscle strength training will lead to increases in muscle specific strength (19). Specificity of training refers to the movement pattern, velocity of muscle contraction, contraction type (ie. eccentric/concentric/isometric), and contraction force. There are very few conditioning activities which will reproduce the specificity of muscle action of the hip flexor and adductor muscle groups in the same fashion as on-ice conditioning. In-line skating, off-ice acceleration treadmill and slider board conditioning would be exceptions. Though Melanson et al (33) demonstrated that similar improvements in cardiovascular fitness are seen following a 9 week running program and a 9 week in-line skating program of similar intensities, this does not suggest that specific muscle conditioning is similar.

Muscle strength gains with training will clearly depend on the specificity of the training program. Fox et al (19) demonstrated significant (>24%) increases in quadracep strength over a 6 week specific strength training program. The maximum strength gain occurred at 6 weeks and then gains declined over a continued 4 week training program. In addition, Staron et al (53) demonstrated significant increases in leg press, squat and leg extension maximum strength following a 20 week training period in a group of weight lifters. Training was then stopped for a 30 week period, which resulted in significant losses in maximal strength in all three events. This strength was regained following a 6 week period of retraining. This gives potential evidence for the argument that at a minimum, 6 weeks of off-season sport specific training prior to NHL training camp may be essential in the prevention of groin strain injury in hockey.

The purpose of developing an off-season sport specific training activity questionnaire is to determine if the level of sport specific training is predictive of groin/abdominal strain injury in the National Hockey League (NHL). The developed questionnaire is to be completed by all consenting NHL players at the beginning of training camp as part of a prospective cohort study examining risk factors for groin and abdominal strain injury in the NHL.

Babbie (3) refers to conceptualization as the refinement and specification of abstract concepts. The conceptualized definition of level of off-season sport specific training is; the amount of training done by each player off-season which involves sport specific muscle groups (hip adductors and flexors) trained in a sport specific fashion (eccentric and concentric muscle strengthening and endurance training). Babbie (3) refers to operationalization as the development of specific research procedures that will result in empirical observations representing those concepts in the real world. This definition of level of off-season sport specific training is then operationalized for the development of the off-season sport specific training questionnaire. The operationalized definition of level of off-season sport specific training is; "the number of weeks and sessions per week (greater than 30 minutes duration) of on-ice training (hockey or power skating) or off-ice sport specific training (in-line skating, slider board or mechanized off-ice training as done on an acceleration treadmill) done by each player prior to the start of training camp". For purposes of investigating the a-priori hypothesis, high level of off-season sport specific training will be considered; "a minimum of 18 sessions of on or off-ice sport specific training (ie. a minimum of 6 weeks/ three 30 minute sessions per week) in the off-season". For the purpose of exploratory analysis, other cut-points for level of off-season sport specific training will be examined.

Measurement validity is defined by Last (28) as an expression of the degree to which a measurement measures what it purports to measure. Babbie (3) defines validity as the extent to which an empirical measure adequately reflects the real meaning of the concept under consideration. Face validity is defined by Babbie (3) as the measure, at face value, appears to provide some measure of the variable. Content validity is defined by Babbie (3) as the degree to which a measure covers the range of meanings included within the concept. Face and content validity are often determined by preliminary interviews with professionals in the field prior to construction of the instrument (questionnaire) and further assessment of the instrument, following it's construction, by professionals in the field.

5.3 Methods

The investigator conducted initial interviews with 5 professionals in the field (team physician, team therapist, team strength and conditioning trainer, elite hockey player and coach) to receive input prior to construction of the questionnaire. Both face and content validity were assessed by the same five professionals in the field following an initial construction of the questionnaire. They were both interviewed by the investigator and asked to write responses to the following questions:

1. Do the questions address adequately the concept of level of off-season sport specific training?
2. Is the questionnaire comprehensive in addressing all areas of off-season sport specific training?
3. Are the response options adequate and appropriate?

Following completion of the final questionnaire (Appendix B2), 24 varsity level hockey players at the University of Calgary were asked to complete it on two occasions, two week apart, early in the season (September 1998). Each participating player read and signed an informed consent. The purpose of this was to evaluate the test-retest reliability of the questionnaire. Twenty-seven players completed and returned the questionnaire on the first occasion. Twenty-four of these players completed and returned a second questionnaire two weeks later.

Position of play, number of years of varsity experience, previous injury status and total number of sport specific training sessions (June to August 1998) were recorded for each player. All data analysis was done using the Stata (54) statistical software package.

Repeated measures analysis of variance was performed to compare the total number of sessions sport specific training (June to August 1998) reported on the first and second questionnaire completed. Intraclass correlation coefficients (ICC's) as described by Shrout and Fleiss (52) was used to measure test-retest reliability following repeated measures analysis of variance for total number of sessions sport specific training reported (June to August 1998).

The one-way analysis of variance intraclass correlation coefficient (ICC) described by Shrout and Fleiss (31) was used to estimate the reliability of peak hip adductor isometric torque measurement. ICC is defined by:

$$ICC = (MSB - MSW) / [MSB + (k - 1) MSW]$$

where, MSB = mean square between (between subject variance), MSW = mean square within (within subject variance), and k = number of tests. The 95% confidence interval for values of ICC were estimated according to Shrout and Fleiss (51).

Simple linear regression analysis was completed to determine the association of reported sport specific training sessions between the two questionnaires completed. Though total number of sessions was an integer variable it is treated as a continuous variable for the purpose of simple linear regression analysis. The coefficients of interest included the slope which represents the change in reported sessions on the second questionnaire per unit change in reported sessions on the first questionnaire and the intercept which represents the predicted number of reported sessions on the second questionnaire by number of sessions on the first questionnaire equal to 0. A perfect correlation between session measurements would of course yield a slope=1 and an intercept=0.

5.4 Results

Some of the major suggestions given by professionals interviewed were as follows;

1. Important to have visuals as many of the NHL players are unable to read English well.
2. Important to assess sport specific training as part of assessing a total training program as player will be less likely to exaggerate number of sport specific training sessions if he is unaware of the specific objective of the questionnaire.
3. Important to be clear, concise and to the point with questions.
4. Will not get compliance of players if questionnaire takes longer than 5 minutes to complete.
5. Important to differentiate between early and late off-season levels of training.

There was no discrepancy in the two questionnaires completed by each player regarding reported position of play, number of years varsity experience, and previous injury status.

Total number of sport specific training sessions per month was calculated by multiplying the average number of sessions/week by the number of weeks for each of June, July and August. The total number of sport specific training sessions was calculated as the sum of the number of training sessions each month. The reliability estimate (ICC and 95% confidence interval) for test-retest reliability of total number of sport specific training sessions reported was 0.915 (0.814, 0.962).

Simple linear regression analysis was done between total number of sport specific training sessions reported on the first and second questionnaires (Figure 5.1). The slope coefficient and 95% confidence interval was 0.77 (0.53, 1.01) and the intercept coefficient and 95% confidence interval was 2.39 (-4.30, 9.08).

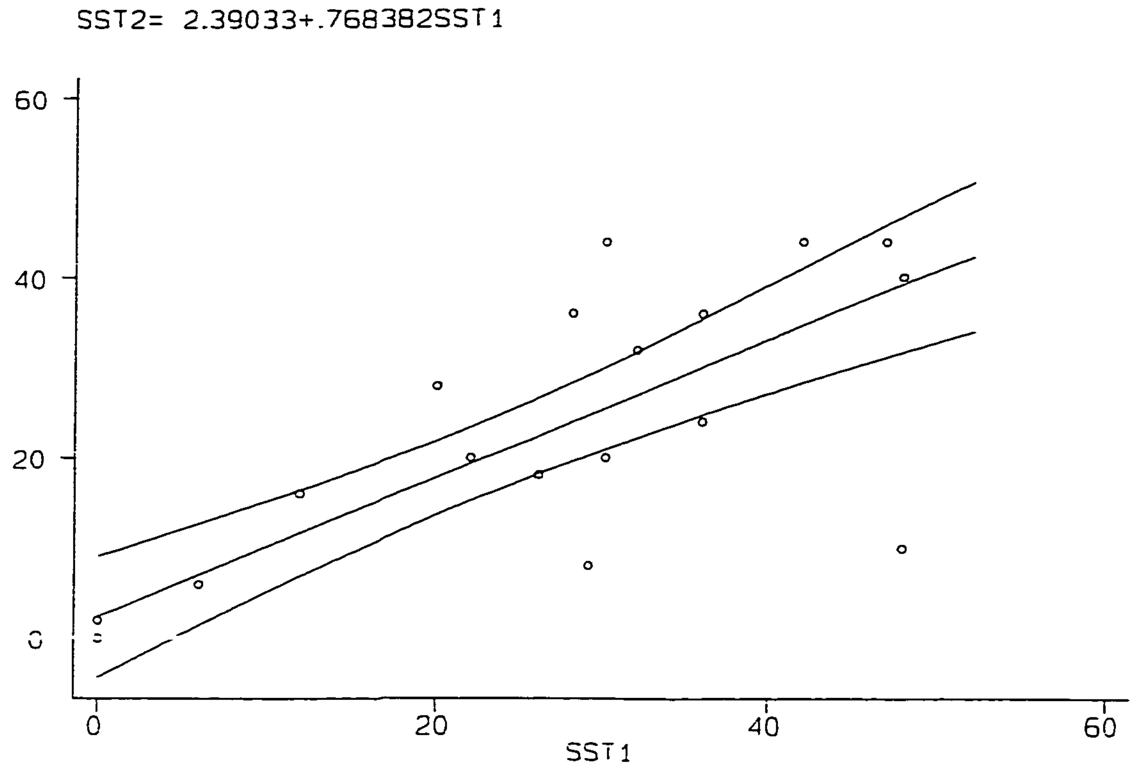

Figure 5.1: Simple linear regression of total number of off-season sport specific training sessions (June to August 1998) reported on questionnaire 2 (SST2) on total number of off-season sport specific training sessions (June to August 1998) reported on questionnaire 1(SST1).

5.5 Discussion

The sport specific training questionnaire developed for use in a cohort study with the NHL population was extremely reliable when tested by varsity hockey players who completed it on two occasions two weeks apart. Reliability was 100% in the reporting of position of play, number of years varsity experience and previous injury status.

The reporting of total sessions sport specific training demonstrated excellent test-retest reliability (ICC=0.915) over 2 questionnaires completed based on Fleiss' (18) definition of excellent reliability (ICC>0.75).

The simple linear regression analysis was provided to confirm reliability between measures which were demonstrated to be reliable by ICC estimates. Excellent reliability between the reported total number of sessions sport specific training on the two questionnaires was confirmed. This conclusion was based on presence of one in the 95% confidence interval for the slope coefficient (ie. estimate of predicted change in reported sessions on the second questionnaire per unit change in reported sessions on the first questionnaire and 0 in the 95% confidence interval for the intercept coefficient (ie. estimate of predicted number of reported sessions on the second questionnaire by number of sessions on the first questionnaire equal to 0.)

5.6 Conclusions

A sport-specific training questionnaire which has been developed for the purpose of evaluating off-season sport specific training activity by NHL players has been validated (face and content) and reliability tested by a sample of varsity hockey players. This questionnaire is thought to be both valid and reliable and will be used in the pre-season evaluation of NHL player's off-season sport specific training. The number of sessions off-season sport specific training will be used in a prospective cohort study to determine whether it is a predictor for groin/abdominal strain injury in the NHL.

CHAPTER SIX: METHODS

6.1 Study Design

A prospective observational cohort design was used to investigate if off-season sport specific training, peak adductor isometric strength, and hip abduction flexibility are risk factors for groin strain injury in the National Hockey League during the 1998/99 training camp period. Players were grouped based on exposure (level of off-season sport specific training) and followed forward through the 1998 training camp. The dependent variable was groin or abdominal strain injury. This included any injury defined as a muscle strain injury of any abdominal, hip flexor or hip adductor muscle. This also included any groin or abdominal hernia. All injuries were reportable regardless of time loss. The predictor (independent) variables were level of off-season sport specific training as determined by a pre-season questionnaire , peak isometric adductor strength as measured using an adapted Nicholas Manual Muscle Tester, and hip abduction flexibility as measured using a universal goniometer. For the purpose of the a-priori hypothesis, level of off-season sport specific training was defined as greater than and equal to or less than 18 sessions (ie. six weeks/ three sessions per week) on-ice training (hockey or power skating), in-line skating, off-ice acceleration treadmill, or slider board training. Peak isometric adductor strength and hip abduction flexibility were defined as greater than and equal to or less than one standard deviation below the mean. For purposes of further exploratory analysis, other cut-points were investigated to determine a minimum level of off-season sport specific activity, peak isometric adductor strength, and hip abduction flexibility which resulted in decreased risk of groin or abdominal strain injury. Exploratory analysis also included investigation of other potential risk factors for groin or abdominal strain injury including; age, previous injury, position of play, NHL experience, and skate blade hollow. These were included in the primary analysis as potential confounding or effect modifying variables.

6.2 Subjects

An inclusive sample of NHL players invited to attend one of 27 team training camps were asked to consent to the study. All consenting players completed a consent form (Appendix C1). All consenting players were asked to complete the off-season sport specific training activity questionnaire. The target population, therefore, included 1557 players.

The sample size required was calculated using Stata statistical software package (54). Sample size calculations were based on the a-priori hypothesis that there would be a difference of greater than 0.1 in the proportion of players injured in the lower level of off-season sport specific training group (exposed group) compared to the higher level group (non-exposed group). The incidence of groin injury was approximately 20 injuries/100 players/year over the past 2 seasons of play (Chapter 2). Based on the a-priori hypothesis that injury would be higher in the exposed group, the risk of injury in this group may be as high as 25 injuries/100 players/season and in the unexposed group may be as low as 15 injuries/100 players/season. Based on a difference in proportions of 0.1, an alpha level of 0.05, and a Beta level of 0.80 a minimum sample size of 270 is required in each of the exposure groups to detect a minimum difference in proportion of players injured of 0.1. It is therefore felt that using the entire population of NHL players, accounting for drop-outs and non-consenters would be appropriate. This would be approximately 1200 players for training camp. By using the entire population, assuming minimal loss to follow-up and loss due to incomplete surveys, there would be minimal risk of selection bias in the study design.

6.3 Data Collection

6.3.1 Questionnaire Administration

An off-season sport specific training questionnaire (Appendix B2) was completed by all consenting NHL players attending training camp at the time of their pre-season medical evaluation. The questionnaire was distributed by the team therapist and players were encouraged to address any questions to them. All therapists were informed clearly by the investigators of the purpose of the questionnaire. The study design and methods were presented to all NHL team therapists in June 1998 at the Professional Hockey Athletic Trainers Society meeting. Any additional questions not addressed in the consent form were addressed on a one to one basis with the study investigator. This included questions regarding sport-specific training activities. This questionnaire also included some baseline player information such as previous NHL experience, previous history of groin/abdominal strain injury, and usual position of play.

6.3.2 Preseason strength measurements

Peak hip adductor isometric strength measurements were done by each teams professional medical staff (team therapist or physician) using an adapted Nicholas Manual Muscle Tester (NMMT) (Appendix A1). The therapist or physician doing the measurements were provided with a score sheet to record all measurements (Appendix C2). In addition, a picture and summary of the measurement procedures (Appendix A2 and A3) were provided. Therapists/physicians were encouraged to contact the investigator by phone at any time if they had further questions regarding the measurements. The player was positioned in supine with hips and knees flexed and feet flat on the examining table. Knee flexion measurement was measured at 90 degrees using a universal goniometer. Feet were aligned with the anterior superior iliac spine on each side. The pads of the NMMT were placed over the vastus medialis as distal as was comfortable for the player. The player was asked to adduct maximally against the pads of the NMMT. The peak force achieved (kg) as recorded by the NMMT was recorded by the examiner. This was repeated 5 times. The lever arm length required to calculate peak adductor torque was measured with a measuring tape. The measurement was done with the player in supine with knees and hips extended. Measurement was taken from the center of the inguinal canal to the superior border of the patella on the right side only. The peak adductor torque was then calculated in Nm by multiplying the maximum force (kg) achieved in 5 trials by the length of the lever arm (m) by 9.806. For purposes of investigating the a-priori hypothesis, high level of peak isometric strength was defined as strength at least one standard deviation above the mean. Low level of peak isometric strength will be defined as strength more than one standard deviation below the mean.

6.3.3 Preseason flexibility measurements

Active hip abduction measurements were taken bilaterally for each consenting player using a Universal Goniometer (UG) by the team medical staff (team therapist or physician). Measurements were done in supine with bilateral active hip abduction assumed by the player in neutral hip extension. The proximal arm of the UG was aligned with the centre of the trunk, the centre of the UG was positioned over the center of rotation of the hip joint, and the distal arm of the UG was aligned with the shaft of the femur (Figure). This measurement was tested for inter and intrarater reliability by Balmer and Brosseau (4) who established intraclass correlation coefficients (ICC) of 0.89 to 0.99 for intrarater reliability and ICC's of 0.80 to 0.92 for interrater reliability using a validated UG. Total hip abduction flexibility was calculated as the sum of unilateral measurements.

The therapist or physician doing the measurements recorded all measurements on the score sheet provided (Appendix C2) In addition, a picture and summary of the measurement procedures was provided (Appendix A4). Therapists/physicians were encouraged to contact the investigator by phone at any time if they had further questions regarding the measurements.

6.3.4 Additional Exposure Data Collection

Previous injury, level of NHL experience, and position of play information was collected on all consenting players as part of the off-season sport specific training questionnaire (Appendix B2). Age was collected with the list of identification numbers from each team therapist. Information on skate blade hollow was recorded by each participating team equipment manager on a form provided (Appendix C3). This included any changes in blade hollow measurement throughout the training camp. Exposure information including total exposures for games and practices. These were obtained from the NHL Injury Surveillance System (NHLISS) (42). This system is currently in place in the NHL. Individual injury and team exposure information is recorded directly into the system by each team athletic trainer.

6.3.5 Injury Data Collection

The 1998 revised National Hockey League Injury Surveillance System (NHLISS) was utilized to obtain all data required regarding groin injury. Groin strain injury was defined as a muscle strain injury of any abdominal, hip flexor or hip adductor muscle. This also included any groin or abdominal hernia. An injury was reported regardless of whether or not the player was removed from the current session. Description of injury, date of injury, time loss due to injury (sessions missed), previous injury (within 1 year), mechanism of injury, and position of play were obtained from the NHLISS.

Each NHL team therapist records injury data electronically directly into a relational data base written using Fox Pro. The data is sent directly by a modem to MedSport Systems where data is collected on all injuries sent from all NHL teams. The relational data base allowed the computer analyst at MedSport Systems to extract all of the data pertaining to groin and abdominal strain injury into an excel file. This file was then sent electronically to the research coordinator at the University of Calgary, Sports Medicine Centre.

6.3.6 Definitions for data collection

For the purpose of this data analysis it would be appropriate to define some terms and variables of interest:

Groin/abdominal strain injury - any injury recorded as a muscle strain injury involving a muscle in any of the abdominal, hip flexor or hip adductor muscle groups. Abdominal and inguinal hernias were also included in this group. A direct blow to a muscle resulting in a muscle contusion was not considered to be a muscle strain injury. An injury was reportable regardless of whether the player was removed from the current practice or game or the player missed the next day's session.

Cumulative Incidence Rate - the number of injuries per 100 players per year.

Incidence Density - the number of injuries per 1000 athlete exposures per defined period of play.

Athlete Exposure - a measure of the opportunity for an injury to occur (1 athlete exposure = 1 game or 1 practice).

NHL Training camp - pre-season play including practice sessions and exhibition games up until but excluding the first regular season game (generally early September until early October).

NHL Regular season - includes all practice sessions and regular season games (generally early October until mid April).

NHL Post season - includes all play-off games up until and including Stanley Cup Final (generally mid April until the beginning of June).

Re-injury - any injury which is reported in which the player had a previous injury in the prior season or off-season to the same body region.

Contact/No contact injuries - in the NHLISS the trainer has the opportunity of coding a reported injury to be a result of direct contact with another player, the boards, and/or equipment or not a result of direct contact.

Mechanism of Injury - in the NHLISS the trainer has the opportunity of recording the primary mechanism of injury to be direct impact, indirect force, torsion, stretch, impingement, overuse, shearing, spontaneous, or insidious onset. Impingement and shearing were not recorded as the mechanism of injury in any groin strain injury reported. For the purpose of this data analysis it was felt that mechanisms including direct impact and indirect force could be considered contact injuries and mechanisms including torsion, stretch, overuse, spontaneous, and insidious considered non-contact injuries.

Sessions missed - recorded number of games and or practices missed (training camp sessions only for purposes of this study) due to reported injury (could record 0 sessions missed). In the NHL the smallest unit recorded is one full session.

6.4 Data Analysis

Descriptive statistics were reported on injury status (muscle strained), incidence density (# of injuries per 1000 athlete exposures), mechanism of injury, time in session injury occurred, and time loss due to injury. Injured and non-injured players were described in terms of the following variables; age, experience of play in the NHL, previous injury (within 1 year), position of play (offence, defense, goalie), peak isometric hip adductor torque (Newton meters), total hip abduction flexibility (degrees) and skate blade hollow (angle of measurement).

Logistic regression analysis was done to determine the relative risk of injury in the high risk group (low off-season sport specific training) to that in the low risk group (high off-season sport specific training). As this is a prospective cohort study, the odds ratio determined will predict the increased risk of injury in the high risk group compared to the low risk group. That is, to test the first a-priori hypothesis that decreased off-season sport-specific training is a risk factor for groin and abdominal strain injury in the NHL. Other potential confounding or effect modifying variables which will be included in the model will be; age (years), experience (years in NHL), previous injury (within one year), position of play (offense, defense, goalie), isometric adductor torque (Nm), total hip abduction flexibility (degrees) and skate blade hollow (inches). The relative risk of injury in players with peak isometric torque and total hip abduction flexibility more than one standard deviation below the mean and those above that cut-point will also be predicted using an odds ratio in this analysis. That is, to test the second and third a-priori hypotheses that decreased peak isometric adductor torque and total abduction flexibility are risk factors for groin strain injury in the NHL.

Further exploratory analysis was done using logistic regression modeling with level of off-season sport specific training used as a continuous variable to determine the change in probability of injury per session increase in off-season sport specific training. This assisted in an attempt to identify a potential dose response relationship. That is, to determine if increasing levels of off-season sport specific training led to reduced risk of groin strain injury.

All data analysis was done using Stata statistical software package (54). Methods used to complete data analysis were variations on methods for logistic regression outlined by Selvin (51).

6.5 Ethical Considerations

Ethical analysis of this study is described based on four basic ethical principles in research. These include; respect for persons (autonomy), beneficence (do good), non-maleficence (do no harm), and justice (exclusion). With regards to respect for persons all players were provided with a consent form attached to the questionnaire which was given to all players attending an NHL training camp in September 1998. This consent form thoroughly described the purpose of the study and information regarding the maintenance of privacy and confidentiality (including privacy of personal information from management). This consent form also addressed the isometric hip adductor measurement which the players will be asked to perform along with other physiological testing pre-season. Each player had player identification number for purposes of data entry into the NHLISS, this same number was used to identify the players for the hip strength measurement and the questionnaire.

With respect to beneficence, it is hypothesized that this research will help lead to prevention strategies for groin and abdominal strain injury in the NHL. This will be a positive step toward reducing injury and time off due to injury in the NHL. Many players presently in the NHL and future NHL players will benefit from this research. This also has implications for injury in hockey at other elite and recreation al levels. With respect to non-maleficence, there is no component of this research that would harm any of the participants.

Justice was not an issue in this study as the entire NHL population was asked to participate in this study.

CHAPTER SEVEN: RESULTS

7.1 Exposure Data

7.1.1 Subject Participation

There were 1557 hockey players attending one of 27 NHL training camps in September 1998. Twenty-three of the 27 NHL team's therapists participated in collecting exposure data for this study prior to the first session of training camp. From those 23 teams, there were 1357 potential participants, of which 1292 (95.21%) consented to participate in the study. A more conservative estimate would be 1292 of 1557, or 82.98% participation. Data collected from the 1292 consenting players is summarized in Table 7.1.

Table 7.1: Exposure data collected from consenting NHL Players

Specific Exposure data collected	Number of players	Proportion of consenting players
Total consenting participants	1292	100%
Partial completion of sport specific training questionnaire	902	69.81%
Completion of sport specific training questionnaire	852	65.94%
Peak isometric adductor torque	995	77.01%
Hip abduction range of motion	997	77.17%
Age reported	685	53.02%
Skate blade hollow	517	40.02%

7.1.2 Descriptive analysis of exposure variables

The mean and 95% confidence intervals (95% CI) for peak adductor torque recorded for 995 players was 203.26 (199.61, 207.31) Newton-meters (Nm). The distribution of peak adductor torque was normal (Figure 7.1).

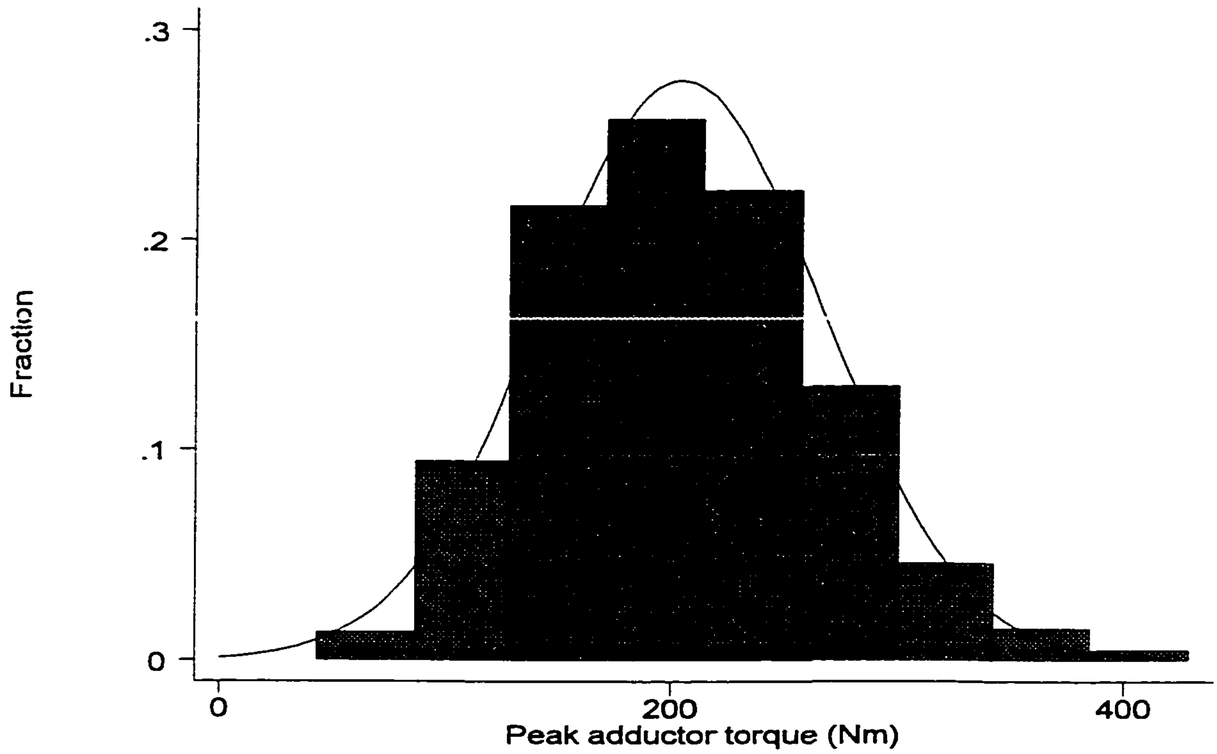

Figure 7.1 : Distribution of peak isometric adductor torque (Nm) (n=995)

The mean and 95% CI for total hip abduction range of motion recorded for 947 players was 102.36 (100.19, 104.53) degrees. The distribution of total hip abduction range of motion was normal (Figure 7.2).

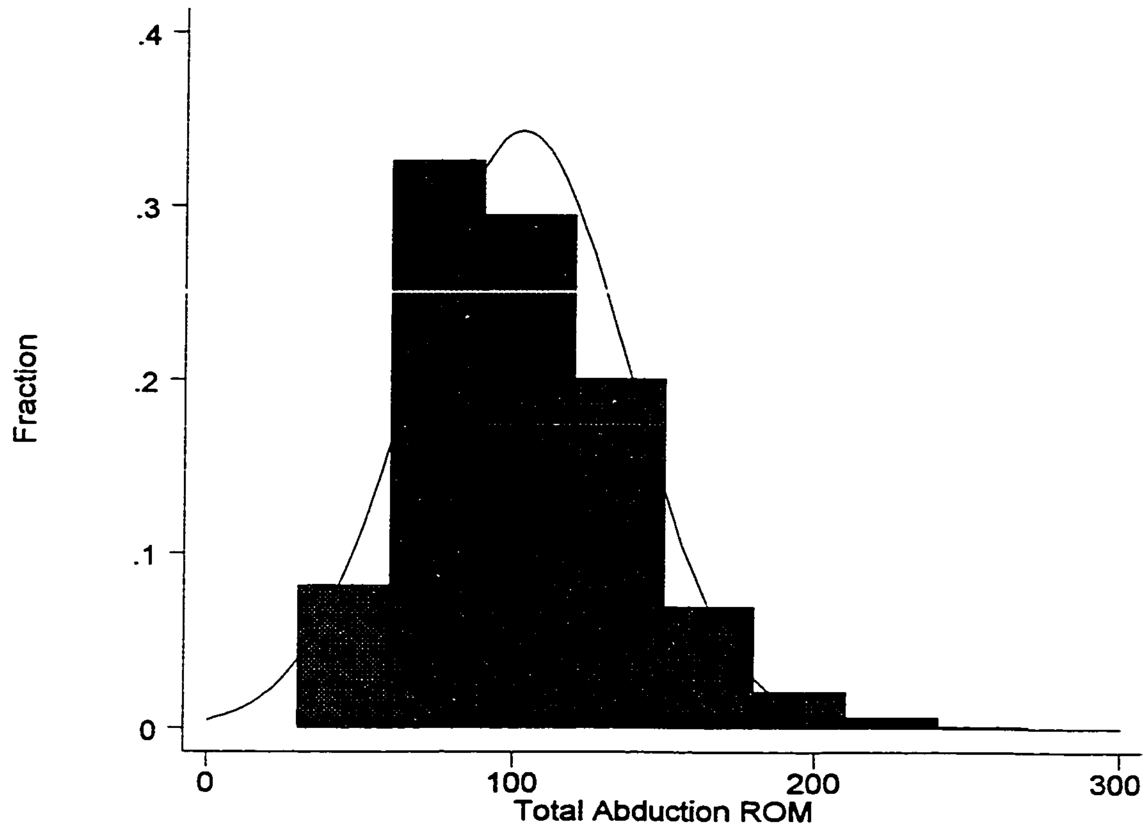

Figure 7.2 : Distribution of total abduction flexibility (degrees) (n=997)

The mean and 95% CI for skate blade hollow measurement recorded for 517 players was 0.50 (0.49, 0.51) inches. The distribution of skate blade hollow measurement was normal (Figure 7.3). There were 53.77% of the players for whom skate blade hollow recorded was 0.5 inches.

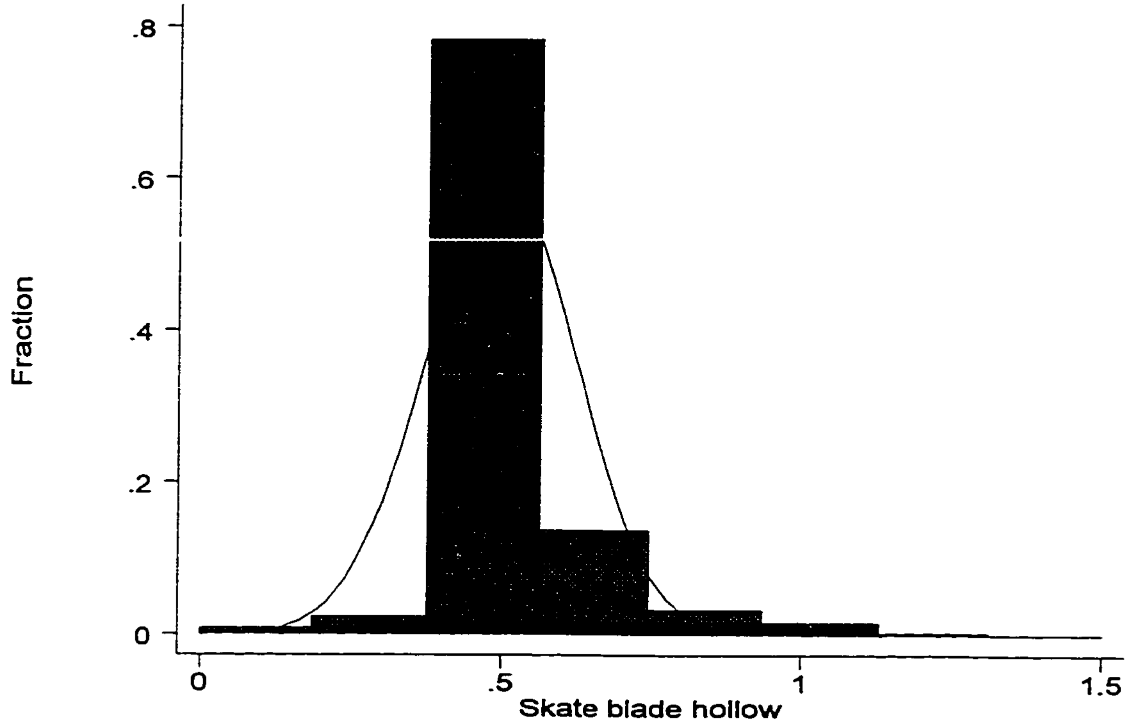

Figure 7.3 : Distribution of skate blade hollow measurement (n=517)

The distributions for total number of off-season sport specific training sessions reported by 852 players over 3 months (June to August) and over 1 month (August) were right skewed (Figures 7.4 and 7.5). The median number of sessions (minimum, maximum) reported over 3 months (June to August) was 19 (0, 140) sessions and over 1 month (August) was 15 (0, 80) sessions.

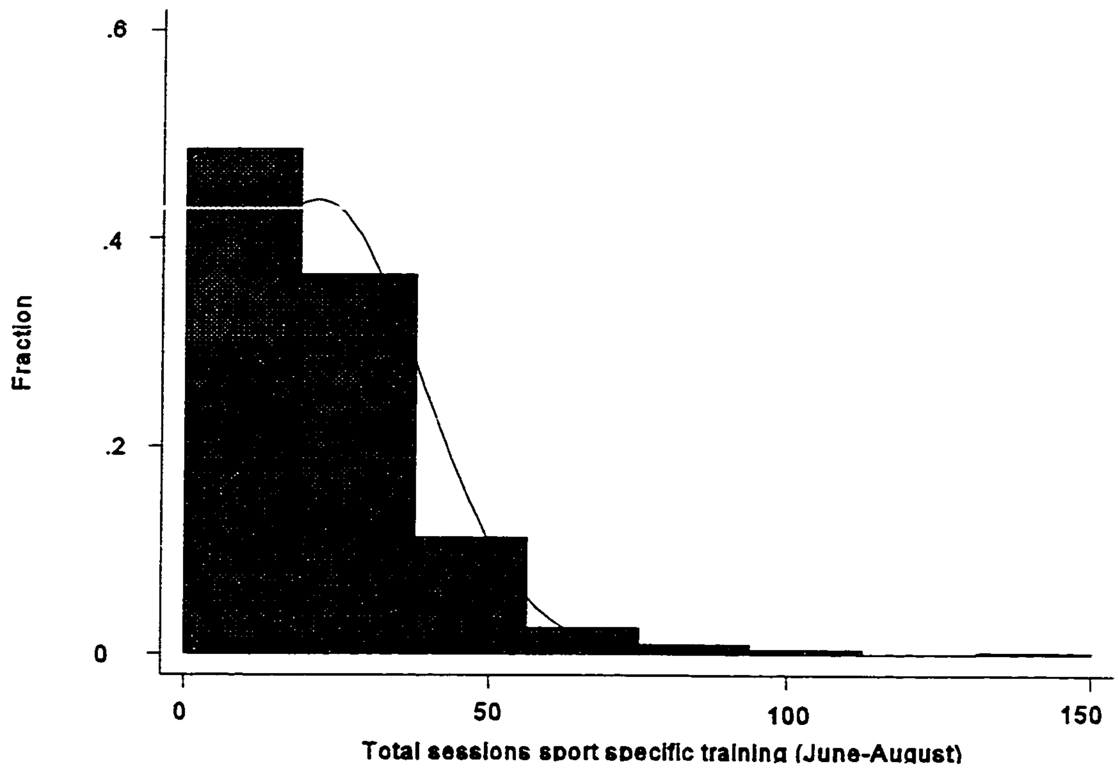

Figure 7.4 : Distribution of total number of sessions sport specific training reported (June to August 1998) (n=852)

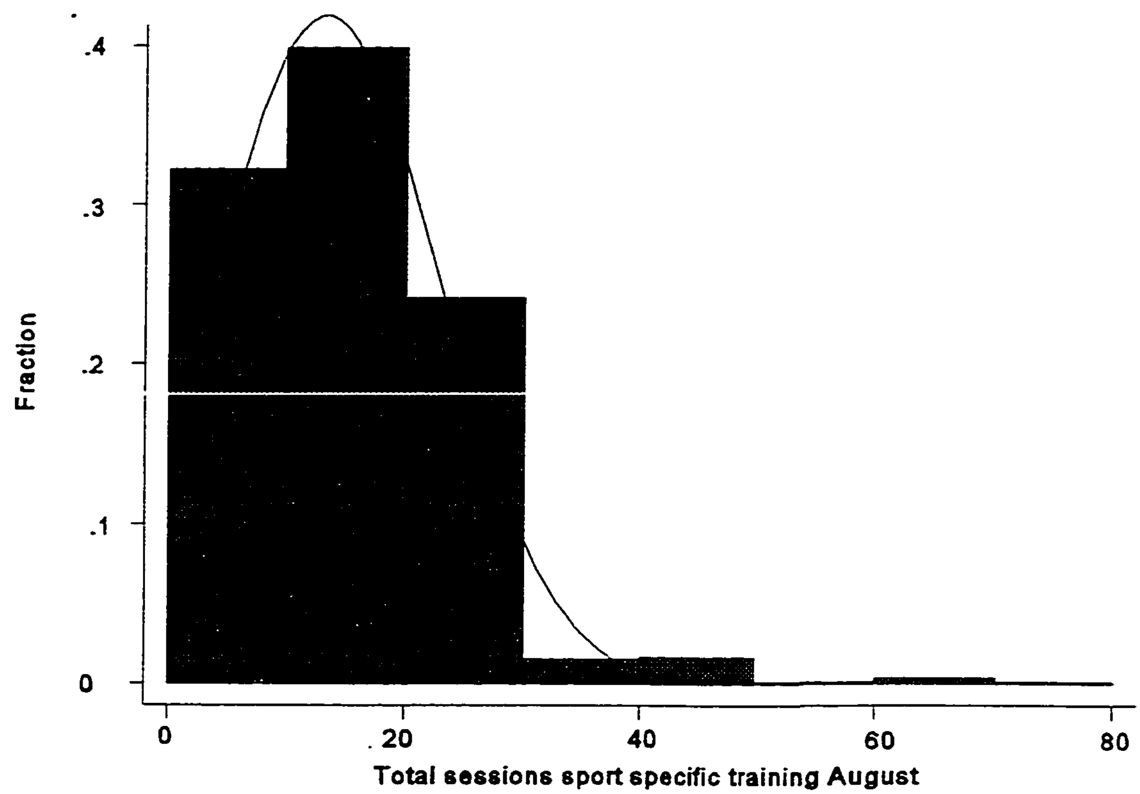

Figure 7.5 : Distribution of total number of sessions sport specific training reported (August 1998) (n=852)

The distribution of years of experience in the NHL reported by 824 players was skewed right (Figure 7.6) as 407 players (49.39% of the players reporting years of NHL experience) were rookies and reported 0 years experience in the NHL. The median (minimum, maximum) was 1 (0, 19) years. The distribution of years of experience in the NHL reported by 417 veteran players was closer to normally distributed but still slightly right skewed (Figure 7.7). The mean and 95% CI for years experience in the NHL by veterans was 6.06 (5.60, 6.52) years. The median (minimum, maximum) for years experience in the NHL by veterans was 5 (1, 19) years.

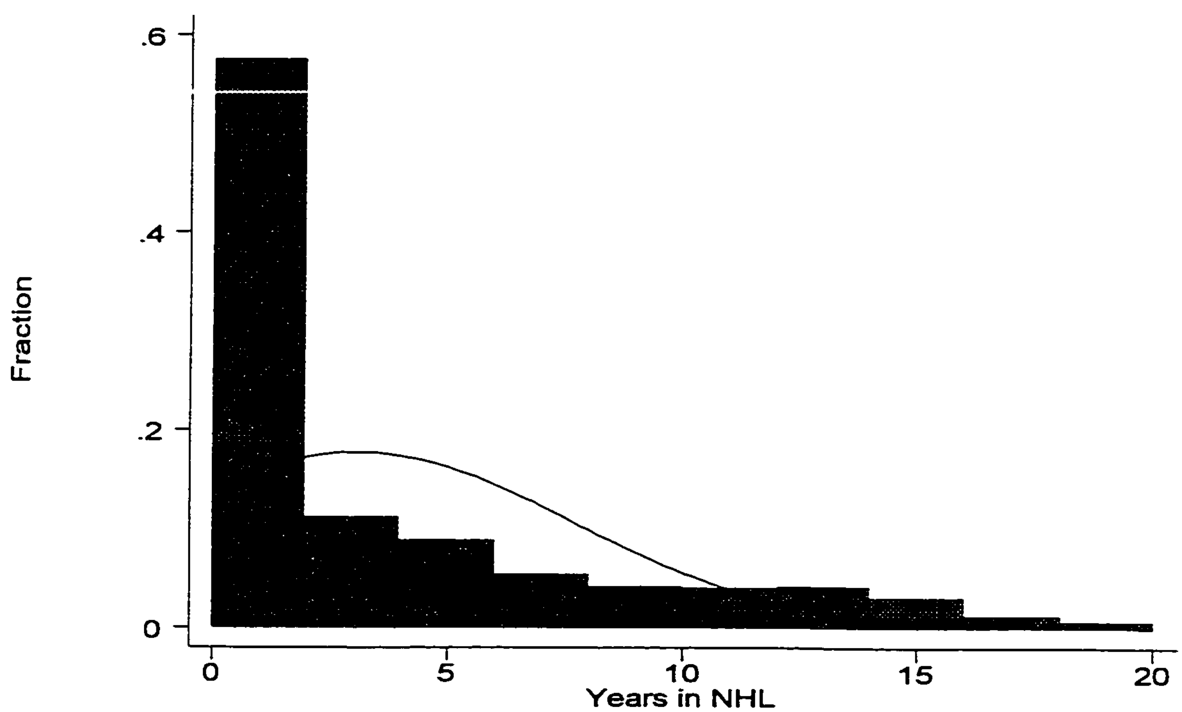

Figure 7.6 : Distribution of Years NHL Experience (n=824)

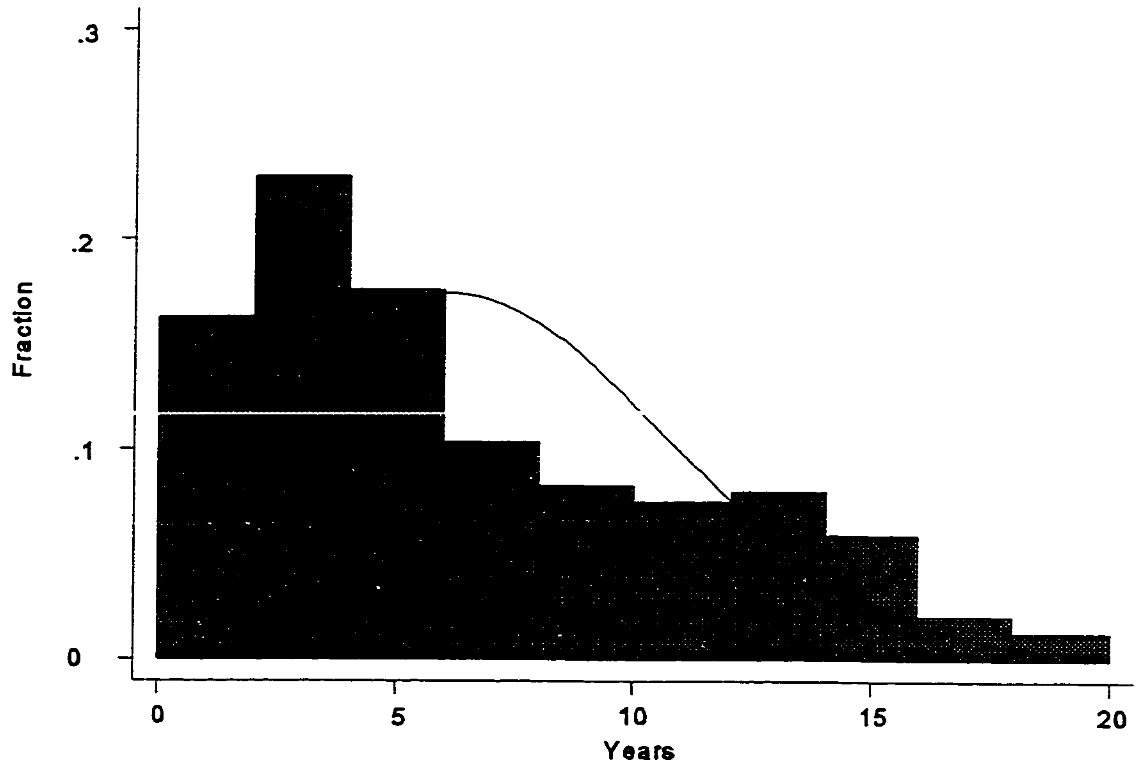

Figure 7.7 : Distribution of Years NHL Experience (Veterans only) (n=388)

The distribution of age reported on 685 players was normal (Figure 7.8). The mean and 95% confidence intervals (95% CI) for age was 25.66 (25.3, 26.02) years. It should be noted that of the 562 players for which both age and years NHL experience was reported, only 24.02% were rookies and 75.98% were veterans.

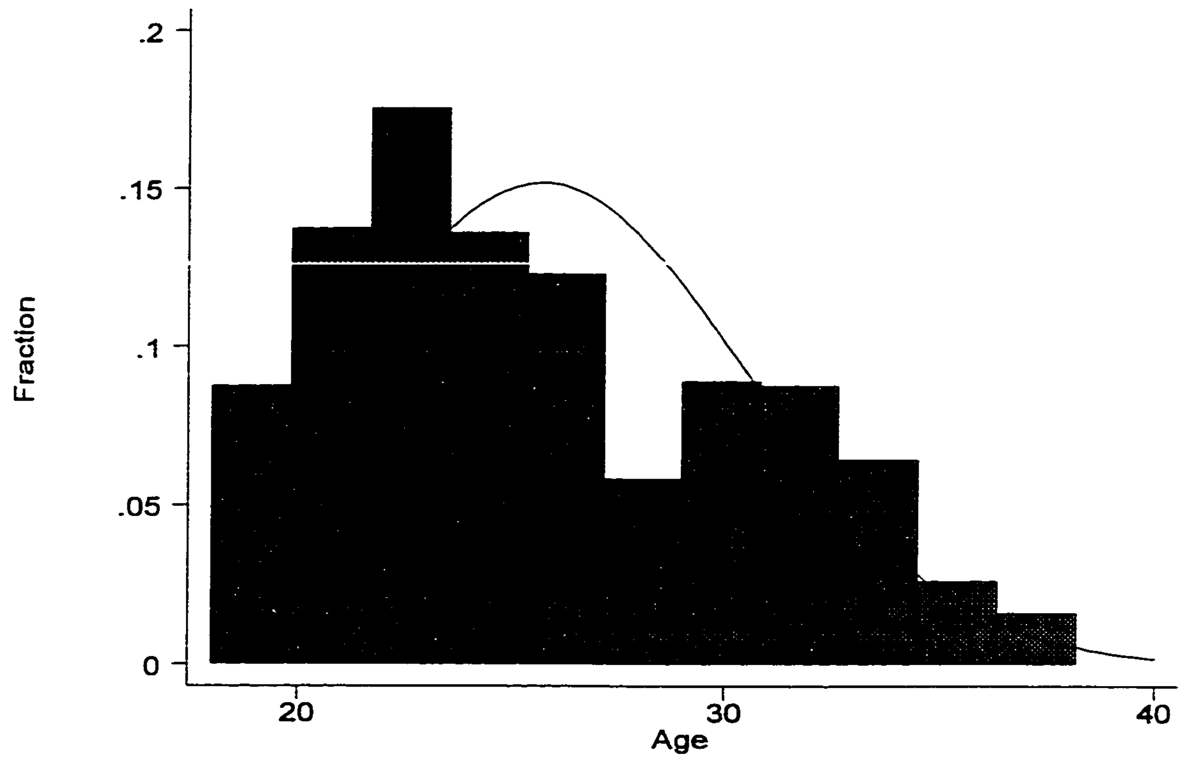

Figure 7.8 : Distribution of Age (n=685)

A total of 899 players reported previous groin or abdominal strain injury status within the last year on the questionnaires. Of these, 77.64% reported no history of previous groin or abdominal strain injury and 22.36% reported a history of previous groin or abdominal strain injury. Only 17 players (1.89%) reported a history of previous hernia (inguinal or abdominal); all of these 17 players also reported a history of previous groin or abdominal strain injury.

For purposes of analysis with contingency tables some continuous and integer variables were dichotomized into two groups as follows;

1. Peak adductor torque was grouped based on a cut-point of 1 SD below the mean (142.54 Nm).
2. Total abduction ROM was grouped based on a cut-point of 1 SD below the mean (67.49 degrees).
3. Total number of sport specific training sessions reported (June to August 1998) was grouped based on a-priori hypothesis where cut-point of 18 sessions was chosen.
4. Total number of sport specific training sessions reported (August 1998) was grouped based on a-priori hypothesis where cut-point of 12 sessions was chosen.
5. Skate blade hollow measurement was grouped based on a cut-point of 1 SD below the mean (0.375 inches).
6. Years experience in the NHL was grouped by rookies (0 years experience) and veterans (>= 1 year experience).
7. Age was grouped based on a cut-point at the mean age of 25 years.

7.1.3 Relationships between exposure variables

Understanding the relationships between various exposure variables is essential prior to examining them as potential risk factors for injury in a cohort analysis

A scatterplot was constructed to demonstrate the relationship between age and years experience in the NHL (Figure 7.9). The Pearson correlation coefficient associated with these two variables was 0.88 ($p<0.0001$), suggesting a significant association. The number of observations for years experience in the NHL was 824 and for age was only 685. In addition, one half of those who reported NHL experience on the questionnaire were rookies, whereas only 24% of the players for which age was reported were rookies. As such, the association with all other variables (both exposure and injury) will be made with years experience in the NHL and not age.

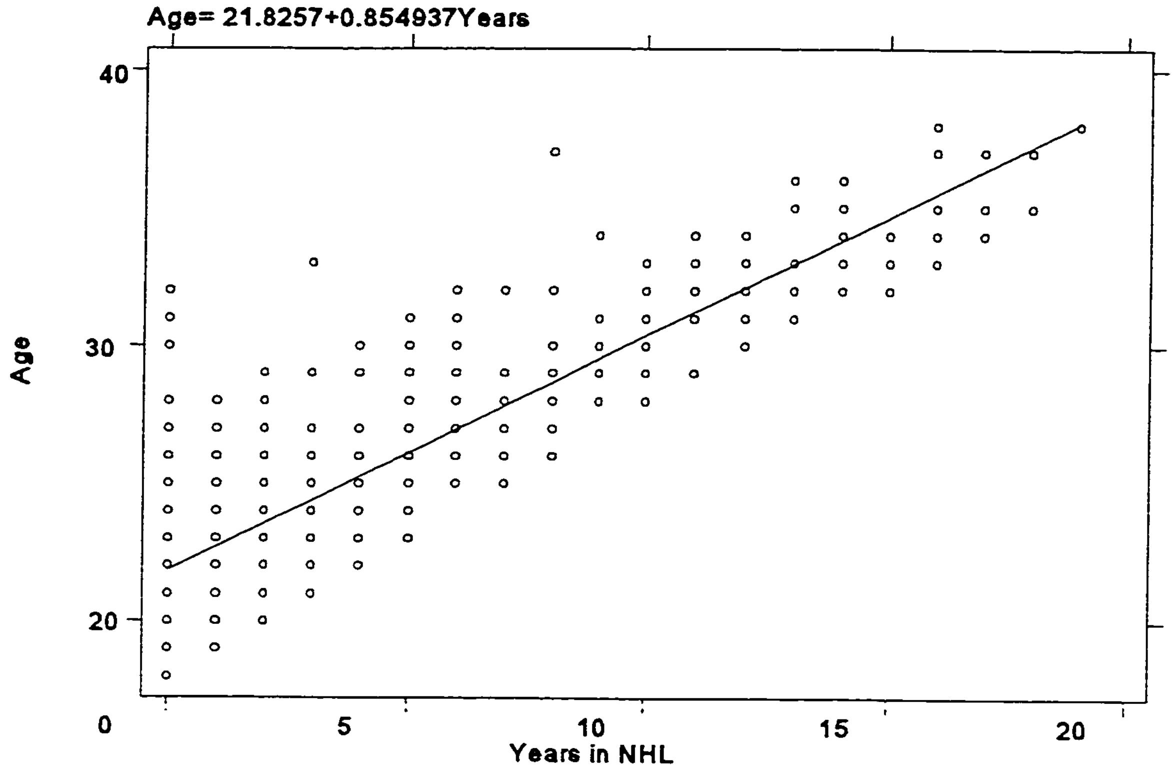

Figure 7.9 : Simple linear regression of Age on Years NHL Experience

Some associations between exposure variables were made by calculating appropriate odds ratios. An odds ratio as defined by Last (28), is the ratio of two odds. An exposure-odds ratio for a set of case-control data is the ratio of odds in favour of an exposure among the cases, to the odds in favour of an exposure among non-cases. In this section cases and non-cases will be defined from a second exposure variable

In the assessment of the exposure variables there were some fundamental differences noted between the rookie and veteran players. Calculated odds ratios (95% CI) are reported in Table 7.2. The odds of a veteran being at least 25 years old was 17 times the odds of a rookie being at least 25 years old. The odds of rookies doing at least 18 sessions sport specific training (6 weeks/ 3 times per week) was 4 times the odds of veterans doing at least 18 sessions (Table 7.2). A scatterplot demonstrates the decreasing trend in the total number of sessions sport specific training reported with increasing number of years NHL experience (Figure 7.10). The slope of the regression line was -1.34 (-1.6 , -1.08). That is, for every one year increase in years NHL experience, one would expect off-season sport specific training sessions to decrease by 1.3 sessions. As the 95% C.I. does not include 0 we confirm an inverse relationship between years experience and sport specific training. The odds of rookies doing at least 12 sessions sport specific training in August (4 weeks/ 3 times per week) was 3 times the odds of veterans doing at least 12 sessions. The odds of veterans reporting previous history of injury in the past year was 1.4 times the odds of rookies reporting previous injury. The odds of veterans having total abduction flexibility more than 1 SD below the mean was 2 times the odds of rookies having total abduction flexibility more than 1 SD below the mean. The odds of veterans having peak adductor torque more than 1 SD below the mean was no different than odds of rookies having peak adductor torque more than 1 SD below the mean.

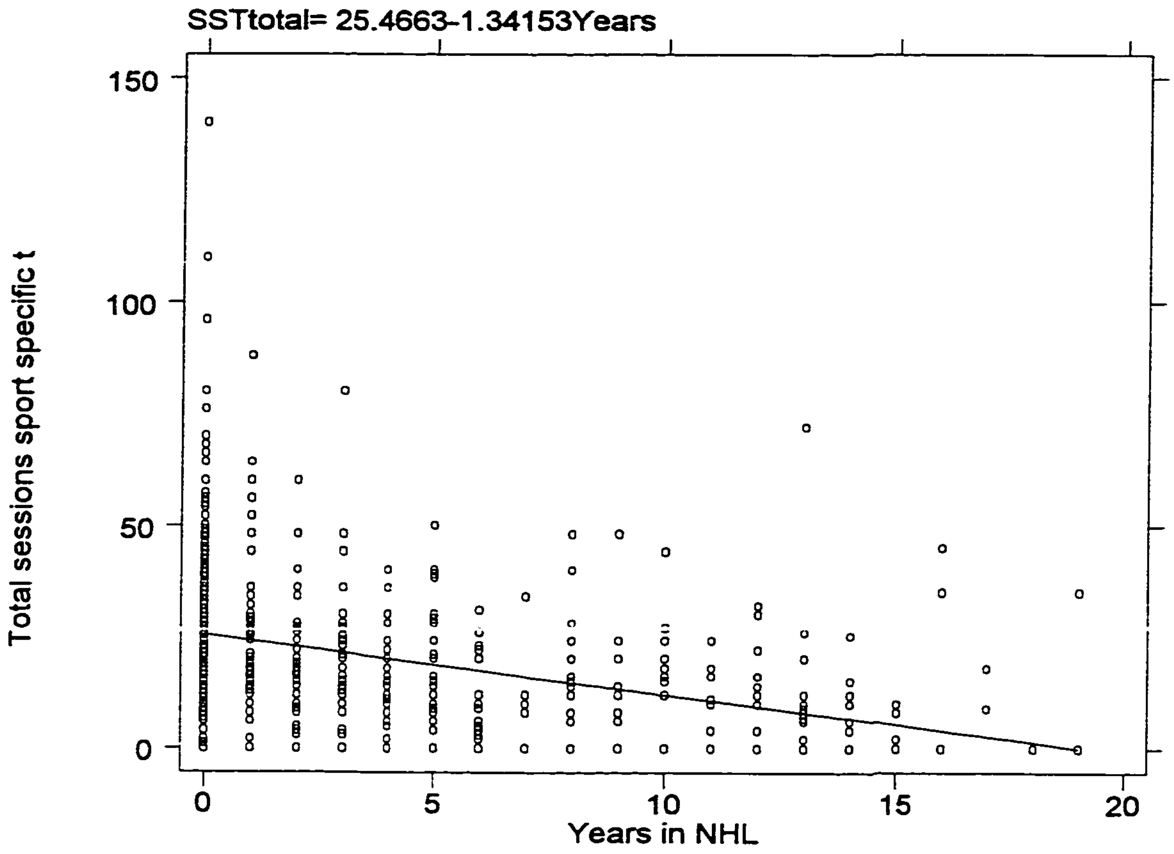

Figure 7.10 :Simple linear regression of total sessions sport specific training (June to August 1998) on Years NHL Experience

Table 7.2: Associations between Years experience in the NHL (Rookie/Veteran) and other exposure variables

Exposure	Rookie	Veteran	Odds ratio (95% CI)
Age < 25 years	117	78	17.42 (9.99, 30.35)
Age >= 25 years	18	209	
Total sport specific training < 18 sessions	109	242	4.13 (3.05, 5.6)
Total sport specific training >= 18 sessions	264	142	
Sport specific training < 12 sessions (August)	94	192	2.96 (2.17, 4.02)
Sport specific training >= 12 sessions (August)	278	192	
Previous injury	78	108	1.43 (1.03, 1.99)
No previous injury	317	307	
Abduction range of motion < 67.5 degrees	38	65	1.92 (1.25, 2.94)
Abduction range of motion >= 67.5 degrees	326	291	
Peak isometric adductor torque < 142.5 Nm	58	58	1.02 (0.69, 1.52)
Peak isometric adductor torque >= 142.5 Nm	305	298	

Those players who reported previous history of groin or abdominal strain injury were also compared to those who reported no previous history on abduction flexibility, peak adductor torque, and sport specific training. The odds ratio explaining those associations are reported in Table 7.3. Those players reporting previous injury are at 1.71 times the odds of having peak adductor torque more than 1 SD below the mean than are those players reporting no previous injury. There is no significant difference in the odds of having total abduction flexibility more than 1 SD below the mean between those reporting previous injury and those reporting no previous injury despite a point estimate of 1.49, as this 95% C.I. includes one. There is no significant difference in the odds of reporting less than 18 sessions sporty specific training between those reporting previous injury and those reporting no previous injury as this 95% C.I. also includes one.

Table 7.3: Associations between previous injury and other exposure variables

Exposure	Previous Injury	No previous injury	Odds ratio (95% CI)
Peak isometric adductor torque < 142.5 Nm	39	94	1.71 (1.13, 2.6)
Peak isometric adductor torque >= 142.5 Nm	131	540	
Abduction range of motion < 67.5 degrees	29	76	1.49 (0.94, 2.36)
Abduction range of motion >= 67.5 degrees	143	557	
Total sport specific training < 18 sessions	84	300	1.04 (0.74, 1.45)
Total sport specific training >= 18 sessions	97	362	

There appears to be no relationship between total number of sessions sport specific training and peak adductor torque or total number of sessions sport specific training and total abduction flexibility. The odds ratio explaining these associations are reported in Table 7.4.

Table 7.4: Associations between total number of sessions sport specific training and other exposure variables

Exposure	Total sport specific training < 18 sessions	Total sport specific training >= 18 sessions	Odds ratio (95% CI)
Peak isometric adductor torque < 142.5 Nm	65	69	1.21 (0.83, 1.75)
Peak isometric adductor torque >= 142.5 Nm	296	379	
Abduction range of motion < 67.5 degrees	52	53	1.25 (0.83, 1.88)
Abduction range of motion >= 67.5 degrees	310	395	

Scatterplots are constructed to confirm this lack of association (Figure 7.11 and 7.12). The slopes of both regression lines contain 0 in the 95% C.I. confirming no association between the variables.

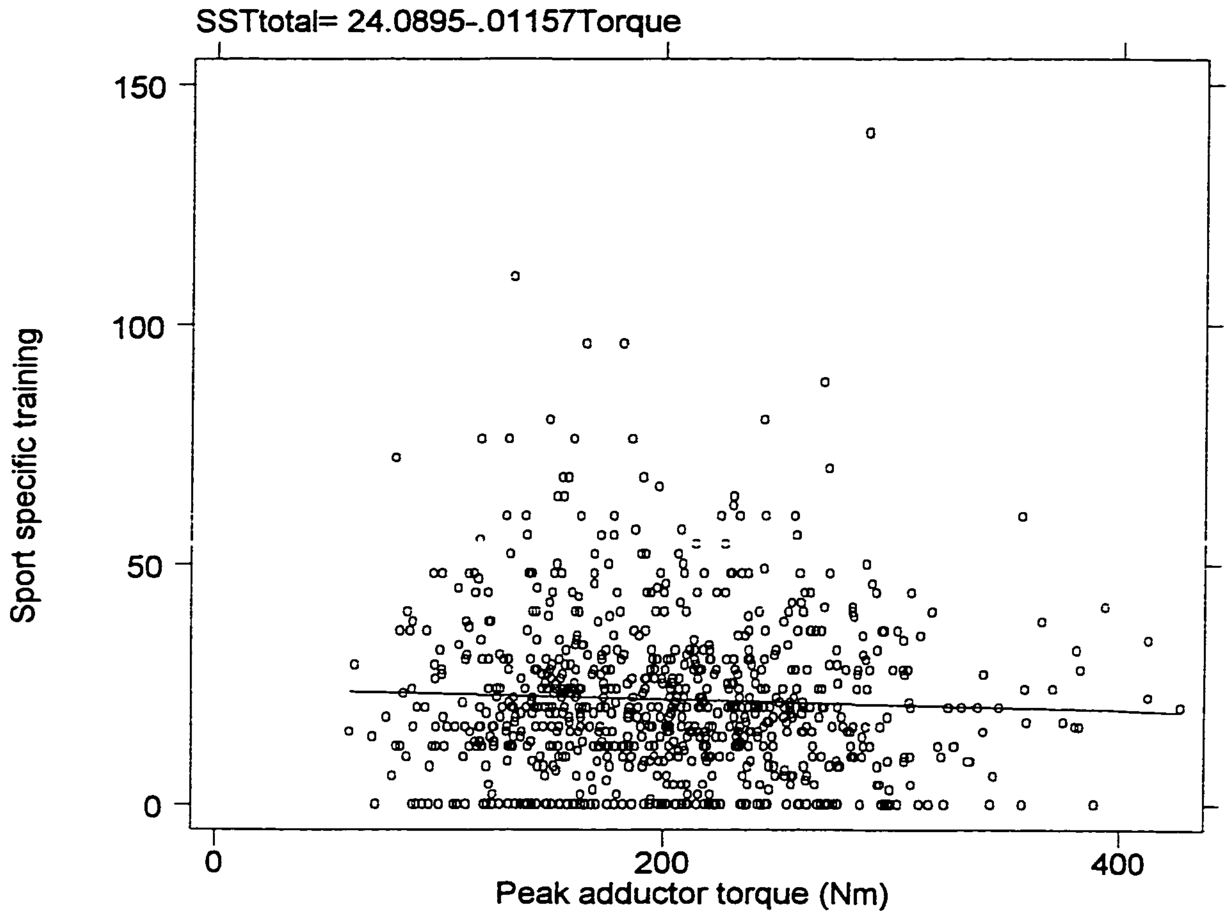

Figure 7.11 :Simple linear regression of total sessions sport specific training (June to August 1998) on Peak isometric adductor torque (Nm)

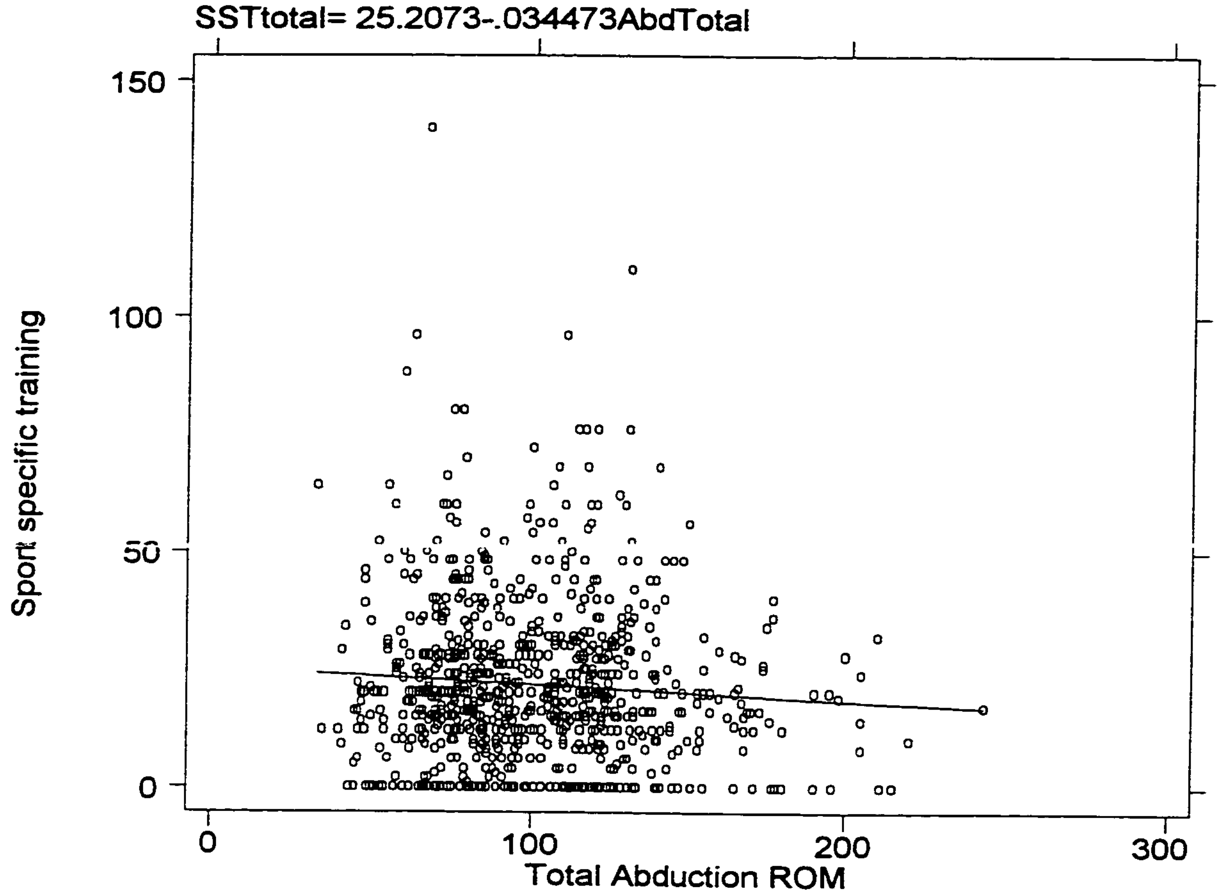

Figure 7.12 :Simple linear regression of total sessions sport specific training (June to August 1998) on Total abduction flexibility (degrees)

7.2. Injury Data Analysis

There were 52 groin and abdominal strain injuries reported during training camp by a total of 23 NHL teams reporting injuries through the NHLISS. An injury was reportable if a player was removed from the current practice or game or the player missed the next day's session. The cumulative incidence rate (95% CI) calculated based on 1357 participating players was 3.83 (2.87, 4.99) injuries/100 players/training camp period. Based on a total number of athlete exposures (total number of sessions x total number of players per session) of 18,132 for training camp the incidence density was 2.87(2.14, 3.76) injuries/1000 athlete exposures.

The groin and abdominal strain injuries reported consisted of 17.31% (8.23, 30.31) abdominal muscle strain injuries and 82.69% (69.67, 91.77) groin muscle strain injuries. There were no abdominal or inguinal hernias reported. Only 17.31% (8.23, 30.31) of the injuries were reported as re-injuries. That is, any injury reported in which the player had a previous injury occurring in the prior season or off-season to the same body region. Ninety-one percent of the injuries reported were reported as non-contact in nature (torsion, stretch, overuse, spontaneous or insidious onset). Player position was not reported for 34.62% (21.97, 49.09) of the injuries, 38.46% (25.3, 52.98) of the injuries were incurred by offensive players, 17.31% (8.23, 30.33) by goalies, and 9.62% (3.20, 21.03) by defensive players. When we examined the proportion of injuries occurring during different time periods within a session, there was no significant difference in the proportion of injuries occurring during the 3 periods in a game session or the 4 quarters of a practice session. The distribution for total sessions (games or practices) missed due to injury was right skewed with 25 injuries reported as no time loss. The median (minimum, maximum) number of sessions missed due to groin and abdominal strain injury in training camp was 2 (0, 31) sessions.

7.3 Primary Cohort Analysis

The initial approach to assessing the relative risk of injury based on the presence or absence of defined risk factors was to assess 2 X 2 contingency tables with risk factors dichotomized as described in section 7.1.2 and to stratify on potential confounding variables where cell sizes were large enough to do so. As defined by Last (28), the relative risk (RR) of injury is the ratio of the risk of injury among the exposed to the risk among those not exposed. The relative risks of injury based on univariate analysis of potential risk factors are reported in Table 7.5. The attributable fraction exposed (AR%), as defined by Hennekens et al (24), is the proportion (%) by which the incidence rate of outcome among those exposed in this sample would be reduced if the exposure were eliminated.

7.3.1 Univariate analysis of sport specific training as a risk factor for groin and abdominal strain injury

Based on the first a-priori hypothesis we looked at the relative risk of injury between those players reporting less than 18 sessions sport specific training (6 weeks / 3 times per week) and those reporting at least 18 sessions between June and August. Those players who did less than 18 sessions sport specific training were at 3 times the risk of groin or abdominal strain injury during training camp. The AR% (95% CI) was 65.43%

(24.89, 84.08). That is, the incidence rate of injury among those reporting sport specific training less than 18 sessions in this sample would be reduced by 65% if these players were to do at least 18 sessions sport specific training in the off-season. Assessing sport specific training in August alone, those players who did less than 12 sessions sport specific training were at 3 times the risk of groin or abdominal strain injury during training camp. The AR% (95% CI) was 65.32% (24.64, 84.03). That is, the incidence rate of injury among those reporting sport specific training less than 12 sessions in this sample would be reduced by 65% if these players were to do at least 12 sessions sport specific training in August of the off-season.

7.3.2 Univariate analysis of peak isometric adductor torque as a risk factor for groin and abdominal strain injury

Based on the second a-priori hypothesis we looked at the relative risk of injury between those players scoring more than one SD below the mean peak adductor torque (142.5 Nm) and those scoring at least 145.2 Nm. As the 95% CI included one we concluded that there was no difference in the risk of injury based on peak isometric adductor torque measured preseason.

7.3.3 Univariate analysis of total abduction range of motion as a risk factor for groin and abdominal strain injury

Based on the third a-priori hypothesis we looked at the relative risk of injury between those players scoring more than one SD below the mean total abduction flexibility (67.5 degrees) and those scoring at least 67.5 degrees. As the 95% CI included one we conclude that there was no difference in the risk of injury based on total abduction flexibility measured preseason.

7.3.4 Univariate analysis of other potential risk factors for groin and abdominal strain injury

In addition, we assessed the relative risk of injury for players who reported previous history of groin or abdominal strain injury (previous season) and those who did not, rookies versus veterans, and players with skate blade hollow less than the mean (0.5 inches) versus those greater than or equal to the mean. Those players who reported previous injury were at almost 3 times the risk of injury during training camp. Veterans were at almost 6 times the risk of groin or abdominal strain injury during training camp than were rookies. There was no increased risk of injury based on skate blade hollow measurement.

Table 7.5: Relative Risk of groin and abdominal strain injury based on univariate analysis of exposure variables

Exposure	Injury	No Injury	Relative Risk (95% CI)
Total sport specific training < 18 sessions	20	370	3.38 (1.45, 7.92)
Total sport specific training >= 18 sessions	7	455	
Sport specific training < 12 sessions (August)	17	306	2.88 (1.33, 6.26)
Sport specific training >= 12 sessions (August)	10	519	
Peak isometric adductor torque < 142.5 Nm	4	148	0.71 (0.26, 1.97)
Peak isometric adductor torque >= 142.5 Nm	29	764	
Abduction range of motion < 67.5 degrees	3	138	0.56 (0.18, 1.76)
Abduction range of motion >= 67.5 degrees	30	776	
Previous injury	12	173	2.69 (1.3, 5.59)
No previous Injury	16	648	
Veteran	37	590	5.69 (2.05, 15.85)
Rookie	4	382	
Skate blade >= 0.5"	15	360	1.42 (0.48, 4.21)
Skate blade < 0.5"	4	138	

7.3.5 Stratified analysis of sport specific training as a risk factor for groin and abdominal strain injury

For the purposes of statistically analyzing the relative risk of injury after stratifying on a potential confounding or effect modifying variable, odds ratios (OR's) were calculated to approximate the relative risk of injury such that the Mantel-Haenszel test of heterogeneity could be used to test for evidence for or against common O.R.'s once stratified. If there was no evidence against combining the O.R.'s ($p > 0.05$) for the tables once stratified then the Mantel-Haenszel combined O.R. (95% CI) was calculated.

Based on the small number of injuries and small cell sizes once a contingency table was stratified once on a potential confounding or effect modifying variable; stratification on a second variable could not be assessed due to empty cells.

Based on investigation of the first a-priori hypothesis we assessed the relative risk of injury between those players reporting less than 18 sessions sport specific training (6 weeks/ 3 times per week) and those reporting at least 18 sessions between June and August, stratifying on other potential confounding or effect modifying variables including previous injury, NHL experience (rookie/veteran), peak isometric adductor torque, and total abduction flexibility. The exposure variable on which the tables were stratified, the p-value for the Mantel-Haenszel test of heterogeneity, and the Mantel-Haenszel combined O.R. (95% CI) are reported in Table 7.6.

Table 7.6: Results of stratified analysis of the association between sport specific training and groin and abdominal strain injury

Exposure Variable for stratification	P-value for Mantel-Haenszel test of heterogeneity	Mantel-Haenszel combined odds ratio (95% CI)
Previous Injury	0.30	3.5 (1.48, 8.51)
Years experience in the NHL	0.66	2.03 (0.81, 5.13)
Peak adductor torque	0.55	4.34 (1.72, 10.92)
Total abduction ROM	0.76	4.37 (1.72, 11.04)

In assessing the risk of injury related to sport specific training stratified separately on previous injury, peak adductor torque and total abduction flexibility there was no evidence against common O.R.'s . The risk of injury for players who reported less than 18 sessions sport specific training in the off-season was close to 4 times the risk of injury for players who reported at least 18 sessions. This risk did not depend on previous history of injury, or peak adductor torque or total abduction flexibility. This risk is also close to the relative risk calculated prior to stratifying on previous injury, peak adductor torque or total abduction flexibility (RR = 3.38). Statistically, previous history, peak adductor torque or total abduction flexibility do not appear to be effect modifiers or confounders in the relationship between sport specific training and injury.

In assessing the risk of injury related to sport specific training stratified on NHL experience (rookie/veteran) there was no evidence against common O.R.'s. The risk of injury for players who reported less than 18 sessions sport specific training in the off-season was the same as the risk of injury for players who reported at least 18 sessions. This risk did not appear to depend on rookie/veteran status and hence rookie/veteran status appeared not to be an effect modifier in the relationship between sport specific training and injury. This risk , however, was very different from the relative risk calculated prior to stratifying on NHL experience (RR = 3.38), as the 95% CI included one. Statistically, years experience in the NHL appears to be a confounder in the relationship between sport specific training and injury.

The calculated incidence rates (95% CI) based on level of sport specific training were 5.13 (3.16, 7.81) injuries/ 100 players/ training camp period for those players who reported less than 18 sessions sport specific training in the off-season and 1.52 (0.61, 3.10) injuries/ 100 players/ training camp period for those players who reported at least 18 sessions sport specific training in the off-season. Other cut points for sport specific training were used to examine cumulative incidence rates (Table 7.7).

Table 7.7: Cumulative Incidence Rates (95% CI) (injuries/100 players/training camp period) calculated based on various cut-points for sport specific training

Cut-point chosen (total # sessions sport specific training)	Cumulative incidence rate Sport specific training < cut-point chosen	Cumulative incidence rate Sport specific training >= cut-point chosen	Relative Risk
1	7.83 (3.64 - 14.34)	2.44 (1.45 - 3.83)	3.2 (1.48, 6.95)
9	6.11 (3.09 - 10.67)	2.38 (1.37 - 3.84)	2.57 (1.21, 5.43)
18	5.13 (3.16 - 7.81)	1.52 (0.61 - 3.1)	3.37 (1.45, 7.92)
27	4.26 (2.77 - 6.22)	0.75 (0.09 - 2.7)	5.64 (1.35, 23.65)
36	3.68 (2.42 - 5.34)	0.69 (0.02 - 3.78)	5.33 (0.73, 38.98)

7.3.6 Stratified analysis of peak adductor torque as a risk factor for groin and abdominal strain injury

Based on the second a-priori hypothesis we assessed the relative risk of injury between those players scoring more than one SD below the mean peak adductor torque (142.5 Nm) and those scoring at least 142.5 Nm, stratifying on other potential confounding or effect modifying variables including previous injury, NHL experience (rookie/veteran), sport specific training, and total abduction flexibility. There was no evidence of effect modification or confounding by any of these other variables. The relative risk of injury approximated by calculating MH combined O.R. always contained one in the 95% CI. Therefore we concluded that there was no difference in the risk of injury based on peak isometric adductor torque measured preseason.

7.3.7 Stratified analysis of total abduction flexibility as a risk factor for groin and abdominal strain injury

Based on the third a-priori hypothesis we looked at the relative risk of injury between those players scoring more than one SD below the mean total abduction flexibility (67.5 degrees) and those scoring at least 67.5 degrees, stratifying on other potential confounding or effect modifying variables including previous injury, NHL experience (rookie/veteran), sport specific training, and peak adductor torque. There was no evidence of effect modification or confounding by any of these other variables. The relative risk of injury approximated by calculating MH combined O.R. always contained one in the 95% CI. Therefore, we concluded that there was no difference in the risk of injury based on total abduction flexibility measured preseason.

7.3.8 Stratified analysis of previous injury as risk factor for groin and abdominal strain injury

In addition, stratified analysis was done assessing the relationship between previous injury and outcome of injury, stratifying on other potential confounding or effect modifying variables (sport specific training, peak adductor torque, total abduction flexibility, NHL experience). The exposure variable on which the tables were stratified, the p-value for the Mantel-Haenszel test of heterogeneity, and the Mantel-Haenszel combined O.R. (95% CI) are reported in table 7.8.

Table 7.8: Results of stratified analysis of the association between previous injury and groin and abdominal strain injury

Exposure Variable for stratification	P-value for Mantel-Haenszel test of heterogeneity	Mantel-Haenszel combined odds ratio (95% CI)
Sport specific training	0.30	2.6 (1.18, 5.74)
Years experience in the NHL	0.65	2.42 (1.08, 5.45)
Peak adductor torque	0.66	2.45 (1.09, 5.52)
Total abduction ROM	0.22	2.35 (1.05, 5.27)

In assessing the risk of injury related to previous injury stratified separately on sport specific training, years experience in the NHL, peak adductor torque, and total abduction flexibility there was no evidence against common O.R.'s. The risk of injury for players who reported previous injury was approximately 2.5 times the risk of injury for players who reported no previous injury. This risk did not depend on sport specific training, years experience in the NHL, peak adductor torque, or total abduction flexibility. This risk is also close to the relative risk calculated prior to stratifying on other exposure variables (RR = 2.69). Statistically, sport specific training, years experience in the NHL, peak adductor torque, and total abduction flexibility do not appear to be an effect modifiers or confounders in the relationship between previous injury and injury during training camp.

7.4. Secondary Cohort Analysis

Logistic regression analysis was used to further explore the relationship between the outcome of groin or abdominal strain injury and the exposure variables in question. In exploring the potential model of best fit to predict the log odds of injury most of the exposure variables are treated as continuous variables (total number of sessions of sport specific training, peak adductor torque, total abduction flexibility, years NHL experience in the NHL, and skate blade hollow measurement) in the models explored. Previous injury is the only exposure variable that remains treated as a categorical variable in the models explored. In a fashion typical to epidemiological research, an initial model was estimated which included all possible exposure variables and potential interaction variables and then subsequent nested models were compared to the more complex model using a likelihood ratio test to determine the best estimated model. If this test was significant then the unrestricted model was chosen as the best estimate.

The prefixes used in the following models are defined as follows;

SST = total # sessions sport specific training reported (June - August)

SST^2 = quadratic term (total # sessions sport specific training reported)^2

Torque = peak adductor torque (Nm)

Years = # years NHL experience

Yr^2 = quadratic term (# years NHL experience)^2

SSTtorque = interaction term (SST x Torque)

PrevInj = previous injury (Yes=1, No=0)

Statistically the model which is the estimated logistic regression model of best fit was the following model;

log odds of Injury = 0.0956SST + 0.0085Torque + 0.3377Years - 0.0202Yr^2 - 0.0007SSTtorque -5.0356

However, previous injury was clinically felt to be integral to the understanding injury outcome based on the stratified analysis and was kept in the model though it was not essential statistically based on the likelihood ratio test. The model thus estimated was the following model;

Model 1: log odds of Injury = 0.0865SST + 0.0083Torque + 0.6931PrevInj + 0.3333Years -0.0201Yr^2 - 0.0007SSTtorque -5.8876

Estimations of probability of injury based on this model are calculated based on the following equation (Table 7.9);

Probability of injury x 100 (%)=($e^{\text{log odds of injury}}$/ 1 + $e^{\text{log odds of injury}}$) x 100

Table 7.9: Predictions of probability of injury (%) (95% CI) using Logistic Regression Model 1; log odds of Injury = 0.0865SST + 0.0083Torque + 0.6931PrevInj + 0.3333Years - 0.0201Yr² - 0.0007SSTtorque -5.8876

Level of SST	Vet/PrevInj=0	Rookie/PrevInj=0	Vet/PrevInj = 1	Rookie/PrevInj =1
SST = 0	4.57% (3.20, 6.43)	1.47% (0.67, 2.56)	8.74% (6.72, 10.99)	2.9% (1.83, 4.46)
SST =18	1.73% (0.87, 2.92)	0.55% (0.15, 1.43)	3.4% (2.17, 4.96)	1.09% (0.49, 1.22)
SST =36	0.24% (0.03, 1.01)	0.2% (0.004, 0.78)	1.28% (0.58, 2.38)	0.4% (0.09, 1.22)

Vet = veteran with median # (5) years experience
Rookie = rookie with 0 years experience
SST = total # sessions sport specific training (June - August)
Torque = peak isometric adductor torque pre-season
Years = # years NHL experience
PrevInj = 0 if no previous injury , =1 if previous injury
Assumption of mean torque = 203 Nm

There is argument for also presenting a model without the interaction term (SST x Torque) included as there was no relationship seen between sport specific training and torque (Figure 11) and clinically the interaction term present cannot be explained. Without the interaction term in question the best fitting model was the following model;

Model 2: log odds of Injury = -0.056SST + 0.00043SST² + 0.00056Torque + 0.3612Years - 0.0213Years² + 0.799PrevInj - 4.458

Estimations of probability of injury (%) based on this model are calculated as above and reported in Table 7.10.

Table 7.10: Predictions of probability of injury (%) (95% CI) using Logistic Regression Model 2; log odds of Injury = -0.056SST + 0.00043SST^2 + 0.00056Torque + 0.3612Years - 0.0213Years^2 + 0.799PrevInj - 4.458

Level of SST	Vet/PrevInj=0	Rookie/PrevInj=0	Vet/PrevInj=1	Rookie/PrevInj=1
SST = 0	4.43% (3.09, 6.27)	1.28% (0.58, 2.38)	9.35% (7.35, 11.76)	2.81% (1.72, 4.29)
SST =18	1.92% (1.08, 3.27)	0.54% (0.15, 1.43)	4.15% (2.85, 5.94)	1.2% (0.53, 2.28)
SST =36	1.07% (0.48, 2.2)	0.3% (0.03, 1.01)	2.35% (1.39, 3.78)	0.67% (0.15, 1.43)

Vet = veteran with median # (5) years experience
Rookie = rookie with 0 years experience
SST = # sessions sport specific training
Torque = peak isometric adductor torque pre-season (Nm)
Years = # years NHL experience
PrevInj = 0 if no previous injury , =1 if previous injury
Assumption of mean torque = 203 Nm

In order to examine the robustness of the coefficients associated with sport specific training and considering the potential issue of multicollinearity between sport specific training and NHL experience a model was estimated using data for veterans only;

Model 3: log odds of Injury = 0.0889SST + 0.0104Torque + 0.7106PrevInj - 0.0007SSTtorque -5.64

The variables associated with NHL experience were no longer significant when eliminating the rookie data from the estimation. Estimations of probability of injury (%) based on this model are calculated as above and reported in Table 7.11.

Table 7.11: Predictions of probability of injury (%) (95% CI) using Logistic Regression Model 3 (veterans only); log odds of Injury = 0.0889SST + 0.0104Torque + 0.7106PrevInj - 0.0007SSTtorque -5.64

Level of SST	PrevInj=0	PrevInj=1
SST = 0	2.85 (1.83, 4.28)	5.63 (4.13, 7.45)
SST =18	1.11 (0.52, 2.12)	2.24 (1.34, 3.53)
SST =36	0.43 (0.08, 1.09)	0.87 (0.35, 1.79)

SST = # sessions sport specific training
PrevInj = 0 if no previous injury , =1 if previous injury
Torque = peak isometric adductor torque pre-season (Nm)
Assumption of mean torque = 203 Nm

To examine the robustness of the coefficient associated with sport specific training by removing the variables associated with torque (due to lack of statistical significance of the association between torque and injury in the stratified analysis) another model was estimated as follows;

Model 4: Log odds of Injury = -0.045SST + 0.921PrevInj - 3.86

Estimations of probability of injury (%) based on this model are calculated as above and reported in Table 7.12. The probability of injury with respect to sport specific training can be demonstrated by graphing the estimated predictions from the above model (Figure 7.17)

Table 7.12: Predictions of probability of injury (%) (95% CI) using Logistic Regression Model 4: log odds of Injury =- 0.045SSTtotal + 0.921PrevInj - 3.86

Level of SST	PrevInj=0	PrevInj=1
SST = 0	2.06 (1.18, 3.21)	5.03 (3.61, 6.68)
SST =18	0.93 (0.41, 1.86)	2.3 (1.36, 3.5)
SST =36	0.42 (0.13, 1.21)	1.04 (0.49, 2.02)

SST = # sessions sport specific training
PrevInj = 0 if no previous injury , =1 if previous injury

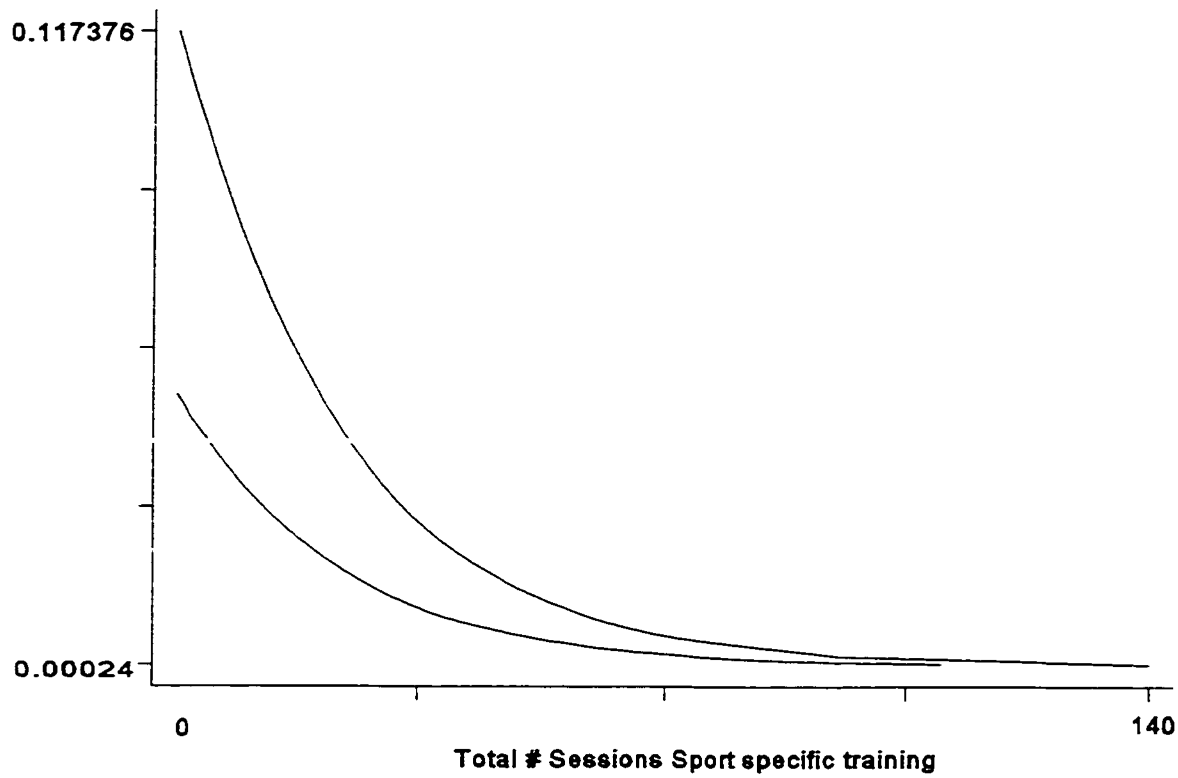

Figure 7.17: Predicted probability of injury for level of sport specific training and previous injury status (Based on Logistic Regression Model 4)

CHAPTER EIGHT: DISCUSSION

8.1 Exposure Data

The mean peak isometric adductor torque for 995 NHL players was 203 Nm. This was higher than the mean peak isometric adductor torque (177 Nm) found in the test-retest reliability study (Chapter 4) using varsity and recreational athletes as subjects. It is not surprising that an elite level of hockey player is producing overall higher peak isometric adductor torque in a sport specific muscle group. The mean total abduction range of motion for 997 NHL players was 102 degrees. This is higher than the average reported by Reid (44) of 90 degrees. Perhaps this is associated with the physiology of elite level hockey players. Some measurements of total hip abduction range of motion recorded, however, were extremely high (Figure 7.2) and arguably outside the range of physiological probability. This may have resulted in a high estimate of mean abduction range of motion. As a result, the validity and inter-rater reliability of this measurement must be questioned and caution taken regarding further interpretations in this study.

The median number of off-season sport specific training sessions reported (June to August 1998) was 19 sessions. The median number of off-season sport specific training sessions reported (August 1998) was 15 sessions. This suggests that many players increase their sport specific training closer to the beginning of training camp.

There was certainly significant evidence of a significant relationship between years of NHL experience and age, as would have been expected. This is supported by both a Pearson correlation coefficient of 0.88 and the simple linear regression. NHL experience was chosen for further statistical analysis as there were a larger number of rookies for whom age was not reported. It was felt that NHL experience reflected age adequately, and there were more players overall for whom NHL experience was reported.

There was a significant association found between NHL experience and sport specific training. Veterans were at 4 times the odds of reporting less than 18 sessions sport specific training (June to August) and at 3 times the odds of reporting less than 12 sessions sport specific training (August only) . The simple linear regression estimation of sport specific training on NHL experience (Figure 7.10) suggests a predicted 1.3 session decrease in sport specific training sessions reported per year increase in NHL experience.

Veterans were more likely to report previous injury (1.4 times the odds of rookies). It may in fact be that veterans were more likely to have sustained injury in the previous season, although rookies were also likely playing at an elite level in the Junior or Minor Leagues and also at risk for injury. It could also be argued that rookies were less likely to report previous injury as they were attempting to get recruited to the NHL and were afraid of management or coaches being aware of their previous history of injury.

The odds of veterans scoring more than 1 SD below the mean total abduction flexibility was 2 times that of rookies. This may be due to physiological differences resulting from age and increased number of years of elite hockey play or it may be associated to veterans diminished likelihood of doing sport specific training in the off-season. There was no difference in peak isometric adductor torque between veterans and rookies which is not surprising given the lack of association between sport specific training and peak adductor torque.

There was an association found between previous injury and peak isometric adductor torque measured. Those players with a previous history of groin or abdominal strain injury were at 1.7 times the odds of scoring greater than 1 SD below the mean peak adductor torque. This may suggest a weakness in those players previously injured. This would be inconsistent with findings by Worrell et al (62) who found no association between strength and hamstring strain injury following injury and recovery. It may, however, be inconsistent because of the different muscle groups studied. Perhaps the true explanation is that players previously injured are less likely to exert maximal effort in a peak torque test for fear of aggravating an injury just prior to training camp. The fact that there was no association found between previous injury and total abduction range of motion may be related to extensive rehabilitation efforts at this level of hockey. There was also no association found between previous history of injury and sport specific training. Perhaps those previously injured were either on extensive rehabilitation in the off-season and likely to be doing sport specific rehabilitation, off-set those previously injured who rested from sport specific training in the off-season.

There was no association found between sport specific training and peak adductor torque. One might have expected peak adductor torque to be greater in players who reported a larger number of sessions of sport specific training.

8.2 Injury Data

The cumulative incidence rate of 3.83 injuries/100 players/training camp period was consistent with the rates reported during training camps the previous 6 seasons of play in the NHL (Chapter 2). The incidence density of 2.87 injuries/1000 athlete exposures was lower than that reported over the previous 2 seasons of play in the NHL where the incidence density was close to 5 injuries/1000 athlete exposures in training camp (Chapter 2). This decrease in incidence density was likely a result of an increase in total number of sessions reported in 1998 training camp (730 sessions for 23 teams) compared to 220 sessions reported in the previous season. In addition, there were likely more players attending training camp sessions in 1998 as the total number of athlete exposures increased from 4591 in 1997 to 18132 in 1998. The collection of exposure data in 1998 also may have been more accurate than in 1997 due to awareness by the therapists of this ongoing cohort study. The actual number of injuries reported increased from 22 in 1997 training camp (over 26 teams reporting) to 52 in 1998 training camp (over only 23 teams reporting). This increase in actual number of injuries reported may be a result of heightened awareness of groin and abdominal strain injury with this study ongoing. In addition, though the injury definition was unchanged from 1997 to 1998 in the NHLISS guidelines (42), therapists were reminded for the purpose of this study to report all injuries regardless of time loss.

The majority (82.68%) of total groin and abdominal strain injuries reported involved a groin adductor muscle and the remainder involved an abdominal muscle. This is consistent with the findings in the previous 2 years of NHL play where 82.69% of the injuries involved a groin adductor muscle (Chapter 2). Seventeen percent of the injuries reported were classified as re-injury from the previous season . This is compared to 10% classified as such in the previous 2 NHL seasons of play (Chapter 2). Ninety-one percent of the injuries reported were secondary to the following mechanisms; torsion, stretch, overuse, shearing, spontaneous or insidious onset (implying no direct contact). This is also consistent with the findings in the previous 2 years of NHL play (Chapter 2). Thirty-eight percent of the injuries were sustained by offensive players, 17% by goalies and 10% by defensive players. Position was not reported for 36% of the injuries reported. This is compared to a 61% offensive, 29% defensive and 6% goalie distribution of injuries in the previous 2 seasons of play. There appears to be an increase in the proportion of injuries sustained by goalies in the 1998 training camp. However, there is also an increase in the number of injuries for which position was not reported. Total number of sessions missed due to injury (median = 2 sessions) cannot be compared directly with the median time loss of 7 sessions in the previous 2 NHL seasons. Some of the players injured in training camp continued their time loss into the regular season and this would not be included in the training camp time loss data.

8.3 Cohort Analysis

Based on analysis of contingency tables alone; players who reported less than 18 sessions sport specific training in the off-season (June to August) were at an increased risk of sustaining groin or abdominal strain injury during training camp. When this association was investigated by stratification on potential confounding or effect modifying exposure variables (including previous history of injury (previous season), peak adductor torque, total abduction range of motion, and skate blade hollow), the association found was consistent with that found upon univariate analysis without stratification. The risk of injury for players who reported less than 18 sessions sport specific training in the off-season (June to August) was found to be 3.5 to 4.4 times the risk of injury for players who reported at least 18 sessions. However, when this association was investigated by stratification on years NHL experience, rookie/veteran status seemed to be a confounder in the association between sport specific training and injury. The O.R. point estimate was 2.03 but the 95% CI included one . Statistically, one could argue that there was no true association between sport specific training and injury. However, there were only three injured rookies in total which resulted in very small cells in stratified tables which resulted in an extremely large 95% CI for estimation of actual relative risk of injury among rookies 5.91 (0.54, 64.49). In addition, there was a significant association found between sport specific training and years NHL experience which may have lead to an issue of multicollinearity in the stratified analysis. As a result, it is argued that NHL experience is not likely a confounder in the relationship between sport specific training and injury status in training camp.

Off-season sport specific training more immediately prior to training camp (August only) was also found to be a predictor of injury in training camp. Those players who reported less than 12 sessions sport specific training in August alone were at 3 times the risk of injury during training camp than those who reported at least 12 sessions. For the majority of players, classification in the high risk group for sport specific training (June to August) also resulted in classification in the high risk group for August alone so this consistency of association between sport specific training and injury was not surprising.

Veterans were found to be at 6 times the risk of injury during training camp than were rookies. However, arguably this was not likely due to physiological differences between rookies at the mean age of 18 years and veterans at the mean age of 25 years. It is more likely that this increased risk is related to the multicollinearity issue between level of sport specific training in the off-season and years of NHL experience.

The association between previous injury (within one year) and injury during training camp was found to be consistent even when stratified on other potential confounding or effect modifying exposure variables. Those who reported previous injury were at 2.35 to 2.6 times the risk of injury than those who reported no previous history. This is consistent with Bennell's (5) findings that Australian rules football players were at 2 times the risk of hamstring strain injury than those with no previous history.

There was no association found between peak isometric adductor torque and injury. This was consistent with Bennell's (5) findings also, but inconsistent with other literature (11,13,38,63) in which an association was found between decreased strength and hamstring strain injury.

There was no association found between total abduction flexibility and injury. This is inconsistent with Liemohn's (29) findings of decreased hamstring flexibility associated with hamstring strain injury in track athletes but consistent with Bennell's (5) findings of no association between flexibility and hamstring strain injury in Australian rules football players.

There was no association found between skate blade hollow measurement and injury. This, however, was not a hypothesis based on the literature but rather a clinical suspicion of some professionals in the NHL.

Actual cumulative incidence rates were reported (Table 7.7) for various cut-points of total number of sport specific training sessions reported (June to August). Consistently, regardless of cut-point examined, there is a higher incidence rate found in the higher risk sport specific training group. Also, the incidence rate in the high risk group decreases as more sessions are chosen as the cut-point for estimation of incidence rate. Based on this data, the proportion reduction in incidence rate between players doing less than 18 sessions sport specific training in the off-season and those doing at least 18 sessions was the greatest in comparison to the first two cut-points (0, 9, and 18 sessions). The calculated relative risk is also greatest for this cut-point of 18 sessions. The larger cut-points (27 and 36 sessions) demonstrate a larger proportional reduction in incidence rate and increased relative risk. However, 18 sessions (6 weeks/ 3 times per week) may be more clinically relevant as it is more feasible to get players to do this amount of sport specific training in the off season than 27 (9 weeks/ 3 times per week) or 36 (12 weeks/ 3 times per week) sessions. There is potentially some evidence here of a dose-response gradient. The relative risk of injury clearly increases as the cut-point chosen increases from 9 to 18 to 27 sessions. However, the lower risk group of comparison does change for every cut-point chosen.

8.4 Secondary Cohort Analysis

Of course there are significant limitations to analyzing cohort data using contingency tables. Arbitrary cut-points to dichotomize continuous and integer variables results in loss of information even if cut-points are chosen carefully. In addition, the stratified analysis resulted in low power and large 95% confidence intervals due to small cell sizes and further stratification could not be analyzed beyond stratification of one potential confounding or effect modifying variable.

Logistic regression analysis permits analysis of potential risk factors for groin or abdominal strain injury by treating most of the exposure variables (with the exception of previous injury) as continuous variables. In the four models presented, there is a consistency in the association between log odds of injury and total number of sessions sport specific training reported. That is, as the total number of sport specific training sessions increases, the log odds of injury decreases (all other exposure variables constant, within the parameters of the sample). This is evidence of a dose-response gradient. The exception to this is in Model 1 (the most complex model) and Model 3 (veterans only model) where we find an interaction term suggesting that the change in log odds of injury per unit increase in sport specific training depends on torque. If torque is high, as the total number of sport specific training sessions increases, the log odds of injury decreases (all other variables constant). However, if we substitute values for torque in model 1, if torque is less than 123.6 Nm then the log odds of injury increases with increase in the total number of sessions sport specific training. As the 10^{th} percentile value of torque was 125 Nm, this is only the case in less than 10% of the sample. This is the opposite to what we have found in the stratified analysis where the risk of injury was greater for players with a low level of sport specific training. This relationship cannot be explained clinically.

There is also a consistency in all four models presented in the association between log odds of injury and previous injury. That is, the log odds of injury is consistently greater for those players with a history of groin or abdominal strain injury. Previous injury is not, however, a confounder or effect modifier in the relationship between sport specific training and injury.

In Model 2 (no interaction term) the log odds of injury increases with an increase in value of torque. This suggests that the stronger the player with respect to peak adductor torque the increased probability of sustaining injury in training camp. Clinically, this cannot be explained. However, if model 2 is examined closely it becomes clear that with values of torque ranging from 61 to 428 Nm, and a coefficient associated of 0.00056, a difference in a players torque value will not change the log odds of injury significantly. If we estimate the probability of injury for a veteran, of median NHL experience (5 years), a history of previous injury, who participates in 0 sport specific training sessions and scores the minimum value of torque in this sample (61 Nm) we can estimated the probability of injury in training camp to be 8.7% (6.72, 10.99). If the same veteran with the same criteria except peak adductor torque measurement equal to the maximum in this sample (428 Nm) we can estimated the probability of injury in training camp to be 10.47% (8.35, 12.99). With significantly overlapping 95% CI's we can conclude that there is no clinically significant difference in the probability of injury in training camp based on torque measurement.

In model 3 we have estimated a model using data for veterans only. Coefficients associated with years experience in the NHL and the quadratic term associated with years NHL experience are no longer significant and are dropped from the equation. One can see that the coefficients associated with the other variables are consistent with those in Model

1 (the most complex model). It appears that years experience in the NHL is only relevant to the log odds of injury when assessing the entire population including rookies.

In model 1 (the most complex model) and 2 (model with no interaction term) the significance of the quadratic term for years experience in the NHL suggests that the log odds of injury increases at an decreasing rate with increase in years NHL experience (all other variables constant). The calculated number of years experience in the NHL at which the log odds of injury is maximized is 8.3 years in model 1 and 8.5 years in model 2. Only 14.44% (12.11, 17.03) of the subjects in this study had more than 8.5 years experience in the NHL. In model 2 where the interaction term between sport specific training and torque is dropped a quadratic term for sport specific training also becomes significant suggesting that log odds of injury decreases at a decreasing rate with increase in number of sessions sport specific training (all other variables constant). The calculated number of sessions sport specific training required (all other variables constant) to minimize the log odds of injury was 65 sessions (the equivalent of more than 5 sessions per week for the entire 12 weeks of off-season). Clinically, it is unlikely that players would do this level of off-season sport specific training.

All four models are consistent with respect to presence of a previous history of groin or abdominal strain injury increasing the log odds of injury (all other variables constant).

In predicting probabilities of injury we see consistency between all models presented with respect to a decreasing probability of injury with increased number of sessions sport specific training and an increasing probability of injury with a previous history of groin or abdominal strain injury (Tables 7.9 - 7.12). In models 1 and 2 we also see consistency with respect to a decreasing probability of injury with increase in number of years NHL experience. The association of probability of injury with torque and the interaction of torque and sport specific training remains unclear, however appears also to be clinically irrelevant as explained above.

In examining the predictions for probability of groin or abdominal strain injury in training camp based on model 1 and 2 (Tables 7.9 and 7.10), the predictions are extremely close for given exposures (history of injury, NHL experience and level of sport specific training). Arguably model 2 would be considered statistically and clinically the best estimated model explaining the prediction of log odds of injury based on the exposure variables measured in this study. Based on the predicted probabilities of injury for model 2 (Table 7.9), clearly the target group for intervention are veterans. Increasing the number of sport specific training sessions from 0 to 18 sessions (6 weeks/ 3 times per week) in the off-season would have the most significant impact on veterans with a history of previous injury but would also have a significant impact by reducing the probability of injury in all veterans. There is very little overlap in the 95% CI's for the probability of injury in veterans with no history of previous injury in those training 0 versus 18 sessions. There is no overlap in the 95% CI's for the probability of injury in veterans with a history of previous injury in those training 0 versus 18 sessions. If we look at point estimates alone the probability of injury could potentially be reduced for players doing no sport specific training in the off-season by 50% by increasing the total number of sport specific training sessions from 0 to 18 sessions (6 weeks/ 3 times per week). This is consistent with the findings in all 4 models presented.

The crude cumulative incidence rate in this sample of 3.83 injuries/100 players/ training camp period could be expressed as a crude overall probability of injury in training camp of 3.83%. We can compare this directly with the estimated probabilities of injury based on the logistic regression models presented (Tables 7.9 - 7.12). The predicted probabilities of injury are consistently higher than the crude probability of injury in veterans who report no sport specific training in the off-season. These probabilities are even greater still for those veterans who report previous injury and no sport specific training in the off-season. In model 4 (most simplistic model) the predicted probability of injury is only higher in players who report previous injury and no sport specific training in the off-season.

8.5 Potential Sources of Bias

The participation rate of players attending one of 23 NHL training camps was extremely high. Some exposure data was collected from 95.21% of players attending these 23 camps. There were four complete teams that did not participate in collecting exposure data. These four teams did not participate for one of two reasons;

1. Three team therapists/physicians did not agree to participate as they felt the time required to do the measurements and distribute questionnaires was too extensive given their prior commitments to the team.
2. One team therapist misplaced the measurement tools in a last minute transition to a new facility.

Last (28) defines selection bias as error due to systematic differences in characteristics between those selected for a study and those not selected. Hennekens (24) specifies that selection bias can only occur when inclusion of subjects into the study depends on both the outcome and exposure of interest. It was felt that there were likely no systematic differences between the exposures or outcomes of players not participating from these 4 teams and those of the players attending one of the participating 23 teams. However, of all the potential players from the 24 teams participating only 65.94% players completed the off-season sport specific activity questionnaire and only 77% completed measurements for peak isometric adductor torque and total hip abduction flexibility. It was felt that players who did not agree to participate did not for the following reasons;

1. Players who did not train extensively in the off-season or had a previous history of groin or abdominal strain injury did not want to divulge that information by completing the questionnaire in fear that a coach or manager may get a hold of that information.

2. Players with a previous history of groin or abdominal strain injury did not want to do the measurements for fear of injury or fear of below average measurements .

3. An entire team in which all of the veterans refused to participate (based on agreement with their NHL Players Association representative that appropriate consent was not established well in advance of training camp).

Those players not participating may be at a higher risk of injury outcome than those who did because they were likely at higher risk of being in the sport specific training exposure group who participated in less than 18 sessions in the off-season. The result of non-participation based on the above 3 reasons would all result in an underestimation of association between exposures (Sport specific training, previous injury, peak adductor torque and total abduction flexibility) and outcome (groin or abdominal strain injury in NHL training camp). Hence, if an association was found (as with previous injury and sport specific training) one could argue that a true association exists. On the other hand, if an association was not found as with peak adductor torque and total abduction flexibility, one can not be sure there is no association. As injury data was recorded for all 24 participating teams there was no risk of selection bias present due to loss to follow-up.

Measurement bias is defined by Last (28) as systematic error arising from inaccurate measurements of subjects on study variables. Some types of measurement bias are also referred to as misclassification bias in which there is erroneous classification of an individual, value or attribute into a category other than it should be assigned. Last (28) categorizes this source of bias into non-differential misclassification in which the probability of misclassification is the same in all study groups and differential misclassification in which the probability of misclassification differs between groups. In this study a source of bias due to differential misclassification of injury status may occur as players may be less likely to report injury as they feel it may affect their recruitment into the NHL. These players are also likely in the higher risk exposure categories based on the a-priori hypotheses. The result of this source of bias would again be to underestimate the association between risk factor and injury. However, it is also possible that rookies were less likely to report injury than veterans. As rookies are also more likely to be in the lower risk categories, this may lead to an overestimation of association between risk factor and injury.

Another source of differential missclassification bias in this study is misclassification of the sport specific training measure as a result of players tending to overestimate or exaggerate estimate of total number of sessions off-season sport specific training, again in fear of coaches or managers seeing the information. This would result in those at higher risk of injury due to low actual number of sessions sport specific training being classified in the low risk sport specific training group. This again would result in an underestimation of the association between sport specific training and injury. Hence, the association found between sport specific training and injury is likely a true association.

Another source of differential misclassification bias may result from those with a history of previous groin or abdominal strain injury may not produce their maximal peak adductor torque in fear of reinjury. This would result in these players already at increased risk of injury due to previous injury being classified into the high risk peak adductor torque group. The result would be an overestimation of the association between low peak adductor torque and injury. As there was no association found between peak adductor torque and injury in this study this is not a bias of concern.

Possible sources of non-differential misclassification bias may result from potential non-systematic measurement errors in testing peak adductor torque and total abduction flexibility and non-differential recall bias on completion of off-season sport specific activity questionnaire. Errors in the peak adductor torque measurement may have resulted from non-systematic differences in the players effort to produce maximal torque or differences in trainers verbal cues. These sources of bias would result in diluting or underestimating any true association, or a bias toward the null. Hence, the association found between sport specific training and injury is likely a true association. The lack of association between peak adductor torque or total abduction flexibility and injury may be questioned.

Another possible source of non-differential misclassification bias may result from potential non-systematic misclassification of injury status based on therapists misdiagnosing a groin or abdominal strain injury and reporting a back injury with pain referral to the groin region or misdiagnosing a back injury and reporting a groin or abdominal strain injury with pain referral to the groin region. This again would result in diluting or underestimating any true association, or a bias toward the null.

Many possible sources of bias have been discussed. It is clear that the impact of most potential sources of bias addressed was to underestimate the relative risk of injury based on previous injury and level of sport specific training. Hence, players previously injured and players who reported a low level of sport specific training in the off-season are likely at a truly increased risk for groin and abdominal strain injury in training camp. In addition, the potential biases addressed also would result in an underestimation of the relative risk of injury related to low peak adductor torque and total abduction flexibility. Hence, the fact that statistically no association was found between either the peak adductor torque or total abduction flexibility and injury may be questioned.

8.6 Limitations of the study

Though the study sample size was large (n=1292) the relative number of injuries in training camp was small (n=52). As a result, the extent to which a stratified analysis of risk factors was possible was limited to stratification on a maximum of two variables at a time.

The dependence of study coordinators on external support of NHL personnel for collection of exposure data was not ideal. Much of the communication between study coordinators and NHL personnel was done by fax, e-mail and telephone due to the large geographical spread of the participating teams. This may have affected the participation rates for consenting players in this study which were somewhat low (66% for completion of sport specific training questionnaire and 77% for pre-season strength and flexibility measurements). In addition, this may have resulted in a greater degree of non-differential measurement bias than if it were plausible for measurements to be done more consistently for all players by the same examiner or if hands-on training sessions for team therapist were given by study coordinators.

The peak adductor torque measurement tool had been previously tested for intra-rater reliability, however, not for inter-rater reliability. Though the device was used somewhat independently of the examiner, the effect of placement of the device and consistency of verbal command may have resulted in poor inter-rater reliability between examiners leading to an increase in non-differential measurement bias. Inter-rater reliability and validity of measurements for total abduction flexibility must also be questioned as a result of some measurements lying outside of the physiologic range of plausible values. As a result of significant concerns regarding these two measurements, a true understanding of the relationship between peak isometric adductor torque and injury is not well understood from this study.

Other potential risk factors which were not addressed specifically in this study were ice conditions and muscle fatigue. Ice condition is an extremely subjective appraisal and ice conditions often change from the beginning to the end of a session. By assessing injury rates at different arenas one may get some understanding of the impact of ice surface on injury. However, this was not possible in this study as the total number of injuries reported in training camp was only 52 and the stadium in which injury occurred was only reported for 7 of these injuries. There were a possible 23 different ice surfaces on which an injury may have occurred. Muscle fatigue was addressed to some degree by examining the proportion of injuries occurring during different time periods within a session. There were no significant differences between time periods indicating that fatigue may not be a risk factor for injury. One may suggest that muscle fatigue may result from overtraining of sport specific muscle groups in the off-season. Clearly this is not the case as increased level of sport specific training reduced the risk of injury in training camp.

The limitation of using the NHLISS in this study was that vigorous reliability and validity testing had not been done. This may have lead to a source of non-differential misclassification bias. Another limitation of the NHLISS, is the inability to determine individual exposure status. Exposure status for the purpose of incidence density calculations was estimated based on the average number of players participating in any given game or practice. This does not take into consideration movement of players in the NHL between teams and leagues throughout training camp. In addition, not all players will have the same exposure status due to injuries and sitting out of games and/or practices. This limitation would likely result in an underestimation of incidence densities due to an overestimation of player exposure.

8.7 Strengths of the study

There was a large sample size (n=1292) used in this study, strengthening the findings of the study by increasing the precision of estimates calculated. Loss to follow-up is minimal. Injury data is reported throughout training camp, for all players, by all participating team therapists. The strength of the NHLISS having been in place for many years prior to this study is that the team therapists were all very familiar with the reporting system.

Though the actual number of injuries was small (n=52) limiting the ability to do a stratified analysis on more than two variables, the use of logistic regression techniques allowed for a more complete analysis of all potential risk factors for groin and abdominal strain injury.

Inherent in the design of a prospective cohort study, it is argued that potential for selection bias is minimized as the outcome of injury has not yet occurred at the time of the collection of exposure data. There is some potential for selection bias due to the possibility of previous history of injury. However, as described above, this would not affect the findings of this study other than to potentially underestimate the associations found.

8.8 Generalizability

It was important to study risk factors for groin and abdominal strain injury in an elite hockey population where an Injury Reporting System was already in place (NHLISS). There are certainly, however, potential implications for generalizability of these findings to a varsity population and likely to other, less elite, hockey populations. A low level of sport specific training increased the risk of groin or abdominal strain injury in the NHL elite hockey population during training camp. The level of training by players in the NHL in the off-season likely exceeds that of other levels of hockey. Of the 24 varsity hockey players who completed the sport-specific training questionnaire (Chapter 5), 37.5% reported no off-season sport specific training and 45.8% reported less than 18 sessions sport specific training in the off-season. In this NHL study, only 13.5% of the players who completed the sport-specific training questionnaire reported no off-season sport specific training and 45.77% reported less than 18 sessions sport specific training in the off-season. The incidence rates for groin and abdominal strain injury in the CWUAA varsity hockey league over three years of play were comparable to those found in the NHL over 6 years of play (Chapter 2).

CHAPTER NINE: CONCLUSIONS

In the area of injury prevention in sport epidemiology, there are very few studies with a strong prospective research design addressing risk factors for injury in sport. Studies identifying risk factors for injury are essential prior to assessing potential prevention strategies for injury in sport. This study investigates risk factors for an extremely common injury in hockey using a prospective cohort design. The research design chosen has resulted in some concrete findings regarding the risks for groin and abdominal strain injury at an elite level of hockey.

The results of this study confirm that players in the NHL with a history of previous groin or abdominal strain injury in the previous year are at greater than two times the risk of injury during training camp. In addition, players who do sport specific training less than 18 sessions (6 weeks/ 3 times per week) are at more than three times the risk of groin or abdominal strain injury in training camp. The group of players who would potentially benefit most from increasing their level of off-season sport specific training are NHL veterans. Any amount of sport specific training (more than 0 sessions) would likely benefit all players by reducing their probability of groin or abdominal strain injury in training camp. At least 18 sessions (6 weeks/ 3 times per week) of off-season sport specific training would likely have the greatest impact in reducing the probability of injury during training camp and be the most feasible for players in the off-season. Though there is some evidence from a secondary cohort analysis that increasing the number of off-season sport specific training sessions to 65 would minimize the probability of groin or abdominal strain injury in training camp, this level of training is not likely feasible for most players in the off-season.

One cannot conclude from this study that there is no relationship between peak isometric adductor torque or total abduction flexibility measured in the pre-season and groin or abdominal strain injury in training camp due to potential sources of bias which may have underestimated these relationships. In addition, this study failed to demonstrate an association between peak adductor torque and off-season sport specific training. A more sport specific strength measurement such as peak eccentric adductor torque may be required to demonstrate possible associations between strength and sport specific training or injury.

There is certainly sufficient evidence from this study to plan future research to assess the impact of increased levels of sport specific training in the off-season in groin and abdominal strain injury prevention, perhaps using a randomized clinical trial. Future research is necessary to determine an objective physiological measurement such as eccentric adductor torque which may be a predictor of sport specific muscle use in hockey. This would assist in identifying players to target with potential injury prevention strategies.

This study likely has implications for prevention of groin and abdominal strain injury in hockey at all levels. Future research, however, is required to confirm an increased risk of groin and abdominal strain injury in players who do a low level of sport specific training in the off-season at other levels of hockey. In addition, future research is required to investigate prevention of groin and abdominal strain injury by increasing levels of off-season sport specific training. Perhaps a sport specific off-ice eccentric training program may have the same impact as on-ice training in the off-season and may be more practical and efficient than on-ice play for players of all levels in the off-season. A randomized clinical trial would be the best suited design to further investigate prevention of groin and abdominal strain injury in hockey.

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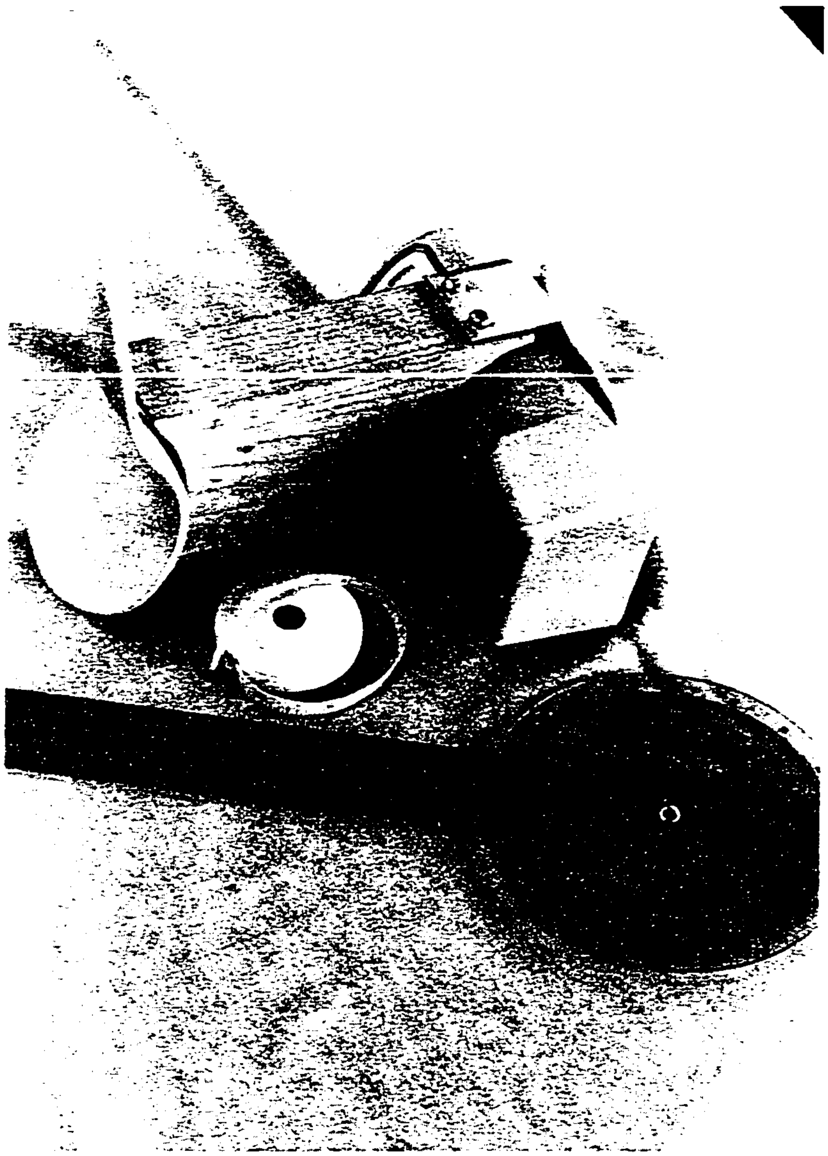
APPENDIX A

Methods of Measurement

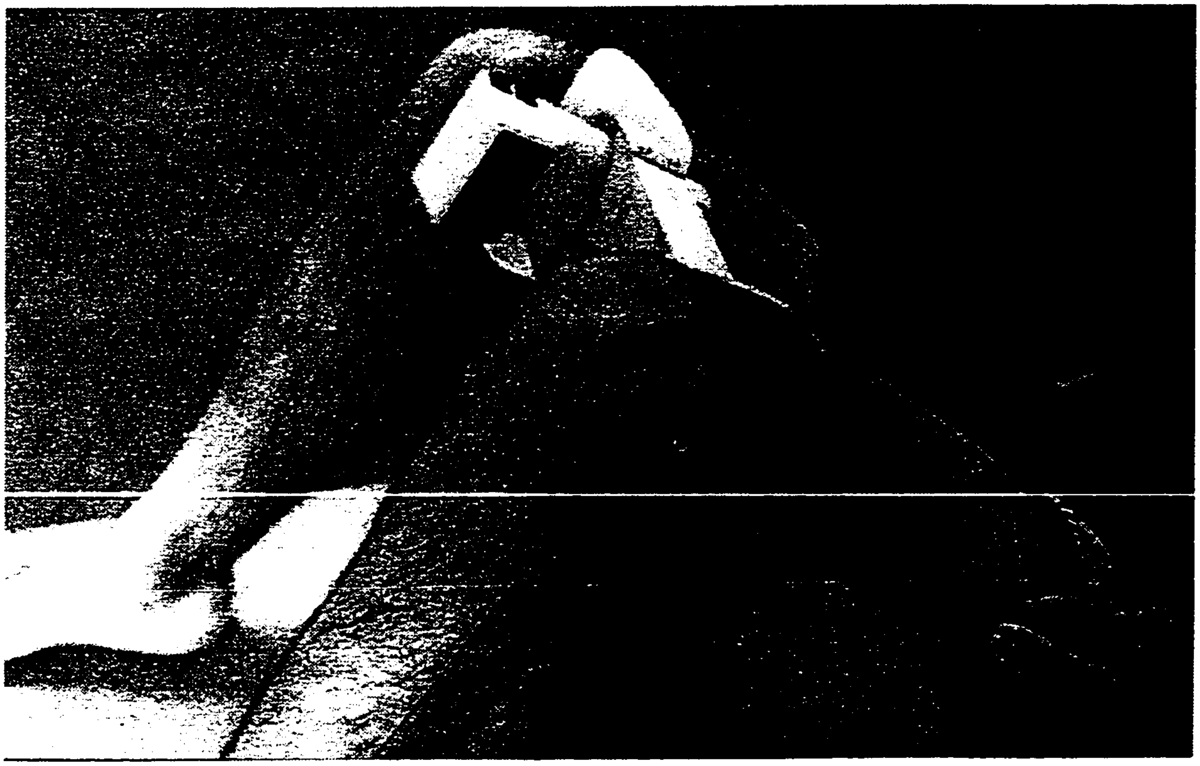
APPENDIX A1

Adapted Nicholas Manual Muscle Tester



APPENDIX A2

Isometric Hip Strength Measurement



Method of Measurement:

Measurements are to be done using an adapted Nicholas Manual Muscle Tester (MMT). Position the player in supine with hips and knees flexed and feet flat on examining table. Knee flexion measurement should be 90 degrees using a universal goniometer. Feet should be aligned with the anterior superior iliac spine on each side. The pads of the MMT should be placed over the vastus medialis muscle as distally as is comfortable for the player. The player will be asked to adduct maximally against the pads of the MMT . The peak force achieved as recorded by the MMT should be recorded. This is to be repeated 5 times at 10 second intervals. The MMT should be reset between measures.

In addition, the player's femoral length is to be measured (see next page).

APPENDIX A3

Femoral Length Measurement

Method of Measurement:

The player's femoral length is to be measured in order to calculate torque produced. This measurement is to be done with a measuring tape and recorded in centimeters. The measurement is done with the player in supine with knees and hips extended. Measure from the midpoint of the inguinal ligament to the superior border of the patella on the right side only.

APPENDIX A4

Hip Abduction Range of Motion Measurement

Method of Measurement:

Please measure hip abduction range of motion bilaterally with the player positioned in supine, hips maximally abducted, and knees fully extended. Using a universal goniometer (UG) align the proximal arm with the long axis of the trunk, position the center of the UG over the center of rotation of the hip joint, and align the distal arm with the shaft of the femur. Repeat this measurement for both the left and right hip.

APPENDIX B

Questionnaires

APPENDIX B1

Post-test muscle soreness survey

1. Name____

2. Study Identification Number_____________________________

3. Session Number: 1_____ 2_____

4. Post-test muscle soreness: Yes_____ No_____

If Yes: Post-test muscle soreness started: (check one only)

1. Within 1 hour of test completion_____

2. Within 6 hours of test completion_____

3. Within 12 hours of test completion_____

4. Within 24 hours of test completion_____

5. Within 48 hours of test completion_____

If Yes: Post-test muscle soreness resolved: (check one only)

1. Within 6 hours of test completion_____

2. Within 12 hours of test completion_____

3. Within 24 hours of test completion_____

4. Within 48 hours of test completion_____

5. Did not resolve by 48 hours_____

APPENDIX B2

Off-Season Activity Questionnaire

ID#.____

Name:____

Team:____

Usual position of play:______________________________

Number of years of NHL experience:______________________

Please answer the following 3 questions:

1. Have you sustained a groin or abdominal strain injury in the past year of play?

_ Yes
_ No

2. Which muscle group was involved?

_ Hip flexor (front of hip)
_ Hip adductor (inner groin)
_ Abdominal muscle

3. Have you sustained a hernia in or around the groin or lower abdominal region in the past year of play?

_ Yes
_ No

Please complete the chart on the following page regarding your training activities for the 1998 off-season.

Enter the average number of weeks and number of sessions per week you participated in each activity for each month (June, July, and August).

One session = minimum 30 minutes.

Example:

ACTIVITY	POWER SKATING HOCKEY	WEIGHT TRAINING	PLYOMETRICS	RUNNING	SWIMMING	CYCLING	GOLFING	IN-LINE SKATING	SOCCER
JUNE NUMBER OF WEEKS		1		2	1		4		
NUMBER OF SESSIONS PER WEEK		4		3	1		2		

ACTIVITY	POWER SKATING / HOCKEY	WEIGHT TRAINING	PLYOMETRICS	RUNNING	SWIMMING	CYCLING	GOLFING	IN-LINE SKATING	SOCCER	TENNIS	OTHER	OTHER
JUNE NUMBER OF WEEKS												
AVERAGE NUMBER OF SESSIONS PER WEEK												
JULY NUMBER OF WEEKS												
AVERAGE NUMBER OF SESSIONS PER WEEK												
AUGUST NUMBER OF WEEKS												
AVERAGE NUMBER OF SESSIONS PER WEEK												

APPENDIX C

Research Forms

APPENDIX C1

Consent Form

Research Project Title: Predictors of groin strain injury in the NHL.

Investigators: Dr. Willem H. Meeuwisse
Carolyn Emery
Sponsor: National Hockey League Injury Committee

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, you should feel free to ask your team trainer or call one of the study investigators. Please take the time to read this carefully and to understand any accompanying information.

The incidence of groin strain injury in the NHL has increased significantly over the past 6 seasons of play. The average time loss due to this injury is 14 sessions (games/practices). The purpose of this research is to examine potential risk factors for groin injury in the NHL in the 1998/99 season of play. Specifically, to examine the level of off-season training as a predictor of groin strain injury.

Most of the data required to examine this problem in the NHL will be acquired from the NHL Injury Surveillance System already in place. In addition, you are being asked to complete the attached questionnaire regarding your off-season training activities from June to August 1998 and to do a quick isometric hip adductor strength test at the time of your pre-season medical examination. There will be nothing further requested of you regarding this research project.

This research will lead to the identification of risk factors for groin strain injury in the NHL and assist in the identification of prevention strategies in the future.

This information will remain confidential, your privacy will be assured. Only the primary investigators of this study will have access to this information. Following completion of this questionnaire you will be asked to seal the envelope within which it is enclosed and sign the envelope on the back where indicated. Please give the sealed envelope to your team trainer who will return it to the investigators. Confidentiality will be protected by using only your NHLISS identification number in the database. Any results of the study which are published will in no way identify study participants.

You will not incur any financial costs as a result of participating in this study.

You still have all your legal rights. Nothing said here will in any way alter your rights to recover damages.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in this research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your contract with the NHL or you health care. If you have further questions concerning matters related to this research, please contact:

Dr. Winne Meeuwisse (403-220-8232) or Carolyn Emery (403-220-8232)

If you have any other questions concerning your rights as a participant in this research, please contact the Office of Medical Bioethics, Faculty of Medicine, University of Calgary, at (403)220-7990.

______________________________ ____________________

Participant signature Date

______________________________ ____________________

Witness signature Date

______________________________ ____________________

Investigator signature Date

APPENDIX C2

NHL Pre-season Evaluation
Groin Injury Study

Player Name: ________________________________

1. Hip abduction range of motion: Right ________ degrees
   Left ________ degrees

2. Hip anteversion measurement: Right ________ degrees
   Left ________ degrees

3. Isometric hip strength: Trial 1 ________ kg
   Trial 2 ________ kg
   Trial 3 ________ kg
   Trial 4 ________ kg
   Trial 5 ________ kg

   Femoral length ________ cm

4. Off-season training questionnaire: Completed ____
   Not completed ____

Goalies only:

A) What is the goalies preferred technique of play?
Positional ___ Butterfly____
B) Handedness?
Right ____ Left____
C) As a child were parents aware of intoeing (walking pigeon toed)?
Yes ___ No___

Physician/Therapist completing form: ______________________________

Date of Evaluation ____________________

Team: ______________________________

APPENDIX C3

Training Camp: Skate Blade Hollow Measurement

This form to be completed by team equipment manager during training camp. Please document skate blade hollow measurement at the beginning of training camp. In addition, please document any changes to this measurement during training camp by documenting the date of change and the new measurement.

Player Name	Initial skate blade hollow measurement	Date of change and new measurement	Date of change and new measurement	Date of change and new measurement