

Risk

Factors for groin injuries in hockey

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ABSTRACT

EMERY, C. A., and W. H. MEEUWISSE. Risk factors for groin injuries in hockey. *Med. Sci. Sports Exerc.*, Vol. 33, No. 9, 2001, pp. 1423–1433. **Purpose:** The objective of this cohort study was 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 (NHL). **Methods:** The subjects were 1292 consenting NHL players. Estimated relative risks of injury are reported 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 of NHL experience, and 6) skate blade hollow measurement. Estimates of probability of injury are predicted for various levels of exposures on the basis of logistic regression analysis. **Results:** During training camp, players who reported less than 18 sessions sport specific training in the off-season were at greater than three times the risk of injury than those who did not (relative risk (RR); 3.38 95% confidence interval (CI), 1.45–7.92). Players who reported previous history of this injury were at more than two times the risk of injury than those who did not (RR, 2.88; 95% CI, 1.33–6.26). Veterans were at greater than five times the risk of injury than rookies (RR, 5.69; 95% CI, 2.05–15.85). Peak isometric adductor torque, total abduction flexibility, and skate blade hollow measurement were not predictive of injury. There is evidence of a dose-response gradient as predicted probability of injury decreases with increasing levels of sport specific training. In the regular season, sport specific training was not as strong a risk factor (RR, 2.32; 95% CI, 1.0–5.39). **Conclusion:** Low levels of off-season sport specific training and previous injury are clearly risks for groin injury at an elite level of hockey. Future research is required to investigate prevention strategies for this injury in hockey.

Key Words: WOUNDS, ABDOMEN, RISK FACTORS, EPIDEMIOLOGY

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 six seasons of play (7) and other relevant literature (3,9,14,16,18). The incidence of groin and abdominal strain injury has increased in the NHL over the past six seasons of play (7). The rate of injury (on the basis of incidence density) in the training camp period was five times that in the regular season and 20 times that in the postseason of play (7). There is also a significant incidence of muscle strain injury (nonspecific) reported at a recreational level of hockey (26). There has been no research published that focuses directly on intrinsic risk factors (i.e., muscle strength, flexibility, and level of off-season sport specific training) for groin and abdominal strain injury in hockey. It is these factors that may be modifiable with preseason training intervention to potentially prevent groin and abdominal strain injury in hockey. The focus of this study was 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 ice hockey.

METHODS

Study Design

A prospective cohort design was used to investigate whether 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 1998–1999 training camp and regular season period.

Subjects

An inclusive sample of NHL players invited to attend one of 27 team training camps were asked to consent to the study. The target population, therefore, included 1557 players.

Data Collection

Questionnaire administration. An off-season sport specific training questionnaire was pilot tested in a varsity hockey population for validity and reliability in a preliminary stage of this research project. It was subsequently completed by all consenting NHL players attending training camp at the time of their preseason medical evaluation.

Preseason strength measurements. Ideally, a preseason assessment of peak eccentric muscle strength and endurance would be ideal to establish muscle group specific strength and endurance as potential predictors of groin and abdominal strain injury in hockey. Emery et al. (6) have established excellent reliability (intraclass correlation coefficient (ICC) = 0.85) of peak eccentric adductor strength

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measured on a Cybex Norm isokinetic dynamometer (Cybex International, Inc., Medway, MA). This testing protocol, however, resulted in significant posttest muscle soreness. As a result, this testing protocol was not deemed appropriate for testing in the elite hockey population, before an intensive training camp period. Therefore, another method to measure strength was developed for use in this study. Excellent test-retest reliability (ICC = 0.95) of peak isometric hip adductor torque as measured using an adapted Nicholas Manual Muscle Tester (NMMT) (Fred Sammons, Inc., Burr Ridge, IL) was found in our pilot study. In addition, there was no evidence of posttest muscle soreness associated with the peak isometric adductor torque measurement using the adapted NMMT. In addition, other studies have shown a significant relationship between isometric strength and muscle strain injury in sport (4,5,15,29). As such, peak isometric adductor torque was chosen to be assessed as a potential predictor of groin and abdominal strain injury in this study.

Peak hip adductor isometric strength measurements were obtained by each team's professional medical staff (team therapist or physician) using an adapted NMMT. The player was positioned in supine position 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 anterosuperior 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 five times. The lever arm length required to calculate peak adductor torque was measured with a measuring tape. The measurement was obtained with the player in supine position 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 newton-meters by multiplying the maximum force (kg) achieved in five trials by the length of the lever arm (m) by 9.806 (N/kg).

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 obtained in supine position with bilateral active hip abduction assumed by the player in neutral hip extension. The proximal arm of the UG was aligned with the center of the trunk, the center 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. This measurement was tested for inter- and intrarater reliability by Balmer and Brosseau (1), who established ICC of 0.89 to 0.99 for intrarater reliability and ICC 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.

Additional exposure data collection. Previous injury, level of NHL experience, and position of play infor-

mation was collected on all consenting players as part of the off-season sport specific training questionnaire. Data on age of player were only available for veteran players and rookie players chosen for NHL teams. Information on skate blade hollow (a measurement defining the sharpness of the skate blade) was recorded on a form provided to each participating team equipment manager. This included any changes in blade hollow measurement throughout the training camp. Athlete exposure information, determined on the basis of total participation for games and practices, were obtained from the NHL Injury Surveillance System (NHLISS).

Injury data collection. The 1998 revised NHLISS was used to obtain all data required regarding groin injury. Description of injury, date of injury, time loss because of injury (sessions missed), previous injury (within 1 yr), mechanism of injury, and position of play were obtained from the NHLISS.

Each NHL team therapist recorded injury data electronically directly into a relational database written using Fox-Pro (Microsoft, Redmond, WA). The data were sent directly by a modem to MedSport Systems, Ltd. (Ann Arbor, MI), where data were collected on all injuries sent from all NHL teams. The relational database allowed the computer analyst at MedSport Systems to extract all of the data pertaining to groin and abdominal strain injury into an Excel (Microsoft) (7) file. This file was then sent electronically to the research coordinator at the University of Calgary Sport Medicine Center.

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 if the player was removed from the current practice or game or if 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: preseason play including practice sessions and exhibition games up until but excluding the first regular season game (generally, early September until early October).

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

Sessions missed: recorded number of games and/or practices missed (training camp sessions only for purposes of this study) because of reported injury (could record 0 sessions

missed). In the NHL, the smallest unit recorded is one full session.

Sport specific training session: any training session (≥ 30 min) in the off-season including ice hockey, power skating, in-line skating, off-ice skating machine, or slider board.

Data Analysis

Descriptive statistics were reported on injury status (muscle strained), cumulative incidence rate, incidence density, mechanism of injury, time in session injury occurred, and time loss because of injury.

Classical contingency table analysis was performed to determine the relative risk of injury in the high-risk group (low off-season sport specific training) compared with that in the low-risk group (high off-season sport specific training). Stratified analysis was performed where contingency table cell size was adequate to assess potential confounding (a situation in which the effect of an exposure variable on risk is distorted because of the association with another exposure variable and the outcome studied) or effect-modifying (a situation in which the level of association between an exposure variable and the outcome studied is dependent on the level of another exposure variable) variables, including experience (years in NHL), previous injury (within 1 yr), 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 1 SD below the mean (cut-point chosen) and those above 1 SD below the mean were also calculated in a similar fashion.

For the purposes of statistically analyzing the relative risk of injury after stratifying on a potential confounding or effect-modifying variable, odds ratios (ORs) 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 ORs once stratified. If there was no evidence against combining the ORs ($P > 0.05$) for the tables once stratified, then the Mantel-Haenszel combined OR (95% confidence interval (CI)) was calculated.

For purposes of analysis with contingency tables, some continuous and integer variables were dichotomized into two groups on the basis of a predetermined cut-point as follows:

1. Peak adductor torque was grouped on the basis of a cut-point of 1 SD below the mean (142.54 Nm).
2. Total abduction ROM was grouped on the basis of a cut-point of 1 SD below the mean (67.49 degrees).
3. Total number of sport specific training sessions reported (June–August 1998) was grouped on the basis of a cut-point of 18 sessions. This was equivalent to 6 wk, 3 times-wk⁻¹, the period of training required to regain maximal quadriceps strength after 30 wk of no training (20,22).
4. Total number of sport specific training sessions reported (August 1998) was grouped on the basis of a

cut-point of 12 sessions (equivalent to 4 wk, 3 times-wk⁻¹).

5. Skate blade hollow measurement was grouped on the basis of a cut-point of 1 SD below the mean (0.375 inches).
6. Years of experience in the NHL was grouped by rookies (0 yr experience) and veterans (≥ 1 yr experience).

Cut-points of 1 SD below the mean were chosen to allow for an extremely-high-risk group for each exposure variable in which only 16% of the sample was grouped more than 1 SD below the mean.

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. This was performed to determine if increasing levels of off-season sport specific training led to a reduced risk of groin strain injury (a potential dose-response relationship). In exploring the potential model of best fit to predict the log odds of injury (an estimate from which probability of injury can be calculated), most of the exposure variables were treated as continuous variables (total number of sessions sport specific training, peak adductor torque, total abduction flexibility, years of NHL experience, and skate blade hollow measurement) in the models explored. Dichotomization of variables using a chosen cut-point is not required in this analysis. 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 that included all possible exposure variables and potential interaction variables, and then subsequent nested models were compared with 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. All data analysis was performed using the Stata statistical software package (23). Methods used to complete data analysis were variations on methods for logistic regression outlined by Selvin (21).

RESULTS

Exposure Data

Subject participation. There were 1557 hockey players attending one of 27 NHL training camps in September 1998. Twenty-three of the 27 NHL teams' therapists participated in collecting exposure data for this study before the first session of training camp. From those 23 teams, there were 1357 potential participants, of whom 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 Tables 1 and 2. Not all exposure variables were collected for all players because of refusal to participate; partial participation of some subjects is reflected in Tables 1 and 2. Of the 1292 participating players during training

TABLE 1. Descriptive analysis of exposure variables for which a normal distribution was found.

Exposure Variable	No. of Players	Proportion of Total Consenting Players (%)	Mean	95% CI
Peak adductor torque (Nm)	995	77.01	203.26	199.61–207.31
Total hip abduction flexibility (degrees)	997	77.17	102.36	100.19–104.53
Skate blade hollow (inches)	517	40.02	0.50	0.49–0.51

camp, 647 players continued to play in the NHL regular season of play.

Descriptive analysis of exposure variables. The mean, 95% CI, and number of players for exposure variables measured that had a normal distribution (peak adductor torque, total hip abduction flexibility, and skate blade hollow) are reported in Table 1. The distributions for torque and flexibility measurements are displayed graphically in Figures 1 and 2. The median, range (minimum, maximum), and number of players for exposure variables measured that had a skewed distribution (total number of sessions sport specific training (June–August), total number of sessions sport specific training (August only), and years of NHL experience) are reported in Table 2.

In the assessment of the exposure variables, there was a fundamental difference noted between the rookie and veteran players with respect to sport specific training reported. A scatterplot demonstrates the decreasing trend in the total number of sessions sport specific training reported with increasing number of years of NHL experience (Fig. 3). The slope of the regression line was -1.34 (95% CI, -1.6 to -1.08). That is, for every 1-yr increase in years of NHL experience, one would expect off-season sport specific training sessions to decrease by 1.3 sessions, confirming an inverse relationship between years of experience and sport specific training.

Injury Data Analysis

There were 52 groin and abdominal strain injuries reported during training camp and 152 during the regular season by a total of 23 NHL teams reporting injuries through the NHLISS. The cumulative incidence rate calculated on the basis of 1357 participating players during training camp was 3.83 (95% CI, 2.87–4.99) injuries per 100 players per training camp period. The cumulative incidence rate calculated on the basis of 647 participating players during regular

TABLE 2. Descriptive analysis of exposure variables for which a skewed distribution was found.

Exposure Variable	No. of Players	Proportion of Total Consenting Players (%)	Median	Range
Total number of sessions sport specific training (June–August)	852	65.94	19	0–140
Total number of sessions sport specific training (August only)	852	65.94	15	0–80
Years of NHL experience	824	63.78	1	0–19

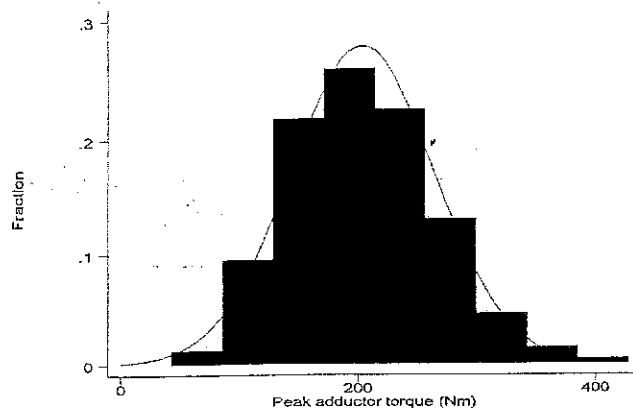


FIGURE 1—Peak hip adductor torque measurement using the adapted Nicholas Manual Muscle Tester.

season was 23.49 (95% CI, 20.28–26.95) injuries per 100 players per regular season period. On the basis of a total number of athlete exposures (total number of sessions \times total number of players per session) for training camp, the incidence density was 2.87 (95% CI, 2.14–3.76) injuries per 1000 athlete exposures and for regular season the incidence density was 1.33 (95% CI, 1.13–1.56) injuries per 1000 athlete exposures.

The groin and abdominal strain injuries reported consisted of 17.31% (95% CI, 8.23–30.31%) abdominal muscle strain injuries and 82.69% (95% CI, 69.67–91.77%) groin muscle strain injuries. There were no abdominal or inguinal hernias reported. Only 17.31% (95% CI, 8.23–30.31%) of the total injuries were reported as reinjuries. By injury classification, 33.33% (95% CI, 2.8–60.05%) of the abdominal muscle strain injuries were reported as reinjuries and 13.33% (95% CI, 5.3–27.94%) of the groin muscle strain injuries were reported as reinjuries. Player position was not reported for 34.62% (95% CI, 21.97–49.09%) of the injuries, 38.46% (95% CI, 25.3–52.98%) of the injuries were incurred by offensive players, 17.31% (95% CI, 8.23–30.33%) by goalies, and 9.62% (95% CI, 3.20–21.03%) by defensive players. When we examined the proportion of

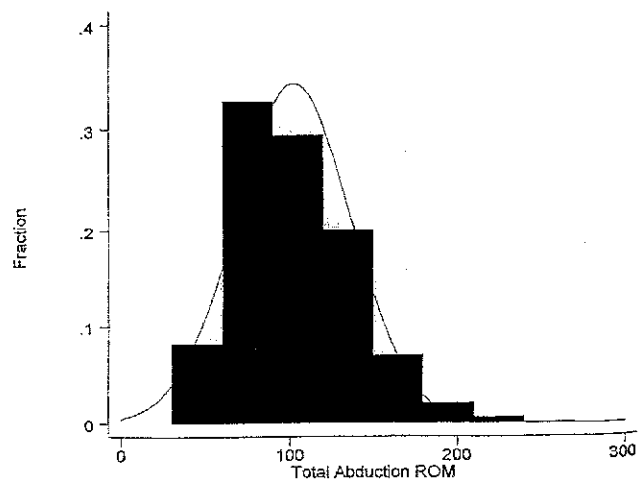


FIGURE 2—Hip abduction ROM measurement using a universal goniometer.

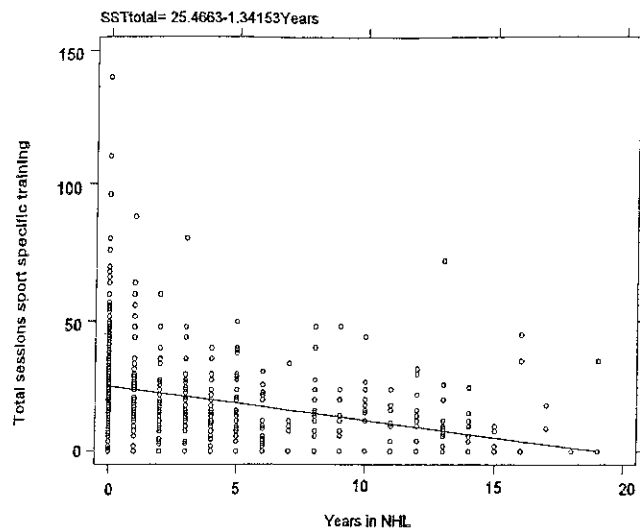


FIGURE 3—Simple linear regression of total sessions sport specific training (June–August 1998) on years of NHL experience.

injuries occurring during different time periods within a session, there was no significant difference in the proportion of injuries occurring during the three periods in a game session or the four quarters of a practice session. The mean number of sessions missed because of groin and abdominal strain injury was 11.42 sessions.

Primary Cohort Analysis

The relative risks of injury for training camp and regular season determined on the basis of univariate analysis of potential risk factors are reported in Tables 3 and 4. In assessing the risk of injury related to sport specific training stratified separately on previous injury, years of experience, peak adductor torque, and total abduction flexibility, there was no evidence against common ORs (P values of 0.30, 0.66, 0.55, and 0.76, respectively). On the basis of the stratified analysis, the risk of injury in training camp for players who reported less than 18 sessions sport specific training in the off-season was close to four times the risk of injury for players who reported at least 18 sessions. This risk did not depend on previous history of injury, peak adductor torque, or total abduction flexibility. This risk is also close to the relative risk (RR) calculated before stratifying on previous injury, peak adductor torque, or total abduction flexibility (RR, 3.38), indicating that these other exposure factors do not confound the relationship between sport specific training and injury. There was no significant association found between sport specific training in the off-season and risk of injury in the regular season.

In assessing the risk of injury related to sport specific training stratified on NHL experience (rookie/veteran), there was also no evidence against common ORs. This risk calculated was 2.03 (95% CI, 0.81–8.51). This was different from the relative risk calculated before stratifying on NHL experience (RR, 3.38), as the 95% CI included 1. Statistically, years of experience in the NHL appears to be a confounder in the relationship between sport specific train-

TABLE 3. Relative risk of groin and abdominal strain injury determined on the basis of univariate analysis of exposure variables for training camp period.

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 \geq 18 sessions	7	455	
Sport specific training < 12 sessions (August)	17	306	*2.88 (1.33–6.26)
Sport specific training \geq 12 sessions (August)	10	519	
Peak isometric adductor torque < 142.5 Nm	4	148	0.71 (0.26–1.97)
Peak isometric adductor torque \geq 142.5 Nm	29	764	
Abduction range of motion < 67.5 degrees	3	138	0.56 (0.18–1.76)
Abduction range of motion \geq 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 \geq 0.5 inch	15	360	1.42 (0.48–4.21)
Skate blade < 0.5 inch	4	138	

* Statistically significant finding ($P < 0.05$).

ing and injury. However, multicollinearity (i.e., high correlation between two independent variables) is likely an issue, and this will be addressed in the Discussion section.

The calculated incidence rates determined on the basis of level of sport specific training were 5.13 (95% CI, 3.16–7.81) injuries per 100 players per training camp period for

TABLE 4. Relative risk of groin and abdominal strain injury determined on the basis of univariate analysis of exposure variables for regular season period.

Exposure	Injury	No Injury	Relative Risk (95% CI)
Total sport specific training < 18 sessions	21	207	1.20 (0.58–2.46)
Total sport specific training \geq 18 sessions	10	120	
Sport specific training < 12 sessions (August)	19	170	1.42 (0.71–2.83)
Sport specific training \geq 12 sessions (August)	12	157	
Peak isometric adductor torque < 142.5 Nm	4	69	0.63 (0.23–1.72)
Peak isometric adductor torque \geq 142.5 Nm	32	334	
Abduction range of motion < 67.5 degrees	3	65	0.48 (0.15–1.53)
Abduction range of motion \geq 67.5 degrees	34	339	
Previous injury	18	103	1.30 (0.77–2.22)
No previous injury	34	264	
Veteran	47	433	*3.56 (1.13–11.22)
Rookie	3	106	

* Statistically significant finding ($P < 0.05$).

TABLE 5. Cumulative incidence rates (injuries per 100 players per training camp period) calculated on the basis of various cut-points for sport specific training.

Cut-Point Chosen (Total No. of Sessions Sport Specific Training)	Cumulative Incidence Rate Sport Specific Training < Cut-Point Chosen (95% CI)	Cumulative Incidence Rate Sport Specific Training ≥ Cut-Point Chosen (95% CI)	Relative Risk (95% CI)
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)

those players who reported less than 18 sessions sport specific training in the off-season and 1.52 (95% CI, 0.61–3.10) injuries per 100 players per 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 5).

The relative risks of injury between the high- and low-risk groups for mean peak adductor torque and total abduction flexibility, stratifying on other potential confounding or effect-modifying variables (previous injury, NHL experience (rookie/veteran), sport specific training), were calculated. There was no evidence of effect modification or confounding by any of these other variables. We concluded that there was no difference in the risk of injury in training camp or the regular season on the basis of peak isometric adductor torque or total abduction flexibility measured during the preseason.

In addition, stratified analysis was performed 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 risk of injury in training camp 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 of experience in the NHL, peak adductor torque, or total abduction flexibility. This risk was also close to the relative risk calculated before stratifying on other exposure variables (RR, 2.69), indicating that these other exposure factors do not confound the relationship between previous injury and injury. There was no apparent increased risk of injury during the regular season for those players reporting previous injury. On the basis of the small number of injuries and small cell sizes once a contingency table was stratified on a potential confounding or effect-modifying variable, stratification on a second variable could not be assessed because of empty cells.

Secondary Cohort Analysis

Logistic regression analysis on the basis of training camp data was performed. Statistically, the model that was the estimated logistic regression model of best fit was the following:

$$\text{Log odds of Injury} = -0.056\text{SST} + 0.00043\text{SST}^2 + 0.00056\text{Torque} + 0.3612\text{Years} - 0.0213\text{Years}^2 + 0.799\text{PrevInj} - 4.458 \quad (1)$$

The prefixes used in the model are defined as follows:

Log odds of Injury = an estimate from which probability of injury can be calculated.

SST = total number of sessions sport specific training reported (June–August).

SST² = quadratic term (total number of sessions sport specific training reported)².

Torque = peak adductor torque (Nm).

Years = number of years of NHL experience.

Yr² = quadratic term (number of years of NHL experience)².

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

Estimations of probability of injury (%) determined on the basis of this model are calculated with the following equation and reported in Table 6:

$$\text{Probability of injury} \times 100(\%) = \left(\frac{e^{\log \text{odds of injury}}}{1 + e^{\log \text{odds of injury}}} \right) \times 100(\%) \quad (2)$$

DISCUSSION

This prospective cohort study of professional ice hockey players resulted in several interesting findings. 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 a test-retest reliability study (7) using varsity and recreational athletes as subjects. The mean total abduction range of motion for 997 NHL players was 102 degrees. This is higher than the average reported for healthy male subjects by Reid (17) of 90 degrees. Perhaps these findings are associated with the physiology of elite level hockey players. Some measurements of total hip abduction ROM recorded, however, were extremely high and arguably outside the range of physiological probability. This may have resulted in a high estimate of mean abduction ROM. As a result, the validity and interrater reliability of this measurement may be questioned.

The median number of off-season sport specific training sessions reported (June–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. Of 852 players completing the sport specific training questionnaire, 115 players or 13.5% (95% CI, 11.27–15.98%) reported 0 sessions sport specific training in the off-season.

There was a significant association found between NHL experience and sport specific training. The simple linear

TABLE 6. Predictions of probability of injury (%) using logistic regression model 2.^a

Level of SST	Vet/PrevInj = 0 (95% CI)	Rookie/PrevInj = 0 (95% CI)	Vet/PrevInj = 1 (95% CI)	Rookie/PrevInj = 1 (95% CI)
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)
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)
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 No. (5) years of experience; Rookie, rookie with 0 years of experience; SST, No. of sessions sport specific training; Torque, peak isometric adductor torque preseason (Nm); Years, No. of years of NHL experience; PrevInj, 0 if no previous injury, 1 if previous injury; assumption of mean torque, 203 Nm.

^a Log odds of injury = $-0.056SST + 0.00043SST^2 + 0.00056Torque + 0.3612Years - 0.0213Years^2 + 0.799PrevInj - 4.458$.

regression estimation of sport specific training on NHL experience (Fig. 3) suggests a predicted 1.3-session decrease in sport specific training sessions reported per year increase in NHL experience.

The cumulative incidence rate of 3.83 injuries per 100 players per training camp period and 23.49 injuries per 100 players per regular season period were consistent with the rates reported during the previous six seasons of play in the NHL (7). The incidence density of 2.87 injuries per 1000 athlete exposures in training camp and 1.33 injuries per 1000 athlete exposures in the regular season were lower than that reported over the previous two seasons of play in the NHL, where the incidence density was close to 5 injuries per 1000 athlete exposures in training camp (7). 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 with 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 18,132 in 1998. The collection of exposure data in 1998 also may have been more accurate than in 1997 because of awareness by the therapists of this 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 (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, 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 groin adductor muscles and the remainder involved abdominal muscles. This is consistent with the findings in the previous 2 yr of NHL play, where 82.69% of the injuries involved groin adductor muscle (7). Seventeen percent of the injuries reported were classified as reinjury from the previous season. This is compared with 10% classified as such in the previous two NHL seasons of play (7). 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 with a 61% offensive, 29% defensive, and 6% goalie distribution of injuries in the previous two seasons of play. There appears to be an increase in the proportion of injuries sustained by goalies in

the 1998 training camp. However, there was also an increase in the number of injuries for which position was not reported. Total number of sessions missed because of injury (median, two sessions) cannot be compared directly with the median time loss of seven sessions in the previous two 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.

On the basis of analysis of contingency tables alone, players who reported less than 18 sessions sport specific training in the off-season (June-August) were at greater than three times the risk of sustaining a groin or abdominal strain injury during training camp. This risk did not depend on previous history of injury (previous season), peak adductor torque, total abduction range of motion, or skate blade hollow). However, when this association was investigated by stratification on years of NHL experience, rookie/veteran status statistically appeared to be a confounder in the association between sport specific training and injury. The OR point estimate was 2.03, but the 95% CI included 1. Statistically, therefore, 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, and a large 95% CI for estimation of actual relative risk of injury among rookies of 5.91 (95% CI, 0.54-64.49). In addition, there was a significant association found between sport specific training and years of NHL experience, which may have led 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 and the relationship between sport specific training and injury is, therefore, valid.

Off-season sport specific training closer 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 three 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-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 expected. Decreased level of sport specific training in the off-season was not found to be a significant risk factor for

groin and abdominal strain injury in the regular season of play.

Veterans were found to be at six times the risk of injury during training camp than were rookies. The risk for veterans was still fourfold during the regular season of play. However, arguably this was not likely because of physiological differences between rookies at the mean age of 18 yr and veterans at the mean age of 25 yr. 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 risk may be less in the regular season because rookies that never made the NHL teams may have been doing more sport specific training in the off-season to prepare for training camp.

The association between previous injury (within 1 yr) 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 in training camp than those who reported no previous history. This is consistent with laboratory findings (8,24,25) and Bennell et al.'s (2) findings that Australian rules football players were at two times the risk of hamstring strain injury than those with no previous history. Perhaps if players with previous injury survive training camp injury free they are more likely to survive the regular season injury free as well.

There was no association found between peak isometric adductor torque and injury. This was consistent with some findings in the literature (2,10,11,13,19,27,28), but inconsistent with other literature (4,5,15,29) 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 the findings by Liemohn (12) of decreased hamstring flexibility associated with hamstring strain injury in track athletes but consistent with the findings by Bennell et al. (2) of no association between flexibility and hamstring strain injury in Australian rules football players. The lack of associations found may be related to the potential problems with inter-rater reliability of measurements between team examiners.

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

Actual cumulative incidence rates for training camp were reported (Table 4) for various cut-points of total number of sport specific training sessions reported (June–August). Consistently, regardless of cut-point examined, there is a higher incidence rate found in those performing less sport specific training. Also, the incidence rate in the high-risk group decreases as more sessions are chosen as the cut-point for estimation of incidence rate. On the basis of these data, the proportion reduction in incidence rate between players performing less than 18 sessions sport specific training in the off-season and those performing at least 18 sessions was the greatest in comparison with 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 wk, 3 times-wk⁻¹) may be more clinically relevant, as it is more feasible to request players perform this amount of sport specific training in the off-season than 27 (9 wk, 3 times-wk⁻¹) or 36 (12 wk, 3 times-wk⁻¹) sessions. There is some evidence here of a dose-response gradient. The point estimate calculated for 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.

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. It does not have the limitations of the stratified analysis discussed previously. In the model presented, as the total number of sport specific training sessions increases, the probability of injury (calculated from the estimate of log odds of injury) decreases (all other exposure variables constant, within the parameters of the sample). This is strong evidence of a dose-response gradient. In addition, the probability 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 this model, the probability of injury increases with an increase in value of torque. This suggests that the stronger the player with respect to peak adductor torque, the higher the probability of sustaining injury in training camp. Clinically, this cannot be explained. However, if the model 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 player's torque value will not change the probability of injury significantly. If we estimate the probability of injury for a veteran, of median NHL experience (5 yr), with 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 estimate the probability of injury in training camp to be 8.7% (95% CI, 6.72–10.99%). In the same veteran with the same criteria except peak adductor torque measurement equal to the maximum in this sample (428 Nm), we can estimate the probability of injury in training camp to be 10.47% (95% CI, 8.35–12.99%). With significantly overlapping 95% CIs, we can conclude that there is no clinically significant difference in the probability of injury in training camp on the basis of torque measurement.

In this model, the significance of the quadratic term for years of experience in the NHL suggests that the probability of injury increases at a reduced rate with increase in years of NHL experience (all other variables constant). The calculated number of years of experience in the NHL at which the log odds of injury is maximized is 8.5 yr. Only 14.44% (95% CI, 12.11–17.03%) of the subjects in this study had more than 8.5 yr experience in the NHL. The quadratic term for sport specific training suggests 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 five sessions per week for the entire 12 wk of off-season). Clinically, it is unlikely that players would perform this level of off-season sport specific training. In predicting probabilities of injury, we see a decreasing probability of injury with increased number of sessions sport specific training and decreased number of years of NHL experience and an increasing probability of injury with a previous history of groin or abdominal strain injury (Table 5).

On the basis of the predicted probabilities of injury, clearly the target group for intervention consists of veterans. There is very little overlap in the 95% CIs for the probability of injury in veterans with no history of previous injury in those training 0 versus 18 sessions, and there is no overlap in the 95% CIs for the probability of injury in veterans with a history of previous injury in those training 0 versus 18 sessions. Increasing the number of sport specific training sessions from 0 to 18 sessions (equivalent to 6 wk, 3 times-wk⁻¹) 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. If we look at point estimates alone, the probability of injury could potentially be reduced for players performing no sport specific training in the off-season by 50% if the total number of sport specific training sessions is increased from 0 to 18 sessions (6 wk, 3 times-wk⁻¹).

The crude cumulative incidence rate in this sample of 3.83 injuries per 100 players per 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 on the basis of the logistic regression model presented (Table 5). 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, again confirming that increasing the level of off-season sport specific training 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.

Limitations in this study include the following:

1. Selection bias may have occurred because of nonparticipation of players (potentially those in the high-risk exposure groups), which may have resulted in an underestimation of association between exposures and outcome. Hence, if an association was found (as with previous injury and sport specific training), one could argue that this association is valid. On the other hand, if an association was not found (as with peak adductor torque and total abduction flexibility), one cannot be sure there is no association.

2. Differential misclassification of injury status may have occurred, as players (particularly rookies) 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. Differential 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. The result of this source of bias would again be to underestimate the association between risk factor and injury.
3. Nondifferential misclassification of injury or measurements may result from potential nonsystematic measurement errors in diagnosing injury status, testing peak adductor torque and total abduction flexibility, and nondifferential recall bias on completion of off-season sport specific activity questionnaire. Errors in the peak adductor torque measurement may have resulted from nonsystematic differences in the player's effort to produce maximal torque or differences in trainers' verbal cues. These sources of bias would again result in underestimating any true association between risk factor and injury.
4. A limitation of the NHLISS is the inability to determine individual exposure status. Exposure status for the purpose of incidence density calculations was estimated on the basis of 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 because of injuries and sitting out of games and/or practices. This limitation would likely result in an underestimation of incidence densities because of an overestimation of player exposure.

There are certainly potential implications for generalizability of these findings to a varsity population and likely to other, less elite, hockey populations. The level of training by players in the NHL in the off-season exceeded that found in the varsity hockey sample who completed the same sport-specific training questionnaire. The incidence rates for groin and abdominal strain injury in the Canada West University Athletic Association varsity hockey league over 3 yr of play were comparable to those found in the NHL over 6 yr of play (7). Further investigation of level of sport specific training in the off-season as a risk factor for groin and abdominal strain injury in less elite hockey populations is required.

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 before 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 perform sport specific training less than 18 sessions (equivalent to 6 wk, 3 times-wk⁻¹) 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 in training camp and the regular season 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 (equivalent to 6 wk, 3 times-wk⁻¹) 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. By increasing the level of sport specific training from 0 to 18 sessions, the estimated risk of groin or abdominal strain injury would be reduced 50%. 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 preseason and groin or abdominal strain injury in training camp because of potential sources of bias that may have underestimated these relationships.

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 that 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 perform 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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