Butterflies and Knees

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Background, Purpose and Hypothesis

In sports, painful injuries come from hyperextension, torque and impact on the joints. The biomechanics of the butterfly movement, when hockey goalies drop to their knees, were investigated to determine whether injuries to the knee were possible. ***Information about the different types of knee injuries, and types of measurements to make, was collected.*** The project was discussed with Professor Brodland and Professor Golnaraghi at the University of Waterloo. No previous information on the mechanics of the butterfly movement was found in any of the searches or consultations, proving that this project is unique [1]. The hypothesis is that hyperextension, impact and torque occurring during the butterfly movement can cause injury to the goalie's knees.

Procedure

The butterfly movement was studied carefully to discover possible ways the knees could be injured. Answers to the following questions were investigated as part of the experiments.

What are the different angles of movement of the knees, normally and during the butterfly?

The normal angles of movement of the upper and lower legs were measured for the goalie (without equipment on) standing naturally, kneeling on the floor and sitting with both legs hanging down. Each leg was lined up with a marker then moved and twisted sideways to a fully extended position and marked again. The angles between initial and final positions were

measured using a protractor. The angles of movement at different stages of the butterfly motion were then measured with the goalie in full equipment. Digital photographs of ***four*** stages in the butterfly motion were taken from the front, back and each side of the goalie. Lines were drawn on the photos to mark the angles of the knees and hips, which were then measured and recorded. The angles measured from the photos were compared to the normal angles of movement to determine whether the knee was overextended at various stages of the butterfly motion. The percentage of overextension of the knee was calculated to find the possibility of injury at a given stage.

How many butterflies does a goalie do in a week?

The number of butterflies that the goalie did at practices, games and skills sessions was counted and averaged, then multiplied by the average number of practices/games each week to determine how many butterflies the goalie did each week during the hockey season.

How much do the goalie and the goalie equipment weigh?

The mass of the goalie and each piece of equipment were measured separately, ***three*** different times, using a Thermo Nobel digital scale. The results were averaged, then added together to find the total average mass of the goalie and equipment.

What are the velocity and acceleration of the goalie?

In this part of the experiment, the goalie, dressed in full goalie equipment, performed a series of butterfly motions and was videotaped at 15 frames per second using a digital video camera. The overall velocity of the goalie was determined by finding the distance travelled by the goalie's head between consecutive images and dividing it by the time between the images (1/15 second). Acceleration was then the velocity divided by the time. The distance travelled was

measured by analysing a sequence of video images taken of the goalie doing the butterfly beside a tape measure. In the initial stance position (before the butterfly), the head of the goalie was lined up with a marker on the tape. The distance that the goalie's head moved downwards between frames was then measured using a clear ruler taped to the computer screen and carefully positioned to be even with the top of the goalie's head at the starting position. Once the distance was found, the velocity (distance moved/time between frames) and the acceleration (velocity/time between frames) of the goalie could be found.

To make more accurate measurements of the acceleration of the goalie, two professional accelerometers were ***used.*** These had to be secured tightly to the goalie so that they did not move or bounce during the test. One was secured to the goalie's leg, just above the knee, and the other was secured to the goalie's stomach. The accelerometers were connected to a laptop computer and set to record 1500 points/sec for 30 seconds. The goalie, in full equipment, performed several butterfly motions on the ice and values of acceleration were collected from both sensors at all stages. The results were made into x-y (time-acceleration) plots from which the maximum acceleration and deceleration were extracted. Average values were compared to values obtained from the video analysis.

What is the force on the knees upon impact and the torque on the knees during the butterfly?

Two different values of forces on the goalie's knee were calculated by multiplying the acceleration found from the accelerometers and from the movies by the average mass of the equipment and the goalie. These values of force were used to determine the torque on the knee at each stage of the butterfly. A video of the goalie doing the butterfly was again broken down into frames and, for each frame, the vertical distance from the goalies knee to the floor was measured, along with the horizontal distance along the floor from the skate blade or ankle to the knee. To

find the torque on the knee, the force at each stage of the movement was multiplied by the matching horizontal distance along the floor. From the results, the stage of the butterfly that resulted in the most torque was determined.

Results, Conclusions and Applications

The average mass of the goalie and equipment was 68.96 kg. The normal range of movement of the goalie's knees is between 15 and 30 degrees. At some stages of the butterfly the angles reached from 62 to 67 degrees (24 to 29% overextended), so overextension is possible.

The videos of the butterfly movement showed that there was an impact force when the goalie's knees hit the ground at the bottom of the butterfly. Measurements from the video produced an average deceleration on impact with the floor of -10.5 m/s^2 and an average force of -725 N. The accelerometers measured a maximum deceleration on impact of -58.98 m/s^2 and a maximum force of -4068 N; this is about the same as the force needed to lift 415 kg, nearly the weight lifted by the international powerlifting champions. The video value is much less than the readings from the accelerometers because the frames in the movie were farther apart in time than the readings of the accelerometer and so did not catch the high deceleration right on impact. The force of 4068 N with which the goalie hit the ground was not great enough to cause any extremely harmful damage, especially with the knee protection on the goalie's pads, but it could cause bruising and make the knee more susceptible to other injuries.

It was found that there is a twisting of the goalie's knees during the butterfly motion, especially at the point where the goalie's skates cease to cling to the ice. The torque on the goalies knees reached values of 640 N-m and 1156 N-m. These exceeded estimated normal torque on the knees of 20 N-m measured during walking and up to 240 N-m found during running/cutting motions in a sport such as soccer [1]. These high values of torque could

definitely cause injuries such as tears of the menisci that prevent rubbing of the bones. (see Figure 1) Tears or pulls of the highly important anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL) also may occur.

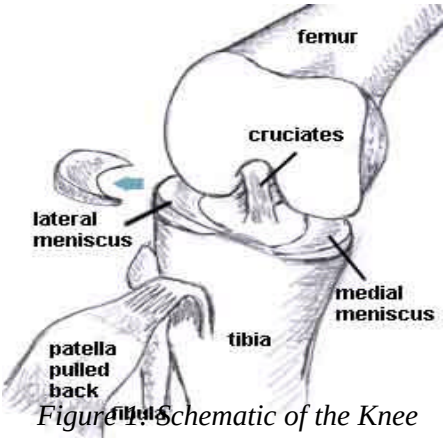

Figure 1: Schematic of the Knee

Since the butterfly motion is repeated about 94 times per week, injuries could result from repeated impacts, overextensions, or torques on the knee. In the future, goalies should increase and redesign the padding around their knees to maximize the absorption of force and minimize the possibility of impact injuries. They should also loosen their pads around their ankles so that their lower legs are more mobile during the downward motion of the butterfly. This will cause less torque on the knees. To prevent hyperextension injuries, butterfly goalies should practise not twisting their legs out too much when they are doing the butterfly.

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References

[1] Besier, T.F., D.G. Lloyd, J.L. Cochrane and T.R. Ackland, External loading of the knee joint during running and cutting manoeuvres, Medical Science and Sports Exercise, Volume 33, No. 7, pp. 1168-1175

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