KNEE INJURIES IN ALPINE SKIING – COMPUTER SIMULATIONS

Kajetan Kietlinski and Cezary Rzymkowski
Warsaw University of Technology, Institute of Aeronautics and Applied Mechanics,
Virtual Safety Engineering and Biomechanics Laboratory

KEYWORDS: Knee injuries, MADYMO, Skiing safety

INTRODUCTION

THE PAPER PRESENTED tries to explain—by means of computer simulation—some aspects of the phenomenon of the knee joint region ski injuries and also shows the mechanisms through which there is high risk of soft tissue injury.

All knee injury mechanisms considered in the study are indirect mechanisms (when load, applied to the body, is transferred through the bones to the joint, characteristic of skiing). Based on the information that was gathered during studies of literature (Jakob 1992, Kapandji 1987) and on previous studies concerning possible injury mechanisms to the soft tissues of the knee and skiing equipment designed to prevent lower limb injuries, two mechanisms through which cruciate ligament injury may occur were proposed to be considered.

The first mechanism is “Two-skier impact” in which one skier travels at a specific speed and collides with another skier stationary on the piste, striking the back of the stationary skier’s boots. In this case the sudden impact force causes very rapid anterior movement of the tibia relative to the femur and may contribute to the ACL injury. The second is called “Boot induced anterior drawer” and occurs when a skier loses his balance while jumping on the mogul and lands on the rear part of one of his skis. As a consequence the resilient strain energy of the rear part of the ski generates a rotating movement which pushes the tibia forward relative to the femur and similarly to the “Two-skier impact” case the ACL may be injured.

METHODS

A multibody skier model with flexible elements and a FEM model of the knee joint were developed in the MADYMO software environment. The anthropometry of the model: 1.82m height, 81kg weight, adult male. The whole model consists of several rigid bodies appropriately joined by means of kinematical pairs with defined stiffness characteristics (TNO 1999). The skier model was additionally equipped with the ski bindings, flexible ski and ski poles.

The model of the ski consists of both rigid and flexible elements. The part of the ski below the ski binding is rigid, whereas front and rear part of the ski were modelled as four flexible beam elements. The material and mass properties of the ski were calculated experimentally, ρ=1169kg/m3—density, E=4.3*10^{10}Pa—Young’s modulus. The moment of inertia of the ski section varies along the ski which makes the ski stiffer from the ends towards the central part.

The model of the knee displays all bones of this region (bones: femur, tibia, fibula and patella), the four main ligaments (ACL, PCL, MCL, and LCL), the patella ligament and the great muscle of the thigh (quadriceps femoris). To generate the geometry of bones of the knee region the Visible Human Project (VHP) data base was used. Because the main aim of this study was to assess a risk of soft tissue injury of the knee joint, all bones were modelled using undeformable elements. All ligaments were modelled as spring—dumper elements. The contact interaction between ligaments and bones cannot be defined which was the biggest simplification caused by using spring—dumper elements. Initial length of the ligaments and position of the insertion points on the bone were based on literature (Kajzer 1994, Sinielnikov 1989). Geometrical properties and stiffness characteristics of ligaments were defined for 16° flexion of the knee joint (initial flexion of the knee is determined by the fixed flexion of the ankle situated in the ski boot). The great muscle of the thigh was modelled as four spring-dumper, passive elements.

RESULTS

For the “Two-skier impact” case simulations were performed in the following conditions: three simulations in which the victim is struck in the middle rear part of his boot at 6m/s, 8m/s and 10m/s velocity respectively. For the “Boot-induced” case two simulations were performed in the following conditions: first one with correct adjustments of the bindings and second one with excessive release force adjusted for the bindings.

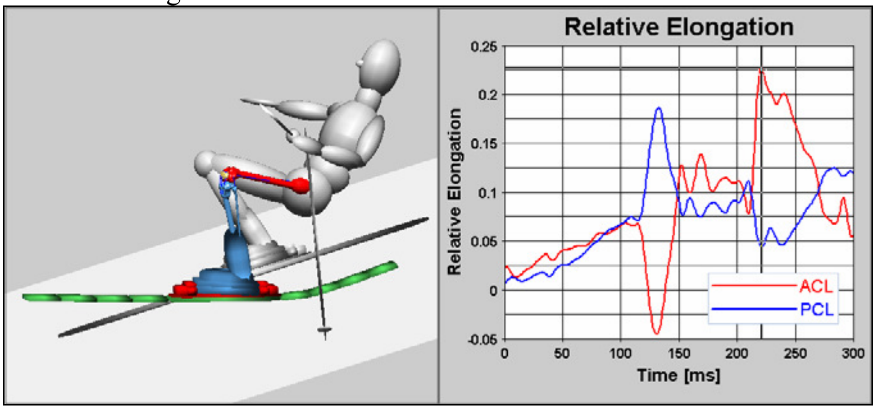

Figure 1 One of the considered injury mechanisms - “Boot induced”.

To classify the results the AIS coefficient was used. In case of knee ligament injury the range of scale is from 0 to 3. The figures “0” and “1” correspond to insignificant injury risk, figure “2” to a high risk of ligament tear and, figure “3-“ to a high risk of severe ligament tear and “3” to a high risk of total rupture.

Injury mechanism	Simulation description	AIS coefficient	
		ACL	PCL
Two-skier impact	6m/s	1	0
	8m/s	3-	0
	10m/s	3	1
Boot induced	Correctly adjusted bindings	3-	3-
	Excessively adjusted release force	3	2

Table 1. AIS coefficient for "Two-skier impact" and “Boot induced” simulations.

The solutions obtained confirmed by a majority that for the previously listed mechanisms (Two-skier impact and Boot-induced) a high risk of cruciate ligaments injury occurs, especially for the ACL. In none of the cases considered was damage noticed to the collateral ligaments the MCL and the LCL.

REFERENCES

Jakob R. P., Staubli Hans-Ulrich, “The Knee and the Cruciate Ligaments, Anatomy, Biomechanics, Clinical Aspects, Reconstruction, Complications, Rehabilitation”, Springer-Verlag, 1992

Kapandji I. A., “The Physiology of the Joints, Annotated diagrams of the mechanics of the human joints”, Volume 2, Lower Limb, 1987

Kajzer J., Yang J., Rzymkowski C., “Three-Dimensional mathematical model of the lower extremity at lateral impacts”, 1994

Sinielnikov R. D., “Atlas of Human Anatomy”, Moscow, Volume 1, 1989

TNO Automotive, “Madymo Manual v.5.4”, 1999