Knee Injury Risk and Risk Reduction of Professional Ski Instructors

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SUMMARY

Purpose. The purpose of this two-year, prospective research investigation was to determine the influence of directional compression tights and a novel ski binding on injury risk and the development of clinical symptoms in professional ski instructors.

Methods. A total of 222 male (49.5 ±16.2 y; 70.6 ± 3.2 in, 179.5 ± 24.2 lbs) and 119 female (45.3 ± 15.7 y, 65.1 ± 2.7 in, 141.1 ± 21.5 lbs) professional ski instructors from three ski areas located in the Rocky Mountains participated in this study. The participants were randomly selected to one of four research conditions: 1) directional compression tights (OPX); 2) a novel ski binding (KB); a combination of OPX and KB intervention products (OPX+KB); 4) control.

The total number of injuries and hours of skiing fulfilling on-mountain employment responsibilities were tracked and the absolute and relative injury risk reduction variables (ARR, RRR) were calculated for knee injuries and the total number of injuries for each research condition (p=.05). The size of the treatment effect was calculated via the numbers needed to treat (NNT) metric. Five participant reported outcome (PRO) variables measured at the beginning and end of each season with electronic surveys were selected to capture the physical demands of employment as a ski instructor and the associated work-related impact on the knee and low back: knee pain during skiing, knee-related physical function, low back pain during skiing, low back-related physical function, knee-related work performance. Knee pain and low back pain during the past week of skiing were measured on a digital visual analog scale; knee-related physical function with the physical function scale of the Western Ontario and McMasters (WOMAC) questionnaire; low back-related physical function with the Oswestry low back disability questionnaire; knee-related work performance with the sport and recreation scale of the Knee Injury and Osteoarthritis (KOOS) questionnaire. The PRO scores ranged from 0 (good) to 100 (poor) and were divided into quintiles for analysis with a 3-way (time, research condition, quintile) repeated measure ANOVA (p=.05).

Results. The OPX condition demonstrated 77.8% RRR in the total number of injuries (ARR, 14.7 (4.1, 28.7), p<.05); whereas the OPX+KB condition demonstrated 60.8% RRR (ARR, 13.3 (2.9, 23.7), p<.05). The OPX and KB conditions both demonstrated 100% RRR in knee injuries (OPX ARR: 8.1 (1.9, 14.3), p<.05; KB ARR: 8.1 (1.9, 14.3), p<.05). The NNT to prevent one body injury ranged from 7.2 (OPX) to 7.6 (OPX+KB); and the NNT to prevent one knee injury was 12.3 (OPX, KB).

The change in PRO scores were found to be dependent upon research condition and quintile group (all p<.001). On average, the low quintile group demonstrated an increase (worse) in PRO variable score at the end of the season for each research condition (Control, 37.7%; OPX, 31.7%; OPX+KB, 31.4%) and the high quintile group demonstrated a decrease (better) in PRO variable score at the end of the season (Control, -51.3%; OPX, -76.9%, OPX+KB, -68.6%). Relative to the control condition, the OPX condition demonstrated greater reductions (%Change) in all PRO variables for the high quintile group and lower increases for all variables except the PRO variable low back pain for the low quintile group. Similarly, the OPX+KB condition also demonstrated greater reductions (%Change) in all PRO variables for the high quintile group compared to the control condition and lower increases for all variables except the PRO variables low back pain and knee-related work performance.

Conclusions. A lower number of total injuries was found for the ski instructors wearing directional compression tights with and without the addition of skiing with the novel ski binding; and a lower number of knee injuries was found when wearing the directional compression tights or while using the novel ski binding. The decrement in PRO variables across a season, particularly knee pain during skiing, were improved by the directional compression tights with and without the use of the novel bindings.

INTRODUCTION

Professional ski instructors ski over 100 days per season and demonstrate a high risk of workplace injury particularly to the knee and low back (Viola et al., 1999). In a cross-sectional survey of ski instructors, Decker (2013) found that 67% of ski instructors reported a history of knee injury of which nearly half required at least one knee surgery. This high prevalence of knee injury and severity in ski instructors increases the risk of a subsequent knee injury (Sterett et al., 2006) and accelerates the progressive decline in knee function leading to osteoarthritis (OA; Lohmander et al., 2007).

Knee OA is characterized by increased activity related knee pain, anterior thigh muscle weakness and reductions in knee motion (Murphy et al., 2008). Altered knee motions have also been shown to cause postural changes in the lumbar spine and pelvis regions ultimately contributing to the onset of low back pain (LBP) (Murata et al., 2003). The concurrent point prevalence of LBP and knee pain was identified in 43% of ski instructors from a survey of the Professional Ski Instructors of America (Decker and Davidson, unpublished). This knee-spine syndrome predisposes an individual to increased symptom severity (Murata et al., 2003; Tsuji et al., 2002) and hypothesized to limit ski area employment longevity (Decker and Torry, 2015).

Backward and forward-twisting falls account for the majority of all knee injuries during alpine skiing and is the primary mechanism of an anterior cruciate ligament (ACL) injury in modern carving skiers for both men and women (Ruedl et al., 2009, 2011; Shea et al., 2014). During a backward or forward-twisting fall the leg twists inwards and the knee moves towards the midline as the ski twists the lower leg outwards ("valgus-external rotation"). Failure of the binding to release at the appropriate time during a forward or backward twisting fall increases ACL strain above the biological failure threshold leading to rupture.

Knee injury risk during alpine skiing may be reduced with a novel ski binding that includes a lateral heel release mechanism (KneeBinding Inc., Stowe, VT). The addition of a lateral heel release increases the probability that the boot will release from the binding during a twisting fall thus reduce knee torque and ACL injury risk. It has been shown through computer modeling that including a lateral release reduces ACL strain when a lateral force simulating a twisting fall is applied to the ski (St-Onge et al., 2004).

Research from the Human Dynamics Laboratory at the University of Denver has found that skiing with directional compression tights (Opedix LLC, Scottsdale, AZ), influences the skier's stance during turning. Skiing with directional compression tights was found to reduce the force applied from the skier to the ground by 9%, the torque on the knee by 16% and the muscular requirement from the quadriceps muscles by 17% (Decker et al., 2016; Simons et al., 2016). These results may indicate that the directional compression tights may positively influence muscle fatigue, knee joint stability and dynamic balance. Hence, a directional compression product may influence overall ski turning technique via neuromuscular mechanisms and provide a simple tool to mitigate ACL injury risk during alpine skiing.

Work place injury rates, worker compensation costs and additional medical and administrative costs, including physical rehabilitation and the training or hiring of additional employees, places an estimated $85.1 million economic burden on the 481 U.S. ski areas (Roberts, 2013). This annual burden has galvanized the efforts to search for better ski equipment to limit (or prevent) the injurious forces and torques at the knee and provide a practical solution to reduce the risk of workplace knee injuries. The purpose this study was to determine the influence of directional compression tights and a novel ski binding on knee injury risk, knee injury risk reduction and the impact on the development of clinical symptoms in professional ski instructors over two ski seasons.

METHODS

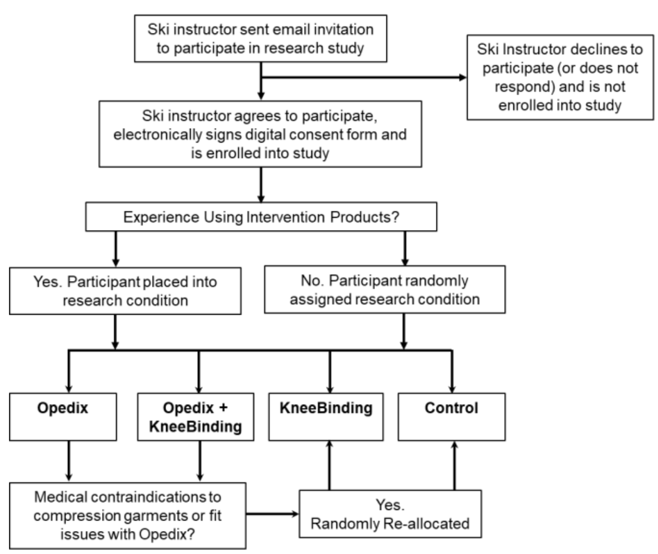
Experimental Procedures

Professional ski instructors from three ski areas located in the Rocky Mountains were sent an email from the University of Denver's Human Dynamics Laboratory requesting their participation in a 2 year research study investigating knee injury risk and risk reduction. The email provided information about the study design, time requirements for participation and inclusion criteria. If the participant was interested in participating and was 18 years of age or older, currently employed as a professional ski instructor and used alpine skis for their ski area employment responsibilities they were asked to follow a digital link located at the end of the email that directed them to a custom electronic enrollment survey designed in a web based software program (Survey Monkey).

The first survey consisted of four sections: 1) an informed consent document; 2) participant demographics and ski area employment information; 3) injury history form; and 4) a standardized orthopaedic questionnaire (International Knee Documentation Committee (IKDC) Subjective Knee Form). The informed consent document was the first page of the survey. At the end of the informed consent document, a box was provided to click (check) if the ski instructor agreed to participate in the study. If the ski instructor agreed to participate, the box was checked and then were asked to provide their digital signature and email address. The web based software had built in logic to ensure that only consenting participants were enrolled and completed the remainder of survey.

The IKDC Subjective Knee Form consists of 18 questions in the domains of symptoms, functioning during activity of daily living and sports, current function of the knee, and participation in work and sports (Anderson et al., 2006). Each question is scored and the sum is expressed as a percentage ranging from 0-100 with higher scores representing better knee function and less symptoms.

Figure 1. Group allocation procedures.



The participants were randomly assigned into 1 of 4 experimental conditions (Figure 1). Condition 1 consisted of ¾ length, directional compression tights (Opedix Dual-Tec Tights, Opedix LLC, Scottsdale, AZ, www.opedix.com); Condition 2 was a novel ski binding with front and rear release mechanisms (KneeBinding, KneeBinding Inc., Stowe, VT, www.kneebinding.com); Condition 3 was the combination of intervention products used in Conditions 1 and 2; and Condition 4 did not use either intervention product (control). If the participant had a history of using either of the intervention products being investigated in this study, then the participant was automatically placed within the corresponding experimental condition(s). Further, if the participant had any medical contraindications to wearing compression clothing including advanced arterial disease of the legs, uncontrolled congestive heart failure, un-treated septic phlebitis of the leg or phlegmasia cerulea dolens (a severe form of deep venous thrombosis); or if the tights did not properly fit the participant then they were randomly assigned to another condition.

After group allocation, an email was sent to the participants notifying them of where to receive a complimentary ski tune, binding mounting and, if applicable, the procedures of picking up their intervention product(s) at their ski area uniform distribution office. At the end of the email, a digital link to a second web-based survey was provided.

The second survey consisted of three orthopaedic questionnaires that were completed within two weeks after the intervention products were distributed: The Knee Injury and Osteoarthritis Outcome Score (KOOS), the Western Ontario and McMasters (WOMAC) and the Oswestry Low Back Disability (Oswestry) questionnaire. The KOOS is a 42-item, knee joint specific questionnaire that assesses people's opinions about any difficulties they experience with activity due to problems with their knees. Scores range from 0 to 100 and a higher score indicates worse knee function. The KOOS has 5 subscales each measuring a specific outcome: pain, symptoms, activities of daily living, sport and recreation function, and knee-related quality of life. The KOOS has been validated in individuals with either healthy (Paradowski et al., 2006) or previously injured knees (Roos et al., 1998). A subset of the KOOS questions was used for the WOMAC questionnaire. The WOMAC is a disease-specific self-report instrument for the knee with 24 questions with three subscales including pain, stiffness and physical function. Scores range from 0 to 100 and a higher score indicates worse function.

The Oswestry has been one of the most commonly used disease-specific measures for patients with low back pain (Fairbank et al., 1980). The Oswestry Disability Index (ODI) is calculated based on the score of 10 items and ranges from 0 to 100 (Fairbank et al., 2000). A higher score on the ODI indicates a more severe disability caused by LBP. The Oswestry Low Back Disability Questionnaire and ODI have been validated for patients with low back pain (Davidson et al., 2002) and only the participants that report a history of low back pain will be asked to complete this questionnaire.

Over the course of the season, random spot checks or audits were performed to confirm that the participants assigned to a particular condition at each ski area were properly and consistently using the provided intervention products. These ski area visits were used to oversee the progression of the study, conduct functional assessments of the equipment and answer any questions regarding the research study.

A third survey was sent via email to the participants at the end of the Season (April 1st). This survey consisted of the same questionnaires as the second survey with the addition of a self-report section to determine the number of days and hours per day the participant worked with and/or without an intervention product (exposure) and any new injuries that required medical attention or kept them from working for at least one day after the day of a work place injury. Additional medical information identifying the biological structure injured, body location and lost time were collected from the participant.

Exposure was defined as the product of the number of skiing days and hours per skiing day fulfilling on-mountain employment responsibilities. The number of days and average number of hours per day that the participant skied for their ski area employment were measured from Likert scales (number of days: 0, 1-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, 91-100, 101-110, 111-120, and >120 days; hours per day: 0, 1, 2, 3, 4, 5, 6, 7, 8, and >8 hours). Skiing exposure was defined as the product of the range of total hours and the average number of hours per day. For example, a participant reporting 101-120 days of skiing with an average of 7 hours per day had a minimum total exposure of 707 hours and a maximum exposure of 840 hours.

The frequency of intervention product use during their ski employment hours was captured on a 12 point Likert scale: 0, 1-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, 91-100%. The range of intervention exposure was the product of minimum total exposure and the lower range of intervention use and maximum total exposure by the higher range of intervention use. Participants were required to use an intervention product greater than 10% of their time fulfilling on-mountain employment responsibilities to be considered a participant in an intervention condition.

Injury Tracking

The self-reported injuries section within the third electronic survey allowed the participant to report the incidence of any new injuries and provide additional information about the injury and details of the accident. Each ski area maintained a record of all work place injuries (injury records) and were used as an additional source of injury reporting. The sharing and transfer of de-identified injury records were performed according to a data sharing agreement between the University of Denver and the ski area management representative/team. The collection of self-reported and ski area reported injury data provided redundant sources of information to enable the understanding of the mechanism and result of each injury. The participants were also asked for their consent to allow their ski area management to share their injury records with the researchers of this study.

An injury was defined as an event that prevented the employee from working as a professional skier for at least one day after the injury or required medical attention and a subsequent worker's compensation claim. Multiple injuries by a single event was considered to be one injury with a multiple diagnosis. An instructor was defined as "injured" until they returned to ski instruction (return to work). The type of injury was defined as acute (injury with a sudden onset associated with a known trauma that occurred in a sudden manner), overuse (injury with a gradual onset without a known trauma or re-injury (injury of the same type and in the same location it was previously sustained within 2 months (early), 2-12 months (late) or >12 months (delayed). The day on which an instructor is injured was Day 0 and was not counted when determining the severity of an injury. The severity of an injury was classified as minimal (absence from ski instruction for 0-3 days), mild (absence from ski instruction for 4-7 days), moderate (absence from ski instruction for 8-28 days) and severe (absence from ski instruction >28 days).

Three injury tracking models were used to appropriately calculate injury rates and estimate changes in injury risk for each intervention condition. At the end of each season, all injuries were collected and counted from each ski area's records and the participant's self-reported injury descriptions (Group Model). The injuries were then evaluated to determine if the participant was using an assigned intervention product at the time of injury while performing their on-mountain employment responsibilities. The injury count was re-allocated between research conditions if the participant reported they were not using their assigned intervention product at the time of injury (Corrected Model) and this count was subsequently adjusted down if the participant reported that the injury occurred outside of their on-mountain employment responsibilities (Valid Model).

The total number of injuries and skier days during work hours were tracked to provide a relative measure of injury rate (number of injuries per 1000 skier hours) and injury incidence (number of injuries per number of participants). The absolute and relative injury risk reduction variables were calculated for the knee and total number of injuries for each research condition and the size of the treatment effect was calculated via the numbers needed to treat (NNT) metric.

Participant Reported Outcomes

Five participant reported outcome (PRO) variables were selected to capture the physical demands of employment as a ski instructor and the associated work-related impact on the knee and low back: knee pain, knee-related physical function, low back pain, low back-related physical function, knee-related work performance. Knee pain during the past week of skiing was measured on a digital visual analog scale. Scores range from 0 (no pain) to 100 (extreme pain) and higher scores represent worse knee pain while fulfilling on-mountain employment responsibilities.

Knee-related physical function was defined by 17 questions comprising the physical function scale of the WOMAC questionnaire. Scores range from 0 (high function) to 100 (poor function) and a higher score indicates worse knee-related physical function.

Low back-related physical function was measured by 10 questions from the Oswestry low back disability questionnaire. Scores range from 0 (high function) to 100 (poor function) and a higher score indicates worse low back-related physical function.

Low back pain during the past week of skiing was measured on a digital visual analog scale. Scores ranged from 0 (no pain) to 100 (extreme pain) and higher scores represent worse low back pain while fulfilling on-mountain employment responsibilities.

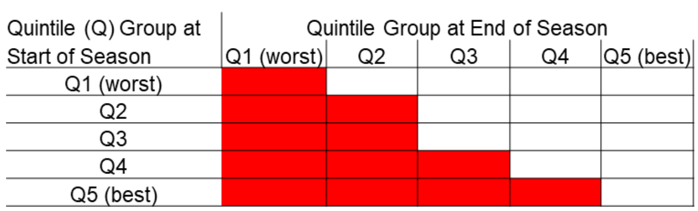
Knee-related work performance was measured from 5 questions comprising the sport and recreation scale of the KOOS. The questions concern the participant's physical function when being active on a higher level and are answered by the degree of difficulty they have experienced during last week due to their knee. Scores range from 0 (high function) to 100 (poor function) and a higher score indicates worse knee-related work performance.

Outcome Assessment

The five PRO variables were assessed at the beginning and end of each season to determine the physical demands of professional ski instruction. To characterize the seasonal experience of each participant, quintile grids were used, with poor PRO defined as remaining within the two lowest quintiles (worst groups) or moving into a worse group. The figure below illustrates how poor outcome was defined for each of the five PRO variables. Quintile groups were defined by the cut-off values of the baseline score quintiles calculated at the beginning of the season from the data of 175 participants captured at the start of the study (Figure 2, top). The outcome was considered "poor" at the end of the season when a participant's PRO score moved into a lower quintile group or remained within the two lowest quintiles (Figure 2, bottom).

Figure 2. Quintile groups were defined by the cut-off values of the baseline score (top). The outcome was considered "poor" at the end of the season when a participant's PRO score moved into a lower quintile group or remained within the two lowest quintiles groups (bottom).

Quintile (Q) Group	Knee Pain	Knee Function	Low Back Function	Low Back Pain	Work Related Knee Function
Q1 (worst)	>24	>10.3	>18	>25	>35
Q2	>13-24	>5.9-10.3	>10-18	>14-25	>20-35
Q3	>4-13	>2.9-5.9	>6-10	>7-14	>10-20
Q4	>0-4	>0-2.9	>0-6	>0-7	>0-10
Q5 (best)	0	0	0	0	0



The impact of employment and the development of clinical symptoms were determined with two analysis methods. The first method tabulated the outcomes scores determined from the quintile grid method and the effects of a research intervention condition on a PRO score calculated with an odds ratio (PRO score "better" or "worse").

The second method focused on the magnitude of the PRO scores collapsed across years at the beginning and end of a season of skiing. The magnitude of the PRO scores were contrasted with a three-way repeated measures ANOVA to determine the effects of time (beginning and end of season), research condition (control, OPX, KB, OPX+KB), and quintile group measured at the end of the season.

RESULTS AND DISCUSSION

Participants. A total of 362 ski instructors provided digital consent to participate in this study. After the first season, 17 participants reported that they were no longer employed as a ski instructor but allowed us to retain their data from their first year of participation. Twenty-one participants opted out of the study or were lost to follow-up.

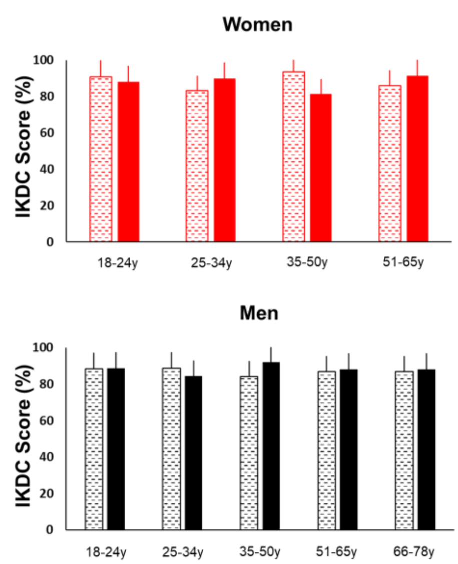
Table 1. Point-prevalence of knee injury, surgery and soft tissue damage in the male and female participants.

	Men		Women		Total	
	N	%	N	%	N	%
Knee Injury History*	**103**	**46.4**	**63**	**52.9**	**166**	**48.7**
Dominant	32	14.4	20	16.8	52	15.2
Non-dominant	36	16.2	23	19.3	59	17.3
Both	33	14.9	20	16.8	53	15.5
Knee Surgery History	**51**	**23.0**	**36**	**30.3**	**87**	**25.5**
Meniscus Injury	**57**	**25.7**	**40**	**33.6**	**97**	**28.4**
Knee Ligament Injuries	**65**	**29.3**	**37**	**31.1**	**102**	**29.9**
ACL	34	15.3	23	19.3	57	16.7
MCL	20	9.0	13	10.9	33	9.7
LCL	9	4.1	0	0.0	9	2.6
PCL	2	0.9	1	0.8	3	0.9

*Two participants did not report which knee was previously injured

A total of 222 men (49.5 ±16.2 y; 70.6 ± 3.2 in, 179.5 ± 24.2 lbs) and 119 women (45.3 ± 15.7 y, 65.1 ± 2.7 in, 141.1 ± 21.5 lbs) participated in this study. The point-prevalence of knee injuries, surgeries and soft tissue damage for the participants at the onset of the study are reported in Table 1. The number of events and the number of events expressed as a percentage for each sex and the total group are reported. Please note (*) that two of the participants did not report which knee was previously injured. Inspection of Table 1 reveals that nearly half of the participants reported a previous knee injury (men, 46.4%; women, 52.9%) and over half of these injuries required at least one surgical intervention (men, 23.0%; women, 30.3%). The three primary soft tissue structures that provide knee joint stability during alpine skiing were found to be the most frequently injured for both men and women: ACL (16.7%), MCL (9.7%) and the meniscus (28.4%). Women demonstrated slightly higher knee injury prevalence to these structures, particularly in the non-dominant leg.

Figure 3. The mean (+SE) IKDC scores for women (red) and men (black) as a function of knee injury history (solid bars) and age.



Knee Function. The IKDC questionnaire was used to measure knee function prior to the participant's first season in the study. The mean IKDC scores for the male (black bars) and female (red bars) participants with (solid bars) and without a history of knee injury are graphically presented as a function of age in Figure 3. Statistical analysis was performed on 328 participants (men, n=205; women, n=113) with (n=151) and without (n=167) a history of a previous knee injury using age as a co-variate (continuous variable). The IKDC scores were on average higher for men (88.3 ± 0.8) compared to women (85.7 ± 1.0) ($F(1,313)=3.996$, $p=.046$). Individuals with a history of knee injury (83.2 ± 0.9) demonstrated lower IKDC scores than individuals without a history of knee injury (90.8 ± 0.9) ($F(1,313)=33.9244$, $p<.001$).

The statistical analysis revealed that female participants with and without a history of a previous knee injury scored lower on the IKDC questionnaire than their male counterparts. These results are consistent with the knee injury history differences noted above and given that mean IKDC scores were under 93.6 the participants on average were likely to demonstrate asymmetrical knee motion and strength; as well as poor knee motion and strength (Zwolski et al., 2015; Palmieri-Smith et al., 2015).

Table 2. The average range (±SE) of on-mountain ski hours (exposure) performed each season for the 4 research conditions.

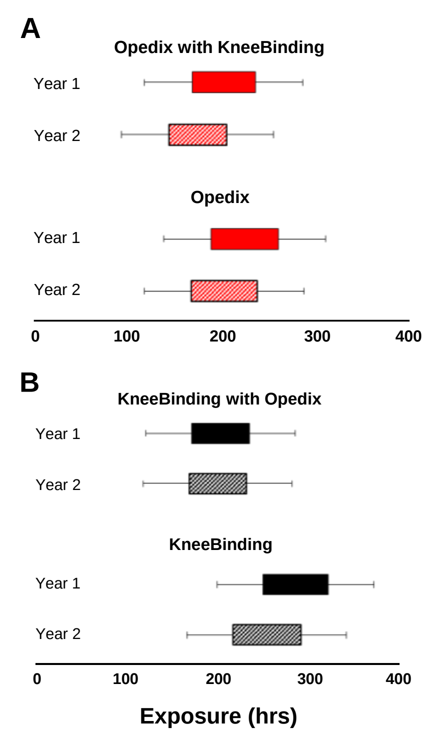
		Control	OPX	KB	OPX+KB
Year 1	Min	267.7 (3.8)	281.9 (3.8)	363.7 (18.0)	275.6 (4.6)
	Max	322.3 (3.8)	338.1 (3.8)	414.7 (18.0)	331.2 (4.6)
Year 2	Min	209.4 (9.7)	259.5 (4.6)	323.5 (11.4)	240.9 (5.8)
	Max	264.3 (9.7)	317.5 (4.6)	380.0 (11.4)	295.4 (5.8)
Total	Min	252.9 (6.8)	271.5 (4.2)	341.8 (14.9)	261.0 (5.2)
	Max	307.6 (6.8)	328.8 (4.2)	395.8 (14.9)	316.1 (5.2)

Exposure. The participant's membership within an assigned research condition was evaluated based on a minimum exposure criteria at the end of each season. Participants remained a member in a research condition if they used their assigned intervention product greater than 10% of their employed ski hours.

The group memberships of 266 (78.0%) participants were confirmed via the minimum exposure criteria (Control, n=74; OPX, n=94; KB, n=27; OPX+KB, n=71). The 75 (22%) participants that were not confirmed into a research condition did not complete the surveys at the end of each season. There were 21 research condition re-assignments (Year 1, n=15; Year 2, n=6). Fourteen re-assigned participants did not use the Opedix tights greater than 10% of their employed ski hours; and 7 did not use the KneeBindings greater than 10% of their employed ski hours. These participants were re-allocated to the appropriate research conditions.

The average range of skiing hours (±SE) performed within each research condition during each season are reported in Table 2. Statistical analysis confirmed that the maximum exposure was equal between research conditions (F(3,191)=.610, p=.609). Although the mean exposure per research condition was on average 10.1% lower during the second season, the maximum exposure remained equal between conditions (F(3,130)=.877, p=.455). The average range (±SD) of on-mountain ski hours performed each season with the intervention products are graphically represented in Figure 4. The intervention exposure was high and on average the participants wore the Opedix products 77.7% and 72.3% of their total skiing hours during the OPX and OPX+KB conditions; and used the KneeBindings 74.9% and 72.1% of their total skiing hours during the KB and OPX+KB conditions.

Figure 4. The average range (±SD) of on-mountain ski hours (exposure) performed each season with A) Opedix (red bars) and B) the KneeBinding (black bars).



Injury Tracking. A total of 29 traumatic injuries with 44 injury locations and 35 injury types were identified. The knee was the most frequently injured body location (22.7%) followed by the head (13.6%) and lower back (11.4%). Muscle injuries were the most frequently reported type of injury (22.8%), followed by concussions (14.3%) and ligament strains (14.3%). The severity of these injuries primarily required less than three days of absence from instruction and were classified as minimal (37.5%). Injury severities classified as moderate (8-28 days), severe (>28 days) and mild (4-7 days) accounted for 33.3%, 20.8% and 8.3% of the injuries.

Over half of the reported injuries (58.5%) incurred during a fall from a collision with another person or object while skiing. Twisting forward was the most commonly reported direction and motion of all falls (35.3%) and was double the frequency of backward twisting falls (17.6%).

Injury Tracking Models. All sources of information regarding each injury event were further evaluated to determine if the participant was using an assigned intervention product at the time of injury while performing their on-mountain employment responsibilities. The injury count was re-allocated between research conditions if the participant reported they were not using their assigned intervention product at the time of injury (Corrected Model) and this count was subsequently adjusted down if the participant reported that the injury occurred outside of their on-mountain employment responsibilities (Valid Model).

The total number of injuries and knee injuries tabulated with Group, Corrected and Valid injury tracking models for each research condition and season are located in Tables 3 and 4, respectively. Seven injuries were re-allocated in the Corrected injury tracking model (Year 1, n=2; Year 2, n=5). In all cases, the injury counts were removed from an intervention condition (OPX, n=4; KB, n=1; OPX+KB, n=2) and re-allocated to the Control condition ("None") because the participants were not wearing and/or using the intervention product on the day and time that the injury occurred.

Table 3. Total number of injuries tabulated with Group, Corrected and Valid Models of injury tracking for each research condition and season.

	Year 1			Year 2			Total		
Condition	Group	Corrected	Valid	Group	Corrected	Valid	Group	Corrected	Valid
OPX	5	3	2	5	3	2	10	6	4
KB	0	0	0	4	3	2	4	3	2
OPX+KB	4	4	3	3	1	1	7	5	4
None	6	8	8	2	7	6	8	15	14
	15	15	13	14	14	11	29	29	24

Table 4. Total number of knee injuries tabulated with Group, Corrected and Valid Models of injury tracking for each research condition and season.

	Year 1			Year 2			Total		
Condition	Group	Corrected	Valid	Group	Corrected	Valid	Group	Corrected	Valid
OPX	0	0	0	2	0	0	2	0	0
KB	0	0	0	1	1	0	1	1	0
OPX+KB	2	2	2	0	0	0	2	2	2
None	3	3	3	2	4	3	5	7	6
	5	5	5	5	5	3	10	10	8

The Valid injury tracking model removed five injury counts (Year 1, n=2; Year 2; n=3). Injury counts were reduced in all research conditions (OPX, n=2; KB, n=1; OPX+KB, n=1, Control, n=1) because the participants reported that the injuries did not occur while fulfilling their on-mountain employment responsibilities. Consequently, the sum of all injury counts were reduced from 29 to 24 total injuries.

Knee Injuries. The Corrected and Valid injury tracking models did not change the knee injury counts within each research condition during the first year of the study. During the second year of the study, however, two injury counts were re-allocated from the Opedix group to the Control group due to their omission of the product during the day and time of their injury event. Two knee injury counts were removed from the Valid injury tracking model because the participants reported that the injury event occurred outside of their on-mountain employment responsibilities (KB, n=1; Control, n=1) and thus modified the sum of all knee injury counts from 10 to 8 knee injuries.

Absolute Risk Reduction. The injury count data from the Corrected and Valid injury tracking models were converted into event rates for each research condition. The arithmetic difference between the event rate of the Control group and the event rate of each intervention condition was performed to calculate the absolute risk reduction (ARR) metric. The ARR (95% CI) for knee and total injuries are located in Table 5. A positive ARR metric with non-negative confidence intervals denoted a statistically significant reduction in injury risk ($p<.05$).

All injury counts tabulated under the Corrected (n=29 injuries) and Valid (n=24 injuries) injury tracking models, were used to calculate the ARR (95% CI) for each intervention condition. The OPX condition demonstrated 68.8% (ARR, 13.9 (3.5, 24.3), p<.05) and 77.8% (ARR, 14.7 (4.1, 28.7), p<.05) reductions in total injury risk; whereas the OPX+KB condition demonstrated 65.3% (ARR, 13.2 (2.3, 24.2), p<.05) and 60.8% (ARR, 13.3 (2.9, 23.7), p<.05) reductions in total injury risk.

All knee injury events tabulated under the Corrected (n=10 knee injuries) and Valid (n=8 knee injuries) injury tracking models were used to compute the ARR for each intervention condition. The OPX condition demonstrated 100% reductions of knee injury risk for both injury tracking models (Corrected Model, ARR, 9.5 (2.8, 16.1), p<.05; Valid Model, ARR, 8.1 (1.9, 14.3), p<.05); whereas the KB condition demonstrated a 100% reduction (ARR, 8.1 (1.9, 14.3), p<.05) under the Valid model.

Table 5. The total number of injuries and knee injuries tabulated with two injury tracking models; the effect of three intervention groups on absolute risk reduction (95% CI) and the numbers needed to treat (95% CI).

			Injury Count		Absolute Risk Reduction (%)		Numbers Needed to Treat	
	Condition	N	Corrected	Valid	Corrected	Valid	Corrected	Valid
All Injuries	Control	74	15	14				
	OPX	94	6	4	13.9 (3.5, 24.3)	14.7 (4.9, 24.5)	7.2 (4.1, 28.7)	6.8 (4.1, 20.6)
	KB	27	3	2	9.2 (-5.8, 24.1)	11.5 (-1.8, 24.8)	ns	ns
	OPX+KB	71	5	4	13.2 (2.3, 24.2)	13.3 (2.9, 23.7)	7.6 (4.1, 43.4)	7.5 (4.2, 34.8)
Knee Injuries	Control	74	7	6				
	OPX	94	0	0	9.5 (2.8, 16.1)	8.1 (1.9, 14.3)	10.6 (6.2, 35.8)	12.3 (7.0, 52.9)
	KB	27	1	0	5.8 (-4.0, 15.5)	8.1 (1.9, 14.3)	ns	12.3 (7.0, 52.9)
	OPX+KB	71	2	2	6.6 (-1.1, 14.3)	5.3 (-2.0, 12.6)	ns	ns

Number Needed to Treat. The treatment effect of the statistically significant ARR calculations was determined with the Number Need to Treat (NNT) metric. This metric represents the number of participants (ski instructors) that would need to be treated with an intervention product or combination of products to prevent one ski instructor from experiencing an adverse effect (injury).

The NNT (95% CI) calculations are located in Table 5 and only statistically significant NNT metrics are provided. The NNT with the OPX intervention product to prevent one body injury ranged from 6.8 to 7.2; and the NNT with the combination of OPX and KB intervention products ranged from 7.5 to 7.6. The NNT with the OPX intervention product to prevent one knee injury ranged from 10.6 to 12.3; and the NNT with the KB intervention product was 12.3.

Outcome Variables. The mean (SE) of five PRO variables measured at the start and end of two consecutive ski seasons (Year 1, Year 2) for each research condition are located in Appendix A. The number of participants within each group and during each year was dependent upon the successful completion of the questionnaires at both the beginning and end of each season (Year 1, N=135 (50.8%); Year 2, N=118, (44.3%)). Inspection of these data for the control condition reveals a general increase, or worsening, across all PRO variables at the end, compared to the beginning of each season. Further, these values were typically higher during the second season with knee pain during skiing doubling the value measured at the end of the previous season. This could be an important finding as nearly 20% of the participants completed the two-year study with knee pain scores consistent with the values noted in patients with knee osteoarthritis (ie., knee pain score of 25 or greater).

The PRO scores during the intervention conditions were on average lower than the values measured for the control condition. In general, the intervention conditions either reduced the magnitude or limited the progressive increase of the PRO score within and between each season.

The start-to-end of the season outcome of each participant for each PRO variable and research condition was performed by consolidating the PRO data from each season and then collapsing the participants from the KB research condition into the KB+OPX condition (due to insufficient number of participants in the KB condition). The outcomes for each participant and PRO variable was then determined with a quintile grid. The outcome was considered "poor" at the end of a season when a participant's PRO score measured at the beginning of the season moved into a lower quintile group or remained within the two lowest quintiles groups.

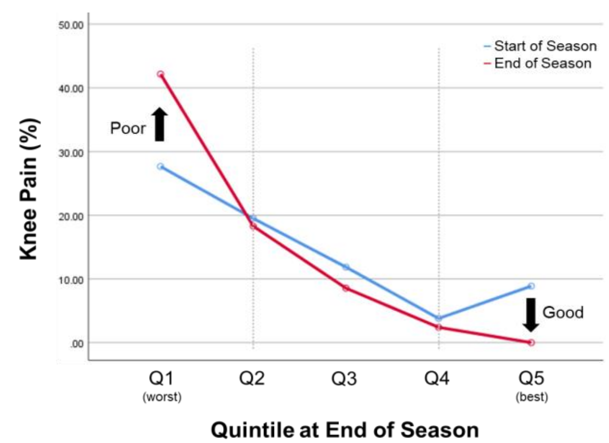
Table 6. The event odds (%) and odds ratio of a research condition demonstrating good or poor outcomes for the five PRO variables.

Variable	Condition	Events Odds (%) Good	Events Odds (%) Poor	Odds Ratio	Result
Knee Pain	Control	55.0	45.0		
	OPX	68.3	31.7	1.76	Better
	OPX+KB	51.9	48.1	1.13	Worse
Knee-Related Physical Function	Control	60.0	40.0		
	OPX	53.7	46.3	1.30	Worse
	OPX+KB	59.3	40.7	1.03	Worse
Low Back-Related Physical Function	Control	45.9	54.1		
	OPX	58.5	41.5	1.66	Better
	OPX+KB	61.1	38.9	1.85	Better
Low Back Pain	Control	71.8	28.2		
	OPX	78.0	22.0	1.40	Better
	OPX+KB	81.5	18.5	1.73	Better
Knee-Related Work Performance	Control	67.5	32.5		
	OPX	65.9	34.1	1.08	Worse
	OPX+KB	54.7	45.3	1.72	Worse

The event odds (%) of a research condition demonstrating good or poor outcomes for the five PRO variables are located in Table 6. The odds ratio was calculated relative to the control condition. If an intervention condition showed a relatively lower proportion of poor outcomes for a PRO variable compared to the control condition then the odds ratio would indicate how many times greater a positive outcome is likely; and the opposite is true for a poor outcome. For example, the OPX condition demonstrated 1.76 times lower risk of increased knee pain during skiing (better) whereas the combination of OPX+KB intervention products demonstrated a 1.13 times greater risk of increased knee pain (worse). Inspection of Table 6 reveals that the OPX and the OPX+KB conditions dramatically reduced the risk of knee pain, low back pain and poor low back-related physical function but had the opposite effect on knee-related physical function and work performance.

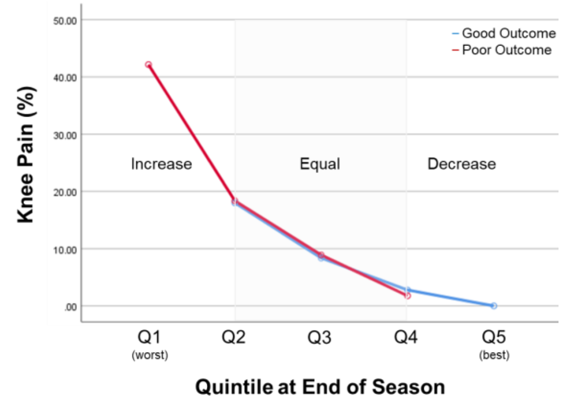
A more involved statistical analysis was performed on the PRO variables with a repeated measures ANOVA that included time (start of season, end of season), research condition (control, OPX and OPX+KB) and quintile group (Q1 to Q5). The results from all of the statistical tests indicated that the effect of the research condition was dependent upon the quintile group that the participant belonged to at the end of the season (knee pain, $F(4,120)=8.908$, $p<.001$; low back-related function, $F(4,120)=5.523$, $p<.001$; low back pain, $F(4,120)=9.676$, $p<.001$; knee-related work performance, $F(4,120)=8.726$, $p<.001$; and knee-related function, $F(4,120)=7.414$, $p<.001$). An illustration of this example is located in Figure 6. The data for this figure is from all of the participants collapsed across each quintile group at the start (red line) and end (blue line) of a ski season. Notice that participants

Figure 6. Knee pain values at the start and end of a season as a function of quintile group.



in the middle three quintiles (Q2 to Q4) had similar knee pain scores at the start and end of the season; participants in the lowest quintile (Q1) had higher scores at the end of the season (poor); and participants in the highest quintile (Q5) had lower scores at the end of the season (good). By definition of the quintile grid method, the middle three quintiles will have participants with a mix of outcomes that demonstrate similar scores and very little change from the start to the end of the season. However, all of the participants in Q1 will have demonstrated poor outcomes and an increase in their PRO score at the end of the season whereas all of the participants in Q5 will have demonstrated good outcomes and a reduction in their PRO score. Re-organizing the data used to design Figure 6 and collapsing across quintiles for the participants with good and poor outcomes demonstrates that the magnitude of the PRO scores for knee pain are identical for outcome groups in the middle three quintiles but higher in the lowest quintile group and lower in the highest quintile group (Figure 7). Given that the magnitude of a PRO score dictates the level of pain and/or dysfunction these results warrant the further analysis of the participants in the highest and lowest quintile groups to determine the wear-and-tear effects of the season on the PRO scores and the possible influence that the intervention products may have had on these scores.

Figure 7. Knee pain values at the end of a season for participants with good and poor outcomes as a function of quintile group.



Further analysis of the PRO scores was performed by comparing the two lowest (Q1 and Q2) and highest (Q4 and Q5) quintile groups at the start and end of the season for each research condition. The data for these analyses are located in Table 7. The results of the statistical tests revealed that the effect of the research conditions on the PRO variables across a season of skiing was dependent upon the quintile group (knee pain, $F(1,100)=15.351$, $p<.001$; low back-related function, $F(1,110)=15.026$, $p<.001$; low back pain, $F(1,96)=14.621$, $p<.001$; knee-related work performance, $F(1,96)=13.188$, $p<.001$; and knee-related function, $F(1,116)=26.707$, $p<.001$). On average, the low quintile group demonstrated an increase (worse) in PRO variable score at the end compared to the start of the season for each research condition (Control, 37.7%; OPX, 31.7%; OPX+KB, 31.4%) and the high quintile group demonstrated a decrease (better) in PRO variable score at the end compared to the start of the season (Control, -51.3%; OPX, -76.9%, OPX+KB, -68.6%).

Table 7. The mean (SE) and percent change (%Change) of five participant reported outcome (PRO) variables for three research conditions with low and high quintile groups collapsed across the start and end of two ski seasons (Start, End).

			Knee Pain			Knee-Related Physical Function			Low Back-Related Physical Function			Low Back Pain			Knee-Related Work Performance		
Condition	Quintile	Time	Mean	SE	%Change	Mean	SE	%Change	Mean	SE	%Change	Mean	SE	%Change	Mean	SE	%Change
Control	Low	Start	23.0	4.0	34.8	13.1	1.9	41.1	20.6	1.8	17.7	21.5	4.1	80.2	27.6	2.6	14.6
		End	31.0	3.5		18.5	1.5		24.2	1.5		38.8	2.6		31.7	1.9	
	High	Start	4.2	2.4	-63.4	1.5	1.4	-62.8	2.4	1.8	-22.7	2.7	2.2	-66.7	4.1	2.3	-40.9
		End	1.5	2.1		0.5	1.1		1.9	1.4		0.9	1.4		2.4	1.7	
OPX	Low	Start	31.2	3.4	-5.2	13.1	1.7	19.0	18.5	1.8	11.5	18.6	4.3	120.8	28.6	2.9	12.5
		End	29.5	3.0		15.6	1.3		20.6	1.5		41.0	2.7		32.1	2.1	
	High	Start	8.8	2.6	-90.5	3.0	1.5	-80.2	4.3	1.7	-75.6	2.1	2.0	-82.1	5.6	2.5	-56.0
		End	0.8	2.3		0.6	1.2		1.1	1.4		0.4	1.3		2.5	1.9	
OPX+KB	Low	Start	19.8	2.6	58.9	11.7	1.6	47.5	15.8	1.6	21.7	19.7	3.6	15.2	29.5	2.6	13.7
		End	31.5	2.3		17.2	1.3		19.2	1.3		22.7	2.3		33.6	1.9	
	High	Start	6.1	2.2	-79.4	3.1	1.2	-71.7	2.9	1.5	-42.9	4.7	1.8	-93.8	5.7	2.0	-55.1
		End	1.3	1.9		0.9	0.9		1.7	1.2		0.3	1.1		2.6	1.5	

Relative to the control condition, the OPX condition demonstrated 49.9% greater reductions in all PRO variables for the high quintile group and 15.8% lower declining scores for all variables except the PRO variable low back pain for the low quintile group. Similarly, the OPX+KB condition demonstrated 33.4% greater reductions in all PRO variables for the high quintile group compared to the control condition and 16.7% lower decrements for all variables except the PRO variables low back pain and knee-related work performance.

SUMMARY

The purpose of this two-year, prospective study was to determine the influence of directional compression tights and a novel ski binding on injury risk and the impact on the development of clinical symptoms in professional ski instructors. A lower number of total injuries was found for the ski instructors wearing directional compression tights with and without the addition of skiing with the novel ski binding; and a lower number of knee injuries was found when wearing the directional compression tights or while using the novel ski binding. The decrement in PRO variables across a season, particularly knee pain during skiing, were improved by the directional compression tights with and without the use of the novel bindings.

Appendix A.

The mean (SE) of five participant reported outcome (PRO) variables for the four research conditions measured at the start and end of two ski seasons (Year 1, Year 2). The number (N) within each group during each year represent the participants that completed questionnaires at the start (N=135) and end (N=118) of each season. Each PRO is on a scale from 0 (best) to 100 (worst).

			Year 1					Year 2			
			Start of Season		End of Season			Start of Season		End of Season	
	Condition	N	Mean	SE	Mean	SE	N	Mean	SE	Mean	SE
Knee Pain	**Control**	40	10.8	1.9	9.0	2.1	17	16.0	4.7	18.0	5.7
	OPX	41	16.2	2.4	10.9	2.2	50	18.2	3.0	14.7	2.3
	KB	11	8.9	3.0	8.8	2.9	17	9.1	3.2	13.2	4.0
	OPX+KB	43	11.2	2.0	13.9	2.9	34	14.9	3.4	14.5	3.6
	Total	135	12.4	1.2	11.1	1.3	118	15.6	1.8	14.9	1.7
Knee Function	**Control**	40	5.3	1.2	6.3	1.6	17	6.9	3.3	7.8	3.6
	OPX	41	7.7	1.4	7.1	1.3	50	4.9	1.0	7.3	1.3
	KB	11	7.5	2.8	5.1	2.9	17	4.4	2.3	7.4	2.6
	OPX+KB	43	5.6	1.1	6.7	1.3	34	4.1	1.0	6.9	2.1
	Total	135	6.3	0.7	6.6	0.8	118	4.9	0.7	7.3	1.0
Low Back Function	**Control**	37	11.4	1.9	11.9	2.1	17	10.5	3.1	10.9	2.9
	OPX	41	10.9	1.6	10.0	1.6	50	8.2	1.2	9.2	1.5
	KB	11	9.3	2.2	8.9	2.4	17	7.0	2.0	11.2	3.8
	OPX+KB	43	9.3	1.4	9.9	1.5	34	8.2	1.4	8.8	1.6
	Total	132	10.4	0.9	10.4	0.9	118	8.3	0.8	9.6	1.0
Low Back Pain	**Control**	39	7.6	2.1	9.5	2.7	17	19.8	8.4	12.2	5.4
	OPX	41	5.3	1.9	7.8	2.8	50	14.8	3.3	12.3	2.7
	KB	11	3.9	2.1	6.3	3.3	17	8.7	3.8	11.3	4.7
	OPX+KB	43	8.6	2.3	4.8	1.4	34	11.6	3.2	10.3	2.7
	Total	134	6.9	1.1	7.2	1.3	118	13.6	2.1	11.6	1.7
Work Related Knee Function	**Control**	40	15.5	3.0	15.8	3.1	17	17.3	6.1	19.7	6.0
	OPX	41	19.9	2.9	18.4	2.6	50	20.4	2.9	22.5	2.8
	KB	11	16.4	5.0	14.5	4.6	17	8.8	3.2	19.1	5.5
	OPX+KB	43	17.0	2.3	19.3	2.9	34	14.7	2.7	19.9	4.0
	Total	135	17.4	1.5	17.6	1.6	118	16.6	1.8	20.8	2.0

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