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Water Ski Binding Release Characteristics in Forward Lean †

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Abstract: To reduce the risk of injury, waterski bindings should secure the foot to the ski when the likelihood of lower leg injury is low (retention) and free the foot when the likelihood of injury is high (release). Unlike snow skiing, there are no standards dictating the release of waterski bindings. Testing was completed to determine release torques in forward lean of three commercially available waterski boot-binding systems. Each binding was mounted to a 66-inch waterski and the boot was fitted on a lower leg surrogate with a torque transducer. A forward-lean bending moment was applied quasi-statically about the transverse axis of the ski until the binding released the boot. For the three boot-binding systems, the range of release torques were 126 to 219, 50 Nm to 141, and 63 to 127 Nm.

Keywords: waterski; waterski binding; release torque

1. Introduction

Similar to snow skis, water skis have bindings that secure the foot to the ski to permit the transfer of forces and torques necessary to ski. In the past, water ski bindings consisted of a soft rubber heel cup and a toe piece and were designed for the foot to release from the boot-binding when large forces and moments were applied, such as during a crash [1]. Water ski binding systems have evolved and some are now comprised of a separate hard boot and binding similar to snow ski boot-binding systems. At least one commercially available water ski binding is a snow sport binding that has been adapted slightly for water skiing.

The release settings for boot-binding systems need to allow a skier to transmit the loads necessary for skiing, but decouple the skier from the ski when the likelihood of injury is high. Standardization (ISO 9462:2014 and ASTM F504-05) of release torques for snow skiing equipment led to a significant reduction of lower leg fractures [2]. According to a study examining water-skiing injuries in the National Electronic Injury Surveillance System (NEISS) between 2000 and 2007, the hip and lower extremity were affected more than any other body part and represented 35.9% of the total water skiing injuries [3]. Standardization of release torques for water ski boot-bindings systems may be a tool to reduce lower extremity injuries in water skiing.

Water skiing involves two distinct activities: (1) bringing the water ski to plane and (2) performing cutting maneuvers often across a boat wake. Each activity produces different loading profiles that are transmitted to the boot-binding system. Water skiing is distinct from snow skiing: the surface (water versus snow), the equipment, and the skier's stance and kinematics differ. For example, slalom water skiing is performed on one ski with one foot placed behind the other where in snow skiing a skier has a ski on each foot. Due to the differences between water and snow skiing, the loads applied to the skis (by the water or snow) are likely different. The release and retention characteristics of a water ski boot-binding system may need to differ significantly from those used in snow skiing. Some water ski boot-binding systems now provide different settings that allow a skier to adjust the release torque of the boot-binding system based on skier traits such as height, weight, and skier type (cautious, average or aggressive).

Previous research on water ski binding retention and release characteristics examined water ski boot-binding systems where the skier's foot released from a binding consisting of a soft rubber boot attached to the ski [1]. The study demonstrated that release torques varied between different soft rubber boot-binding systems. In the early years of snow skiing the boots used by skiers were softer and ankle injuries were problematic; this issue caused the snow-skiing industry to move to stiffer boots with a hard-plastic shell to reduce the risk of ankle injuries [4]. When this transition occurred in snow skiing, the retention torques necessary to ski properly were unknown and the release and retention characteristics of the boot-binding systems were essentially a guess. This led to an increase in spiral fractures and boot-top fractures of the tibia-fibula [2,5]. It was not until release settings and binding calibration methods were standardized that the incidence of tibia-fibula fractures decreased [2]. Stiffer boots provide more stability to the ankle and allow better transmission of force between the foot and the ski; in the context of boot-binding systems, stiffer boots can provide more reliable release. However, the appropriate release torques need to be determined to reduce the likelihood of injury. The water ski industry may be able to adopt the lessons learned from snow ski bindings to reduce lower leg injuries.

Unlike snow ski bindings, there are currently no standards governing the selection of release and retention torques for water ski bindings. While some manufacturers of water ski boot-binding systems provide settings based on skier traits, the release torques are unknown. The objective of this study was to characterize the release and retention characteristics of three commercially available water ski boot-binding systems.

2. Materials and Methods

Three water ski boot-binding systems were tested: Binding 1—an adjustable plunger release system; Binding 2—a spring loaded release system (a repurposed snow sport mountaineering binding); and Binding 3—a reclosable fastener system. Each binding was mounted to a 66-inch O'Brien Sixam Slalom water ski. Boots for each system consisted of a left foot shell that had a boot sole length between 300 and 305 mm. The left boot for each system was cut, an aluminum cast was placed in the boot, and the boot was filled with epoxy. The rigid boot specimens were secured to a torque transducer (±800 Nm; resolution 0.01 Nm) located on a lower leg surrogate; see Figure 1.

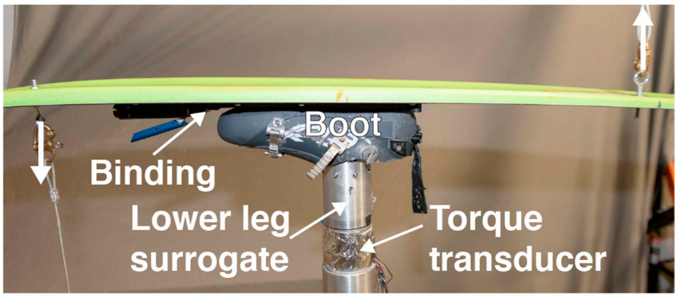

Figure 1. Water ski binding testing apparatus. The boot was secured to a lower leg surrogate instrumented with a torque transducer. A bending moment was applied about the transverse axis of the water ski using the cables attached to the forebody and tail sections of the ski (vertical arrows).

For each boot-binding system, the full range of settings available was tested; see Table 1. Binding 1 and Binding 2 had setting recommendations for skier weight and skill level. Binding 3 had no recommendations for release level based on any skier characteristics; the manufacturer for

Binding 3 recommended that reclosable fastener be removed or added between the binding plate (where the boots were fixed to) and ski to change the release torque.

Table 1. Binding descriptions and settings tested for each binding. The manufacturer of Binding 1 provided recommended settings based on skier weight, skier height and skier preference. The manufacturer recommended moving down the chart (to the right) one to two settings for more aggressive skiers. The manufacturer of Binding 2 provided recommended settings based on skier weight. The manufacturer of Binding 3 recommended that the reclosable fastener be removed or added between the binding plate and ski to change the release torque. Each setting is relative to the full amount of reclosable fastener provided by the manufacturer when purchased.

Binding	Description	Settings Tested								
Binding 1	Adjustable plunger release	**Setting**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	
		Skier Weight (kg)	41–48	49–57	58–68	69–79	80–95	96–104	105–113	
		Skier Height (cm)	147	148–155	156–165	166–178	179–193	193+		
Binding 2	Spring loaded release	**Setting**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
		Skier Weight (kg)	20–10	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100
Binding 3	Reclosable fastener	**Setting**	50%	75%	100%						

The release and retention characteristics of the water ski boot-binding systems were tested using a snow ski binding testing system that conformed to standards ISO 9462:2014 and ASTM F504-05. A forward-lean bending moment was applied quasi-statically about the transverse axis of the ski until the binding released the boot; see Figure 2. The peak torque was recorded for each test and three tests were conducted for each setting. The data were collected at 1000 Hz and filtered with a fourth-order low-pass Butterworth filter (with 10 Hz cut-off frequency). The mean of the peak release torques were compared amongst each binding for the range of settings. Student t-tests (alpha = 0.05) were conducted to determine significant differences between the release torques of each of the binding systems.

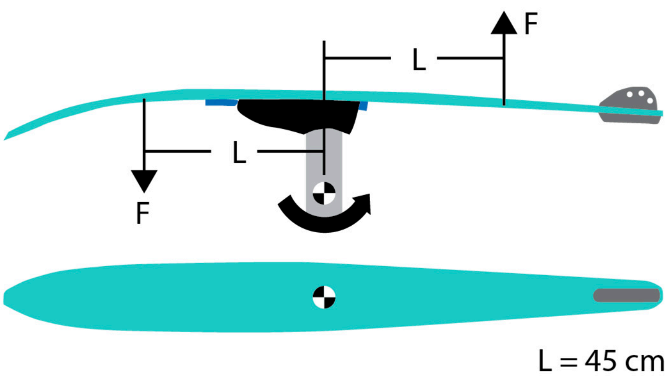

Figure 2. Schematic of test apparatus that conformed to ISO 9462:2014 and ASTM F504-05 demonstrating the principal release axis of pure forward lean.

3. Results

For the three boot-binding systems, the release torque ranges are 126 to 219 Nm for Binding 1, 50 to 141 Nm for Binding 2, and 63 to 127 Nm for Binding 3. Binding 1 released at significantly higher ($p < 0.05$) torques than Binding 2 and Binding 3; see Figure 3. For Bindings 1 and 2, the release torque increased as the setting increased with skier weight. The release torque for Binding 3 increased as more of the reclosable fastener was adhered between the binding plate and ski.

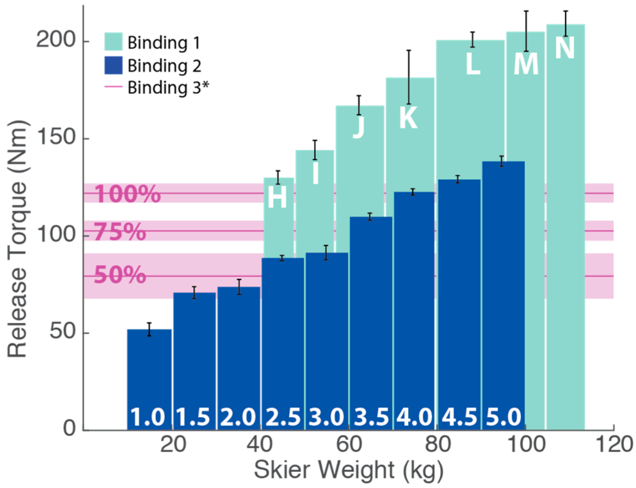

Figure 3. Mean and standard deviation release torque for different settings of each binding. For Bindings 1 and 2 the settings are categorized by skier weight as recommended by the manufacturer while for Binding 3, the setting is based on the amount of reclosable faster adhered between the binding plate and the ski.

4. Discussion

In the current study, boot-binding systems released between 50 to 219 Nm. Each boot-binding system had different release torque ranges. In the study by Merala & Piziali (1996), the release torque was determined for water ski boot-binding foot-release systems; the release torque range for forward lean was 65 to 165 Nm. These values fall within the range we measured in the current study and suggest that water ski boot-binding systems that use hard boots have similar release and retention characteristics to foot-release systems that use soft boots to couple the foot to the ski.

The manufacturer of Binding 1 provided release torque values for each setting available for the boot-binding system. For each setting, the release torques provided in the manufacturer's table are much lower than what was measured in the current study. For example, although the manufacturer specifies that the lowest setting "H" should release at 42 Nm, we measured a release torque of 129 Nm. Similarly, for the highest setting "N," the manufacturer specifies a release torque of 100 Nm and we measured a release torque of 209 Nm. One possible discrepancy between the manufacturer's release values and the release values we measured may be due to how the torques were measured. The manufacturer did not provide information on how they determined release torques and their method may differ from the standard snow ski device used in our testing. This difference in release torques for the same boot-binding system highlights the need for a standardized method to measure release torques for water ski boot-binding systems.

The release torques measured for each boot-binding system were not consistent across manufacturers for the settings based on skier weight categories. Using settings for a 40 kg water skier, we measured release torques of 130 and 89 Nm for Binding 1 and Binding 2. Likewise, using settings for an 80 kg water skier, we measured release torques of 201 and 129 Nm for Binding 1 and Binding 2. If a water skier were to select a setting based on their weight, he or she could experience drastically different release torques depending on the boot-binding system and this could increase the risk of injury to the skier. For example, if an 80 kg skier applies a forward lean torque of 175 Nm during a fall, Binding 1 would retain the boot (and skier) and Binding 2 would release the boot (and skier). Using Binding 1, the skier would be exposed to a larger torque on their lower leg increasing their likelihood of injury.

According to ISO 9462:2014, snow ski bindings should release with a pure forward lean moment of 18 to 425 Nm, depending on the setting that corresponds to a skier's height, weight, age, skier type, and boot sole length. The release torque range determined for water ski boot-binding systems in this study fall within this range specified by ISO 9462:2014 and is approximately half of the snow ski boot-binding range. In order to determine if the release torques we measured for the three water ski boot-binding systems are appropriate, the forces and moments applied by the water skier to the boot-binding system and water ski need to be characterized. The release values should be above what is necessary to support on-water loading to prevent inadvertent release of the ski during normal maneuvers and below the twisting and bending moments associated with injury. Characterizing the forces and moments on the boot-binding system and water ski for a wide range of skier sizes, ages, and abilities would promote standardizing release torques settings to reduce the likelihood of injury during water skiing.

5. Conclusions

The water ski boot-binding systems available commercially provide different methods of release of a skier from a water ski. The release characteristics of water-ski boot-binding systems vary by manufacturer for the same skier characteristics (such as weight). On-water forces and moments need to be measured in order to determine appropriate settings and release characteristics of water ski boot-binding systems.

Conflicts of Interest: The authors declare no conflict of interest.

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