

## [ Primary Care ]

# Anterior Cruciate Ligament Injuries in Wakeboarding: Prevalence and Observations on Injury Mechanism

Harlan M. Starr, MD,\*† and Brett Sanders, MD‡

**Background:** Wakeboarding is an increasingly popular sport that involves aggressive stunts with high risk for lower extremity injury, including anterior cruciate ligament (ACL) rupture. Little has been reported on prevalence or mechanism of ACL injury while wakeboarding.

**Hypothesis:** The prevalence of ACL injury in wakeboarding approaches that of other high-risk sports. Analyzing the mechanism of ACL injury may aid in future efforts of prevention.

**Study Design:** Descriptive epidemiology study.

**Methods:** In sum, 1580 surveys were sent internationally to professional and amateur wakeboarders. The survey questioned the participants on their history of an ACL tear while wakeboarding and asked them to describe the mechanism of injury and treatment.

**Results:** A total of 123 surveys were returned. Of this group, 52 (42.3%) acknowledged having had an ACL tear while wakeboarding. The majority described feeling a pop or buckle after attempting to land a high jump. Only 5 participants (13.5%) described a rotational mechanism created by catching the board edge in the water. Thirty-seven participants (71.15%) said that the injury ruined their ability to wakeboard before reconstruction, and 41 (78.85%) had the injury repaired surgically.

**Conclusion:** The prevalence of ACL tears in this data set, 42.3%, is the highest reported in the literature for wakeboarding and one of the highest for any sport. The main mechanism of injury appears to involve axial compression while one lands in a provocative position; it is not related to a rotational force created by fixed bindings. The injury should be surgically repaired to effectively continue the sport. Further study is needed to determine if wakeboarding represents a high-risk sport for ACL injury.

**Clinical Significance:** Wakeboarding may be a high-risk sport for ACL injury. Noncontact axial compression appears to be the main mechanism of injury.

**Keywords:** anterior cruciate ligament; injury; reconstruction; wakeboarding; extreme sports; water skiing

Over the past 30 years, wakeboarding has become an increasingly popular sport for all ages, reaching a peak in the past 5 years. An estimated 3.4 million people were wakeboarding in 2003, and this number continues to increase.<sup>11,16</sup> Similar to the increased following of snowboarding, as witnessed in recent Winter Olympic Games, wakeboarding has gained rapid popularity as an “extreme” version of water skiing. As opposed to the quick, sharp turns sought in water skiing, wakeboarders attempt more aggressive stunts, such as flips, spins, and inverts across the wake at high speeds.

One report by Hostetler et al utilizing the National Electronic Database system revealed head injuries to be the most common wakeboarding injury (28.8%), 6.7 times more common compared with water skiing, signifying the differing injury patterns in the more extreme sport.<sup>7,11</sup> Moreover, the combination of high kinetic energy, fixed bindings, and a large board surface area can lead to an increased risk of lower extremity injury.<sup>6</sup>

Carson provided the first attempt at quantifying wakeboarding injuries by sending questionnaires to orthopaedic surgeons and wakeboarders.<sup>6</sup> He determined that the most common injuries

From †Emory University, Atlanta, Georgia, and the ‡Center for Sports Medicine and Orthopaedics, Chattanooga, Tennessee

\*Address correspondence to Harlan M. Starr, MD, Department of Orthopaedics, Emory University, 59 Executive Park, Dr S, Atlanta, GA 30329

(e-mail: hmstarr3@gmail.com).

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reported by orthopaedic surgeons were anterior cruciate ligament (ACL) tears (31%), shoulder dislocations, fractures, and ankle sprains. Additionally noted was that 14 of 86 (16.3%) wakeboarders who responded had previously sustained an ACL rupture.<sup>6</sup> This finding suggested that the incidence of ACL tear in wakeboarding may be comparable with that of other high-risk ACL sports, such as alpine skiing, basketball, soccer, and football.

Within these high-risk sports, up to 70% of ACL injuries are noncontact.<sup>19</sup> In addition, female athletes sustain noncontact ACL injuries at a rate 2 to 8 times greater than that of males.<sup>1,3,14</sup> A meta-analysis of ACL rupture rates has revealed the incidence to be highest in the team sports of female collegiate basketball and soccer, roughly 0.30 per 1000 exposures.<sup>14</sup> In comparison, male collegiate counterparts in the same sports have an incidence of roughly 0.10 per 1000 exposures.<sup>14</sup> In the recreational sport of alpine skiing, 1 study reported an incidence as high as 0.63 per 1000 exposures.<sup>14</sup> The predominant mechanism of ACL injury in wakeboarding has not been described, but in general, most wakeboarding injuries occur by direct or twisting contact made with the water and not by collision.<sup>6</sup>

## METHODS

Institutional review board approval for this study was granted on July 1, 2009. Initially, we began by posting on the bulletin board of numerous wakeboarding association web pages. There were a total of 20 wakeboard associations with posts on their bulletin boards. Our post included a short description of the survey and described how the patients' data would be handled. A total of 9 surveys were received in this manner (see appendix online available at <http://sph.sagepub.com/content/suppl>). To increase the response rate, a form was created in Google Docs with a link in which the wakeboarders could immediately and conveniently fill out the survey. A national organization provided assistance with the data collection by sending out an e-mail to 1389 wakeboarders listed in this association on August 24, 2009. The organization then sent out another e-mail on October 9, 2009, to 1580 association members (including the 1389 from the previous e-mail list). The final survey was received on July 9, 2010. In all, 123 surveys were completed, 9 from the first method and 114 returned from the e-mail questionnaire (7.22%). The survey questioned the participant on history of an ACL injury or other knee injury as well as what trick was being performed during the injury and the mechanism of injury. In addition to reviewing the injury mechanism description, exemplary videos were viewed to better understand the landing mechanics of the tricks performed during the injury. Injury mechanisms were divided into those occurring after attempting to land with the board in a flat position versus those occurring after a twisting mechanism produced by catching the board edge. In addition, the survey reported the respondents' age, exposure time to wakeboarding (reported in hours per week), and their self-rated skill level. The responses were then adjusted in a master spreadsheet to delineate the correct answer. A biostatistician

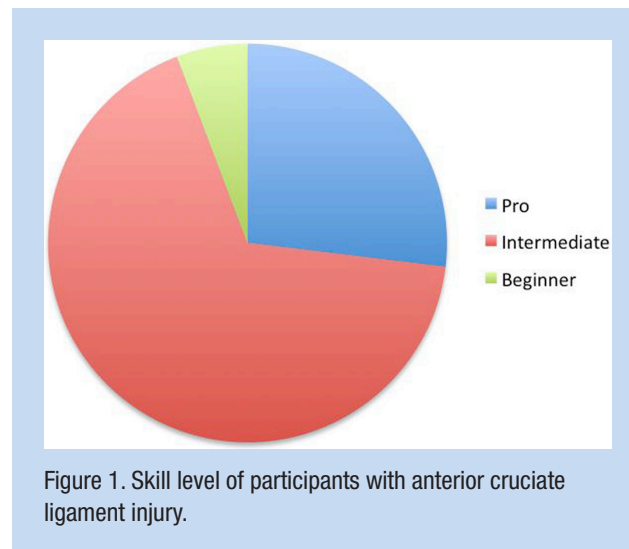


Figure 1. Skill level of participants with anterior cruciate ligament injury.

was then employed to produce a sound statistical analysis of the data. The institutional review board granted a continuing review for this study in June 2010 for another year of data collection.

## RESULTS

A total of 123 surveys were returned, which included 102 males and 21 females. Nine wakeboarders responded after seeing the inquiry posted on a web page bulletin board. Furthermore, 114 of 1580 (7.22%) e-mail surveys were received using Google Docs as the method of collection.

Of this group, 52 (42.3%) participants acknowledged having had an ACL injury while wakeboarding: 43 of 102 males (42.2%) and 9 of 21 females (42.9%). In the ACL injury group, 14 (26.9%) were classified as *pro/advanced*, 35 (67.3%) as *intermediate*, and 3 (5.8%) as *beginner* (Figure 1). There was no statistically significant association with ACL injury and self-reported skill level ( $P = 0.25$ ,  $\chi^2$  test). As expected, the hours per week of training were significantly different between those at the self-reported advanced level, 13.4 hours/week, and the intermediate/beginners, 7.1 ( $P = 0.04$ ). There was a marginally significant difference in ACL injury and age. Those not having an ACL injury were younger, 25 years old, compared with 27.8 years for those with an ACL injury ( $P = 0.06$ , 2-sample pooled  $t$  test). Interestingly, exposure time to wakeboarding was not a significant risk factor in the ACL injury group ( $P = 0.75$ , 2-sample pooled  $t$  test). The average hours per week spent wakeboarding by those with an ACL tear was 8.20 hours, compared with 8.78 hours per week in those not having sustained the injury.

Of the ACL injuries, 27 (51.9%) had an injury to the left side. There was a statistically significant finding between side of injury and skill level, with 78.6% at the *pro/advanced* level injuring the right knee but only 36.8% of those at the *intermediate/beginner* level doing so ( $P = 0.01$ ). Thirty-two participants with ACL injury (61.5%) reported an additional injury while wakeboarding.

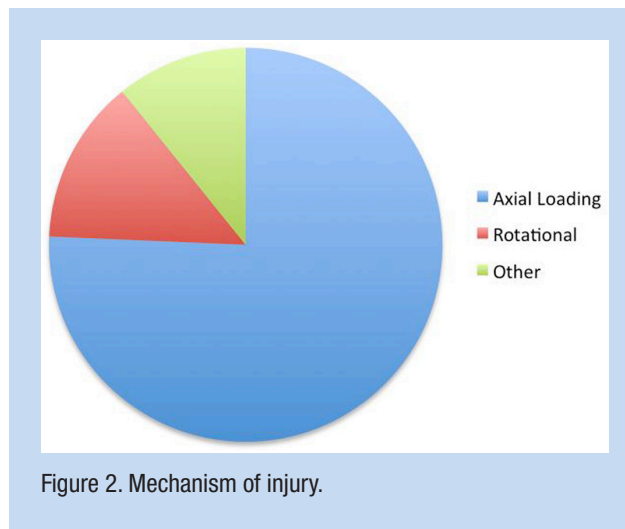


Figure 2. Mechanism of injury.

Of those sustaining an ACL injury, 14 (26.9%) visited an emergency room after the injury. Average age of those who did not go to the emergency room was 29.4 years, while average age of those who did go to the emergency room was 22.4 years ( $P < 0.01$ ). Also of note, 41 (78.85%) had the injury repaired surgically, and 37 (71.15%) said that the ACL injury ruined their ability to wakeboard before it was fixed.

In sum, 37 of 52 participants attempted to describe the mechanism of their knee injury in addition to listing the trick performed. Of these, 5 (13.5%) described a rotational mechanism created by catching the edge or tip of the board in the water with their foot fixed in the binding; of these, 4 were described as intermediate and 1 as beginner. The majority of respondents, 28 of 37 (75.67%), described feeling a pop or buckle in their knee when landing with the flat undersurface of the board against the water in an axial loading type mechanism (Figure 2).

In sum, 49 of 52 participants with ACL tear listed the trick being performed while injured (Figure 3). The most common response was a high jump, also referred to as “big air” or “double-up”; the injury occurred during landing. Participants were also asked to list other injuries that they had sustained while wakeboarding. The most common injury was concussion ( $n = 26$ ), followed by medial collateral ligament sprain, meniscus tear, and lower extremity fracture (Figure 4).

## DISCUSSION

The prevalence of wakeboarders with ACL tears in this data set was very high at 42.3%. This number significantly exceeds the only other reported prevalence, 16.3% by Carson, after evaluation of responses from 86 wakeboarders.<sup>6</sup> Varying claims have been made regarding which sports are highest risk for ACL tears. A meta-analysis by Prodromas et al attempted to canvas the literature to determine overall ACL tear incidence (tears per 1000 exposures) in various sports.<sup>14</sup> This study found basketball (0.30 female, 0.08 male), soccer (0.33 female, 0.13 male), football (0.11 male), and alpine skiing (0.49 amateurs,

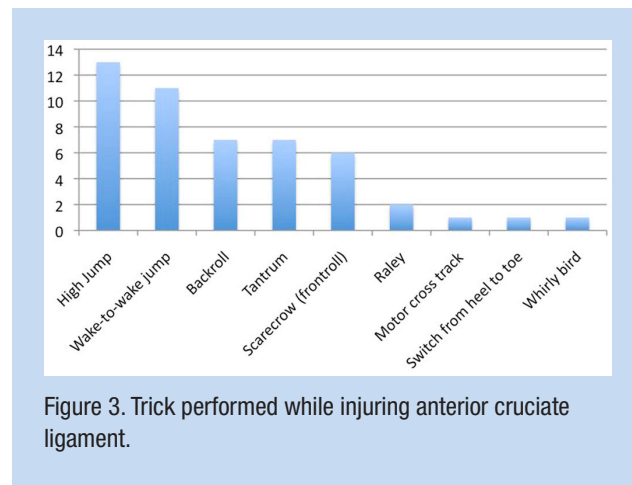


Figure 3. Trick performed while injuring anterior cruciate ligament.

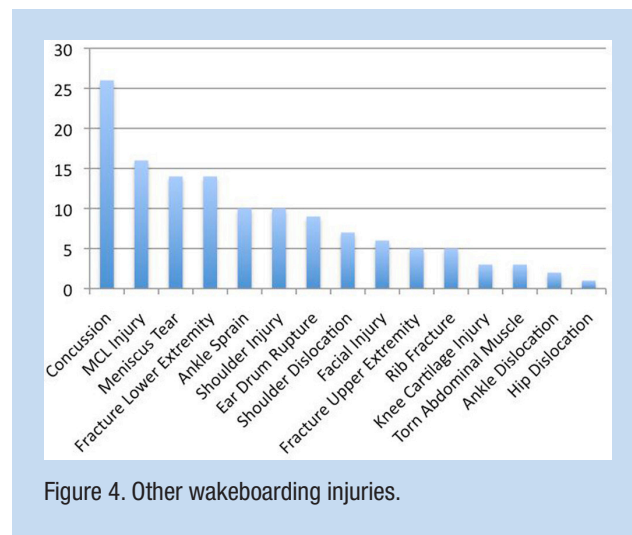


Figure 4. Other wakeboarding injuries.

0.03 professional) to have the highest incidences in large exposure studies.<sup>15</sup> However, with regard to alpine skiing, this study contrasts a recent 25-year investigation of elite French alpine skiers that found a higher incidence of ACL injury, at 8.5 per 100 skier seasons.<sup>15</sup> Interestingly, there have been no ACL injury data to our knowledge on water skiing, and ACL injuries in snowboarding are rare, with one data set reporting only 1.1% of all snowboarding injuries diagnosed as an ACL rupture.<sup>8</sup> While it has been documented that female athletes have a 2 to 8 times higher risk of ACL injury, our data failed to show a difference (male vs female, 42.2% vs 42.9%).<sup>1,3,14</sup> However, the power of this study is insufficient to draw conclusions on sex-specific wakeboarding ACL injuries, especially given the low response rate of only 21 females. Unfortunately, given the recreational and unorganized nature of wakeboarding, we were unable to collect a number of exposures for each respondent. While precluding us from calculating an incidence for comparison to other sports, our 42.3% prevalence indicates that there may be a high risk of ACL tear associated with wakeboarding.

While not statistically significant, the majority (73.1%) of those injured did describe themselves as beginner or intermediate-level wakeboarders. Interestingly, there was no significant difference between ACL injury and hours per week of training or skill level. In fact, those having not sustained an ACL tear averaged more time wakeboarding weekly (8.76 hours) than those who have torn their ACL (8.20 hours). However, as expected, pro/advanced respondents did train an average of 6.3 h/wk more than their intermediate/beginner counterparts. This may mean that the generalized incidence (tear per 1000 exposures) is lower in pro/advanced wakeboarders compared with intermediate/beginners, but further study is needed to evaluate this finding. Similar to prior literature on alpine skiing, our data suggest that participants with higher skill levels have a lower ACL tear risk, even without sport-specific injury-reduction training.<sup>14</sup> In addition to actual skill level, the increased fitness, coordination, and muscle balance of the pro wakeboarder may have a preventative role.

There was a statistically significant finding that 78.6% of pro/advanced wakeboarders injured the right knee, compared to only 36.8% of intermediate/beginners. For most wakeboarders' stance, the right (dominant) foot is placed at the back of the board and, when landing correctly, absorbs the most ground-reactive forces from impact. It is possible that the improved body control of the advanced boarder leads to a more consistent injury pattern to the dominant leg, as opposed to the intermediate/beginner, who may more frequently be landing off balance on the nondominant (left) leg.

Reinforcing Hostetler's findings, concussions ( $n = 26$ ) were the other most common injury listed by our participants. Additionally, ankle sprains, shoulder injuries (including 7 dislocations), and lower extremity fractures were common in our data set, supporting Carson's findings. Also of interest was the high number of medial collateral ligament and meniscal injuries noted. Our data showed that 13% of participants have sustained a medial collateral ligament injury and 11.4%, a meniscus tear.

Along with the high prevalence percentage in our data set, 71.15% of respondents with an ACL tear stated that the injury interfered with their ability to wakeboard before undergoing reconstructive surgery. These data demonstrate that even though wakeboarding does not involve planting and traditional cutting, an ACL-deficient knee appears to impede the athlete's ability to perform at the preinjury level in the majority of athletes. In our data set, 78% of respondents proceeded with elective surgical stabilization of the knee to facilitate return to sport.

Many wakeboarders believe that tight-fitting bindings are necessary for stability while performing high-amplitude tricks. One might surmise from Narita's report that a breakaway binding might help prevent the transmission of rotational forces to the knee.<sup>12</sup> There are no such bindings on the market to our knowledge.

Of the wakeboarders describing their mechanism of injury in our data set, the majority (75.67%) did not describe a mechanism related to the board catching in the water and creating a rotational force. Instead, the boarders described

feeling a pop or buckle in their knee when landing a trick with the flat undersurface of the board against the water, most commonly after a high jump. This mechanism description best fits that involving axial compression forces across the knee joint. These forces are generated across the knee (eg, during a transition from nonweightbearing to weightbearing) and, when combined with increased posterior tibial slope, produce an anterior tibial force in the knee capable of rupturing the ACL.<sup>2,4,9,10</sup> The wakeboarders transition from nonweightbearing to weightbearing when landing airborne tricks and often land in a provocative position on the water.

Using video-based analysis, Boden et al described whole body dynamics associated with ACL tears. They demonstrated that landing on the ground with the foot flat increased the risk of ACL tear compared to landing with the foot in plantar flexion.<sup>4,5</sup> The flat foot position reduces the ability of the calf muscles to absorb ground-reactive forces, and it converts the leg into a 2-segment column, resulting in column buckling. Videotape analysis also showed that higher hip flexion angles at ground contact were more common in ACL ruptures.<sup>4,5</sup> The increased hip flexion increases the vertical orientation, or posterior slope, of the tibial plateau compared with the femoral shaft and, when combined with an axial compression force, creates an anterior tibial force.<sup>4,5</sup>

The technique of wakeboarding involves securing the foot into a flat position on the board, lateral to the direction of motion, with the use of secure bindings. This technique differs from that of waterskiing, where the athlete's feet are parallel to the direction of motion with looser bindings, but it is similar to that of snowboarding.<sup>12</sup> This positioning in itself means that when landing an airborne trick, the athlete's foot will likely be in the flat position against the horizontal slope of the water. This position, as described by Boden, may increase the wakeboarders' risk of ACL rupture when landing.<sup>4,5</sup> Interestingly, the sport of snowboarding, which also involves securing the foot into a flat position lateral to the direction of motion, has had very few ACL injuries reported.<sup>8,12</sup> This may be partially explained by the fact that the snowboarder often lands on a sloped surface, as opposed to the horizontal water, allowing plantar flexion of the foot and a safer landing position.<sup>12</sup> However, expert snowboarders who have sustained an ACL injury report a mechanism similar to the one described by wakeboarders in our data set.<sup>8</sup> As reported by Davies et al, these snowboarders describe a flat landing with the knee flexed and significant axial compression, leading to resistive maximal eccentric quadriceps contraction and ACL rupture.<sup>8</sup>

As noted by previous authors, rotational forces may lead to ACL injury in some cases, as generated by the board edge catching against the water with the feet in tightly secured bindings.<sup>12</sup> However, our data potentially suggest a noncontact, axial load mechanism in the majority of cases.

The limitations of our data are, by and large, due to a low response rate (7.22%) and the possibility of selection bias. The low response rate may introduce bias into our reported ACL injury prevalence and other data reported. While we



attempted to obtain data representing a true cross section of the wakeboarding general population, the low response rate reinforces the difficulty in gathering information for this extreme, recreational, and burgeoning professional sport. In addition, there is likely selection bias in that those with previous ACL injuries were probably more likely to take an interest in responding to the study. That the survey and e-mail contained the words "ACL injury" may have contributed to selection bias. While the 42.3% prevalence reinforces the significant risk of ACL tear in wakeboarding, it is difficult to compare with other high-risk sports. Most numeric data reported in the literature refer to ACL incidence as being "tears per 1000 exposures," with an exposure being practice, game, or skier day.<sup>14</sup> While our onetime questionnaire did provide average hours of exposure per week, this cannot be extrapolated into total number of exposures to provide a meaningful incidence. The low response rate, the amount of time to collect data, and the intrinsic nature of the sport precluded us from acquiring a true incidence in this population. Inadequate follow-up and tracking of the participant in a sport with such a high percentage of recreational and amateur participants is difficult to reliably perform.

Our study also aimed to focus on mechanism of injury resulting in ACL injury while wakeboarding. While this can be adequately analyzed, even with a low response rate, the data were limited by the fact that only 37 of 52 (71%) of those with an ACL injury attempted to describe the mechanism. Video footage of the actual participant's injury would have greatly aided in better understanding the exact mechanism of injury, but none was produced by the respondents of the study. In addition, access to the magnetic resonance imaging of the injuries could have aided in better understanding the mechanism of injury. Speer et al has shown that patterns of osseous contusions in high-load athletics have predictably been located in the lateral compartment, indicating an injury component of valgus force with lateral joint compression.<sup>17</sup> Speer et al also described a more posterior-located osseous lesion in snow skiers with ACL injuries, indicative of a mechanism of injury involving more knee flexion than nonskiing-related ACL tears.<sup>18</sup> By viewing the wakeboarder's magnetic resonance imaging scans, we could have better understood the location of joint loading and, thus, the mechanism of injury.

## CONCLUSIONS

The prevalence of ACL tears in this data set, 42.3%, is the highest reported in the literature for wakeboarding. This

emphasizes the possibility that wakeboarding is a high-risk sport for ACL injury, especially with intermediates and beginners. Further prospective studies are needed to determine the true prevalence and to better understand injury mechanism.

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