Barbell Squat Relative Strength as an Identifier for Lower Extremity Injury in Collegiate Athletes

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ABSTRACT

The aim of the study was to determine the efficacy of using the relative strength level of Division I athletes in 1RM barbell back squat as an identifier of seasonal lower extremity (LE) injury. 1RM back squat (kg) and reported LE injuries were retrospectively collected for Division I male football (n=46), female volleyball and softball athletes (n=25). Maximum pre-season relative (body mass normalized) back squat strength values were compared with two ANOVAs ($p < 0.05$) between injured and uninjured male (football) and female athletes (softball & volleyball). Relative back squat strength was significantly lower in injured athletes than uninjured athletes in both males ($F = 6.03$, $p = 0.02$) and females ($F = 4.68$, $p = 0.04$) with a moderate to large effect size ($g = 0.86$ to 0.85). These data indicate the potential of 1RM back squat relative strength serving as one tool in multi-factor pre-season screening for LE injury risk in these sports. Male athletes with relative squat strength below 2.2 and female athletes below 1.6 in these sports could be more susceptible to LE injury over a season. Strength professionals should consider using body mass normalized 1RM back squats as a screening tool for seasonal lower extremity injury risk in college athletes.

Key Words: 1RM, screening, football, softball, volleyball

INTRODUCTION

Vigorous physical training and competition common in sports often result in musculoskeletal injury. Researchers have focused on documenting the risk of injury, identifying specific athletes with greater risk, and training to reduce potential risk of injury (27,28,34,36,45). One of the most effective methods to reduce the risk of injuries may be resistance training (28). As shown in a recent meta-analysis, resistance training (RT)-based sports injury prevention programs reduced injuries on average by 66% compared to prevention programs without a muscular strength focus (27). RT not only makes an athlete stronger to allow them to perform better but also theoretically attenuates the risk of injury by increasing the structural strength of ligaments, tendons, cartilage and connective tissue within muscle, hereby increasing the safety factor before tissue limits are exceeded (14). RT can also increase joint stability through improved muscle recruitment and improved rate of activation which can lead to an increase in musculotendinous stiffness resulting in more support for the joint (41). Sports injuries occur when excessive force is applied to body tissue resulting in damage (force in region of the hamstrings that disrupt muscle fibers resulting in a strain), however with the increase in tissue integrity and joint stability from additional relative strength, the threshold for potential injury can be elevated to handle higher training and competition intensities (44).

Some sports medicine professionals have proposed body weight-based screening tools (9,10,18,20) that involve basic movements, range of motion (ROM) and balance in hopes of identifying athletes with greater risk of injury. Numerous studies on the validity of these tools in identifying athletes with higher rates of injury show mixed findings. Reviews of this extensive research, including several prospective studies, report either no association with injury risk

identification (3,33,43) or some potential use of elements of the screening tools as part of a multi-faceted approach in identifying injury risk (12,17,38). Since these body weight screening tools have limited evidence in identifying persons and particularly athletes with higher rates of injury, there is a need to explore other more physically challenging maximal strength-related fitness tests to identify athletes with higher rates of injury. Several lines of research on maximal strength show promise for screening musculoskeletal injuries. Maximal isometric and isokinetic strength of the back and LE are moderately related to musculoskeletal injury risk in civilian and military populations (13).

Maximal single joint isokinetic strength levels have been explored for identifying athletes whom may be at higher risk of LE injury. O'Kane et al. (36) prospectively studied a cohort of 351 female soccer players, examining the relationship of LE hip and knee strength and overuse injuries. The researchers found that for every 1 standard deviation (SD) above the mean hip flexor, hamstring and quadricep strength as measured with both hand held and isokinetic dynamometers, resulted in a 28, 35 and 30% lower risk of LE overuse injury, respectively, over a 4-year period. Another study explored physical and performance characteristics of 95 special operators in the United States Army and the ability to predict musculoskeletal injuries from isokinetic strength measures. Soldiers with isokinetic knee extension strength below the 25th percentile were 5.7 times more likely to sustain a LE injury over the course of 1 year, compared to the soldiers above this level of strength (21). In the frontal plane, hip abductor strength deficits have also been reported to be associated with higher rates of LE injuries. Powers et al.(37) examined male soccer players for an entire 30-week season and found that as hip abductor strength decreased, the likelihood of injury rose from 12 to 27%. Results of intervention studies

have indicated the utility of increasing muscular strength in decreasing the rate of injuries. Over the course of 2 years the implementation of an RT program for male soccer players caused a decrease in team LE injuries (29). While the causes of LE injuries are multifactorial (e.g., collision, fatigue, poor movement technique), these data support the hypothesis that LE strength deficits may be an influential factor in risk of injury.

Increasing an athlete's overall muscular strength has well documented positive benefits on both athletic performance and injury rates. Specifically, improvements in relative (weight lifted / body mass) strength improvements have shown to benefit several performance variables (7,8,11,15,30,35,40,42) along with attenuating LE injuries (14,27,30,42). Furthermore, relative strength measures allow for within group comparisons regardless of body mass. Multi-joint movements like the barbell back squat have been used to assess strength of large muscle groups in the LE at risk of injury in sport (6). The dynamic nature, balance, and strength required in the back squat might make it a good screening test for risk of LE injury in competitive sports. 1RM barbell back squat strength assessments have been demonstrated as highly reliable and accurate in assessing strength of LE musculature with an ICC of 0.91-0.99 and CV < 4.3% (32). Since a one-repetition max (1RM) barbell back squat measures overall trunk and LE maximal strength and control under heavy loads, it is possible this exercise could be a more effective tool to screen collegiate athletes for risk of LE injury than current clinical screening tools or expensive single-joint isokinetic testing.

The purpose of this study was to explore the efficacy of using relative strength levels of Division I athletes in 1RM barbell back squat as an identifier of seasonal LE injury. We

hypothesized that 1RM back squat relative strength would be negatively associated with seasonal LE injury, specifically athletes with higher relative strength having lower numbers of LE injuries.

METHODS

Experimental Approach to the Problem

To examine the feasibility of 1RM back squat strength as a screening tool for risk of lower extremity injuries, a retrospective study over a competitive season was performed using Division I football, women's volleyball and softball teams. Body mass normalized squat strengths were measured and compared between uninjured and athletes diagnosed with injuries by team medical services.

Participants

A convenience sample of Division I athletes was examined following approval by the university Institutional Review Board. The investigators obtained data from all athletes in sports with intense, running and jumping sports (football, softball, volleyball) that pose greater risk of LE injuries at the university. Inclusion criteria required teams where 1RM back squat strength tests were administered and data was collected and saved by the strength staff. Athletes excluded from the study were players who sat out their first season (redshirts), those not making the team, with missing data, and others not able to complete testing due to injuries. Kickers were also excluded from football in accordance to previous studies examining performance characteristics of players because their exposure to LE injury was clearly different from other athletes (2,16,24).

A total of 71 athletes from football (*n*=46), softball (*n*=10) and volleyball (*n*=15) were included in the final sample of this study (Table 1). Following consent, injury and performance data were collected retrospectively from athletic training and strength & conditioning records over a competitive season. A competitive season was defined as preseason, regular season and postseason to include initial practices, exhibition games, regular season games and practices, along with any practices after the end of regular season (26).

Procedures

Physical, squat strength, and medical data were retrospectively collected. Back squat strength data were collected from two NSCA certified university strength and conditioning coaches. Injury reports from the prior competitive season and physical data were collected from Board of certification (BOC) certified athletic training staff using the Sports Injury Monitoring System (SIMS, Iowa City, IA). Maximum absolute 1RM (kg) back squat was collected during pre-season testing for each athlete. Physical data (Table 1) included most current body mass (kg), height (cm) and age (y). Since strength varies with body mass, squat strength was normalized to body mass for each athlete.

(Table 1 about here)

Back Squat 1RM

Each participant trained with the barbell back squat within their respective strength and conditioning program and had performed 1RM back squat testing. Participants performed a general 10-minute dynamic warm prior to any testing. After warm up the participants began with

an empty barbell and slowly began ramping up weight to 90% of their previous 1RM. Three attempts were given after this threshold to establish a new 1RM. The players were visually assessed by a NSCA certified strength coach during each 1RM attempt and depth was assessed by making sure the hip crease moved below the top of the knee.

Injury Definition

Investigators reviewed SIMS data extracted and all LE injuries that fell in the all-encompassing injury definition, meaning that any physical or medical condition that was reported to medical staff that occurred as a result of participating in competition and training activities and required medical attention were recorded (5,22). Over the training and competition period, 78% of football players had a LE injury reported while the women's sports (volleyball and softball) were pooled and reported a LE injury rate of 52%.

Statistical Analyses

For data analysis players were grouped by sex (n=46 males & n=25 females). Using Shapiro-Wilk tests, 1RM data were determined to be normally distributed (p = 0.51 and p = 0.11). Two analysis of variance (ANOVAs) were used to look for a difference between mean 1RM relative back squat strengths across injury status for both males and females. Given the exploratory nature of the study, a type I error rate $p < .05$ was considered statistically significant for all tests. Due to the directional hypotheses being tested, one-tailed tests and rejection regions were used. Statistical analyses were all performed in JMP Pro version 14.0.0 (Cary, NC). The size of effects were examined using Hedges' g to adjust for the small sample size. The magnitude of effect sizes were interpreted based on the recommendations by Rhea (39) for

highly trained individuals. The participants were categorized as highly trained since they are Division I athletes and fit the criteria of training >5 years used by Rhea (39).

RESULTS

Relative 1RM back squat strength was significantly lower in injured players than uninjured players for both males ($F = 6.03$, $p = 0.02$) and females ($F = 4.68$, $p = 0.04$), with uninjured males and females having higher (Figure 1) mean back squat relative strengths of 2.20 ± 0.38 and 1.63 ± 0.29, respectively, than injured males (1.89 ± 0.35) and females (1.39 ± 0.26). Mean absolute and relative squat strengths for males and females are reported in Table 1.

(Figure 1 about here)

DISCUSSION

Pre-season relative 1RM back squat strength was significantly higher in the uninjured male and female athletes compared to the injured groups. The magnitude of this effect was moderate for both males ($g = 0.86$) and females ($g = 0.85$) and supported the hypothesized association between high relative strength and lower risk of LE injury in a competitive season. These results indicate that strength coaches for football, softball , and volleyball could consider using 1RM back squat normalized to body mass to screen athletes for the risk of LE injury. Increased relative squat strength, however, cannot prevent seasonal LE injury. Inspection of Figure 1 shows a small number of the strongest males and females still suffered injury, as well as a small number of weaker athletes did not sustain LE injury.

The mean relative squat strength of the male athletes with injuries was qualitatively lower (1.89) than overall mean national norms of (2.07 – 2.14) for similar Division I football athletes (2,16). Uninjured males in this study had relative squat strength slightly higher than national norms (2,16) and the 2.0 times body weight squat recommended to reduce injury in a review of literature by Suchomel et al. (42). The data indicate that prescribing RT for these athletes to make moderate to large improvements in squat relative strength might reduce their risk of seasonal LE injury. This improvement in strength is certainly possible given longitudinal mean annual increases between 3.3 to 15.8 percent in 1RM back squat strength has been reported for Division I players depending on year of play and position (24). This hypothesis should be confirmed by replication of this study analyzing larger sample sizes of collegiate athletes and extended by prospective studies of the association of injury rates with 1RM back squat relative strength and improvements in that strength from RT programs.

Seasonal LE injury in female athletes was also significantly related to lower mean 1RM squat relative strength (1.39) than uninjured players (1.63). There are limited normative relative strength during the barbell squat data for female college athletes, however the injured volleyball athletes had qualitatively lower (33%) mean 1RM squat strengths (1.43) than reported in a previous study (1.59) of intercollegiate volleyball athletes (15). More research with larger samples of female athletes are needed to identify 1RM relative back squat strength ranges that may be associated with risk of LE injury. Identifying a male or female athlete that falls below some critical relative LE strength value measured by 1RM barbell back squat for each sport could prove beneficial as one tool in multi-dimensional screening between the strength and sports medicine team in identifying those who are at a higher risk of seasonal LE injury (12,38).

LE injuries account for over 50 percent of all reported injuries across multiple collegiate sports (23). The seasonal injury rate for football was higher (78%) than national norms of 56% for similar Division I athletes (25). This could be due to many factors; however, the lower mean relative squat strength (1.89) in these players compared to typical competitors (2.1-2.2) likely contributed to the higher injury rate. LE seasonal injury rates for women differed between sports with volleyball falling below (33%) the national norm of over 55% (1) and softball above (80%) the national norm of 66% (31) in Division I athletes. Volleyball participants reported overall average relative back squat strength (1.6) close to previous national norms (15), while the lower relative strength (1.40) of softball athletes may explain, in part their higher reported LE injury rate. Apparent sex related differences in injury rates were qualitatively seen in this study, but aside from ACL injuries being more prevalent among collegiate female athletes, findings are still unclear if there are sex-related differences in LE injury rates in specific sports among NCAA collegiate athletes (34).

The current association between higher relative squat strength and lack of seasonal LE injury was consistent with studies of RT to attenuate injury risk (27,28). The possible mechanism of this benefit is multi-faceted due to the increase in structural integrity of tendons, ligaments, cartilage and bone (14). Strength-based RT programs using multi-joint free weight movements recruit more muscle stabilizers which in turn can equate to improved coordination leading to improvements in sport performance (41), body control, and potentially a greater safety factor in handling higher workloads or peak forces compared to relatively weaker athletes (30). The

barbell back squat can be used safely and effectively to increase LE relative strength (4,19) resulting in a decrease in the occurrence of LE injuries (42).

The study had limitations including a small sample of collegiate athletes in 3 sports with available retrospective data on pre-season 1RM back squat strength. Since pre-season strength was studied, it is unknown what 1RM relative strength athletes may have had when sustaining injury. Despite these limitations, the consistency of the normative strength and injury data in football and volleyball provide preliminary support for the hypothesis of lower than sport-specific relative back squat strength being a possible screening tool within a multifactorial approach for seasonal LE injury risk in these male and female collegiate athletes.

PRACTICAL APPLICATIONS

Understanding if levels of 1RM squat relative strength are likely related to risk of seasonal LE injuries in collegiate athletes could give strength coaches valuable programming information. The current data indicate that male football players and female softball and volleyball players might benefit from increases of relative lower body strength measured by body mass normalized 1RM back squat. A higher risk of seasonal LE injuries is possible if relative back squat strength is below 2.2 in males and 1.6 in females. Strength and conditioning staff can use these data while max testing to identify athletes that may need specialized programming to increase lower body relative strength to attenuate the likelihood of LE injuries. Furthermore, sports medicine staff may also be able to use back squat strength data as part of rehab protocols so that athletes are not returned to competition until adequate relative strength has been attained.

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Table 1. Physical and performance Characteristics (n = 71).

Characteristics	Mean ± SD		Range	
	Male	Female	Male	Female
Age (y)	21.2 ± 1.2	20.8 ± 1.2	19 – 24	19 – 23
Height (cm)	185.4 ± 6.3	173.7 ± 8.6	170.2 – 195.6	157.5 – 188.0
Body Weight (kg)	103.1 ± 18.5	73.3 ± 11.1	71.2 – 139.3	56.7 – 99.8
1 RM Back Squat (kg)	196.4 ± 24.3	108.8 ± 17.6	142.9 – 249.5	79.8 – 147.4
Relative Strength (1RM/BW)	2.0 ± .37	1.5 ± .30	1.1 – 2.7	1.1 – 2.2

RM = repetition maximum; SD = standard deviation.

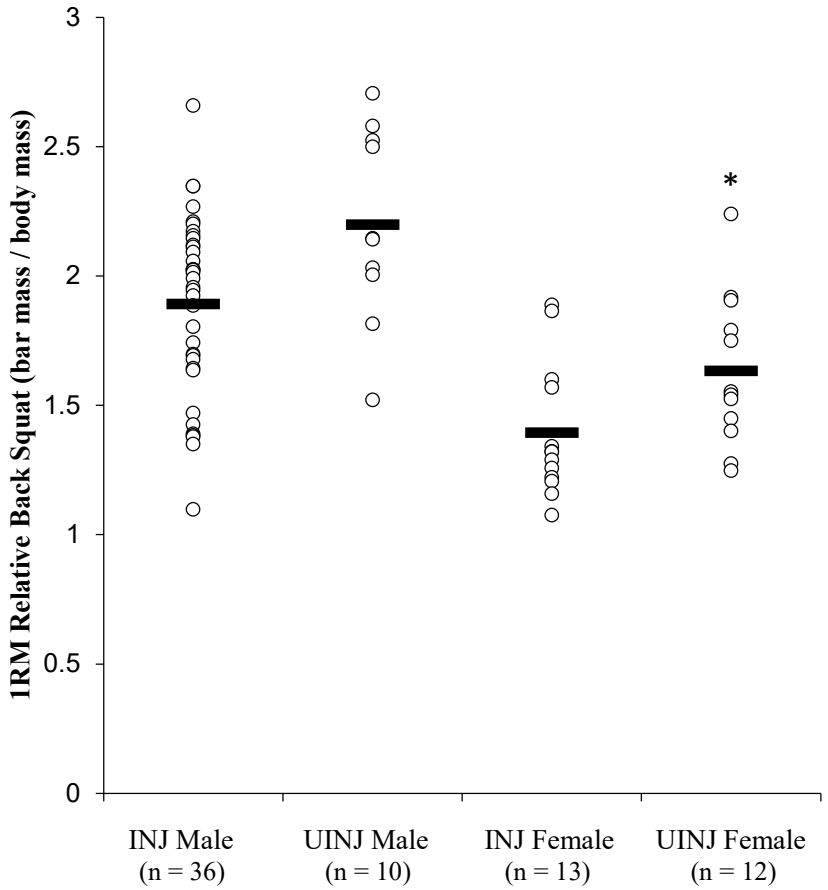

Figure 1. Individual and mean 1RM relative back squat strength values. Uninjured (UINJ) athletes had significantly higher relative back squat strength than injured (INJ) in both males (p = 0.02) and females (p = 0.04).