Physical and Mechanical Properties of Various Field Lacrosse Balls

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Although the sport of lacrosse has evolved dramatically over the last few decades and is presently the fastest growing team sport in the United States, the current specifications for balls date back to 1943. The purpose of this study was to see if various commercially available field lacrosse balls meet these specifications and to determine additional mechanical properties of the ball that may more completely characterize ball performance. Eight models from several manufacturers were tested. Seven models were designated for game play, while one model was promoted as a practice ball. In accordance with the specifications, the mass, circumference, and rebound height were recorded for one dozen balls from each model. The load required to compress the balls 0.0125 m and the coefficient of restitution (COR) with an incident speed of 26.80 m/s were also determined. We found that some balls met several of the specifications, but none of the models had every ball meet all the specifications. For the two measures of ball liveliness, rebound height had a weak correlation with COR. Ball compression loads averaged about 750 N over most models, but were almost 85\% less for the practice model. It appears that current governing body specifications are outdated, as no ball model we tested met these specifications. The determination of ball liveliness at more realistic speeds should also be taken into account. Since balls with low compression loads can pass through face protectors worn by lacrosse players, the sport’s governing bodies may wish to consider a specification on ball compression.

Key Words: coefficient of restitution, compression, NCAA/NFHS specifications, sports

The sport of lacrosse has experienced a rapid increase in popularity since the 1970s and is one of the fastest growing team sports in the United States (‘‘About
Lacrosse, 2004). Referred to as the “little brother of war,” field lacrosse originated as a Native American training exercise for combat. Although it was played by many Native American nations, the play of the game varied. Some played on fields that were miles long, others played on horseback, while still others competed with a stick in each hand (Fisher, 2002). In 1867 in Montreal, Dr. William George Beers first standardized the game and developed the modern playing rules. The first American intercollegiate tournament was held at Westchester Polo Grounds in New York some 14 years later. In the U.S., lacrosse remained limited to a few exclusive eastern academic intuitions until the 1970s. Field lacrosse has evolved into a high-speed game of passing, catching, and shooting for men and women of all ages. Women’s lacrosse in North America appears to have originated in 1902, with rules similar to those of the men’s game. In the following decades, however, men’s and women’s versions of lacrosse have become dramatically dissimilar. Despite differences in the rules of play, levels of contact, number of players, and field dimensions, both men’s and women’s lacrosse use the same ball.

Ball liveliness, typically quantified by the coefficient of restitution (COR), can have a profound influence on play and is tightly regulated in sports such as baseball and softball. Ball COR is defined as the ratio of the rebound speed to the incident speed; a COR of unity defines an ideally elastic ball, while a COR value of zero characterizes a ball that does not bounce at all. Although the rules for ball performance vary, even in the same sport, softballs and baseballs are generally required to have COR values ranging from 0.43 to 0.57, as measured with an incident speed of 26.80 m/s against a flat, rigid target (American Society of Testing Materials [ASTM], 2004a). This relatively high incident speed is used to approximate game conditions because it has been well established that the COR values of softballs and baseballs vary with incident speed, and that the values at lower speeds do not directly correlate with values at higher speeds (Adair, 1994; Heald & Pass, 1994; Hendee, Greenwald, & Crisco, 1998). Higher ball compression loads (i.e., stiffness) have also been shown to be associated with higher ball COR values and increased ball liveliness (Haake, Carre, & Goodwill, 2003). Further details on the dynamics of collisions of sports balls and COR have been presented by Cross (1999a).

The lacrosse rules of the National Collegiate Athletic Association (NCAA) and National Federation of State High School Associations (NFHS) specify ball mass (between 141.8 g and 148.8 g), circumference (between 0.186 m and 0.203 m), and rebound height (Winters, 2002). When dropped from a height of 1.829 m onto a concrete floor at a temperature of 18.3 °C to 21.1 °C, the ball must rebound to a height between 1.092 m and 1.295 m. The International Federation of Women’s Lacrosse Associations (IFWLA) rules have very similar specifications (Ganzenmuller, 2003).

These specifications have remained unchanged since 1943, although the composition of the floor was changed from wood to concrete in 1978. The required drop test with an incidence speed of approximately 6 m/s is intended to quantify ball liveliness, but lacrosse shots can often exceed 40 m/s. Given the known influence of ball speed on COR and the high-speed nature of lacrosse, this low velocity measurement may not be an accurate measure of ball liveliness during actual play. To the best of our knowledge, a comprehensive study of commercially available lacrosse balls has never been undertaken, despite the age of these specifications and the known limitations in measuring ball liveliness via a rebound height test.
The purpose of this study was to determine whether various commercially available ball models conform to the current NCAA/NFHS specifications for lacrosse balls. To further evaluate the physical and mechanical properties of these balls, we measured COR values at a more realistic speed and sought to determine whether the simple drop test correlated with these values. We also measured the compression load of the balls to determine whether these values correlated with COR values. Should governing bodies address concerns of lacrosse balls penetrating facemasks, these compression loads could also serve as reference values.

Methods

The 8 ball models used in this study were either donated by the manufacturer or purchased at a local retail store. All models were described by the manufacturers as “typical” balls used in competitive lacrosse play, except for one, which was marketed as a practice ball. The balls were uniquely numbered and the manufacturer’s labeling was recorded. All balls were stored in a humidity controlled chamber set to 45 to 55% and were removed for only short periods of time for testing. All tests were performed at room temperature. Every ball was tested in accordance with the NCAA/NFHS rules. Then, COR tests were conducted on 6 balls of each model and compression tests were conducted on the remaining 6 balls.

Ball mass was measured using a digital balance (Mettler, Hightstown, NJ). Three measurements were made for each ball and the average value was recorded. The circumference of each ball was measured twice, once along the mould parting line and once perpendicular to the parting line using a thin, flexible thread and a ruler. These values were also averaged.

Rebound height was measured after the ball was dropped from a height of 1.892 m onto a concrete floor as described in the ball specifications (Winters, 2002). The drop height and rebound height were measured visually to the nearest 0.006 m using a wooden ruler mounted on the wall. Measurements were made relative to the top of the ball. Each ball was dropped 5 times and the average value was reported as the rebound height. Drops that resulted in a rebound trajectory with a substantial horizontal component were discarded and repeated.

Ball COR was determined by firing each ball from an air cannon (Lansmont Corp., Monterey, CA) into a rigid steel plate using methodology similar to that used for evaluating baseballs and softballs (ASTM, 2004a). Two pairs of laser sensors (Banner Engineering Corp., Minneapolis) were positioned 0.308 m apart and 0.305 m from the rigid plate; they measured ball speed (Heald & Pass, 1994). Six rebound speeds associated with incident speeds of 26.4 to 27.3 m/s were obtained and averaged for each ball. The COR was calculated as the ratio of the rebound speed to incident speed.

Compression testing was performed on the remaining 6 balls from each model. Using test methodology similar to that used for evaluating baseballs and softballs (ASTM, 2004b), we placed each lacrosse ball between two flat rigid plates and compressed 0.0125 m at a rate of 0.025 m/min using a servo hydraulic material tester (Instron Corp., Canton, MA). The compression displacement was chosen to be twice that required by ASTM F1888-02, due to the increased flexibility of lacrosse balls as compared to baseballs or softballs. Load and displacement data were recorded at 100 Hz during this test. Each ball was compressed twice, once along the parting line and once perpendicular to the parting line. The load values at a compression of
Stiffness was defined as the maximum compressive load divided by the compression distance.

Only pass/fail criteria were considered for the NCAA/NFHS specification measurements. Differences in COR and compression load values between ball models were compared using a one-way analysis of variance (ANOVA) with a Tukey-Kramer multiple comparison post hoc test. A significance level of $p < 0.05$ was set a priori. Linear regression was used across all ball models to assess the correlations between compression values and COR and rebound height and COR.

Results

Seven of the ball models possessed NCAA and/or NFHS lettering on the label. However, the exact wording on each one varied slightly (Table 1). Ball models had smooth surfaces except Models H and B, which exhibited a fine diamond texture and triangular dimples, respectively (Figure 1).

Table 1  Model, Number of Balls, Markings, and Color of Each Ball Studied

<table>
<thead>
<tr>
<th>Ball model &amp; no. of balls</th>
<th>Markings</th>
<th>Color</th>
<th>Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 12 balls</td>
<td>NCAA specs</td>
<td>White</td>
<td>Smooth</td>
</tr>
<tr>
<td>B 12</td>
<td>Official NCAA</td>
<td>White</td>
<td>Triangular dimples</td>
</tr>
<tr>
<td>C 12</td>
<td>NCAA specs</td>
<td>White</td>
<td>Smooth</td>
</tr>
<tr>
<td>D 12</td>
<td>NCAA specs</td>
<td>Yellow</td>
<td>Smooth</td>
</tr>
<tr>
<td>E 12</td>
<td>NFHS, NCAA, CLA specs</td>
<td>White</td>
<td>Smooth</td>
</tr>
<tr>
<td>G 12</td>
<td>NCAA, NFHS specs</td>
<td>Pink</td>
<td>Smooth</td>
</tr>
<tr>
<td>H 12</td>
<td>NCAA, NFHS specs</td>
<td>White</td>
<td>Fine diamonds</td>
</tr>
<tr>
<td>I 12</td>
<td>None</td>
<td>Blue/green</td>
<td>Smooth</td>
</tr>
</tbody>
</table>

Note: The markings were recorded for all governing bodies listed on each ball. All were “typical” balls used in competitive lacrosse play (i.e., games and practices), although Model I was packaged as a practice ball.

Figure 1 — A typical white, smooth lacrosse ball (Model A), a ball with a fine diamond texture (Model H), and a ball with triangular dimples (Model B).
Figure 2 — All balls of 4 models exceeded the limit on ball mass (2A), while the practice model (I) was substantially lighter. All but the practice model were within the specs for circumference (2B). Models B, G, and I were within the specs for rebound height (2C). Dashed lines indicate upper and lower limits of current NCAA/NFHS specs. Data plotted is for all balls tested.
All balls of Models A, D, and E met the NCAA/NFHS mass specifications (Figure 2A). Some balls of Models B and G were within the limit, and the remaining balls were above the limit. All balls of Models C and H were above the mass limit. All balls of Model I, the practice ball, were slightly more than half the mass of the lower limit. All balls from all models, except Model I, were within the circumference limits of the NCAA/NFHS specifications (Figure 2B). All balls of Models B, G, and I were within the limits for rebound height, while only some of the balls in Models A and H were within the limits. The remaining balls of Models A and H, as well as all balls of Models C, D, and E, had rebound heights that were higher than the specified limit (Figure 2C).

The load-displacement curves generated from the compression tests were similar for all balls and were slightly nonlinear with a small hysteresis loop. The load-displacement curves of Models H and I illustrate the range of mechanical behavior from the traditional models to the practice model (Figure 3). Models B and I had compression loads that were significantly less \( (p < 0.05) \) by 45% and 85%, respectively, than the other 6 models (Figure 4A). The compression loads of these 6 models were approximately within a 200-N range, but most models were statistically different from one another \( (p < 0.05) \), with the exception of A vs. G, C vs. D, and E vs. G and H.

The average stiffness values were as follows: 594.4 ± 47.3 N/cm (Ball A); 336.3 ± 27.2 N/cm (Ball B); 543.6 ± 18.9 N/cm (Ball C); 511.4 ± 44.2 N/cm (Ball D); 632.9 ± 27.2 (Ball E); 628.2 ± 33.5 N/cm (Ball G); 662.7 ± 30.1 N/cm (Ball H); and 107.5 ± 9.5 N/cm (Ball I). The COR of all balls from Models A, C, D, E, G,
Figure 4 — Compression load of Model B was substantially and significantly less than the 7 other models by approx. 45%, while the compression load of Model I was even less, approx. 85% less than most other models (4A). The COR of the 6 models (A, C, D, E, G, and H) was within 0.62 to 0.66, while the COR of Model B was significantly less than these models and the COR of Model I was over 15% less than the other models (4B). Data plotted is for all balls tested.
Figure 5 — Ball COR in general increased with increasing compression value ($r^2 = 0.90$) (5A). Overall, increasing rebound height was associated with an increasing COR (5B). When Model I, the practice ball, was excluded, the correlation was weak ($r^2 = 0.73$). The mean and one standard deviation of each variable are plotted for each ball model.
and H were within the range of 0.62 to 0.66 and these models were not significantly different from one another (Figure 4B). The COR value 0.599 ± 0.002 of Model B was significantly \((p < 0.05)\) less than these 6 models and the COR value 0.508 ± 0.011 of Model I was more than 15% less \((p < 0.05)\).

There was a strong correlation between compression load and COR when all ball models were considered \((r^2 = 0.90)\) (Figure 5A). Excluding the practice ball lessened this correlation \((r^2 = 0.72)\). Conversely, if all ball models were considered, then there was a poor correlation between COR and rebound height \((r^2 = 0.53)\) (Figure 5B). However, if the data from the practice ball was not accounted for, the relationship between COR and rebound height was slightly stronger \((r^2 = 0.73)\).

**Discussion**

The purpose of this study was to examine the physical and mechanical properties of lacrosse balls in a laboratory setting in order to compare the results with NCAA/NFHS ball specifications. We examined a variety of commercially available ball models, including one designated for practice play and two with textured surfaces. Current rules for NCAA/NFHS lacrosse balls do not restrict the ball surface, but they do specify limits on ball color (white, yellow, orange, or lime green), mass, circumference, and rebound height. Surprisingly, none of the models had all balls pass these specifications. Overall, the values we measured had reasonably small standard deviations, but it is unknown how other balls of these models would perform.

While the COR of both baseballs and softballs significantly decreases as incident speed increases, this trend is not predictable from a COR measurement at a single speed (Hendee et al., 1998). This finding, in addition to the fact that the drop test is an unrealistically slow speed, was our motivation for measuring the high-speed COR. The methods we used for measuring ball COR are specified in current standards for baseballs and softballs (ASTM, 2004a, 2004b). As one would expect, lacrosse balls were more lively, yet the practice ball had a COR similar to some baseballs and softballs. Rebound height, which is a low-speed measure of ball liveliness, did not correlate well with the COR at 27 m/s, a more realistic speed. Therefore, the current approach of regulating ball liveliness with a drop test may not be sufficient. We measured lacrosse ball COR at only one temperature, so it is not known whether temperature affects lacrosse ball COR. Standards for the testing of baseballs and softball also specify humidity. We studied only a single humidity value, but given the solid rubber composition of lacrosse balls it is unlikely that differing humidity conditions would affect the results.

Using methods similar to those utilized in this study, it has been determined that the static stiffnesses of traditional baseballs range from 2,000 to 3,000 N/cm, baseballs modified for youth play range from 50 to 1,000 N/cm (Hendee et al., 1998), softballs range from 161 to 952 N/cm (Heald & Pass, 1994), and tennis balls range from 109 to 143 N/cm (Cross, 1999b). Most of the lacrosse ball models we tested had stiffness values similar to those for youth baseballs and softballs (Models A, C, D, E, G, and H were all 500–700 N/cm), while Model I, with a stiffness of about 110 N/cm, was more similar to a tennis ball. Unfortunately, direct comparison with the literature is limited by differences in the definition of stiffness. A limitation to our definition of stiffness is that it provides an average value, ignoring the effect of the slack toe region.
It has been shown that the baseball compression load correlates with the ball COR (Hendee et al., 1998). In our study we found a similar correlation: as the compression load of the lacrosse balls increased, the COR did as well. This trend of increasing COR with increasing stiffness has also been reported for balls from other sports (Haake et al., 2003). This correlation is likely due the fact that energy loss is proportional to ball deformation, which is less for the stiffer balls.

Softer baseballs have been shown to reduce the risk of head injury, eye injury, and commotio cordis (Crisco, Hendee, & Greenwald, 1997; Heald et al., 1994; Link, Maron, Wang, et al., 2002; Vinger, Duma, & Crandall, 1999). The practice ball we tested had a compression load nearly five times less than the regular balls. Unlike baseballs, we cannot recommend the use of softer lacrosse balls (i.e., those with a lower compression load) until further research has been completed, because softer lacrosse balls could potentially pass through the facemasks and eyewear worn by players. Balls that are too soft may also pose a risk to the eye as a result of their ability to penetrate more deeply into the orbit (Vinger et al., 1999).

The rule with respect to surface texture is not clear. From our interpretation of these rules, balls of different surface textures are acceptable in NCAA/NFHS regulation play. Model B, with a triangular dimpled surface (Figure 1), had a lower compression load and lower COR than the other ball models. These lower values might be expected since this pattern places less material on the outer surface of the ball. However, the effects of the surface pattern are not conclusive since we did not control the material composition of the ball models. It is also unknown whether surface texture on the ball would alter the interaction with the stick or playing surface and affect play during a game. Specific labeling requirements for the balls are also not clearly stated in the rules. Labels such as “Official NCAA” or “Meets NCAA Specs” both suggest compliance with the requirements of the NCAA.

In summary, we found that none of the ball models we tested met all the specifications of the NCAA/NFHS. We found that the current rebound method used for quantifying ball liveliness correlated weakly with the COR measured at 27 m/s. We suggest that governing bodies consider updating their specifications to adopt more game-relevant performance tests. Specifications for the compression loads of competitive-play lacrosse balls should also be considered, but further studies are needed in order to determine the relationship between compression loads and the likelihood of facemask and goggle penetration.

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