Background: Baseball is the leading cause of sports-related eye injuries in young persons. It is known that softer baseballs reduce the potential for brain and cardiac injury, but it has been speculated that softer baseballs may increase eye injuries by intruding more into the orbit. It also has been claimed that softer baseballs would change the “feel” of the game.

Objectives: To determine the orbital intrusion and eye injury potential of baseballs of varying hardness, and whether a player can feel the difference between these different baseballs.

Main Outcome Measures: Orbital force and penetration of baseballs of various hardness into an artificial orbit. Ability of subjects of varying age and baseball experience to determine the hardness of baseballs.

Results: The peak orbital force and force onset rate from softer baseballs, at all impact velocities, were less than the force and force onset rate from baseballs that had hardness equal to, or greater than, major league baseballs. The softest (10% of major league hardness) baseballs intruded into the orbit significantly more than balls that were 15% of major league hardness or harder. Children younger than 14 years could not differentiate balls 15% of major league hardness or harder, and adults could not differentiate 20% of major league hardness or harder from each other or from major league balls.

Conclusion: The potential for injury to the unprotected eye from soft baseballs is significant, but not greater than that from a major league baseball. Baseballs that are 15% to 20% of major league ball hardness are recommended for youth baseball because these balls feel like major league balls, reduce the potential for brain injury and commotio cordis, cause less pain on impact, and do not increase the potential for eye injury to the unprotected player. Eye injuries in youth baseball could be minimized by the use of protective eyewear that conforms to the standard specifications of the American Society of Testing and Materials (Philadelphia, Pa), standards F910 (for batters and baserunners) and F803 (for fielders).

MATERIALS AND METHODS

Fifty baseballs of 6 different hardnnesses were used as test objects (Table 1). All of the baseballs were covered with a 2-piece leather cover sewn together with 108 stitches, and were between 22.9 and 23.5 cm (9-9.25 in) in circumference. The liveliness of the baseballs was measured by the coefficient of restitution; i.e., the ratio of the ball exit speed after contact with a rigid, flat wall to the incoming speed (60 mph, 26.8 m/s).7

Ball hardness was measured by the compression-displacement (CD), in which the ball is compressed to a standard displacement of 6.35 mm (0.25 in) between 2 flat plates in 12 to 15 seconds.8 The CD is the average force, in pounds, of 2 compressions 90° apart; softer balls have lower values. The softer baseballs conformed to the National Operating Committee on Standards for Athletic Equipment (NOCSAE) standard requirements as to head impact with no head protection.9

EXPERIMENT 1

Eight balls of each hardness were propelled by an air cannon10 into an artificial orbit (Figure 1) at velocities typical for youth players (M. Clark, PhD, unpublished data, 1997) (Table 2). Each ball was used for 1 impact. The orbit was designed to model the human orbit, with one side made of transparent polycarbonate to permit photographing ball intrusion (Figure 1, B). Peak orbital force was determined by combining values from the quartz piezoelectric load sensors (Figure 1, C) (model P212-B; PCB Piezotronics, Depew, NY), located at each of the 4 supports. The total force was inertially compensated for the mass of the orbit structure (Figure 1, A) using data from the piezoelectric accelerometer (Figure 1, F) (7264A; Endevco, San Juan Capistrano, Calif). The entire structure was mounted on a NOCSAE sliding table (Figure 1, E).9 The force onset rate was taken from the linear portion of the force time curve. Ball velocity and orbital intrusion were determined for both experiments 1 and 2 using high-speed (1000 frames/s) color videotape (Kodak, Reston, Va).

EXPERIMENT 2

A matched pair of unembalmed cadaver eyes were held in a 10% gelatin mold and placed separately into the same artificial orbit as in experiment 1. Prior to impact, normal intraocular pressure was restored with saline. The left eye was impacted at 75 mph (33.5 m/s) with a CD-25 soft baseball, while the right eye was impacted at 55 mph (24.5 m/s) with a CD-250 major league baseball.

EXPERIMENT 3

Subjects with experience in organized baseball, aged 6 to 10 years (n=4), aged 11 to 14 years (n=4), and adult men (n=10), as well as female adults with no baseball experience (n=5), were asked to rate 3 samples of each of the test balls, plus 3 additional samples of a major league CD-250 baseball made by a different manufacturer, as to relative hardness compared with a known major league ball. The youth baseball players, in game conditions, threw, caught, and batted balls of varying hardness and then were asked if they could perceive a difference in how the balls felt when thrown, caught, and batted.

When considering whether to use softer baseballs, we must weigh all factors. The purpose of youth baseball should be enjoyment. Attempts to improve safety should have as little effect on the appeal of the game as possible.11 The inability of youth players to differentiate a baseball that is only 14% the hardness of a major league ball is related to grip strength. Once ball compression hardness exceeds grip strength, there is no perceived difference among balls of different hardnesses. Even a semi-professional baseball pitcher and several coaches were unable to differentiate 50-CD baseballs from major league baseballs. Because the balls are approximately the same weight, liveliness, and exterior construction, it was almost impossible for youth to differentiate among them, except for the very soft CD-25 ball. The lack of complaints about the fact that balls currently used in most youth leagues are harder than major league balls, while there are objections to the use of softer balls, is most likely due to traditional resistance to softening the "hard ball."12

Eye injury criteria based on kinetic energy and peak force can be found in the literature, but cannot be directly compared with the results of the current study owing to stiffness and geometrical differences between the baseballs and the impactors used in other studies.13,14 The force values are aggregate values for the eye and surrounding structures and not specific to particular ocular structures. However, experiment 1 characterizes the effect of ball stiffness (CD) on the peak force and force onset rate and demonstrates that the softer balls produce lower peak forces and lower onset rates for a given
velocity when the ball impacts the orbit centrally and perpendicular to the vertical orbital plane. No attempt was made to determine the effect of impacts that were not centered in the orbit and/or were nonorthogonal.

The eye can be modeled as a viscoelastic tissue whose response depends not only on the applied force but also the rate of applied force. This concept is highlighted in experiment 2, wherein the left eye remained intact while the right eye ruptured completely on impact. The harder ball produced a 17% higher peak force and a 30% higher force onset rate than the softer ball, despite a 27% lower impact velocity.

Are softer balls safer? It is known that the risk of brain injury is related to the ball hardness. A depressed comminuted skull fracture in a human cadaver results from the impact of a standard (CD-250) major league baseball at speeds between 55 and 60 mph and from a softer (CD-35) ball at 81 mph.15 Experimental and observational studies are supported by theoretical models that suggest that softer baseballs reduce the impact response of head and chest models and may be safer.16 Softer baseballs, as compared with regulation balls, may reduce the

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**Table 1. Test Baseballs**

<table>
<thead>
<tr>
<th>CD, lb†</th>
<th>COR</th>
<th>Weight, g (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softest</td>
<td>25</td>
<td>.53 146.5 (1.4)</td>
</tr>
<tr>
<td>Medium hard</td>
<td>35</td>
<td>.53 138.7 (2.6)</td>
</tr>
<tr>
<td>Hardest</td>
<td>50</td>
<td>.53 138.6 (2.1)</td>
</tr>
<tr>
<td>Major league</td>
<td>250</td>
<td>.56 143.9 (1.5)</td>
</tr>
<tr>
<td>Harder than major league</td>
<td>266</td>
<td>.53 142.6 (1.3)</td>
</tr>
<tr>
<td>Hardest</td>
<td>291</td>
<td>.53 141.1 (0.90)</td>
</tr>
</tbody>
</table>

*CD indicates compression-displacement; COR, coefficient of restitution. †Per industry tradition, units are not SI (Système International).

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**Table 2. Baseball Velocities**

<table>
<thead>
<tr>
<th>Age, y</th>
<th>Pitched Ball, mph, Mean (SD) [Range]</th>
<th>Batted Ball, mph, Mean (SD) [Range]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-8</td>
<td>Not applicable*</td>
<td>30.1 (8.0) [13-55]</td>
</tr>
<tr>
<td>9-10</td>
<td>34.5 (6.9) [17-53]</td>
<td>35.6 (8.6) [13-65]</td>
</tr>
<tr>
<td>11-12</td>
<td>46.2 (5.9) [30-59]</td>
<td>39.8 (10.2) [20-65]</td>
</tr>
<tr>
<td>13-14</td>
<td>55.8 (5.8) [30-72]</td>
<td>47.9 (12.7) [15-80]</td>
</tr>
<tr>
<td>≥15</td>
<td>67.3 (7.0) [41-81]</td>
<td>59.1 (15.5) [25-90]</td>
</tr>
</tbody>
</table>

*Ball thrown by a coach or struck from a tee in this age group.

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**Table 3. Peak Orbital Force Correlations and Values for 2 Impact Velocities**

<table>
<thead>
<tr>
<th>Ball CD, lb</th>
<th>Linear Regression ($R^2$)</th>
<th>Calculated Force at 55 mph, N</th>
<th>Calculated Force at 70 mph, N</th>
<th>Force Onset Rate at 55 ± 1 mph, N/ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>0.997</td>
<td>2250</td>
<td>3088</td>
<td>1747</td>
</tr>
<tr>
<td>35</td>
<td>0.981</td>
<td>3070</td>
<td>4092</td>
<td>2249</td>
</tr>
<tr>
<td>50</td>
<td>0.988</td>
<td>3282</td>
<td>4283</td>
<td>2630</td>
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<tr>
<td>250</td>
<td>0.982</td>
<td>3691</td>
<td>4717</td>
<td>3313</td>
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<tr>
<td>266</td>
<td>0.987</td>
<td>3583</td>
<td>4715</td>
<td>3203</td>
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<tr>
<td>291</td>
<td>0.994</td>
<td>3616</td>
<td>4678</td>
<td>3198</td>
</tr>
</tbody>
</table>

*CD indicates compression-displacement. Per industry tradition, units are not SI (Système International).

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**Figure 1. Artificial orbit. A indicates steel orbit. Orbital opening is 35 mm high, 42 mm wide (at center line), and 38 mm deep; mass=1.140 kg (including B). B indicates polycarbonate orbital side through which photographs are taken; C, load cells, 4 total; D, head mass=4.545 kg (including A+B+4 C+D ); E, aluminum sliding table (National Operating Committee on Standards for Athletic Equipment, Providence, RI); and F, accelerometer mounted to back side of orbital plate.**

**Figure 2. Peak orbital force vs impact velocity for 6 types of balls.**

**Figure 3. Force-time histories at 55 ± 2 mph for all ball types.**
It also has been shown that softer balls cause less pain on impact. It seems that all baseballs, no matter the hardness, impart sufficient energy to the orbital area and have sufficient penetration into the orbit to cause severe eye injury. Eye injuries in youth baseball would be reduced if batters and baserunners wear eye protection meeting the requirements of ASTM F910 attached to the helmet. Fielders should wear eye protection that conforms to the requirements of ASTM F803.

While the softest (CD-25) baseballs reduce the peak force and onset rate, they do intrude more significantly into the orbit and should only be used for the very young (age <6 years), who have little grip strength and propel

![Figure 4. Peak orbital intrusion vs velocity for different ball hardnesses.](image)

![Figure 5. Peak orbital intrusion for selected tests. A, Compression-displacement (CD) at 25 lbs (CD-25) ball at 55 mph. B, CD-35 ball at 55 mph. C, CD-250 ball at 55 mph. D, CD-25 ball at 75 mph. Note that Système International (SI) units are not used per industry tradition.](image)

![Table 4. Peak Intrusion Correlations and Average Peak Intrusions for All Velocities](image)
the ball at very low velocities. The differences in orbital intrusion of all balls CD-35 and harder are not clinically meaningful and, with the decrease in peak force and onset rate, the soft CD-35 and CD-50 balls should not cause an increase in eye injuries. The major league ball will have a slightly higher batted velocity, which may be noticed by the most experienced and older youth players. The pitched velocity of baseballs with the same mass will be unaffected. It seems reasonable to use CD-35 balls for players aged 6 to 10 years, CD-50 balls for players aged 11 years and older, and major league CD-250 balls for those very experienced in the game.

We believe that baseballs for youth players should be made softer because softer balls reduce the potential for brain injury and commotio cordis, cause less pain, and do not increase the risk of eye injury, yet still feel like major league balls.

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