Incidence of Anterior Cruciate Ligament Injuries Among Elite Ballet and Modern Dancers: A 5-year Prospective Study
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Numerous studies have established that the incidence of sports-related anterior cruciate ligament (ACL) noncontact injuries has risen substantially over the past 30 years and that women in sports involving jumping and cutting movements are at higher risk for noncontact ACL ruptures than the men involved in those same sports. Up to 70% of sports-related ACL injuries are noncontact in nature, distinguished from contact-type ACL injuries by their mechanism of injury (ie, jump landing vs collisions with another player or ball, or excessive knee joint loading during athletic actions such as the plant-and-cut maneuver).

In an effort to better understand the risks associated with noncontact ACL injury occurrence, many investigators have studied intergender differences, including anatomic, neuromuscular, or hormonal factors, while others have focused on intragender differences between same-sex ACL-injured and noninjured athletes within a given sport. A substantial body of work has also emerged on the relationship between extrinsic variables and ACL injury occurrence, and 2 recent studies have investigated an association between psychometric variables and ACL injury. To date, no prospective studies have

Incidence of Anterior Cruciate Ligament Injuries Among Elite Ballet and Modern Dancers

A 5-year Prospective Study

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Background: Ballet and modern dance are jump-intensive activities, but little is known about the incidence of anterior cruciate ligament (ACL) injuries among dancers.

Hypothesis: Rigorous jump and balance training has been shown in some prospective studies to significantly reduce ACL injury rates among athletes. Dancers advance to the professional level only after having achieved virtuosic jump and balance technique. Therefore, dancers on the elite level may be at relatively low risk for ACL injury.

Study Design: Descriptive epidemiology study.

Methods: Dance exposure, injuries, and injury conditions were systematically recorded at 4 dance organizations over 5 years. Select neuromuscular and psychometric variables were compared between and within ACL-injured and noninjured dancers.

Results: Of 298 dancers, 12 experienced an ACL injury over the 5-year period. The incidence of ACL injury was 0.009 per 1000 exposures. Landing from a jump onto 1 leg was the mechanism of injury in 92% of cases. Incidence was not statistically different between gender or dance groups, although women modern dancers had a 3 to 5 times greater relative risk than women ballet dancers and men dancers. No difference between ACL-injured and noninjured dancers emerged with regard to race, oral contraceptive use, or select musculoskeletal measures.

Conclusion: Dancers suffer considerably fewer ACL injuries than athletes participating in team ball sports. The training dancers undertake to perfect lower extremity alignment, jump, and balance skills may serve to protect them against ACL injury. Anterior cruciate ligament injuries happened most often late in the day and season, suggesting an effect of fatigue.

Keywords: anterior cruciate ligament; incidence; gender; ballet; dance; jump; fatigue

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examined factors associated with incidence of ACL injury among dancers, an activity rife with jumping demands.

Classical ballet dancers perform more than 200 jumps per 1.5-hour daily technique class, more than half of which involve single-leg landing.\(^{46}\) Forces at the knee during some dance jump landings have been measured to exceed 12 times body weight.\(^{46}\) Despite this, the occurrence of ACL injury among dancers has been reported as low in 2 unpublished retrospective studies (Liederbach, Dilgen, and Rose, unpublished data, 1998; and Ambegaonkar, Shultz, Perrin, and Schulz, unpublished data, 2006). One of the retrospective studies compiled survey responses from members of the International Association of Dance Medicine and Science and subsequently estimated a prevalence of 0.3 ACL injuries per year per dance company of 20 dancers. In that study, no gender difference was found between women and men in ballet, but a 13-times greater reporting of ACL injury was observed among women in modern dance compared with men in modern dance (Liederbach, Dilgen, and Rose, unpublished data, 1998). The present study was undertaken to more rigorously measure ACL injury incidence over a 5-year period of time in modern and ballet dancers by prospectively comparing exposure-controlled ACL injury rates. The aim of the present study was to measure the incidence of ACL injury among elite ballet and modern dancers, to compare rate ratios between genders and dance groups, and to compare selected intrinsic and extrinsic variables between the dancers who experienced ACL injury with those who did not.

MATERIALS AND METHODS

Research Design

A prospective epidemiologic design was used to compare ACL injury rates and rate ratios between elite men and women dancers and between ballet and modern dancers.

Subjects

Data were captured on 298 dancers from 2 internationally ranked ballet companies, 1 internationally ranked modern dance company, and 1 university-level conservatory of dance over a 5-year period. Dancers were not included in the data analysis if they had a history of ACL injury or ACL reconstruction. All 4 dance organizations were located in the New York City area and represented different dance styles, movement, and positions in the studio. All dancers were required to report every new injury to the assigned ATC or PT as close to the time of each injury event as possible. Injury event conditions were documented in a standardized way to determine whether factors such as time of day or season, shoe type, surface type, menstrual status, movement activity type, set design, costume, environmental lighting, or prop handling were associated with ACL injury events.

The POMS, a 65-item synonym-based questionnaire, was used to measure mood state. The POMS has a 5-point adjective rating scale from 0 (not at all) to 5 (extremely), divided into 6 affective mood state categories: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment. The POMS was administered to all dancers during the preparticipation screening and again to ACL-injured dancers at the time of their ACL injury report. The dancers were asked to use the instrument’s rating scale to describe how they had been feeling “over the past week.”

Exposure Measurement

To compare our injury rate data with published reports on athlete studies that used the National Collegiate Athletic Association Injury Surveillance System,\(^{64}\) a dance exposure was defined as any participation in a class, rehearsal, or performance in which a dancer was exposed to the possibility of a dance injury. The nature and length of each dance exposure was not further weighted.\(^{58}\) Exposure was captured systematically each week throughout the 5-year period by the on-site trainer or therapist and was verified by the appropriate administrator at each dance institution. Exposure was then calculated by totaling the number of dance exposure events.
of classes, rehearsals, and performances undertaken by each dancer each day.

Primary Outcome Measurement

The definition of injury used in the IPAIRS system was “any injury resulting in one or more complete or partial sessions of time lost beyond the day of the injury event itself.” An injury was documented as reportable if the dancer was unable to participate in 1 or more classes, rehearsals, or performances for 1 or more days beyond the date of the injury event. An ACL injury was defined in this study as a first-time partial or complete rupture of the ligament confirmed by clinical and radiologic examination. One injury report form per new injury documented each dancer’s musculoskeletal complaint, mechanism of injury, severity of injury, exposure type at time of injury (class, rehearsal, or performance), level of functional disability, menstrual status and phase, time of day, number of hours and type of activity undertaken up to time of injury on the same day, time of season, shoe wear, floor type, set design, prop use, and costume type, as well as ambient conditions of the environment.

Data Analysis

Injury rates were calculated as the number of ACL injuries divided by the number of exposures, then multiplied by 1000. Rate ratios and confidence intervals were calculated using OpenEpi version 2.0 software (Centers for Disease Control and Prevention, Atlanta, Georgia), and ACL incidence proportions by race and oral contraceptive use were compared between dance groups using \(\chi^2\) analysis and/or Fisher exact test, as appropriate. To examine whether differences in select intrinsic variables and POMS scores existed between the dancers who sustained ACL injuries and those who did not, we used a multivariate analysis of variance. Repeated-measures analysis of variance was used to compare POMS values obtained at the time of ACL injury with values obtained from the same dancer during preparticipation screening. These data were processed with SPSS version 10.0 software (SPSS Inc, Chicago Illinois) at an alpha level of \(P < .05\).

RESULTS

Over 5 years, 3721 injury reports were produced from the 298 dancers (183 females, 115 males), representing an average of 2.5 reportable (\(\geq 1\) exposure activity loss) injuries per year per dancer with a range of 0 to 7 reportable injuries per year per dancer. Before the end of the 5-year study period, 32 of the 298 dancers were lost to attrition from relocation after graduation or promotion, so their exposure and injury data was prorated for the amount of time they participated in the data collection effort. None of the 32 dancers who left the study suffered an ACL injury while participating in the study. From the aggregate injury data, 12 ACL injuries were confirmed, 11 of which were noncontact in nature and 1 of which was contact in nature, occurring to a woman modern dancer during a dancer-to-dancer partnering maneuver when she was lifting the opposite dancer’s body weight off the ground. Of the 12 ACL injuries reported, 10 were to women (2 ballet dancers and 8 modern dancers) and 2 were to men, (1 ballet dancer and 1 modern dancer). Women and men shared the same mechanism of injury in 92% of cases—landing from a jump onto a single leg (see Figure 1; a video supplement is available at http://ajs.sagepub.com/supplemental). The average age at the time of ACL injury was 24.0 ± 4.9 years for the women and 21.5 ± 3.5 years for the men.

Women modern dancers had the highest rate of ACL injuries at 0.015 per 1000 exposures, compared with the women ballet dancers at 0.005 per 1000 exposures and the men modern and ballet dancers at 0.004 and 0.003 per 1000 exposures, respectively, but a statistically significant difference in incidence between gender or dance groups was not attained. Table 1 shows ACL incidence, confidence intervals, and rate ratio data for all dancers and for sub-groupings of dancers by gender and dance type.

An overview of all injuries reported during the 5 years by anatomic region is provided in Table 2.

No difference was found between dancers with ACL injury and dancers without ACL injury with regard to race \((P = .74)\) or between ACL-injured and noninjured women with regard to oral contraceptive use \((P = 0.13)\) (Table 3).

A multivariate analysis was undertaken to assess the combined and independent effects of 7 intrinsic variables on discrimination between ACL-injured dancers and...
noninjured dancers according to gender. The variables evaluated were BMI, knee hyperextension, static Q-angle, passive measures of hip rotation, a manual muscle test score for total leg strength, and a navicular drop-test score. No significant within-group changes occurred in these measures over the course of the study, so the values obtained during the initial screening were used for the present analysis. No differences were found between ACL-injured and noninjured groups for either the men or the women dancers (Table 4).

None of the mood categories tested during preparticipation screening was associated with later ACL injury occurrence (Table 5A). Among the ACL-injured dancers, statistically significant changes were observed in the POMS scores taken at the time of the ACL injury relative to the time of preparticipation screening. The measures of fatigue-inertia and depression-dejection both increased, while the measure of vigor-activity decreased (Table 5B). Three patterns emerged with regard to the time of ACL injury and activity type at the time of ACL injury. Of the 12

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**TABLE 1**

Anterior Cruciate Ligament (ACL) Injury Rate, Confidence Intervals, and Rate Ratios by Gender and Dance Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of ACL Injuries/ Total Participants</th>
<th>Total Dance Exposures</th>
<th>ACL Injury Rate (per 1000 Exposures)</th>
<th>95% Confidence Interval</th>
<th>95% Rate Ratio</th>
<th>95% Confidence Interval</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballet</td>
<td>Men</td>
<td>1/53</td>
<td>303 396</td>
<td>0.003</td>
<td>0.0004, 0.018</td>
<td>1.6</td>
<td>0.1, 18.2</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>2/64</td>
<td>367 489</td>
<td>0.005</td>
<td>0.0006, 0.019</td>
<td>3.8</td>
<td>0.5, 30.6</td>
</tr>
<tr>
<td>Modern</td>
<td>Men</td>
<td>1/62</td>
<td>241 870</td>
<td>0.004</td>
<td>0.0005, 0.023</td>
<td>3.8</td>
<td>0.5, 30.6</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>8/119</td>
<td>505 578</td>
<td>0.015</td>
<td>0.006, 0.028</td>
<td>1.3</td>
<td>0.7, 20.0</td>
</tr>
<tr>
<td>Men Ballet</td>
<td>1/53</td>
<td>303 396</td>
<td>0.003</td>
<td>0.0004, 0.018</td>
<td>1.3</td>
<td>0.7</td>
<td>14.3</td>
</tr>
<tr>
<td>Modern Ballet</td>
<td>2/64</td>
<td>241 870</td>
<td>0.004</td>
<td>0.0005, 0.023</td>
<td>2.9</td>
<td>0.6</td>
<td>13.7</td>
</tr>
<tr>
<td>Aggregate</td>
<td>Men</td>
<td>2/115</td>
<td>545 266</td>
<td>0.004</td>
<td>0.0006, 0.012</td>
<td>3.1</td>
<td>0.7, 14.3</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>10/183</td>
<td>873 067</td>
<td>0.012</td>
<td>0.005, 0.024</td>
<td>2.7</td>
<td>0.7, 9.9</td>
</tr>
<tr>
<td>Ballet</td>
<td>3/117</td>
<td>670 885</td>
<td>0.005</td>
<td>0.001, 0.012</td>
<td>2.7</td>
<td>0.7</td>
<td>9.9</td>
</tr>
<tr>
<td>Modern</td>
<td>9/181</td>
<td>747 448</td>
<td>0.012</td>
<td>0.006, 0.022</td>
<td>2.7</td>
<td>0.7</td>
<td>9.9</td>
</tr>
<tr>
<td>All dancers</td>
<td>12/298</td>
<td>1 418 333</td>
<td>0.009</td>
<td>0.004, 0.014</td>
<td>2.7</td>
<td>0.7</td>
<td>9.9</td>
</tr>
</tbody>
</table>

**TABLE 2**

Total Reportable Injuries Over 5 Years by Anatomic Region

<table>
<thead>
<tr>
<th>Group</th>
<th>Total Time Lost Injuries (≥1 Missed Dance Exposure)</th>
<th>Foot/Ankle</th>
<th>Knee</th>
<th>Hip</th>
<th>Spine</th>
<th>Upper Extremity</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballet</td>
<td>1427 (2.44 per dancer per year)</td>
<td>57%</td>
<td>6%</td>
<td>9%</td>
<td>12%</td>
<td>3%</td>
<td>13%</td>
</tr>
<tr>
<td>Modern</td>
<td>2294 (2.62 per dancer per year)</td>
<td>47%</td>
<td>8%</td>
<td>11%</td>
<td>16%</td>
<td>8%</td>
<td>10%</td>
</tr>
</tbody>
</table>

**TABLE 3**

Fisher Exact Test Results: Incidence Proportions by Race and Oral Contraception Use

<table>
<thead>
<tr>
<th>Race</th>
<th>ACL Injury No ACL Injury</th>
<th>P Value</th>
<th>ACL Injury No ACL Injury</th>
<th>P Value</th>
<th>ACL Injury No ACL Injury</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>2 (3.3)</td>
<td>59 (96.7)</td>
<td>1.0</td>
<td>6 (3.9)</td>
<td>149 (96.1)</td>
<td>.12</td>
</tr>
<tr>
<td>Nonwhite</td>
<td>1 (1.8)</td>
<td>55 (98.2)</td>
<td>1.0</td>
<td>3 (11.5)</td>
<td>23 (88.5)</td>
<td>4 (4.9)</td>
</tr>
<tr>
<td>Oral contraception</td>
<td>Yes</td>
<td>1 (2.1)</td>
<td>47 (97.9)</td>
<td>.44</td>
<td>4 (4.5)</td>
<td>84 (95.5)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1 (6.3)</td>
<td>15 (93.8)</td>
<td>4 (12.9)</td>
<td>27 (87.1)</td>
<td>5 (10.6)</td>
</tr>
</tbody>
</table>

*ACL, anterior cruciate ligament.*
ACL injuries, 9 occurred during the middle to end of a performance season, compared with 2 that occurred during off-season and 1 during early season. Eight of the 12 ACL injuries occurred during evening hours after several hours of activity, compared with 3 that occurred in the afternoon and 1 in the morning. Seven of the 12 ACL injuries occurred during a performance event, compared with 5 during daytime rehearsal and 1 during morning technique class (Figure 2).

**DISCUSSION**

The incidence of ACL injury among the dancers in this study was very low when compared with published reports of ACL injury rates among athletes in studies that used a similar definition of injury and exposure.1,3-5,15-17,27,58,59 Anterior cruciate ligament injuries represented 0.2% (ballet) and 0.4% (modern dance) of the total injuries reported among these dancers over 5 years. Viewed from a relative

---

**TABLE 4**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Men (Mean ± SD)</th>
<th>Women (Mean ± SD)</th>
<th>P Value&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Men (Mean ± SD)</th>
<th>Women (Mean ± SD)</th>
<th>P Value&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACL-Injured</td>
<td>No ACL Injury</td>
<td></td>
<td>ACL-Injured</td>
<td>No ACL Injury</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.5 ± 0.7</td>
<td>25.5 ± 1.1</td>
<td>.20</td>
<td>20.5 ± 1.8</td>
<td>19.5 ± 1.4</td>
<td>.07</td>
</tr>
<tr>
<td>Supine Q-angle (deg)</td>
<td>13.0 ± 0.4</td>
<td>12.9 ± 0.5</td>
<td>.81</td>
<td>15.9 ± 0.8</td>
<td>15.9 ± 1.0</td>
<td>.94</td>
</tr>
<tr>
<td>Knee hyperextension (deg)</td>
<td>7.5 ± 3.5</td>
<td>6.5 ± 3.3</td>
<td>.68</td>
<td>10.7 ± 1.9</td>
<td>9.3 ± 2.6</td>
<td>.09</td>
</tr>
<tr>
<td>Hip internal rotation (deg)</td>
<td>30.0 ± 1.4</td>
<td>33.8 ± 8.0</td>
<td>.49</td>
<td>34.8 ± 8.9</td>
<td>34.2 ± 7.9</td>
<td>.83</td>
</tr>
<tr>
<td>Hip external rotation (deg)</td>
<td>50.0 ± 7.1</td>
<td>46.2 ± 6.7</td>
<td>.42</td>
<td>45.7 ± 7.1</td>
<td>46.9 ± 6.7</td>
<td>.57</td>
</tr>
<tr>
<td>MMT–TLS (kg)</td>
<td>73.5 ± 6.4</td>
<td>76.8 ± 5.1</td>
<td>.37</td>
<td>50.0 ± 5.2</td>
<td>51.3 ± 4.5</td>
<td>.36</td>
</tr>
<tr>
<td>Navicular drop test (mm)</td>
<td>4.5 ± 2.2</td>
<td>4.4 ± 1.9</td>
<td>.97</td>
<td>3.9 ± 1.2</td>
<td>4.2 ± 1.5</td>
<td>.46</td>
</tr>
</tbody>
</table>

<sup>a</sup>ACL, anterior cruciate ligament; SD, standard deviation; BMI, body mass index; MMT-TLS, manual muscle test–total leg strength (the sum of handheld dynamometry scores for hip flexion, abduction, and adduction).

<sup>b</sup>All P values were nonsignificant.

---

**TABLE 5A**

<table>
<thead>
<tr>
<th>POMS Variable</th>
<th>Noninjured (Mean ± SD)</th>
<th>ACL-Injured (Mean ± SD)</th>
<th>P Value&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension-anxiety</td>
<td>16.0 ± 1.2</td>
<td>15.8 ± 0.8</td>
<td>.695</td>
</tr>
<tr>
<td>Depression-dejection</td>
<td>14.2 ± 1.9</td>
<td>14.0 ± 1.7</td>
<td>.913</td>
</tr>
<tr>
<td>Anger-hostility</td>
<td>13.9 ± 0.7</td>
<td>13.8 ± 0.5</td>
<td>.706</td>
</tr>
<tr>
<td>Vigor-activity</td>
<td>16.6 ± 1.3</td>
<td>17.2 ± 0.9</td>
<td>.090</td>
</tr>
<tr>
<td>Fatigue-inertia</td>
<td>8.1 ± 0.8</td>
<td>8.3 ± 0.6</td>
<td>.602</td>
</tr>
<tr>
<td>Confusion-bewilderment</td>
<td>7.0 ± 1.1</td>
<td>7.2 ± 0.8</td>
<td>.622</td>
</tr>
</tbody>
</table>

<sup>a</sup>ACL, anterior cruciate ligament; SD, standard deviation.

---

**TABLE 5B**

<table>
<thead>
<tr>
<th>POMS Variable</th>
<th>Preseason (Mean ± SD)</th>
<th>Time of ACL Injury (Mean ± SD)</th>
<th>P Value&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension-anxiety</td>
<td>15.8 ± 0.8</td>
<td>16.3 ± 1.0</td>
<td>.152</td>
</tr>
<tr>
<td>Depression-dejection</td>
<td>14.0 ± 1.7</td>
<td>16.1 ± 2.5</td>
<td>.002&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Anger-hostility</td>
<td>13.8 ± 0.5</td>
<td>13.7 ± 0.7</td>
<td>.530</td>
</tr>
<tr>
<td>Vigor-activity</td>
<td>17.3 ± 0.9</td>
<td>12.8 ± 1.2</td>
<td>&lt;.001&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fatigue-inertia</td>
<td>8.3 ± 0.6</td>
<td>16.3 ± 0.8</td>
<td>&lt;.001&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Confusion-bewilderment</td>
<td>7.2 ± 0.8</td>
<td>7.7 ± 1.1</td>
<td>.061</td>
</tr>
</tbody>
</table>

<sup>a</sup>ACL, anterior cruciate ligament; SD, standard deviation.

<sup>b</sup>Significant.
perspective, this compares with published injury percentages of anywhere from roughly 1% to 8% in team ball sports.\textsuperscript{1,3,15,17,59} Dance, with an overall incidence of 0.009 ACL injuries per 1000 exposures, thus ranks in the lowest relative risk category for ACL injury according to the National Collegiate Athletic Association’s four-point Injury Rate Equivalent, a classification system that grades injury risk on a continuum from 1 (very low risk) to 4 (very high risk) based on injury rate data,\textsuperscript{64} a fact that in no way diminishes the devastating emotional and financial impact on both dancer and dance company alike when an ACL injury does occur.

Several possible explanations for this phenomenon exist. One is that dance training produces highly skilled balance ability,\textsuperscript{14,26,61,79} as well as superlative proficiency in jumping tasks that involve intricate foot work and neutrally aligned, toe-to-heel, highly controlled landing techniques. Accomplishment of aesthetically precise balance and jumping skills is necessary for both men and women in dance to advance to the professional ranks. Unlike many sports, in which jumping is practiced as a means by which to contact a ball for the purpose of goal-scoring, jumping in dance is used in and of itself solely for the purpose of helping to convey a dramatic story, expressing an emotion, or displaying technical virtuosity.\textsuperscript{43}

Several studies focusing on preventive interventions have found that supervised jump and balance training programs that emphasize neutral lower extremity alignment and progressive difficulty result in dramatic declines in both adverse joint forces and subsequent-season ACL injury rates.\textsuperscript{33,49,62,65,66,71} Although one study dissented from this consensus.\textsuperscript{73} Because dancers practice hundreds of jumps each day as part of their routine technique training, the results of this study may lend credence to the hypothesis that regular exposure to supervised, progressive jump loads practiced with neutral lower extremity alignment and toe-to-heel landing techniques\textsuperscript{33,87} can be protective against ACL injury.

Another reason why dancers may experience fewer ACL injuries than other athletes is that dancers are generally not exposed to unanticipated environmental events including real-time management of a ball in play. Dancers generally know what to expect during each exposure and spend considerable time practicing known routines. Ninety-two percent of the dancers in this study who experienced an ACL injury had a noncontact mechanism of injury, landing from a jump onto 1 leg. Among athletes, the percentage of noncontact injuries is reported to be between 30% and 70% of all ACL injuries, with a sizable proportion of ACL injuries resulting from contact with another player or object, such as a ball.\textsuperscript{10,25,34,57,58,68} Five experimental studies\textsuperscript{8,21,55,74,78} investigated the effect of unanticipated circumstances on knee joint angles and forces by simulating in a laboratory some features that would be present in a sport-specific environment, and all reported significant biomechanical changes in the lower extremities indicating an increased risk for ACL injury. Chaudhari et al\textsuperscript{12} examined the effect of sport-specific arm positions on knee joint loading during a cut-and-run maneuver and found a significant change at the knee when the arm position was constrained by a ball or equipment-carry posture as compared with an unconstrained arm position. Agel et al\textsuperscript{2} reported a significantly higher risk for noncontact ACL injury in women basketball players compared with women soccer players, despite both sports involving running, cutting, and jumping activities, citing a possible link with the ball-in-hand versus ball-at-foot nature of basketball or other possible intersport differences such as surface of play, shoe type, and directional speed of play.

The 95% confidence intervals for the rate and ratio data in this study are wide (see Table 1), and thus no statistically significant difference for incidence was obtained between men and women dancers or between dance types. Nevertheless, a trend toward significance was observed among the women modern dancers, warranting a brief discussion about specific activity risk. Compared with a 1.6-times greater rate of ACL injury among the women in ballet relative to the men in ballet, the women in modern dance had a 3.8-times greater rate than the men in modern dance. Furthermore, they had a 2.9-times greater rate than the women in ballet and a 4.8-times greater rate than the men in ballet, which may suggest that there is an effect of gender that is activity-specific.\textsuperscript{53,76} Several differences in postural and movement practices exist between ballet and modern dance that may partially explain this observation. For example, ballet dancers, by and large, maintain an upright and square torso, using their feet as their base of support almost exclusively, while much of modern dance is performed “off center” and often between quickly changing bases of support including the knees, buttocks, back, shoulders, and

![Figure 2. Time and type of activity when anterior cruciate ligament (ACL) injuries occurred.](http://ajs.sagepub.com)
Ballet dancers rarely improvise, whereas modern dancers often do. Furthermore, ballet traditionally has not required its women participants to lift other dancers, but the women in modern dance often are required to lift other dancers of both sexes for various partnering maneuvers, which was the mechanism of injury for the 1 dancer (a woman modern dancer) in this study who experienced a contact-type ACL rupture. In addition, the jump exposures differ in ballet compared with modern dance. In 1 study, ballet dancers had the same number of single-leg landing contacts per daily technique class as the modern dancers, but were observed to practice twice as many angular-motion jump landings (bodily rotations while airborne) versus linear-motion jump landings, which may influence proprioception of the knee joint.46 Lastly, ballet dancers routinely train and perform in laterally rotated (turned out) stance positions, which is shown to produce a distinctive effect on strength of the hip musculature,30 while modern dancers often shift between turned-out and parallel-stance positions. Numerous expert investigators studying the effects of intrinsic variables on ACL injury risk have concluded that neuromuscular conditioning emphasizing strength, alignment, and motor control of the trunk and lower extremities—in particular of the hip—contributes to the prevention of knee injuries.11,25,37,54,62,66,93

Unlike previous studies that found a difference in BMI, pronation, or knee hyperextension between injured and noninjured athletes,10,35,46,84,90 we found no difference between ACL-injured and noninjured dancers on this level of skill with regard to any of the intrinsic variables measured. However, the power for comparison in this study is low due to the fact that so few dancers sustained an ACL injury, making a type II error possible. It is also worth noting here that very few dancers who begin their training at a young age make it to the elite levels of performance demonstrated by the dancers in this study sample. Hamilton et al29 have reported that injuries, physical deficits on orthopaedic examination, and eating problems are the top 3 reasons for attrition among ballet students and that classical dance weeds out students without the right bodies and psychological profile to survive the rigors of the profession. In national ballet schools, only 5% of the children who begin their training at 8 years of age graduate 9 years later19; of approximately 20,000 dance students auditioning annually for company-affiliated schools, only 10% will be chosen for the school and only 0.1% will make it to the stage.52

We found no difference between the ACL-injured and noninjured dancers in this study with regard to race or oral contraceptive use (see Table 3), although again, so few dancers experienced ACL injuries during the course of the study that the data are subject to type II error. One recent study found that white women basketball players suffered significantly more ACL injuries than did their nonwhite counterparts, but the study contained methodologic challenges that ultimately weakened its results.80 A number of researchers began investigating whether hormonal fluctuation associated with the menstrual cycle and/or oral contraceptive use were risk factors for ACL injury shortly after Liu et al17 and Dragoo et al18 identified estrogen and relaxin receptors, respectively, on the ACL itself.2,7,9,15,31,32,81 At present, the relationship remains unclear. In this study, no difference was found between the women dancers who experienced an ACL injury and those who did not with regard to oral contraceptive use, corroborating the findings of Agel et al,9 who prospectively compared contraceptive use between ACL-injured and noninjured women in basketball and soccer and found no within-sport difference between the ACL injury rates by hormone therapy use.

Several studies have reported an increase in the general occurrence of injury during the later part of the day or season,72,25,43,60,72 suggesting that fatigue may be a factor due to accumulated or condensed exposure hours. A dancer’s day typically begins at 10:00 AM with a 1.5-hour technique class, followed by a several-hours–long rehearsal period and, during performance season, a several-hours–long performance event.44 In the present study, 75% of the ACL injuries occurred during the second half of a performance season and 67% happened at the end of a day, after several hours of activity had already accumulated (see Figure 2). Fatigue is known to contribute to the risk for altered neuromuscular control of the lower limb and an individual’s subsequent ability to dynamically stabilize the knee joint.40,53,67,70,95

Smith et al82 and Liederbach et al44 found that the mood state of fatigue, as measured by POMS, significantly predicted injury in high school ice hockey players and professional ballet dancers, respectively. In the present study, we were not able to predict ACL injuries with the POMS, but this may be due to the fact that we issued the inventory during preparticipation screenings scheduled several months in advance of performing seasons, whereas both of the previously mentioned studies had issued the POMS just before the start of a season and/or during the season itself. At the time of their ACL injury, dancers scored significantly higher for fatigue and depression as well as significantly lower for vigor, with a trend toward increased confusion. Changes in the POMS score of fatigue at the time of ACL injury may have resulted from, rather than preceded, the ACL injury. Previous studies have reported that feelings of depression, anger, confusion, fear, and frustration are commonplace among athletes immediately after injury,39,89 and a myriad of psychometric variables including an athlete’s self-efficacy,66 attitude toward risk, level of attention, level of anxiety, ability to cope, and general perceptions have been identified as having the potential to influence physical outcomes and injury risk.6,28,29,35,41,65,83,85

Additional research in the realm of psychometric variables may prove to be fertile ground for gaining further insight about factors related to cause and prevention of ACL injury as well as to postinjury outcome.

Limitations

We attempted to define exposure in this study the same way many sports medicine authors traditionally have done, but we have no certainty that the measure of exposure is comparable. While dance shares many of the same action tasks with basketball, soccer, and other sports (eg, jumping, running, pivoting), it is a completely different form of activity in terms of its movement demands, shoe-surface conditions, posture, visual cuing, anticipatory
events in the environment, and overall training behavior, including periodization strategies.  

As there are many different styles of ballet and modern dance, the results of this study cannot be generalized to the entire population of dancers. We do not know what the ACL injury rate is among individuals in other dance companies or at different skill levels. It may be that the dancers who make it to the top level of training, such as those represented by our study samples, have resisted injury, whereas others aspiring for the same level have not.  

Future study will be needed to elucidate this information.

CONCLUSION

We found a very low incidence of ACL injury among elite ballet and modern dancers compared with published reports on athletes from other sports that involve jumping movements. No statistically significant difference was achieved between genders or dance types for ACL injury incidence, but women modern dancers possessed a 3- to 5-times greater relative risk than women ballet dancers and men dancers. Dancers train extensively to master virtuosic jump and balance technique and they purposefully endeavor to maintain neutral lower extremity alignment at all times. We speculate that the low rate of ACL injury among dancers may give further credence to prevention programs that emphasize lower extremity alignment and jump and balance training. Further, we speculate that advanced skill in jump and balance activities, along with the relatively predictable nature of the dance environment that usually does not involve ball-handling, may spare elite dancers from high risk for ACL injury. In this study, we found no distinguishing effect of race, oral contraceptive use, or select intrinsic variables on ACL occurrence, but we did observe that most of the injuries happened late in the day and late in the season, suggesting an effect of fatigue. Fatigue monitoring and incorporation of fatigue-resistance elements and unanticipated-events management into prevention programs that involve core and lower extremity strength and motor control training with attention to neutral alignment, along with assessment of psychometric variables, may be important to consider as part of the overall effort to reduce ACL injury rates.

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