PART 1

SUMMER SPORTS
Introduction

Although aquatic sports have been part of the Olympic Games since the 1896 Athens Games, the establishment of the International Amateur Swimming Federation (FINA) in 1908 provided much-needed structure to the aquatics competitive program.

Diving evolved from the early “plunging” (1904 St. Louis Games) and “fancy diving” competitions that first appeared over a century ago. Technological advances (i.e., water agitators, springboard metal alloys, video, etc.) have resulted in ostensibly safer facilities but ever more complicated dives. However, few studies exist regarding injuries during training or competition for competitive diving (Anderson & Rubin 1994; Badman & Rechtine 2004).

Competitive swimming has been a constant in the Olympic Games since 1896 for men and since the 1912 Stockholm Olympics for women. Unfortunately, the injury profile for swimming is unclear, as almost all studies on swimming injuries are retrospective and do not account for exposure in determining injury rates.

Synchronized swimming is the most recent addition to the aquatics competition program and has evolved from a mostly esthetic sport in the early 1900s to be included in the Olympic program for the first time in the 1984 Los Angeles Games. Although Weinberg (1986) characterized synchronized swimming as a sport “relatively free of injury,” the lack of available data-based evidence makes it difficult to assess the accuracy of this statement.

Water polo was played as “football in the water” starting around 1870 in England; in 1900 it was the first team sport introduced in the Olympic Games. The inclusion of women’s water polo at the 2000 Sydney Games indicates that the sport remains popular and has successfully transcended the sex barrier. Few studies have provided a systematic accounting of injuries in water polo, and much remains to be investigated.

This review summarizes existing knowledge and provides guidance for future research regarding the epidemiology of injuries in aquatic sports. In general, multiple methodologic limitations were found in the reviewed literature, including variable injury definitions, differences in the athlete population studied (age, sex, ability, and years of training), small numbers of participants, and problematic data-collection instruments (i.e., recording methods). The majority of the studies were retrospective in design and injury rates were not based on exposure data. This summary of the extant literature on injuries in aquatic sports should be viewed with these limitations in mind.

Who Is Affected by Injury?

A summary of the studies reporting injury rates in aquatic sports is shown in Table 1.1. All of the studies in this review were retrospective, with varying sample sizes (10 to 2496 subjects) and competitive levels, but both sexes were represented. It must also be noted that most of the studies only reported injuries per 100 participants because of the lack of exposure data.
Table 1.1 Injury rates in aquatic sports.

<table>
<thead>
<tr>
<th>Study</th>
<th>Method ( ^a )</th>
<th>No. Sex</th>
<th>Level ( ^b )</th>
<th>No. of teams</th>
<th>Years of Training (range)</th>
<th>Study Duration</th>
<th>Total No. injuries</th>
<th>No. of injured athletes</th>
<th>% of athletes injured</th>
<th>No. of injuries per 100 athletes**</th>
<th>Rate (injury / 100 player-hours)</th>
<th>Rate (injury / 1000 athlete exposures)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Swimming</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kennedy &amp; Hawkins 1974b</td>
<td>R</td>
<td>Q</td>
<td>2496</td>
<td></td>
<td></td>
<td>1 year</td>
<td>8</td>
<td>261</td>
<td>10.4</td>
<td>(2.7, 2.7)</td>
<td>(0.001, 0.001)</td>
<td></td>
</tr>
<tr>
<td>Graham &amp; Bruce 1977</td>
<td>R</td>
<td>Q</td>
<td>78</td>
<td>F</td>
<td>CT</td>
<td>1 year</td>
<td>8</td>
<td>10.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garrick &amp; Requa 1978</td>
<td>R</td>
<td>I/ME</td>
<td>159</td>
<td>77M, 82F</td>
<td>C</td>
<td>2 years</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kennedy et al. 1978</td>
<td>R</td>
<td>ME/R</td>
<td>35</td>
<td></td>
<td></td>
<td>1 year</td>
<td>43</td>
<td>122</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Richardson et al. 1980</td>
<td>R</td>
<td>I/ME/Q</td>
<td>137</td>
<td>54M, 83F</td>
<td>E, NT</td>
<td>10</td>
<td>3</td>
<td>63</td>
<td>58</td>
<td>42</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>Zaricznyj et al. 1980</td>
<td>R</td>
<td>R</td>
<td>74</td>
<td></td>
<td></td>
<td>2 years</td>
<td>2</td>
<td>2</td>
<td>2.7</td>
<td>2.7</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Mutoh et al. 1981</td>
<td>R</td>
<td>Q</td>
<td>19</td>
<td>9M, 10F</td>
<td>E, NT</td>
<td>8.5 ± 2.6</td>
<td>37</td>
<td>19</td>
<td>100</td>
<td>194</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bak et al. 1989</td>
<td>R</td>
<td>Q</td>
<td>268</td>
<td></td>
<td></td>
<td>1 year</td>
<td>100</td>
<td>125</td>
<td>30</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lanese et al. 1990</td>
<td>P</td>
<td>R</td>
<td>57</td>
<td>36M, 21F</td>
<td>CT</td>
<td>2</td>
<td>1 year</td>
<td>29</td>
<td>22</td>
<td>38.5</td>
<td>51</td>
<td>0.12M, 0.08F</td>
</tr>
<tr>
<td>Goldstein et al. 1991</td>
<td>R</td>
<td>I/ME</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>3</td>
<td>15.8</td>
<td>15.8</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td>McFarland &amp; Wasik 1996</td>
<td>R</td>
<td>ME</td>
<td>68</td>
<td></td>
<td></td>
<td>1 year</td>
<td>56</td>
<td>2.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capaci et al. 2002</td>
<td>R</td>
<td>Q</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td>23</td>
<td>23</td>
<td>60.5</td>
<td>60.5</td>
<td>2.12</td>
<td></td>
</tr>
</tbody>
</table>

**Diving**

<table>
<thead>
<tr>
<th>Study</th>
<th>Method</th>
<th>No.</th>
<th>Level</th>
<th>Years of Training (range)</th>
<th>Study Duration</th>
<th>Total No. injuries</th>
<th>No. of injured athletes</th>
<th>% of athletes injured</th>
<th>No. of injuries per 100 athletes**</th>
<th>Rate (injury / 100 player-hours)</th>
<th>Rate (injury / 1000 athlete exposures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krejkova et al. 1981</td>
<td>R</td>
<td>ME</td>
<td>40</td>
<td>1 to 30</td>
<td>1 year</td>
<td>33</td>
<td>33</td>
<td>82.5</td>
<td>82.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Type</td>
<td>R</td>
<td>Q</td>
<td>Gender</td>
<td>Age</td>
<td>Years</td>
<td>Injuries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------</td>
<td>---</td>
<td>---</td>
<td>--------</td>
<td>-----</td>
<td>-------</td>
<td>----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubin 1983</td>
<td></td>
<td>R</td>
<td>Q</td>
<td>38</td>
<td>14M, E</td>
<td>24F</td>
<td>8 ± 3.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mutoh et al. 1988</td>
<td></td>
<td>R</td>
<td>Q</td>
<td>10</td>
<td>5M, 5F, E, NT</td>
<td>30</td>
<td>10</td>
<td>100</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anderson &amp; Rubin 1994</td>
<td></td>
<td>R</td>
<td>Q</td>
<td>37</td>
<td>16M, E</td>
<td>34</td>
<td>92</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubin et al. 1994</td>
<td></td>
<td>R</td>
<td>Q/ME</td>
<td>20</td>
<td>10F, 10M, NT</td>
<td>11.8–12.7</td>
<td>35</td>
<td>8E, 80F, 175</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baranto et al. 2006</td>
<td></td>
<td>R</td>
<td>ME</td>
<td>18</td>
<td>14F, E</td>
<td>89</td>
<td>16</td>
<td>89</td>
<td>494</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Synchronized Swimming**

<table>
<thead>
<tr>
<th>Study</th>
<th>Type</th>
<th>R</th>
<th>Q</th>
<th>Gender</th>
<th>Age</th>
<th>Years</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mutoh et al. 1988</td>
<td></td>
<td>R</td>
<td>Q</td>
<td>24</td>
<td>F, E, NT</td>
<td>7.9 ± 2.1</td>
<td>31</td>
</tr>
<tr>
<td>Kirkley 1991</td>
<td></td>
<td>R</td>
<td>Q</td>
<td>85</td>
<td>F, AG, E</td>
<td>9</td>
<td>51</td>
</tr>
</tbody>
</table>

**Water Polo**

<table>
<thead>
<tr>
<th>Study</th>
<th>Type</th>
<th>R</th>
<th>Q</th>
<th>Gender</th>
<th>Age</th>
<th>Years</th>
<th>Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biener &amp; Keller 1985</td>
<td></td>
<td>R</td>
<td>Q</td>
<td>147</td>
<td>M, C, E</td>
<td>35</td>
<td>189</td>
</tr>
<tr>
<td>Mutoh et al. 1988</td>
<td></td>
<td>R</td>
<td>Q</td>
<td>13</td>
<td>M, E, NT</td>
<td>27</td>
<td>12</td>
</tr>
<tr>
<td>McLain &amp; Reynolds 1989</td>
<td></td>
<td>R</td>
<td>ME</td>
<td>54</td>
<td>36M, 16F, C</td>
<td>8.5 ± 1.5</td>
<td>2</td>
</tr>
<tr>
<td>Jerolimov &amp; Jagger 1997</td>
<td></td>
<td>R</td>
<td>Q</td>
<td>102</td>
<td>M, C, E</td>
<td>329</td>
<td>322</td>
</tr>
<tr>
<td>Annett et al. 2000</td>
<td></td>
<td>R</td>
<td>ME</td>
<td>77</td>
<td>M, E, NT</td>
<td>13 years</td>
<td>278</td>
</tr>
<tr>
<td>Junge et al. 2006</td>
<td></td>
<td>R</td>
<td>R</td>
<td>156**</td>
<td>M, NT</td>
<td>17</td>
<td>17</td>
</tr>
</tbody>
</table>

1 pain; 2 medical problem that resulted in time loss; 3 any musculoskeletal complaint
4: R = Retrospective
5: I = Interview; Q = Questionnaire; ME = Medical Exam; R = school/accident report
6: * Data for organized school teams only, ** Calculated from data
7: M = Males, F = Females
8: C = Competitive, AG = Age Group, NT = National Team/Olympic/World Championships, E = Elite, M = Masters, CT = College team
Diving

Only Mizel et al. (1993) examined injuries in groups other than elite or national team level, and all but Mizel et al. (1993) and Anderson et al. (1993b) indicated clinical injury rates in divers between 80% and 100%. Rubin and Anderson (1996) presented data from Zimmerman (1993), who reported 8.8 injuries per 1,000 training hours, and Gabriel (1992), who studied medical insurance carrier reports of injury over 3 years that indicated 6.5 injuries per 100 participants per year for divers.

Swimming

As shown in Table 1.1, available studies indicated a prevalence of overall injuries ranging from 2.7 to 194 injuries per 100 athletes. Only McFarland and Wasik (1996) reported an exposure-based injury rate (2.12 injuries per 1,000 athlete exposures) for “any musculoskeletal problem reported to medical personnel.”

Water Polo

Few studies have systematically examined injuries in water polo, and all are retrospective, with sample sizes ranging from 13 to 156, mostly using male participants. Injuries are primarily reported as prevalence, ranging from 5% to 92%.

Where Does Injury Occur?

Anatomical Location

A summary of the available data on percent distribution of injuries by anatomical location for aquatic sports is presented in Tables 1.2 (diving, synchronized swimming, water polo) and 1.3 (swimming). Some studies also reported rates by specific body location, which will be discussed below.

Diving

In divers, most injuries involve the low back (18.8% to 89%), neck (10.3% to 65.7%), and shoulder (20.7% to 85%). Rubin (1983) cited an unpublished study by Mangine (1981) on 66 divers, 89% of whom experienced back pain on multiple occasions. He then surveyed 37 elite divers (ages, 11 to 26 years), 61% of whom reported upper-extremity injuries, 61% back injuries, and 40% neck problems. Anderson, Gerard and Zlatkin (1993a) noted that 42% of elite divers experience neck pain. Others have also noted frequent injuries (24% to 29%) at the hand and wrist (Anderson et al. 1993b, Mutoh, Takamoto & Miyashita 1988). Mizel et al. (1993) found that 45% of injuries in a sample of 120 competitive divers were to the ankle and foot.

Swimming

A review of Table 1.3 reveals that the most frequent injury location for swimmers is the shoulder (12% to 87%), followed by the knee and the lower back. A multitude of investigators have examined the effects of swimming on shoulder injuries alone (i.e., Dominguez 1978b, Richardson et al. 1980, McMaster et al. 1989, McMaster & Troup 1993, Burchfield et al. 1994, Stocker et al. 1995, Bak & Fauno 1997, Johnson et al. 2003) with similar results. Dominguez (1978b) reported that 22% of swimmers 11 to 12 years of age and 65% of swimmers 13 to 18 years of age reported shoulder pain.

The knee is the second most common injury site among swimmers, with prevalences ranging from 6% to 28%, although Hahn and Foldspang (1998) described 62.3% in 53 Danish swimmers. According to Vizsolyi et al. (1987), breaststrokers experienced a higher prevalence of knee-related problems than non-breaststrokers (73% and 48%, respectively). Rovere and Nichols (1985) added that 47% of swimmers cited weekly knee pain, with 75% having knee pain at least three times per season.

Capaci et al. (2002) concluded that 33.3% of butterfly swimmers and 22.2% of breaststroke swimmers experienced lower back injuries. Mutoh (1978) found a 37% rate of injuries for butterfly swimmers. Drori et al. (1996) reported a 50% rate of injuries for butterfly swimmers and 47% for breaststrokers.

In a study of 45 cases of insertion tendonitis in swimmers, Merino and Llobet (1978) conveyed that 73% were shoulder-related (51% freestyle, 42% backstroke, and 6% butterfly), 13.5% were in the groin (17% each in breaststroke and backstroke and 66% in the butterfly), and 13.5% involved the knee (66% in breaststroke and 34% in the butterfly).
Table 1.2 Comparison of injury onset.

<table>
<thead>
<tr>
<th>Study</th>
<th>Diving</th>
<th>Synchronized Swimming</th>
<th>Water Polo</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of athletes</td>
<td>10</td>
<td>24</td>
<td>147</td>
</tr>
<tr>
<td>Total No. of injuries</td>
<td>30</td>
<td>31</td>
<td>189</td>
</tr>
<tr>
<td>Head/face</td>
<td>3</td>
<td>39</td>
<td>96.4</td>
</tr>
<tr>
<td>Neck</td>
<td>10.3</td>
<td>6.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>20.7</td>
<td>41</td>
<td>4</td>
</tr>
<tr>
<td>Shoulder</td>
<td>20.7</td>
<td>41</td>
<td>4</td>
</tr>
<tr>
<td>Elbow</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Forearm</td>
<td>24.1</td>
<td>25.8</td>
<td>28</td>
</tr>
<tr>
<td>Wrist/hand/finger</td>
<td>8</td>
<td>18.2M, 22.9F</td>
<td>8</td>
</tr>
<tr>
<td>Lower Extremity</td>
<td></td>
<td></td>
<td>28</td>
</tr>
<tr>
<td>Hip/groin</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Knee</td>
<td>7.1</td>
<td>14.7M, 13.2F</td>
<td>12.9</td>
</tr>
<tr>
<td>Ankle</td>
<td>7.1</td>
<td>14.7M, 13.2F</td>
<td>12.9</td>
</tr>
<tr>
<td>Foot</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Toe</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Trunk/Low back</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other/Not specified</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Sex is reported when known.
*Calculated from data.
<table>
<thead>
<tr>
<th>Study</th>
<th>No. of athletes</th>
<th>Total no. of injuries</th>
<th>Head/face</th>
<th>Neck</th>
<th>Upper Extremity</th>
<th>Shoulder</th>
<th>Elbow</th>
<th>Forearm</th>
<th>Wrist/hand/finger</th>
<th>Lower Extremity</th>
<th>Trunk/Low back</th>
<th>Other/Not specified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kennedy &amp; Hawkins 1974b</td>
<td>2496</td>
<td>261</td>
<td>51</td>
<td>12.5</td>
<td>31</td>
<td>12.5</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>32.5</td>
<td>12.5</td>
<td>9.7</td>
</tr>
<tr>
<td>Graham &amp; Bruce 1977</td>
<td>78</td>
<td>8</td>
<td>43</td>
<td>10</td>
<td>12.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kennedy et al. 1978</td>
<td>35</td>
<td>43</td>
<td>19</td>
<td>3</td>
<td>31</td>
<td>37</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>32.5</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>Zaricznyj et al. 1980</td>
<td>19</td>
<td>37</td>
<td>51</td>
<td>2</td>
<td>31.4</td>
<td>38</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>53</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>Mutoh et al. 1988</td>
<td>268</td>
<td>239</td>
<td>37</td>
<td>3</td>
<td>31.4</td>
<td>38</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>32.5</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>Bak et al. 1989</td>
<td>473</td>
<td>56</td>
<td>268</td>
<td>2</td>
<td>31.4</td>
<td>38</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>32.5</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>McMaster et al. 1989</td>
<td>68</td>
<td>56</td>
<td>473</td>
<td>2</td>
<td>31.4</td>
<td>38</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>32.5</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>McFarland &amp; Wasik 1996</td>
<td>886</td>
<td>886</td>
<td>68</td>
<td>2</td>
<td>31.4</td>
<td>38</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>32.5</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>Richardson 1999</td>
<td>38</td>
<td>23</td>
<td>886</td>
<td>2</td>
<td>31.4</td>
<td>38</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>32.5</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>Capaci et al. 2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a When totals are greater than 100%, multiple injuries are involved.*
Water Polo

Water polo players suffer chronic shoulder injuries at varying rates (3% to 38%) (Rollins et al. 1985, Webster et al. 2009). Knee injuries (3.6% to 25.9%), acute head and orofacial injuries (15.5% to 53%), and hand injuries (8% to 29%) are also common. Jerolimov and Jagger (1997) estimated 3.1 orofacial injuries per player. The prevalence of shoulder injury detailed by Colville and Markman (1999) approached 80%, and this remains the most current estimate. Biener and Keller (1985) stated that 39% of all injuries were to the head and face and that 28% involved the wrist, hand, and fingers.

Environmental Location

Diving

Rubin and Anderson (1996) cited a study by Gabriel (1992) in which 60% of injuries in athletes 13 to 18 years of age and 43.3% of injuries in divers 19 to 30 years of age occurred during practice. They also included work by Zimmerman (1993), in which 92% of the 37 recorded injuries took place during training. Mizel et al. (1993) reported that springboard diving accounted for 55% of foot and ankle injuries, dry-land training (i.e., gymnastics, trampoline) for 13%, platform diving for 4%, and other events (such as exiting the pool) for 28% of injuries in a sample of divers. In terms of the timing of injury within a dive from the springboard, 12% were related to the approach, 35% to the hurdle, and 53% to the press phase just prior to take off.

Swimming

The available data suggested that most swimming injuries occur during training. For example, Garrick and Requa (1978) reported that 100% of injuries in male and 57% in female high-school swimmers occurred during practice; 4% of female swimmers were injured during competition. McMaster et al. (1989) noted that 5.1% of males and 14.6% of females aged 13 to 14 years found weight training painful. McFarland and Wasik (1996) detailed similar injury rates from swimming and cross training for swimming (1.05 and 1.07 injuries per 1,000 athlete exposures, respectively). Weight-bearing activities accounted for the majority of the cross-training injuries (running, 47%; running steps, 13%; pulling sleds, 9%), and weight training caused 24%. Richardson (1999) found that 42% of injuries occurred in the water, 22% on the deck, 7% outside the pool, 6% in the locker room, 5% on the bleachers, 3% on the starting blocks, 2% each for hallway and gym, 1% on stairs; 10% were from unspecified causes, although these figures involved 91% athletes and 9% nonathletes or guests. The author also noted that 54% of injuries occurred during competition, 31% during practice, 8% at warm-up, 2% on dry land, and 5% other.

Synchronized Swimming

Most injuries affecting synchronized swimmers can be attributed to activities in the water, although Kirkley (1991) reported that 27% of shoulder injuries and 12% of knee injuries occurred during weight training.

Water Polo

An analysis of injuries in team sports during the 2004 Olympic Games indicated that male water polo players suffered 30 injuries per 1,000 matches, 63 injuries per 1,000 player-hours, or 2.8 injuries per 1000 athlete exposures (Junge et al. 2006). Biener and Keller (1985) reported injury rates differed between games (4.16 injuries per 100 games), practices or friendly games (1.64 injuries per 100 games), and practices (2.7 per 1,000 hours of practice). The authors also reported that goaltenders suffered 43% of injuries during training (mostly from shots from other players), as opposed to 22% of field players. There are no reports of water polo injuries taking place in areas around the pool or in other training facilities.

When Does Injury Occur?

Injury Onset

Most injuries in aquatic sports are chronic in nature, and are associated with highly repetitive motions (i.e., arm cycles in swimming or eggbeater kicks in water polo). However, onset may also vary by anatomical location and the mechanism of injury. For example, acute shoulder injuries are common in divers during impact with the water (i.e., Anderson &
Rubin 1994, Rubin et al. 1993), whereas chronic shoulder injuries are common in swimmers (see discussion below).

Diving
Rubin and Anderson (1996) cited a study by Zimmerman (1993) in which 62.2% of injuries were acute and 37.8% classified as “overuse.” Baranto et al. (2006) reported that the median age for the first episode of back pain in divers was 15 years old.

Swimming
Stulberg et al. (1980) reported that 82% of swimmers experienced knee pain within 3 years of beginning the breaststroke. Rovere and Nichols (1985) suggested that knee pain in breaststroke may involve a short-term problem characterized by overuse and a long-term progressive chronic condition.

Water Polo
Annett et al. (2000) classified 73.4% of water polo injuries as acute, 26.6% as due to overuse, and 20.5% as chronic in nature (lasting 6 weeks or longer) (Figure 1.1).

Chronometry
Diving
Baranto et al. (2006) studied 18 elite divers (average age, 17 years) using magnetic resonance imaging and clinical examination and reported that 67% suffered abnormalities in the thoracolumbar spine, with the first incident of back pain coinciding with a growth period (median, 15 years), and 94% of the injuries occurring when the athletes were 14 to 17 years of age. The authors also estimated that the probability of experiencing back pain within 1 year was 45% after divers reached 13 years of age.

Swimming
Ciullo and Stevens (1989) cited data from Troup et al. (1987), who found that most injury referrals started around the age of 18, when swimmers had been training for approximately 10 years and are entering a more intense training and competition schedule. Of elite swimmers who experienced shoulder pain during swimming, 83% indicated that the pain was more prevalent during the early and middle section of the swimming season (Richardson et al. 1980). The authors also noted an increase in injuries as swimmers move from competitive (27%; males, 38%; females, 23%) to elite (52%; males, 47%; females, 57%) to championship caliber (57%; males, 50%; females, 68%). Dominguez (1978b) studied three age groups (≤8 years old, 9–12 years old, and 13–18 years old) and reported a 2% prevalence of pain in 9-to-12-year-old swimmers, and 65% in 13-to-18-year-olds. Richardson et al. (1980) found that 47% to 68% of elite swimmers experienced pain, as opposed to 23% to 38% of younger, nonelite swimmers.

Figure 1.1 In water polo, contact with the opponent is often a cause of acute shoulder injury. © IOC /Tsutomu KISHIMOTO.
Stulberg et al. (1980) and Hahn and Foldspang (1998) reported 82% of swimmers had knee pain within 3 to 4 years of beginning breaststroke.

**Synchronized Swimming**

Kirkley (1991) stated that 64% of all injuries occurred during the conditioning part of the training season (speed swimming, synchronized swimming, weight training, and flexibility conditioning) and 36% occurred during the routine preparation phase (choreography, compulsory figures, and practice of routine).

**Water Polo**

Junge et al. (2006) found that 41% more injuries occurred in the second half of games as compared with the first half. However, the timing of injury was not reported for 35% of recorded injuries.

**What Is the Outcome?**

**Injury Type**

This review included only reports that addressed injuries specific to aquatic sports. Illnesses in aquatic athletes such as mononucleosis or anemia were excluded. For specific conditions such as otitis externa (swimmer’s ear), which is often attributed to infections from *Pseudomonas aeruginosa*, readers are referred to several reviews (i.e., Calderon & Mood 1982, Gerrard 2004, Nichols 1999, Wang et al. 2005).

**Diving**

Since the first reports of injuries in competitive divers (Groher 1973), several studies have discussed different types of injury outcomes such as damage to soft tissue or ligaments or both, intervertebral disk protrusions and degeneration, and stress fractures (Carter 1994, Kimball et al. 1985, Rubin 1983). Mizel et al. (1993) reported that in 55 injuries suffered by 41 divers (age ≥ 18 years) 33% were ankle sprains, 31% fractures (all lower-extremity), 9% Achilles tendon contusions, 7% midfoot strains, 5% cuticle injuries, and 15% miscellaneous injuries. Anderson et al. (1993b) noted that fractures were the most common injury for both male and female junior Olympic divers (44.2% and 52.9%, respectively). Anderson et al. (1993a) reported that specific diagnoses included asymmetry in muscle development (57% of divers), cervical-motion restriction (15–50%), positive Spurling’s test (50%), facet-joint tenderness (79%), spasm of the trapezius (79%), and bone spurs (57%; 50% of females and 62.5% of males). Rubin et al. (1993) reported that 80% of a group of 20 elite divers exhibited shoulder instability, inflammation, and acromioclavicular-joint injury, including acute subluxations and dislocations, and traction tendinitis.

In an early report, Rossi (1978) noted that 25 of 30 divers (83.3%) exhibited isthmic modifications, with 63.3% exhibiting spondylolysis and 15.8% spondylolisthesis. Rossi and Dragoni (2001) reported that divers had the highest prevalence of spondylolysis (23 of 57 athletes, 40.35%) of 37 sports studied.

**Swimming**

Of age group swimmers who reported shoulder pain, Dominguez (1978a) identified 39% with coracoacromial ligament tenderness and another 10.9% with Class 3 symptoms (disabling pain during and after the activity to the degree that it affects performance). Mutoh (1978) reported that 22% of butterfliers suffered from spondylolysis and intervertebral-disk narrowing. McMaster et al. (1989) found that 4% of age-group swimmers experienced shoulder dislocation or subluxation, and 13.5% of males and 12% of females also experienced nonspecific neck pain. A variety of studies have established that breaststrokers experience knee injury in significant numbers (54–100%), including medial and lateral collateral ligament sprains, medial femoral condyle contusion, and synovitis of the medial compartment (Hahn & Foldspang 1998, Hawkins & Kennedy 1974, Kennedy & Hawkins 1974a, Keskinen et al. 1980, Rodeo 1999, Rove & Nichols 1985, Stulberg et al. 1980, Vizsolyi et al. 1987). Finally, Soler and Calderon (2000) found that spondylolysis developed in 10.2% of swimmers, although a third were asymptomatic.

**Synchronized Swimming**

Kirkley (1991) conducted a cross-sectional study that showed that 71% of swimmers with shoulder injury were diagnosed with rotator cuff tendinitis, 24% of swimmers presented with patellofemoral
pain syndrome (24%), and 100% of lumbar spine injuries were muscle strains.

Water Polo

Junge et al. (2006) recorded foot fracture (1 case), tympanic membrane rupture (2), eye contusion (1), shoulder dislocation (1) and sternal fracture (1) during the 2004 Athens Olympic Games water polo competition. In a retrospective study of 77 elite players, Annett et al. (2000) found that frequent injury types included finger and thumb sprains (8.3% of total injuries) and supraspinatus tendinitis (7.9%), eye injuries (6.1%), and tympanic-membrane trauma (6.1%). Jerolimov and Jagger (1997) concluded that 96.4% of water polo injuries were orofacial, with cuts to the lips accounting for 48%, followed by the tongue (12.8%) and cheek (9.1%). Finally, Merino and Llobet (1978) reported shoulder and elbow insertion tendinitis in water polo players.

Time Loss

Diving

Anderson and Rubin (1994) indicated that cervical injuries required 43% of elite divers (67% of females, 25% of males) to miss at least 1 week of training. Similarly, Rubin et al. (1993) reported that 16 of 20 national team divers missed at least 1 week of practice at some point because of shoulder injury associated with diving. Conversely, Rubin and Anderson (1996) cited Zimmerman (1993), where 31 of 40 divers (77.5%) who reported an injury missed 4 hours of practice or less, and 90% returned to practice within 2 weeks.

Swimming

Dominguez (1978b) reported that at least 10% of age-group swimmers (13–18 years) missed practice or swimming meets. Richardson et al. (1980) indicated that 81% of swimmers with shoulder pain diminished daily training and 40% had to stop training for a short period. Garrick and Requa (1978) found 71% of female high-school swimmers missed 5 days or more. Hip abductor injury caused 9.2% of breaststrokers and 6.3% of individual medley swimmers to miss competition (an average of 2.2 and 2.6 missed competitions, respectively), but 42.7% of breaststrokers missed an average of 11.5 practices, and 21.5% of nonbreaststrokers missed an average of 6.9 practices (Grote et al. 2004). Hahn and Foldspang (1998) also noted that 24.5% of swimmers missed time because of breaststroke-related knee injury. McFarland and Wasik (1996) stated that only 4 of 56 injuries in their study resulted in ≥21 days away from participation in practice. Lanese et al. (1990) reported 241.5 disability days for males and 63.5 for females (1.43 and 0.62 disability days per 100 person-hours, respectively) in their 1-year study of a collegiate swim team. Merino and Llobet (1978) concluded that tendinitis does not adversely affect swimmers, as 84% returned to full performance in 1 month or less, with only 3% not being able to return to the sport.

Synchronized Swimming

Kirkley (1991) reported an average of 28 hours of practice time and 6% of synchronized swimming competitions lost due to injury, for an average of 1 week without training over the course of one full competitive season.

Water Polo

McLain and Reynolds (1998) noted that injuries in male high-school water polo players resulted in the athletes missing an average of 5 days of participation. Junge et al. (2006) reported that time away from participation because of injury ranged from 2 days (eye contusion) to ≥30 days for a fractured sternum for participants in the 2004 Olympic Games, with an incidence for time-loss injuries of 8.7 per 1,000 matches (19 injuries per 1,000 player-hours). Annett et al. (2000) noted that no acute water polo injury resulted in more than 6 weeks away from participation in their 13-year study of elite male players. Finally, Biener and Keller (1985) found that in a sample of 147 players, 48% did not miss practice or playing time because of injury, whereas 24% missed unspecified time, 10% missed one practice, and 18% did not report.

Clinical Outcome

Diving

Lebwohl (1996) reported two fatalities on record worldwide due to impact of the head with the
platform during a complicated reverse somersault dive. Rubin (1983) referenced a study by Groher (1973) on divers who trained for more than 5 years, in which 33% experienced “unusual rigid attitude in their lumbar spine,” 55% demonstrated restricted flexion, and 40% had limited extension. Of these, arthritis of the spinous processes developed in 50%, arthritis of the vertebral joints in 55%, and spondylolysis in 20%. Krejcova et al. (1981) indicated that 67% of divers exhibited reduced mobility of the spine, 47% had rotation blockade, 23% had reduced mobility of the lumbosacral region, and 47.5% scoliosis, but the authors did not connect these outcomes to specific prior or current injuries. Baranto et al. (2006) reported that in a 5-year follow-up after an initial examination, 12 of 17 divers (median age, 17 years at baseline) experienced a total of 89 spinal abnormalities and 3 quit competing altogether.

Krejcova et al. (1981) also found, from vestibular and optokinetic examinations, evidence of vestibular disease in 75% of all divers (27.5% peripheral and 47.5% central) and electroencephalogram examination revealed abnormal patterns in 57.5% of divers.

Swimming

A review of the National Center for Catastrophic Sport Injury Research (NCCSI) website indicated five indirect (systemic failure as a result of exertion or complication secondary to nonfatal injury) and eight direct (caused by participation in the sport) catastrophic injuries in high-school female swimmers and one indirect fatality in a female college swimmer from 1982 through 2007 (National Center for Catastrophic Sport Injury Research 2008). Richardson (1999) indicated that among 886 accidents reported during USA Swimming–sanctioned competitions, 78% were minor (i.e., minor contusions, falls around the pool, small lacerations, etc.), 19% were major (undefined), and 3% were fractures. Dominguez (1978a) presented a case series of three swimmers with debilitating chronic shoulder pain who underwent successful coracoacromial ligament resection, resulting in pain-free participation in swimming. McFarland and Wasik (1996) noted low rates of surgery for swimming and swimming cross-training injuries (4% and 5%, respectively).

Synchronized Swimming

Mutoh et al. (1988) reported that in their study, 19 of 24 participants (79%) experienced chronic pain; 73.7% of them required medical treatment.

Water Polo

The NCCSI records indicated a total of four indirect high-school fatalities in water polo and one at the college level from 1992 to 2007 (National Center for Catastrophic Sport Injury Research 2008). Jerolimov and Jagger (1997) found that 33% of water polo injuries required medical treatment, and Annett et al. (2000) reported that 20.5% of acute and overuse water polo injuries became chronic. Biener and Keller (1985) noted that 36% of injuries required no treatment, 36% were self-treated and 22% required a visit to a physician or hospital, mostly for dental injuries. Hame et al. (2004) described a total of 20 fractures (16 male and 4 female) in collegiate Division I water polo players during a review of fractures spanning 14 years.

Economic Cost

This literature review did not identify any studies that analyzed the economic costs associated with injuries in aquatic sports.

What Are the Risk Factors?

Intrinsic Factors

Swimming

Gender differences: Sallis et al. (2001) concluded that female swimmers at Pomona College sustained more injuries than their male peers (47.08 vs. 12.37 injuries per 100 participant years, \( P < 0.001 \)). Specifically, differences in rates (injuries per 100 participant-years) existed in the shoulder (21.05 vs. 6.55, \( P < 0.01 \)), knee (5.85 vs. 1.45, \( P < 0.01 \)), back and neck (8.19 vs. 1.45, \( P < 0.01 \)), and hip (2.34 vs. 0.00, \( P < 0.01 \)).

Age differences: Vizsolyi et al. (1987) concluded that swimmers who were older and trained more had a greater incidence of injury than younger, less experienced swimmers (\( P < 0.001 \)), but the authors did not distinguish between age and training as causes for injury. Bak et al. (1989) indicated that medley
swimmers had a significantly higher proportion of injuries (54%) as compared with swimmers specializing in a single stroke (freestyle, 41%; backstroke, 32%; breaststroke, 32%; and butterfly, 37%).

Water Polo
To date, no study has conclusively connected risk factors to specific injuries in water polo, although Sallis et al. (2001) reported that female collegiate players experienced significantly more injuries than their male peers (18.38% vs. 7.10%, \( P < 0.001 \)), with shoulder injury rates also significantly higher (8.09% vs. 3.40%, \( P < 0.01 \)). Hame et al. (2004) concluded that male water polo players had a significantly greater rate of fractures than female players (4.1 vs. 1.3 injuries per 100 athlete-years of participation).

Extrinsic Factors
Some studies have attributed injuries to specific equipment, or lack thereof. For example, Burchfield et al. (1994) argued that the introduction of hand paddles and pull buoys correlated temporally with the onset of, and increases in, the prevalence of shoulder pain in age-group swimmers (33 of 56 swimmers aged 13 to 18 years, \( P < 0.001 \)). In water polo, Jerolimov and Jagger (2007) concluded that the use of mouth guards would result in fewer orofacial injuries during water polo. However, there is a complete void of research describing the role of extrinsic factors in the development of injuries in aquatic sports.

What Are the Inciting Events?

Diving
Few researchers have presented information as to the inciting events of injuries in diving. According to several authors (i.e., Anderson & Rubin 1994, Kimball et al. 1985, Rubin 1983), the acrobatic nature of diving and the impact with the water are the inciting events associated with the anatomical distribution of injuries in diving.

Swimming
Kennedy and Hawkins (1974a) and Capaci et al. (2002) identified the whipkick during breaststroke as the cause of all knee injuries in swimmers. Stulberg et al. (1980) concluded that all 23 swimmers in their study experienced pain during the final thrust of the whipkick. Based on a 48% prevalence of knee pain in nonbreaststrokes, Vizsolyi et al. (1987) concluded that the breast-stroke kick can generate pain even when used on a limited basis during training. Rovere and Nichols (1985) reported that the most notable event associated with the onset of knee pain in breaststrokes was an increase in breaststroke training distance (81%), followed by weight lifting (19%), and running and inadequate warm-up (16% each). Pain in the lower extremity has also been linked to the use of the kickboard in 9% of females and 11% of males aged 13 to 14 years (McMaster et al. 1989).

Capaci et al. (2002) indicated that 11 of 23 swimmers experienced pain during and after workouts (\( P < 0.0001 \)). Richardson et al. (1980) reported that 81% of swimmers stated that hand paddles exacerbated their shoulder pain. In contrast, Stocker et al. (1995) found no association between paddle use and shoulder pain, but 50% of the swimmers associated pain with increased distance or intensity or both. McMaster et al. (1989) concluded that although 77% of females and 88% of males used paddles in training, only 16.8% of females and 20.7% of males experienced pain during swimming. However, shoulder pain was positively correlated (\( P < 0.05 \)) with stretching, weight training, kickboard use, and sleep (in females). Burchfield et al. (1994) indicated that 49 of 56 swimmers who incorporated weight lifting in their training experienced shoulder pain.

Synchronized Swimming
In the single study that provided data on the activities that resulted in injury during synchronized swimming, Kirkley (1991) reported that the precipitating events for shoulder injury were weight training (29%), butterfly swimming (24%), and sculling (43%). For knee injury, the causes were eggbeater motion (70%), synchronized swimming in general (18%), and weight training (12%).
Water Polo

Junge et al. (2006) found that all injuries reported during the 2004 Olympics were due to contact with another player. Biener and Keller (1985) indicated that 65% of injuries in field players were caused by contact with an opponent (48% accidental and 17% intentional), whereas the ball caused 13% of injuries and players’ own mistakes caused 19% of injuries. In contrast, 74% of injuries sustained by goalkeepers were due to contact with the ball, with only 14% resulting from accidental contact with another player. Annett et al. (2000) stated that kicks were the cause of chest and abdominal injuries in water polo (9 of 334 injuries overall).

Injury Prevention

Few well-designed studies on the impact of injury-prevention strategies in aquatic sports exist. For example, Rovere and Nichols (1985) reported that reducing breaststroke training was the most effective treatment for knee-pain reduction in breaststrokers (84%). Dominguez (1978b) stated that a weight-lifting program diminished shoulder pain in 8.5% of male swimmers ages 13 to 18. Ciullo (1986) cited his earlier study, in which the initiation of a stretching program decreased shoulder impingement in swimmers training over 12,000 yards per day from 80% to approximately 14%. However, none of these were controlled studies. Overall, this review revealed a dearth of prospective studies that examined injury-prevention protocols in any aquatic sports in a scientifically valid way.

Further Research

One consistent pattern that emerges from this review was the difficulty of accurately describing injury rates, causes of injury, or strategies that can reduce the risk of injury, because of the lack of valid studies. The small number of participants, lack of controls, and diversity of data-acquisition methods (i.e., medical insurance reports vs. reports to a coach), classification (i.e., chronic vs. acute, sprain vs. strain, etc.) and treatment of injuries, make identification of injury characteristics (severity, type, etc.) difficult. Above all, this review underscores the need for standardized injury surveillance systems in all aquatic sports without which a comprehensive understanding of injury risks and resolutions is not possible. For example, in examining sex as a risk factor, Troup et al. (1987) identified differences in prevalence of pain between male and female swimmers (70% vs. 65%, respectively) but Richardson et al. (1980) reported the opposite effects of sex and shoulder injuries among elite and national team swimmers (47–50% for males and 57–68% for females). Lanese et al. (1990), however, found no differences between the sexes.

In a separate example in water polo injuries, the single study that included longitudinal data (13 years) did not provide insights as to injury rates across that time span (Annett et al. 2000). Similarly, Jerolimov and Jagger (1997) found that pivot players experienced a higher rate of orofacial injuries (5.5 injuries per player) than defensive/attacking players (3.5 injuries per player), attacking players (3.1 injuries per player), and goalkeepers (0.6 injury per player), but these data were not evaluated for significance. There is a clear need for well-designed prospective cohort studies to address these basic issues.

Questions that remain unanswered for each of the aquatic sports include the following: What training practices result in injuries? What can be done to minimize or eliminate these injuries? What is the relationship between growth rates and injury rates? When is it safe to introduce certain elements, such as weight training or paddles into the training schedule, and how should these be introduced? What are the long-term effects of injuries in aquatic sports? These examples of specific areas for future research in all the aquatic sports will enable coaches, medical personnel, researchers, and athletes to ensure safe and productive training and competition experiences for all.

References


