THE BASICS OF COMPETITIVE DIVING AND ITS INJURIES

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On the roof of a burial vault in Naples, Italy, is a painting of a young man diving from a narrow platform. The Tomba del Tuffatore (the Tomb of the Diver) constructed in 480 BC is the earliest documented evidence of the sport of diving. The evolution of diving can be traced to the seventeenth century, when German and Swedish gymnasts moved their equipment to the beaches and performed acrobatics over the water. Thus, diving is closely related to gymnastics, with the additional factor of entry into a water medium.

The first “modern-day” diving competition was held in England around 1880. At the 1904 Olympic Games in St. Louis, Missouri, men’s springboard diving was included as part of the swimming program. Platform diving was added at the 1908 Olympics in London, England. The recognition of women’s diving did not occur until 1912 when “plain” high diving was added to the Olympics. Springboard diving followed in 1920, and “fancy” high diving in 1928.

In the early 1900s there were only 14 platform and 20 springboard dives being performed in competition. Today, there are 77 springboard and 97 platform dives possible. The difficulty of dives has increased dramatically, from a double somersault from platform being considered dangerous in 1904, to the common performance of the reverse three and one-half somersault today. With the increasing difficulty of dives being performed, there have been changes in the associated techniques, intensity, and frequency of training, and a commensurate increase in the incidence of injuries.

The format for Olympic competition involves 3-meter springboard and 10-meter platform events for men and women. United States National and other international competitions, including the World Championships, include 1-meter springboard, and synchronized diving for 3-meter springboard and 10-meter platform. During the course of an event, the competitor must demonstrate proficiency in forward, backward, reverse, inward, and twisting dives. Male
platform divers must perform a dive from the armstand group. Although this is not required of women, more are electing the armstand position for an optional dive. Upon leaving the board or platform, the diver can assume one of the following positions: straight (no flexion at either the hips or knees); pike (flexion at the hips only); tuck (flexion at the hips and knees); or free (a combination of the other three positions used in some twisting dives). A diver must perform from 9 to 11 dives, depending on the event. Approximately half the dives are optional, and half are voluntary (formerly called "required" or "compulsory"). Each dive is assigned a degree of difficulty from 1.2 to 3.6. The total degree of difficulty of the voluntary dives may not exceed a predetermined, event-dependent maximum number. The optional dives are without limit with regard to degree of difficulty.\textsuperscript{12}

The dives are scored by a panel of seven judges, based on the approach, takeoff, elevation, technique, and grace exhibited in the air, the angle of entry, and the amount of splash. Because a dive is not completed until the diver's body is completely submerged, the score may be increased by altering the underwater trajectory in order to allow the feet to enter the water at the same place as the hands, thus minimizing the amount of splash. This is referred to as "saving" a dive.

**ORIGINS OF INJURIES**

Much of the medical literature about diving has dealt with unsupervised, recreational participation, with an unacceptably high number of head and neck injuries involving death or paralysis. The absence of similar injury patterns in competitive diving argues for a clear distinction between the recreational and competitive versions of the sport when considering issues of safety and injury. This discussion will focus specifically on those injuries observed or reported in organized, competitive diving.

Relatively few studies regarding the incidence of injuries in competitive diving have been reported.\textsuperscript{2, 7, 20, 23, 24, 28} Collectively, these studies indicate an incidence of injury ranging from 92% to 100% (an injury being defined as the inability to train for at least 1 week), a trend toward increasing numbers of injuries with increasing years of training and competition, and no male-female differences. The incidence of injuries is higher for pool training than dryland training, higher for platform than springboard divers, and more common in practice than in competition. Strupler and Saxon\textsuperscript{28} found no association between degree of back pain and the number of dives attempted from 7.5 and 10 meters over the career of divers; however, they did observe a correlation with increasing difficulty of dives performed.

**PATHOMECHANICS OF DIVING INJURIES**

Understanding the cause of a diving injury is essential for providing appropriate treatment, determining readiness to return to participation, and establishing preventative programs. Injuries occur as a result of either a rapidly applied excessive force (macrotrauma), or repetitive, submaximal forces (microtrauma or overuse). The likelihood of breakdown in response to these forces is determined, in part, by the presence of extrinsic and intrinsic factors for injury. In diving, extrinsic factors include the training regimen, coaching, facilities, and equipment used for water and dryland training.\textsuperscript{4, 5} Intrinsic factors for injury include indi-
idual variables such as flexibility, strength, joint motion and stability, matura-
tional status, skills, spatial orientation, and psychosocial characteristics. It is
important to identify the contributing extrinsic and intrinsic risk factors when
evaluating an injured diver, so that the cause as well as the symptoms of the
injury can be addressed.

In order to understand the physical demands of diving and begin to analyze
mechanisms of injury, it is beneficial to divide the dive into phases: takeoff,
flight, and entry.

Takeoff

The takeoff involves the work done while the diver is in contact with the
springboard or platform. For a front or reverse dive, this involves the approach
(a minimum of three steps), a hurdle (the upward jump from one foot to the end
of the board), and the press (depression of the board and upward acceleration of
the body). On springboard, an important factor in the height achieved on takeoff
is the diver’s ability to synchronize the descent from the hurdle with the descent
of the board, enabling him to "ride" the board for a more efficient and less
physically stressful press. On platform the dive can be initiated from a standing
position. Platform divers, of course, must generate height for their dive from
pushing against an immovable surface. The takeoff for back or inward dives
involves the preparatory arm swing that sets the board and the body in motion,
and the press.

The injuries associated with the takeoff phase of the dive are related to
jumping and deceleration; thus, the area primarily affected is the extensor
mechanism of the knee. The most commonly observed injuries related to this
part of the dive are patellar tendinitis, quadriceps tendinitis, and patellofemoral
compression syndrome. Posterior tibial and Achilles tendinitis secondary to
eccentric overload, impact, and overtraining have been observed. Excessive
stress may be placed on the lumbar spine, especially if the diver is out of
position during the press and hyperextends the low back when attempting to
increase elevation upon leaving the board. Performance of a pelvic tilt at the
time of the press is beneficial in preventing this problem.

Handstand dives, which must be initiated from a controlled, stable position
at the end of the platform, require tremendous isometric strength and balance.
The weight bearing demands on the upper extremity and the required wrist
dorsiflexion contribute to the incidence of wrist, elbow, and shoulder problems,
especially when joint mobility, stability, or muscular support are compromised.

Flight

The flight, or midair maneuver, phase of the dive begins when the diver
leaves the board or platform and ends with initial contact with the water. During
this phase, the diver spins either forward or backward, in a pike or tuck position,
and twists along the long axis of the body. To initiate these motions, the diver
throws his arms in the direction of spin. This can cause the manifestation of a
shoulder instability pattern. In twisting, the diver throws one arm across the
chest and the other arm behind or on top of the head, placing the shoulder in
abduction and external rotation. Irritation of the long head of the biceps tendon
has been associated with this latter maneuver. The potential for torsional over-
load to the spine also exists. Strength and control in the trunk is necessary to maintain body position, especially in the pike position. The rapid and forced flexion of the trunk during this action causes increased loading of the vertebral body and disc (anterior segment), and is thought to be a factor in the development of disc pathology as well as thoracic and lumbar strains. Hyperextension can cause posterior segment pathology, as well as thoracic and lumbar strains.

During the flight phase, body awareness, spatial orientation, and "spotting" ability play a major role in determining the success of the dive. To aid the diver in "spotting" the water surface, pools for diving competition are equipped with a system to break the surface tension with gently bubbling water or a spray that strikes the water in the area of the entry. Most of the injuries that occur during flight are the result of compensation for a flawed takeoff. The diver may strike the board or platform with their hands, feet, or head, resulting in contusions, lacerations, or fractures.

**Entry**

Most diving injuries occur upon entry into the water. This phase includes impact with the water surface, the swim out, and underwater maneuvers to save the dive and facilitate a splashless entry. The velocity of entrance varies with the height of the apparatus from which the diver performs, and the height achieved on takeoff. The approximate range is 8.4 m/s (18.75 mph) from a 1-meter springboard to 16.4 m/s (36.8 mph) from a 10-meter platform. The average force at impact for a 10-meter dive varies from 2.0 to 2.4 Gs (1G = 9.8m/s²). The diver is completely submerged in 128 to 140 milliseconds, by which time there is a 53% decrease in velocity. LeViet et al. have observed a sudden decrease in speed from 51 km/h to 33 km/h at the moment of entry, with no change during entry of the rest of the body.

The challenge for the diver is to dissipate the impact forces and control deceleration in the water while accomplishing a splashless entry. In order to accomplish this feat, and to protect the head and cervical spine from axial loading, divers use a flat-hand entry technique. Just before entry, the hands are brought together, the wrists are dorsiflexed, pronated, and radially deviated, one hand is clasped over the other with the palms facing the water, and the shoulders are internally rotated (Fig. 1A). Some divers use a closed-fist technique. As the hands strike the water, the head is moved in line with the trunk, the arms squeeze the ears, the scapula is elevated, and the arms "push through" the surface, in effect "punching a hole in the water" (Fig. 1B and 2). Upon breaking the surface, the arms are pulled forward or in the scapular plane in a swimming motion to propel the diver through the water. The swimming motion is initiated within 1 foot of the surface.

The swimming out motion also is used to "save" a dive that is short of or beyond vertical. The diver turns underwater in the same direction as the mid-air maneuver to maintain a smooth, continuous arc of motion. Saving is more common during the performance of back and reverse dives for a number of reasons. The diver's vision of the water surface is oriented in the direction opposite of the somersault and away from the point of entry. Also, because these dives are inherently more difficult than forward or inward dives there is less time to complete the dive, and they more frequently wind up short of vertical. Saving back and reverse dives involves hyperextension of the back and hyperflexion of the shoulders. This position subjects the athlete to increased risk of anterior glenohumeral subluxation as well as injury to the posterior elements
of the lumbar spine. The timing of the underwater maneuvers, the position of the arms, and the adequacy of strength to support sudden changes in direction and velocity are factors in the production of injury, and should be considered during treatment.

A successful entry requires enough strength to maintain a handstand with the added demands created by deceleration forces at the water surface. LeVieu et al. have calculated a decrease in speed of 4.85 m/s, comparable with diving from a 1.2-meter platform and striking a hard surface. These forces sequentially cause forced dorsiflexion of the wrist and flexion or buckling of the elbow. Stress fractures, sprains, and strains of the wrist and triceps strains may result from repetitive overload of the upper extremities. As the forces are transmitted proximally, the shoulder must absorb significant axial loads while the humeral head is superiorly translated. The bony stability becomes dependent on adequate scapular abduction (see Fig. 1B). If the shoulder position is compromised, excessive stresses are placed on the soft tissue supporting structures of the shoulder while attempting to maintain glenohumeral stability. The result can be the development of instability of the shoulder and strains of the shoulder girdle musculature.

"Dry land" training, which includes practice on a trampoline, a board with a portable landing pit, and an overhead spotting belt, also contributes to diving injuries. These devices allow a diver to practice basic diving skills, including board work and "spotting," and progress toward more difficult spinning and
twisting dives. The spotting belt allows the diver the freedom to practice mechanics in a progressive manner on equipment similar to that upon which he will later perform, with the security that his coach can control his maneuvers and prevent injury. This also allows the diver to train his ability to "spot" landmarks to distinguish the number of somersaults and twists being performed. Injuries can occur as a result of too many repetitions, poor fitting spotting belts, or inadequately trained spotters.3

COMMON DIVING INJURIES

This discussion of specific diving injuries is divided into those affecting the musculoskeletal system (the spine and extremities), and those of a nonorthopedic nature. Because there is considerable overlap between the injuries seen in competitive divers and athletes in other sports, this section will focus mainly on those aspects of the injuries pertinent to diving.
Spine Injuries

Diving-related injuries to the cervical spine have received attention because of the catastrophic nature of spinal cord injuries reported in recreational “divers.” These injuries are usually related to the lack of formal training in diving, inadequate water depth, inadequate supervision, and, often, alcohol ingestion. There has not, however, been a single reported fracture or dislocation of the cervical spine in organized diving. The potential exists for noncatastrophic injuries from repetitive impact loading to the cervical spine; however, no significant incidence of a degenerative process has been observed. Cervical sprains and strains, infrequently associated with brachial plexus stretch injuries, have been observed; however, because of the protection afforded by the hands and arms at entry, they are less frequent than would be expected. Sprains and strains of the thoracic region usually are related to twisting and arching during the flight and entry of the dive. They also are associated with segmental hypomobility or hypermobility of other areas of the spine, and as such are compensatory injuries.

The sport of diving requires mobility and stability in the lumbar spine. The anterior segments (vertebral body, vertebral end plate, and intervertebral disc) are particularly vulnerable to compressive forces or increased load. Increased disc loading occurs during the press phase of the take off, at entry, and with trunk flexion during flight. The combination of a flexed or rotated spine during maximum loading is most likely to lead to disc injury.

There is increased stress placed on the lumbar spine during board work on the springboard compared with the platform as a result of the upwardly directed force of the springboard during the press, and because more of the axial stress is absorbed by flexion of the hips and knees on platform.

Stress on the posterior elements (facet joints, pars interarticularis) is a more common cause of injury in divers. The posterior elements are subjected to overload during maximal lumbar extension or extension combined with rotation. This can occur during take-off for a back or reverse dive, on entry for a back rotating dive that is short of vertical, or a front rotating dive that is beyond vertical. Spondylolysis, spondylolisthesis, “kissing spines” and lumbar facet arthropathy have been observed, but with much less frequency than in gymnasts. Groher and Heindensohn observed a higher incidence of lumbar spondylosis in the platform diver compared with the springboard diver.

Shoulder

In a recent study of the United States National Team, 80% were found to have had shoulder injuries that precluded training for at least 1 week. There was no relationship between injury and range of motion, lateral scapular slide, direction of twisting, or hand position on impact. Cybex data revealed a significant reduction in peak torque and peak torque/body weight in external rotation in injured extremities. The multidirectional laxity required for the divers to perform their technical maneuvers is the most likely precipitating factor in many of the shoulder injuries that are observed. Almost all platform divers demonstrate a positive sulcus sign, even in asymptomatic shoulders. Occasionally, a single incident will cause the delicately balanced capsule-labral complex to fail, resulting in a dislocation and chronic instability. More often, the repetitive microtrauma associated with the continual use of the arms in an overhead position to save short dives and to swim entries will cause the attenuation of
the anterior capsule (inferior or middle glenohumeral ligament and rotator interval) or superior labral attachment causing a SLAP (superior labrum anterior posterior) lesion, with subsequent development of instability. Bankart lesions, both anterior and posterior, humeral avulsion of glenohumeral ligaments (HAGL) lesions, labral splits, acromioclavicular arthritis, and proximal triceps tears also have been observed. Instability problems are frequently compounded by the presence of a secondary traction tendinitis of the supraspinatus, infraspinatus, teres minor, and long head of biceps, which are confused with primary impingement syndrome that rarely occurs in competitive divers. Articular side partial tears of the supraspinatus on the basis of tension failures commonly are observed arthroscopically in unstable joints. Full thickness tears have been observed only in acute dislocations in platform divers.

The importance of the scapular stabilizers in the prevention of shoulder injuries cannot be overemphasized. Frequently divers present with symptoms consistent with recurrent anterior or anterior-inferior subluxation of the humeral head which is secondary to a malposition of the scapula caused by a weakness of the serratus anterior, lower trapezius, and rhomboids. It is extremely important for the root problem to be identified so that therapy can be directed to the specific pathology causing symptoms, with a resultant increased chance of success. The scapular stabilizers should be strengthened in a functional position, that is, with the arms overhead and the humerus in the entry position while axial loads are applied, as a functional progression following a more "routine" strengthening program.

Elbow

The elbow is subjected to maximal stress during the entry phase, when it is locked in extension and the triceps is firing isometrically to prevent flexion. Hyperextension may cause injury to the medial collateral ligament, and the resultant instability may contribute to the development of ulnar neuritis. Failure to maintain full extension on impact with the water results in an eccentric overload to the triceps. The strains that are seen are usually at the musculotendinous junction; however, more proximal injuries have been observed in older divers, whereas distal triceps injuries are more common in age group divers. Triceps tendinitis or strains are seen more frequently in platform divers.¹⁸

Wrist and Hand

Wrist injuries occur from the repetitive impact and forced dorsiflexion at entry using the flat-hand technique, especially in platform divers. Armstands and the act of pushing on the deck when getting out of the pool are also contributory. The most common causes of wrist pain in divers include subtle carpal instability, dorsal impaction syndrome, sprains, dorsal ganglion cyst, and flexor carpi ulnaris tendinitis.¹⁷, ²⁴ Recently, McClure (personal communication, 1991) has described specific patterns of carpal subluxations in divers, including volar subluxation of the lunate (the most common), and posterior and ulnar subluxation of the scaphoid. Sprains of the ulnar collateral ligament or the basilar joint of the thumb may occur at impact or as a result of missing the grab with the opposite hand prior to entry. Contusions and fractures of the metacarpals and phalanges may occur when the hand strikes the board during midair maneuvers. In young divers who do not have the required triceps strength to
keep their elbows locked at entry, contusion of the hand on the cranium is not uncommon.

Many divers, especially platform competitors, wear protective tape, splints, or wraps that restrict dorsiflexion stresses.5, 17, 24

Lower Extremity

With the exception of contusions and fractures of the metatarsals and phalanges, which result from striking the board during the flight phase, most lower extremity injuries usually are associated with jumping. Patellofemoral symptoms are caused by patellar or quadriceps tendinitis, and maltracking of the patella or patella compression syndrome. Other jumping related conditions that have been observed include posterior tibial and Achilles tendinitis, and tendinitis of the foot and ankle. Ankle and foot sprains and fractures of the fifth metatarsal have been observed when the foot lands in an awkward position during the approach or on landing from the hurdle at the end of the springboard. Foot and ankle injuries more commonly are associated with dives done in the pike than in the tuck position, and with reverse take-offs.19

Nonorthopedic Injuries

Most nonorthopedic injuries sustained by divers affect the eyes and ears and are related to the forces exerted upon entry into the water. Perforations of the tympanic membrane usually occur as a result of the diver landing directly on the side of the head during a twisting dive; however, similar injuries have occurred on well-executed dives from the pressure of the water enveloping the diver on entry.6, 16, 21 Otitis externa (swimmer’s ear) is not uncommon; however, there are no known specific pathophysiologic factors associated with diving. The critical variable in the development of ear canal infections is retained moisture.16, 27 Vestibular abnormalities have been reported in the Eastern European literature. They are felt to be a result of the upside down position, acceleration due to gravity, repeated changes in linear acceleration, and rotational stimuli elicited by somersaults and twists, water impact, rapid body deceleration owing to water resistance, fluctuation of the intrathoracic pressure due to hyperventilation and breath holding, and irritation of the cervical sympathetics owing to movements of the cervical spine.15

Reversible microdefects on the corneal epithelium and changes in the composition of the tear film have been observed.11 In trained divers, repeated ocular contusions have not caused any permanent injuries or changes in the intraocular pressure. Retinal detachment occurs infrequently with blunt facial trauma on the water surface, especially in platform diving.5, 13 Scalp lacerations occur on inward or reverse dives when the diver leans toward the board while spinning in that direction, usually as a result of a flawed approach. These injuries are quite dramatic as there usually is significant bleeding; Occasionally, there is loss of consciousness; however, neurologic sequelae other than headache rarely are observed. Two cases of fatal head injuries have occurred in the history of competitive diving. In both cases, the divers were attempting a reverse three and one half somersault in the tuck position, and struck their heads on the 10-meter platform.

Landing flat on the water surface from the 10-meter platform has been associated with chest and pulmonary contusion with the resultant disruption of
pulmonary blood vessels and hemoptysis. This injury can be quite unsettling to those unfamiliar with the sport of diving; however, pneumothorax has not been observed, and all divers have returned to practice or competition within 48 hours.

SUMMARY

This article reviews the history of competitive springboard and platform diving, the basic rules of competition, and the epidemiology and pathomechanics of diving injuries, with reference to the specific parts of the dive. Injuries are more commonly associated with the entry phase of the dive, and are more frequently associated with back and reverse dives, and with platform rather than springboard diving. The most frequently injured areas are the wrist, shoulder, and lumbar spine. It is crucial that treating medical professionals understand the physical demands of the sport and the pathogenesis of injury to affect successful treatment and prevention strategies, and to determine safe return to participation after injury.

References


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