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Medical Aspects of Competitive Diving – A Popular Summary of a Private Literature Collection and a Personal Opinion

1 Introduction

To the spectator diving is a beautiful and potentially dangerous sport. Spectacular accidents can happen and are televised in news bulletins the world over. To diving coaches and participants accidents are not the main concern. They struggle with the daily frustration of overuse injuries that keep divers from optimal training and competition form.

What does the medical literature say on diving accidents and injuries? This review tells you where to find articles on the medical aspects of diving, what is written in them and what is missing.

The author ends with a plea to update the international diving rules and regulations to improve safety for junior elite divers and senior master divers.

2 A private literature collection

Starting in 1985, the author has compiled a bibliography on competitive diving with 4500 references to books and articles. Many of the books and articles have been collected via university libraries, colleagues and the internet. The complete list of titles is directly accessible for everybody through www.divingliterature.com.

For this review 341 articles marked as "medical" in the bibliography were grouped according to topic. Table 1 shows the number of articles per topic, whether they are available in the private collection (yes/no) and the years of publication. In the following paragraphs some topics are briefly summarized.

Tab. 1. *485 articles on the medical aspects of competitive diving, regrouped in 24 topics*

	topic	number	yes	no	years
	expert opinion, epidemiology, safety				
1	expert opinion	51	42	9	1945-2009
2	epidemiology of injuries	28	24	4	1940-2011
3	safety research	41	26	15	1961-2003
	areas of concern				
4	head / neck injuries	18	11	7	1960-2004
5	back injuries	24	20	4	1969-2011
6	case report	12	11	1	1979-2011
7	nutrition / eating disorders	22	16	6	1985-2012
8	shoulder injuries	10	9	1	1982-2010
9	wrist / hand injuries	13	10	3	1981-2007
10	eyes / lenses	8	7	1	1979-2008
11	ear / nose / throat	7	3	4	1949-2003
12	neurology	10	4	6	1961-2009
13	infection / skin	5	5	0	1987-1999
	training the body of the diver				
14	orientation / vestibular organ	37	27	10	1937-2006
15	human movement sciences	41	26	15	1961-2010
16	bodybuild / medical measurements	46	25	21	1966-2007
17	treatment / therapy	13	13	0	1987-2009
18	talenttesting / measurements by coaches	62	33	29	1970-2009
19	physiology	18	13	5	1974-2012
	other				
20	age group / masters	5	4	1	1987-2007
21	heart	4	4	0	1967-1994
22	doping	1	1	0	1996
23	organization of care	5	4	1	1980-2009
24	psychology of injury	4	3	1	1989-2009
		485	341	144	

3 Expert opinion, questionnaires and safety research

Experts agree, diving is a safe sport, when calculating the number of recorded deaths (two divers in the 1980's, both on a reverse somersaulting dive on the platform) and permanently paralyzed (one diver, 1965, Japan). Experts also agree that divers can have many types of accidents and injuries. This is due to the diverse nature of the sport, diving has both a high speed impact and chronic repetitive character and also to the different locations a diver receives training: in- and outdoor pools, dry-land areas with boards and mats, on a trampoline, in a weight room. To put it simply: any injury imaginable can and probably has occurred in springboard and platform diving.

To discover the number and nature of the injuries of divers several questionnaire studies have been undertaken (2011 Japan, 2002 Canada, 1993 USA, 1985 Japan, 1982 Switzerland, 1981 USA) and two prospective studies (1999 China, 1993 Netherlands). All studies show the same trend: most divers had injuries at some point in their career, many in the last 12 months before the survey and the majority

of divers reports competing with injuries, at the time of the questionnaire. All authors come to the same conclusion: elite divers deserve and should actively seek more medical attention.
Safety research has concentrated on the prevention of catastrophic (head and neck) injuries. From these studies a simple advice can be extracted: only dive in a diving pool that is build according to FINA recommended minimum dimensions and find a qualified coach. In addition some authors recommend an x-ray of the (cervical) spine at the beginning of platform diving to preclude divers with congenital abnormalities.

4 Doctors and diving: areas of concern

A 2006 MRI study of divers of the Swedish national team confirms what experts had already warned for 35 years ago. Divers very often have back pain. They have more abnormalities of the spine on x-ray and MRI than non-divers and in a five year follow up the number of MRI abnormalities of the spine increased. This is the strongest evidence so far that competitive diving has an adverse effect on the back, especially in youngsters, who are still growing. It is up to the coaches, the divers and their parents to determine how far they want to push the limits. In a 1982 Swiss survey 8 of 11 retired divers, in the age category 20-30 years old, complained of back problems which they attributed to their diving careers.
In 1991 a high incidence of shoulder injuries among American elite divers was reported, 16 of 20 divers were afflicted. It was found that the symptomatic (painful) shoulder had a lack of muscular strength in the direction of external rotation. Strengthening exercises in this direction seemed a logical preventative advice. Unfortunately there are no follow up reports since, it is not known if the prevalence of shoulder injuries has dropped.
In 1993 18 of 21 platform divers at the French national championships indicated that they had occasional or frequent wrist pain. The injured wrist was always the top hand in the flat-hand-grab water entry technique. Worldwide most divers have switched from a two fist (thumb in fist) entry technique around 1980. Shortly after came the first reports on wrist injuries in divers, linked to the new entry technique. Taping the wrists, to prevent maximal dorsal flexion when hitting the water, seems a particularly effective treatment to keep divers in training.
Extensive neurological testing of 31 divers, with a mean age of 13.3 years, in 1981-1982, in the former republic of Czechoslovakia, produced the following findings: 72% of the divers had an increase of the threshold of the acoustic reflex, 51% of the divers had abnormal results in standardized medical tests of the vestibular system. The authors concluded that these symptoms represented evidence for repetitive brain micro-injuries. It is not known whether the symptoms are reversible and if divers suffer consequences later in life. Other authors have suggested that it would be wise to develop protective headgear for divers, considering the forces that act on the divers head when hitting the water from 10-meter platform (repetitively), or

when hitting the platform with the head (accidentally). In a more recent study, in the year 2000, divers were given neuro-psychological tests before and after diving from 1- and 3-meter springboards. No difference between pre- and post diving scores could be detected.

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Diving queen threatened by detached retina again

Gold medalist diver Guo Jingjing during the visit of China gold medal winners' delegation to Hong Kong, Friday, Aug. 39, 2008. [File Photo: Xinhua]

Diving queen Guo Jingjing, who claimed two springboard gold medals in the Beijing Olympics, will undergo surgery in Hong Kong to repair a detached retina that resulted from her training.

Chinese authors show great concern with the eyes of divers on the national team. From six years observation on 54 divers, 50 where found to have different degrees of retinal and vitreous humor diseases (vitreous humor = the gel filling of the eye-ball). From popular media we know that Chinese Olympic star Jingjing Guo suffered from a retinal detachment and had to have corrective surgery (twice?). It is believed that hitting the water surface upon entry and the effect of water pressure after entry are directly related. The authors assume that their findings have "always been under concern", however none of the articles found for this review mention eye injuries in divers other than bruises ("black eye"). More information on this topic and follow up research seems required.

5 Training the body of the diver

At the 1964 Tokyo Olympics for the first time the bodies of divers were subject to study. Only age, height and weight were recorded. In the following years, at several occasions, this was repeated and the number of body dimensions measured, with the diver in resting position, steadily increased. The results can be summarized as follows: divers are smaller than the average population, they have broader shoulders, narrower hips and a lower body fat percentage. Divers are similar in body build to gymnasts, male divers even more so than female divers. Elite junior divers have the same body types as elite senior divers. Based on one study, following 20 divers for one year, it has been concluded that, compared to non-athletes, the growth rate of young divers is normal and the age at first menstruation is later, but not as late as in gymnasts.

The next step in understanding the body of the diver was to investigate it during motion. It is not yet possible to measure exactly which muscles are active during a full dive, myographical electrodes are not yet waterproof. It is possible to collect data in dryland simulation settings (German: Messplatz). With the help of high speed cameras and modern software it is possible to see in slow motion the angles of the body parts during the dive. From this it can be estimated how much flexibility is needed in the joints of divers and at which angles the muscles must deliver force. On the biomechanical aspects of diving many more articles are written than on the medical aspects. Medicine and biomechanics do have an interesting overlap.

Testing the muscles of divers in the doctor's office shows patterns of training deficits. In divers the following muscles are at risk for shortening: m. rectus femoris (front of upper leg), m. tensor fasciae latae (side of upper leg) and m. trapezius pars descendens (side of neck). Muscles at risk for weakness are: the flexor muscles in the front of the neck, m. serratus anterior (from shoulder blade to ribs) and m. rectus abdominis (the abdominal muscles). From this it can be concluded that only a doctor who knows the sport of diving can design a useful medical screening protocol for divers.

Around 1980 US diving published it's first papers on physical tests to identify talented divers.

The process of finding talents among non-diving schoolchildren is called "talent identification", the process of identifying talents among divers who are already competing is called "talent selection". Most successful nations in diving have both talent identification and talent selection procedures in place for more than 30 years. It is relatively easy to measure which divers possess characteristics that are favorable to diving performance (fitness testing etc). Experts in the field of talent development warn that is it still very difficult to predict the development of physical and mental characteristics over a longer time (e. g., puberty) or a full athletic career.

Orientation during flight is achieved by the combined input to the brain from the visual system, the vestibular organ and the somatosensory-system. The somatosensory-system is composed of the tension receptors in muscles, tendons and joints.

Divers refer to the somatosensory-system as "the feeling of one's body position in the air". Disorientation can happen when a person is rotated in the air. The vestibular system informs the brain that the body is changing direction in the air, the eyes make involuntary movements and briefly loose focus. Scientists in the former republic of East Germany have clearly proven that trained divers are better than schoolchildren of the same age in identifying shapes and figures while being spun around in a laboratory somersaulting and twisting machine and less disoriented immediately after. With an intensive training program in a somersault machine, with rapid rotations, the disturbance of the vestibular system can be reduced and therefore the ability to focus with the eyes during rotation can be improved. After eight weeks of rest the training effects are lost. It is therefore necessary to keep training rotations on a daily basis, to prevent loss of orientation ability.

6 What is missing in the literature?

341 articles on the medical aspects of diving is not much. For example, the number of publications on the medical aspects of gymnastics is at least 10 times as large.
The quality of the diving research is also not up to date. Studies on injuries and accidents based on expert opinion are nowadays considered suboptimal. Modern standards in sports medicine demand evidence, based on continuous registration of injuries and proof (measurement) of the effects of preventative recommendations.

7 A personal opinion

The rules and regulations for international diving competitions still have several shortcomings concerning safety. It is possible for a youngster at the age of 13 to win an international senior tournament on the 10-meter platform, before he or she is eligible to compete in an international junior tournament (e. g., Thom Daley, winner of the European senior 10-meter platform title in 2008 at the age of 13, too young to compete in junior age-group B). This shortcoming in the rules causes some coaches to prepare very young divers for senior competition. It is the opinion of the author that in several training centers in the world high performance coaches do not abide by the guidelines of the IOC statement on training the elite child athlete (2008), which state that sports should be "age-appropriate, pleasurable and fulfilling". Although we are in awe of the accomplishments of some of the successful child athletes it is important to point at a serious warning from professor Raspopova (Russia) who is arguably the leading expert in the world on the topic of talent selection in diving:

The history of Russian diving shows that speeding up of diving into adolescence never led to higher results and usually ended with injuries (physical or psychological) and the early completion of the athletic career (Raspopova, 2005).

The rules for masters divers (age groups 25 - 90+!) also need revision for safety. There is no consensus to what age it is safe to dive of the 10-meter platform and which degree of difficulty of dives may be performed. Possible solutions may be found in fitness testing and diving skill testing before entry into competitions is allowed.
Looking at regulations in other sports may also give us ideas to improve diver safety. In sports like judo and boxing a doctor decides whether an athlete may continue the competition if an injury has been sustained. In diving this is also necessary when a diver has injured him- or herself immediately before the competition or during the competition and the question arises whether to continue in the contest. From football (soccer) we may adopt the rule that all participants at the world championships present proof of medical clearance and the absence of injuries that make participation medically irresponsible. Finally, from tennis we can learn that all top players go to one medical center (London, GB) to receive treatment from doctors and therapists that specialize in the medical aspects of one sport.

8 Summary and take home messages

This review of the literature shows diving to be a safe sport with regard to major, catastrophic accidents. The number of reported overuse injuries of the neck, back, shoulders and wrists and possible irreversible damage to the eyes, ears and vestibular organ of divers is alarming. Divers are advised to actively seek medical care for their injuries. Diving federations are encouraged to initiate more research and publications on the medical aspects of diving. The author proposes that the international diving rules should be revised for safety.

Take home messages:

- Diving literature is available on *www.divingliterature.com*
- Divers have few catastrophic accidents
- Divers have many overuse injuries
- Divers should actively seek more medical care
- Modern research on the medical aspects of diving is needed
- The international diving rules and regulations can be improved on safety.

9 Recommended reading

Gabriel, J. L. (1999). *U.S. Diving safety training manual* (2nd edition). US Diving, Indianapolis.
Rubin, B. D. & Anderson, S. (1996). Diving. In D. J. Caine, *Epidemiology of sports injuries*, pp. 176-185.