Review articles

Diving with hypertension and antihypertensive drugs

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Key words
Diving medicine; Hypertension; Drugs; Fitness to Dive; Medicals – diving

Abstract

(Westerweel PE, Rienks R, Sakr A, Taher A. Diving with hypertension and antihypertensive drugs. Diving and Hyperbaric Medicine. 2020 March 31;50(1):49–53. doi: 10.28920/dhm50.1.49-53. PMID: 32187618.)
Hypertension is a common condition, which is highly prevalent amongst scuba divers. As a consequence, a substantial proportion of divers are hypertensive and/or on antihypertensive drugs when diving. In this article, we review available literature on the possible risks of diving in the presence of hypertension and antihypertensive drugs. Guidelines are presented for the diving physician for the selection of divers with hypertension suitable for diving, along with advice on antihypertensive treatment best compatible with scuba diving.

Introduction

Hypertension is a common condition affecting approximately 30–45% of the general population, with a steep increase in relation to age.[1] Several cohort studies have shown that hypertension is highly prevalent in recreational scuba divers and many use antihypertensive drugs. In a survey of Dutch divers, 12% reported to be hypertensive. Of the total divers, 4.3% used an ACE-inhibitor or angiotensin-receptor antagonist, 1.4% used a diuretic, 1.8% used a calcium-antagonist, and 1.0% used a beta-blocker.[2] In a Divers Alert Network (DAN) survey of US divers 24.6% reported being hypertensive, although this was lower than in the general US population.[3] In another US-focused survey, the Behavioural Risk Factor Surveillance System, an even higher prevalence was noted; 32.7% of divers were hypertensive.[4] In an analysis of divers treated at a hyperbaric facility, 8.9% were on antihypertensive drug treatment.[5]

In this perspective paper, we review available literature on the medical relevance of hypertension and antihypertensive drugs for scuba diving and provide practical advice for counselling divers with hypertension. This is based on best available evidence and expert opinions. The 2018 ESH/ESC guidelines for the management of arterial hypertension are used as a reference for the standard of general care.[6]

Methods

A systematic literature review was performed using the search string '(*diving* OR *scuba*) AND (*hypertension* OR *antihypertensive*)' in PubMed and the Rubicon repository in January 2017. From this, a literature summary was composed, and recommendations were drafted. This was limited to recreational scuba diving, thus excluding occupational and breath-hold diving. The findings were presented at an international educational meeting on diving medicine with various attending experts in May 2017 (mini-congress on diving medicine by Capita Selecta Duikgeneeskunde in Marsa Alam, Egypt). A revised draft including practical recommendations was then submitted for review by members from the Dutch Society for Diving Medicine and a final set of recommendations was adopted as a national recommendation for diving with hypertension and antihypertensive drugs at the Society meeting of 09 December 2017. For the current paper, the search was repeated on 30 May 2019. In PubMed, 161 hits were assessed for an applicability based on the abstract. In the Rubicon Research Repository, 43 hits were reviewed for applicability. Various observations have been published only in abstract form after presentation at scientific conferences, without having been published as a full article. These were included in this overview and designated as 'abstract' in the reference list.

Hypertension: definition and treatment

DEFINITION OF HYPERTENSION

The optimal blood pressure (BP) is < 120 mmHg systolic and < 80 mmHg diastolic. However, in the current society, most people have a blood pressure of 120–139 mmHg systolic and 80–89 diastolic, which could therefore be referred to as 'normal'. Hypertension is defined as an office blood pressure reading of systolic BP ≥ 140 mmHg and/or diastolic BP ≥ 90 mmHg. In cases of suspected situational hypertension, also known as 'white coat hypertension', the use of home blood pressure measurement or and 24-hour ambulatory blood pressure measurement may be more reliable. For home blood pressure measurement performed using a validated automatic device operated by the patient, hypertension is defined as a blood pressure ≥ 135/85 mmHg. For a 24-hour blood pressure reading, hypertension is defined as an average blood pressure exceeding ≥ 130/80 mmHg on average with ≥ 135/85 mmHg for daytime ambulatory blood pressure and/or ≥ 120/70 mmHg for night-time blood pressure. Of note, subjects with situational hypertension are at increased vascular risk compared to true normotensives.[6]

ANTIHYPERTENSIVE DRUG TREATMENT IN THE GENERAL POPULATION

Hypertension is a highly relevant risk factor for cardiovascular (CV) disease. The central aim of antihypertensive treatment is to prevent CV events. In low-risk individuals, the absolute risk reduction may be too small to justify treatment. Therefore, the indication for antihypertensive treatment depends not only on the grade of hypertension, but also on the overall absolute risk for a CV event. According to current ESC guidelines, all patients with hypertension grade 2 or higher should receive antihypertensive drug intervention irrespective of cardiovascular risk. Hypertension grade 2 is defined as a systolic blood pressure of ≥ 160 mmHg or a diastolic blood pressure of ≥ 100 mmHg. Patients with grade 1 hypertension (≥ 140/80 mmHg but not meeting the thresholds for grade 2) should be assessed for total CV risk based on concomitant presence of diabetes, symptomatic CV disease, chronic kidney disease, smoking, age, sex and plasma cholesterol. If their CV risk is high, drug treatment should be initiated. If their risk is low to moderate, the effect of life style interventions may first be observed.[6] Some other guidelines are more conservative in initiating drug treatment in low-risk individuals, such as the Dutch national guideline on cardiovascular risk management for general practitioners that advises limiting treatment in low-risk individuals with a blood pressure < 180/90 mmHg to lifestyle interventions only.[7] As a resultant, not all hypertensive subjects with grade 1 and even grade 2 receive drug treatment if their absolute CV risk is relatively low.

ANTIHYPERTENSIVE DRUGS

For antihypertensive drug treatment, the most common classes of antihypertensive drugs are:

- Angiotensin converting enzyme inhibitors (ACE-I);
- Angiotensin II receptor blockers (ARBs);
- Calcium antagonists (Ca-A);
- Diuretics;
- Beta-blockers.

More rarely used antihypertensive drugs are alpha-blockers, renin inhibitors, endothelin-inhibitors, alpha-2 adrenergic receptor agonists and direct-acting vasodilators. These will be considered beyond the scope of this article.

LIFESTYLE CHANGES

Appropriate lifestyle changes may prevent or help treat hypertension. The following lifestyle measures are recommended:

- Salt restriction to 5 $g \cdot day^{-1}$;
- Moderation of alcohol consumption (< 14 units per week for men and < 8 units for women);
- Increased consumption of vegetables, fresh fruits, fish, nuts, unsaturated fatty acids (olive oil), low consumption of red meat, and consumption of low-fat dairy products;
- Body weight control to avoid obesity (body mass index [BMI] > 30 $kg \cdot m^2$ or waist circumference > 102 cm in men and > 88 cm in women), aiming at a healthy BMI (20–25 $kg \cdot m^2$) and waist circumference (< 94 cm in men and < 80 cm in women);
- Regular aerobic exercise (≥ 30 min of moderate dynamic exercise on 5–7 days per week);
- Smoking cessation.

TREATMENT STRATEGY AND TARGET BLOOD PRESSURE

Lifestyle interventions are recommended for all subjects with hypertension. Prompt initiation of antihypertensive drugs is recommended in patients with grade 2 or more hypertension and/or at high CV risk. When treatment is indicated, this may be done using ACE-I, ARB, Ca-A, beta-blocker or diuretic; or a combination thereof. An initial BP goal of ≤ 140/90 mmHg is recommended in all hypertensive patients with a preferable target of ≤ 130/80 if the treatment is well tolerated.[6]

Diving-related risks in relation to hypertension

AGGRAVATION OF CENTRAL BLOOD PRESSURE BY IMMERSION AND EXERCISE

The presence of hypertension is likely to be aggravated during recreational diving through several mechanisms:

- Immersion, as this leads to a fluid shift from the extremities to the central core. This fluid shift has been estimated to comprise approximately 600–700 ml;[8]
- Peripheral vasoconstriction, particularly when diving in cold water conditions, which will exacerbate the central pooling of blood and thereby the increase in central

blood pressure;[9]
- Exercise, which may temporarily increase arterial blood pressure substantially.[10]

As a consequence, a significantly elevated blood pressure prior to a dive may accumulate to a cardiovascular strain that could elicit a cardiovascular event. After a dive, systemic blood pressure is unchanged compared to the pre-dive values.[11]

In addition to the above, there is also the effect of activity related stress (psychological), which is significant among novice divers and directly proportionate to the level of general physical fitness. Environmental conditions will also affect the conditions of exercise and stress levels thus potentially affecting blood pressure levels.

For physical activities and competitive sports in general, ACC/AHA/ESC guidelines recommend a blood pressure < 160/100 mmHg.[12] Together with the notion that immersion could increase blood pressure in patients with grade 1 hypertension, diving should be discouraged for subjects with a blood pressure > 160/100 mmHg. Of note, this implies that there may be subjects with a low CV risk and a systolic blood pressure between 160 and 180 mmHg that are not receiving drug treatment, but therefore should not dive. Alternatively, these subjects could consider taking antihypertensive drugs to be allowed to dive.

IMMERSION PULMONARY OEDEMA

There is substantial evidence suggesting that hypertensive subjects may be more prone to develop immersion pulmonary oedema (IPO). Hypertension was found to be relatively prevalent in a study of underlying predisposing factors in patients with IPO.[13] In a small observational study of divers suffering IPO, a disproportionally high number (eight out of 10) were on antihypertensive treatment at the time of their dive.[14] In subjects who have suffered an episode of IPO, the presence of hypertension is associated with a higher chance of later recurrence.[15] Finally, normotensive subjects who experienced IPO during scuba diving or swimming were more likely to develop arterial hypertension later in life.[16]

DECOMPRESSION ILLNESS

In an animal experiment, decompression sickness was found to occur more than twice as often in spontaneous hypertensive rats than in control rats.[17] This observation (only published as an abstract) indicates that hypertension may be a risk factor for decompression illness, but requires further research for confirmation.

SCUBA DIVING INDUCED CARDIOVASCULAR EVENTS

A substantial proportion of scuba-diving related incidents and fatalities are related to cardiovascular events.[18] As hypertension is a prominent risk factor for cardiovascular events, the risk of scuba-diving related cardiovascular events may be expected to be increased in hypertensive divers. In some cases of diving fatalities, hypertensive cardiomyopathy or hypertensive atherosclerotic vascular disease were indeed specifically identified as the suspected cause of death.[18]

Diving-related risks in relation to antihypertensive drugs

ANGIOTENSIN CONVERTING ENZYME INHIBITORS

Pulmonary symptoms, particularly a dry cough, may occur as a side effect for this drug class, which should be carefully evaluated. Otherwise, few specific diving-related risks are expected from this drug class, if well tolerated by the diver.

ANGIOTENSIN II RECEPTOR BLOCKERS

Few specific diving-related risks are expected from this drug class, if well tolerated by the diver.

CALCIUM ANTAGONISTS

Ca-A are vasodilators that act on smooth muscle cells in the arterial wall. A common side effect is orthostatic hypotension. A specific diving-related risk may involve a sudden drop in blood pressure when exiting the water as the central blood pooling effect of immersion is reversed at a time when the circulating blood volume has been reduced during the dive. Divers using Ca-A may be needed to take specific care to gradually exit the water to allow for blood pressure adaption during emersion. Otherwise, there are no specific diving-related risks.

DIURETICS

In the treatment of hypertension, the most commonly used diuretics are thiazide diuretics. These have a modest effect on water clearance and plasma volume contraction. Dehydration is commonly thought to be a risk factor for decompression sickness. Of note, although there is a strong theoretical basis for this notion, the scientific evidence is very limited with conflicting results in animal models[19–21] and only small supportive human studies.[22,23] Nonetheless, this does raise concern that plasma volume contraction may theoretically result in some degree of increased risk of decompression sickness when using thiazide diuretics. Although modest under otherwise normal circumstances, this may be greater during a tropical scuba diving trip: high fluid losses due to excessive sweating, repetitive diving and possible travellers' diarrhoea may be severely aggravated by use of thiazide diuretic. In the hypovolemic state, thiazide-induced electrolyte disturbances may also become more likely to occur.

BETA-BLOCKERS

Beta-blockers may adversely affect diving safety through

multiple mechanisms. First, beta blockers may cause chronotropic incompetence of the heart by limiting heart rate modulation during exercise. This may impair exercise capacity.[24] Secondly, beta blockers may induce a reduction in FEV1 (forced expiratory volume in 1 second) by off-target inhibition of bronchial beta-2 receptors in susceptible individuals,[25] although this effect seems to diminish after prolonged use.[26] Finally and of note, there have been multiple cases of immersion pulmonary oedema in divers using beta blockers (personal communication by Dr Adel Taher, Sharm el Sheik Hyperbaric Treatment Facility); an observation previously reported by others.[27,28] However there are no systematic studies investigating these clinical observations in properly controlled cohorts.

Summarized advice for divers with hypertension

It is recommended that individuals with a blood pressure exceeding 160/100 mmHg do not participate in scuba diving until the blood pressure has been treated appropriately. Subjects with a blood pressure < 160/100 mmHg may participate in scuba diving, irrespective of receiving treatment.

It is recommended that in subjects with hypertension receiving treatment, the hypertension should be well controlled to a minimal level of < 160/100 mmHg, but preferably to the general target range of < 140/90 mmHg.

It is recommended that certain antihypertensive drugs may be preferred to others in the context of scuba diving, and participation in scuba diving may be of consequence for antihypertensive treatment choices.

It is recommended that subjects with hypertension be assessed for signs of cardiac ischaemia and/or dysfunction and be referred to a vascular specialist or cardiologist for cardiovascular screening when deemed appropriate.

It is recommended that divers with hypertension should dive with an increased margin of safety to lower the risk of decompression sickness.

It is recommended that divers with hypertension be informed about the symptoms of IPO and receive specific instructions to immediately abort a dive in case of these symptoms. In case of suspected occurrence of IPO, the diver should undergo careful evaluation by a diving physician, pulmonologist and/or cardiologist before resuming diving.

Summarized advice on diving with antihypertensive drugs

ACE-I or ARBs: No specific concerns in relation to diving safety. Treatment of first choice for divers, if well-tolerated with specific attention to pulmonary symptoms.

CALCIUM ANTAGONISTS: Caution divers about orthostatic phenomena, particularly when exiting the water.

DIURETICS: Not preferred. Discontinue diuretics when suffering from diarrhoea and/or excessing sweating. Emphasize the importance of hydrating properly before and after diving.

BETA-BLOCKERS: Not preferred, but may be allowed when negative effects on exercise tolerance and pulmonary function are excluded.

Conclusions

Hypertension is prevalent amongst scuba divers and many divers use antihypertensive drugs. Hypertension may be aggravated by immersion and is associated with endothelial dysfunction and increased cardiovascular risk. This may increase the susceptibility to diving related illnesses and this is indeed observed in accident statistics. A specific concern is an increased risk for immersion pulmonary oedema. Antihypertensive drugs could influence diving safety. Preferred anti-hypertensive drugs in scuba divers requiring anti-hypertensive treatment are ACE-I or ARBs, followed by Ca-A. Less preferred are beta-blockers and diuretics.

References

1 Chow CK, Teo KK, Rangarajan S, Islam S, Gupta R, Avezum A, et al. Prevalence, awareness, treatment, and control of hypertension in rural and urban communities in high-, middle-, and low-income countries. JAMA. 2013;310:959–68. doi: 10.1001/jama.2013.184182. PMID: 24002282.

2 Westerweel P, Fijen V, van Hulst RA. Results from the DIDIH study using the Dutch Language Questionnaire. European Underwater and Baromedical Society Annual Meeting. 2013. p. 24. [Abstract]. Available from: http://www.eubs.org/wp-content/uploads/2019/03/EUBS2013%20AbstractBook.pdf. [cited 2019 June 22].

3 Ranapurwala SI, Kucera KL, Denoble PJ. The healthy diver: A cross-sectional survey to evaluate the health status of recreational scuba diver members of Divers Alert Network (DAN). PLoS One. 2018;13(3):e0194380. doi: 10.1371/journal.pone.0194380. PMID: 29566018. PMCID: PMC5864008.

4 Buzzacott P, Edelson C, Bennett CM, Denoble PJ. Risk factors for cardiovascular disease among active adult US scuba divers. Eur J Prev Cardiol. 2018;25:1406–8. doi: 10.1177/2047487318790290. PMID: 30045634.

5 Smerz RW. Drugs downed divers did. Undersea Hyperb Med. 2007;34(Suppl). [Abstract]. Available from: http://dspace.rubicon-foundation.org/xmlui/handle/123456789/5181. [cited 2019 June 22].

6 Williams B, Mancia G, Spiering W, Agabiti Rosei E, Azizi M, Burnier M, et al. 2018 ESC/ESH guidelines for the management of arterial hypertension. Eur Heart J. 2018;39:3021–104. doi: 10.1093/eurheartj/ehy339. PMID: 30165516.

7 Nederlands Huisartsen Genootschap. Cardiovasculair risicomanagement. [Dutch national guideline for primary care physicians]. 2019. Available from: http://www.nhg.org/

standaarden/volledig/cardiovasculair-risicomanagement. [cited 2019 June 22].
8 Arborelius M Jr, Balldin UI, Lilja B, Lundgren CE. Hemodynamic changes in man during immersion with the head above water. Aerosp Med. 1972;43:592–8. PMID: 5035546.
9 Mawhinney C, Jones H, Low DA, Green DJ, Howatson G, Gregson W. Influence of cold-water immersion on limb blood flow after resistance exercise. Eur J Sport Sci. 2017;17:519–29. doi: 10.1080/17461391.2017.1279222. PMID: 28100130.
10 Chrysant SG. Current evidence on the hemodynamic and blood pressure effects of isometric exercise in normotensive and hypertensive persons. J Clin Hypertens (Greenwich). 2010;12:721–6. doi: 10.1111/j.1751-7176.2010.00328.x. PMID: 20883233.
11 Marabotti C, Scalzini A, Chiesa F. Increase of pulmonary arterial pressure in subjects with venous gas emboli after uncomplicated recreational SCUBA diving. Respir Med. 2013;107:596–600. doi: 10.1016/j.rmed.2013.01.002. PMID: 23375948.
12 Kaplan NM, Gidding SS, Pickering TG, Wright JT Jr. Task Force 5: systemic hypertension. J Am Coll Cardiol. 2005;45:1346–8. doi: 10.1016/j.jacc.2005.02.012. PMID: 15837285.
13 Peacher DF, Martina SD, Otteni CE, Wester TE, Potter JF, Moon RE. Immersion pulmonary edema and comorbidities: case series and updated review. Med Sci Sports Exerc. 2015;47:1128–34. doi: 10.1249/MSS.0000000000000524. PMID: 25222821.
14 Garcia E, Padilla W, Morales V. Acute pulmonary edema in recreation scuba divers with cardiovascular diseases. Undersea Hyperb Med. 2005;32(Suppl). [Abstract]. Available from: http://dspace.rubicon-foundation.org/xmlui/handle/123456789/1737. [cited 2019 June 22].
15 Gempp E, Demaistre S, Louge P. Hypertension is predictive of recurrent immersion pulmonary edema in scuba divers. Int J Cardiol. 2014;172:528–9. doi: 10.1016/j.ijcard.2014.01.021. PMID: 24485632.
16 Wilmshurst PT, Nuri M, Crowther A, Webb-Peploe MM. Cold-induced pulmonary oedema in scuba divers and swimmers and subsequent development of hypertension. Lancet. 1989;1(8629):62–5. doi: 10.1016/s0140-6736(89)91426-8. PMID: 2562880.
17 Dutka A, Pearson R. Spontaneously hypertensive (SH) rats are more likely to develop decompression sickness than Sprague-Dawley (SD) rats. Undersea Biomed Res. 1992;19(Suppl). [Abstract]. Available from: http://dspace.rubicon-foundation.org/xmlui/handle/123456789/6446. [cited 2019 June 22].
18 Buzzacott P, editor. DAN Annual Diving Report 2017 Edition – A report on 2015 diving fatalities, injuries, and incidents. Durham (NC): Divers Alert Network; 2017. p. 134.
19 Broome J, Kittel C, Dick E. Failure of pre-dive hydration status to influence neurological DCI rate in pigs. Undersea Hyperb Med. 1995;22(Suppl):52. [Abstract].
20 Fahlman A, Dromsky DM. Dehydration effects on the risk of severe decompression sickness in a swine model. Aviat Space Environ Med. 2006;77:102–6. PMID: 16491576.
21 Skogland S, Stuhr LB, Sundland H, Olsen RE, Hope A. Venous gas emboli in normal and dehydrated rats following decompression from a saturation dive. Aviat Space Environ Med. 2008;79:565–9. PMID: 18581939.
22 Gempp E, Blatteau JE, Pontier J-M, Balestra C, Louge P. Preventive effect of pre-dive hydration on bubble formation in divers. Br J Sports Med. 2009;43:224–8. doi: 10.1136/bjsm.2007.043240. PMID: 18308884.
23 Suzuki N, Yagishita K, Togawa S, Okazaki F, Shibayama M, Yamamoto K, et al. A case-control study evaluating relative risk factors for decompression sickness: a research report. Undersea Hyperb Med. 2014;41:521–30. PMID: 25562944.
24 Vanhees L, Defoor JG, Schepers D, Lijnen P, Peeters BY, Lacante PH, et al. Effect of bisoprolol and atenolol on endurance exercise capacity in healthy men. J Hypertens. 2000;18:35–43. doi: 10.1097/00004872-200018010-00006. PMID: 10678541.
25 Morales DR, Jackson C, Lipworth BJ, Donnan PT, Guthrie B. Adverse respiratory effect of acute beta-blocker exposure in asthma: a systematic review and meta-analysis of randomized controlled trials. Chest. 2014;145:779–86. doi: 10.1378/chest.13-1235. PMID: 24202435.
26 Salpeter SR, Ormiston TM, Salpeter EE. Cardioselective beta-blockers in patients with reactive airway disease: a meta-analysis. Ann Intern Med. 2002;137:715–25. doi: 10.7326/0003-4819-137-9-200211050-00035. PMID: 12416945.
27 Grindlay J, Mitchell S. Isolated pulmonary oedema associated with SCUBA diving. J Emerg Med. 1999;11:272–6. doi: 10.1046/j.1442-2026.1999.00061.x.
28 Hampson NB, Dunford RG. Pulmonary edema of scuba divers. Undersea Hyperb Med. 1997;24:29–33. PMID: 9068153.

Conflicts of interest and funding: nil

Submitted: 22 June 2019
Accepted after revision: 24 October 2019