The role and efficacy of ECG screening in assessing fitness to dive in military divers: implications of sports medicine standards

Bas L van der Kooi[1], Alef DM Hoedemaeker[1], Lysette N Broekhuizen[2], Pieter-Jan AM van Ooij[1], Thijs T Wingelaar[1]

[1] *Royal Netherlands Navy, Diving and Submarine Medical Center, Rijkszee and Marinehaven, 1780 CA Den Helder, the Netherlands*
[2] *Ministry of Defense, Central Military Hospital, Utrecht, the Netherlands*

Corresponding author: *Dr Thijs T Wingelaar, Royal Netherlands Navy, Diving and Submarine Medical Center, Rijkszee and Marinehaven, 1780 CA Den Helder, the Netherlands*
ORCiD: *0000-0001-7740-7392*
tt.wingelaar@mindef.nl

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Abstract
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Introduction: Diving necessitates significant physiological adaptations, particularly within the cardiopulmonary system. Resting electrocardiograms (ECGs) are widely used in fitness to dive assessments, but their effectiveness in healthy young divers remains unclear. This study assessed the impact of applying sports medicine ECG criteria compared to traditional clinical standards, aiming to reduce (unnecessary) referrals to a cardiologist without compromising diver safety.
Methods: In this retrospective study covering 10 years, ECGs from Royal Netherlands Navy divers were analysed. Abnormal ECGs identified by clinical criteria between 2010 and 2019 were re-evaluated using international sports medicine ECG criteria. A control group of normal ECGs was matched based on demographic factors. Statistical analyses were performed using Pearson's chi-squared and Fisher's exact test, with significance set at $P < 0.05$.
Results: Of a total of 3,020 ECGs, 156 were classified as abnormal by clinical criteria. Reassessment using sports medicine standards reduced the number requiring further investigation by 85.9%. In the control group, 1.0% of previously unremarkable ECGs were identified as requiring further investigation upon reassessment. Conduction disorders and rhythm disturbances were the most common findings.
Conclusions: The findings of this study suggest that the application of sports medicine ECG interpretation criteria effectively reduces the number of ECGs requiring further investigation, thereby minimising referrals and associated costs. These results advocate for a re-evaluation of routine ECG screening practices in fitness to dive assessments in military divers, promoting a more tailored approach for this specific group.

Introduction

Immersion or submersion, such as in diving, necessitates significant physiological adaptations of the human body to maintain sufficient vital functions.[1] Pre-existing medical conditions, such as hypertension, cardiomyopathy, left ventricular hypertrophy (LVH) and valvular disease, can adversely affect these compensatory mechanisms, potentially leading to diving-related incidents and diseases.[2] While physiological changes are required across multiple systems, adaptations within the cardiopulmonary system are particularly critical. Specifically, central circulating blood volume may increase by 500 to 700 millilitres due to the redistribution of blood associated with submersion, resulting in heightened pressures within the atria and ventricles.[3,4] Additionally, exposure to cold water can induce peripheral vasoconstriction, further exacerbating cardiac pressures.[5] Such increases in cardiac stress during diving pose an increased risk of adverse cardiac events in individuals with underlying cardiac conditions, underscoring the necessity of fitness to dive assessments in preventing accidents.[6]

Sudden cardiac death (SCD) is a leading cause of mortality among young athletes during exercise. The majority of underlying conditions responsible for SCD can be identified through abnormalities on an electrocardiogram (ECG), including cardiomyopathies, electrical heart diseases and abnormal pathways.[7] In the field of diving medicine, the resting ECG is a widely utilised, cost-effective and non-invasive screening tool for identifying these overt electrical abnormalities indicative of cardiac pathology in fitness to dive assessments of both occupational and recreational

divers. However, the effectiveness of the resting ECG as a screening measure for cardiac issues among healthy, relatively young divers remains inadequately understood. Prior studies in general medicine suggest that screening asymptomatic young adults yields a low prevalence of abnormal ECG findings, with many of these categorised as normal variants, such as early depolarization.[8–10]

This uncertainty prompts critical questions regarding the ongoing utilisation of the ECG as a routine screening instrument in fitness to dive assessments, particularly given the substantial number of false-positive results when applying traditional ECG criteria to a young, usually sportive, population. Such outcomes can lead to unnecessary additional procedures and associated costs, while unjustly declaring military divers unfit for duty for extended periods, without clear benefits to diver safety.

Therefore, it is crucial to distinguish pathological abnormalities, such as cardiomyopathies and primary electrical disorders, which may manifest on an ECG as ventricular arrythmias or left bundle branch block (LBBB), from physiological adaptations to regular exercise or training, such as increased QRS voltage indicative of LVH, or (incomplete) right bundle branch block (RBBB). Recognising this need, an expert panel comprising specialists in sports cardiology, inherited cardiac disease and sports medicine convened in Washington in 2015 to revise the international criteria for interpreting ECGs in sports medicine. This update, based on emerging research, aimed to provide a better indication of commonly found ECG alterations in the young, asymptomatic and athletic population and may also be applicable to occupational divers.[11]

Currently, there is no international consensus on the criteria for interpreting resting ECGs in the context of fitness to dive assessments. In contrast to European and UK diving medical guidelines, Dutch guidelines mandate a resting ECG during fitness to dive assessments.[12,13] Despite this, research on this topic within the diving medicine literature remains limited. In aviation medicine, some evidence suggests that initial ECG screening for asymptomatic military aircrew leads to an extremely low number of individuals requiring further evaluation.[14] Possibly, selection bias may have contributed to this result. However, the relevance of these findings for military or occupational divers may be constrained, given the distinct physiological demands of diving compared to aviation and the differing criteria employed in ECG interpretation.

This study aimed to investigate the impact of modifying ECG interpretation criteria from clinical to sports medicine standards. We hypothesised that employing sports medicine criteria would reduce the number of ECGs requiring further investigation by a cardiologist, thereby decreasing unnecessary referrals.

Methods

The methods for handling medical information comply with national and European legislation and the guidelines of the Association of Universities in the Netherlands.

CONTEXT

The Royal Netherlands Navy Diving Medical Centre is responsible for the medical well-being of the Dutch armed forces' divers, submariners, and hyperbaric personnel. As mentioned in the introduction, the aforementioned group is subjected to annual medical assessments as part of national legislation.[13]

DATA COLLECTION

For this study, the ECGs from fitness to dive assessments, both initial screenings and revisions, of all divers between 1 January 2010 and 31 December 2019, were included. The conclusion of the assessment of the ECGs, conducted by the examining diving medicine physician on the day of the fitness to dive assessment, was recorded in a separate database. In the studied period, the Netherlands Armed Forces (including the Royal Netherlands Navy Diving and Submarine Medical Centre) classified ECGs according to the criteria of the AHA/ACCF/HRS Recommendations for the Standardization and Interpretation of the Electrocardiogram, I-VI, as published in 2007 and 2009.[15] These publications mention that ECG criteria may differ in several sub-groups, like young adults, but do not provide specific guidelines as to what may be considered normal in these groups. ECGs classified as abnormal according to these criteria were labelled as 'cases', and were matched by twice the number of normal ECGs from the entire dataset, labelled as 'controls'. This matching was based on criteria like initial screening or revision, smoking, age, height and weight. There was direct access of the examining diving medicine physicians to the cardiologists of the Central Military Hospital in Utrecht for consultation to discuss the interpretation of the ECGs. However, differences in ECG reading and interpretation skills among the examining diving medicine physicians may still have led to different interpretation and policy in similar cases.

The re-assessment for this study utilised the international criteria for interpreting ECGs in athletes, performed by two military diving medicine physicians (AH and TW) and a researcher (BK), who operated independently of each other.[10] In cases of differing interpretations, results were discussed until consensus was reached. If discrepancies arose among the evaluators, the ECGs were referred to a cardiologist (LB) for a final assessment. The results were coded in the database as 'normal variant' or 'further investigation required', as outlined in the aforementioned criteria. According to these criteria, certain findings may not be abnormal in isolation;

however, when considered alongside other findings, such as a right bundle branch block in conjunction with a right axis deviation, they may be deemed significant and necessitate further examination.

ANALYSIS

Data analysis was primarily descriptive. As the Kolmogorov-Smirnov test showed that none of the parameters were normally distributed, the median and interquartile range (IQR) were determined. All statistical analyses were performed with SPSS Statistics for Windows software (2022, version 29.0; IBM Corp; Armonk, NY). Differences were analysed with Pearson's Chi-squared test and Fisher's exact test where appropriate. Statistical significance was defined as $P < 0.05$.

Results

Between 1 January 2010 and 31 December 2019, a total of 3,020 ECGs were registered as part of fitness to dive assessments. Of these, 156 ECGs (5.2%) were labelled as abnormal. These ECGs were retrospectively re-examined using the international ECG criteria for athletes. From the 312 matched ECGs in the control group, a final total of 276 ECGs were analysed due to missing data. The baseline characteristics of the groups are presented in Table 1, with no significant differences observed between the groups.

The reassessment of the 'cases' and 'controls' revealed a total of 24 ECGs (0.8%) that required further investigation (see Figure 1). For the cases, this represents an 85.9% reduction in the number of ECGs requiring further investigation compared to the initial interpretation using clinical criteria. The majority of the 85.9% ECGs, which were identified as 'abnormal' at first assessment, were attributed to a complete right bundle branch block (cRBBB), left or right axis deviation and incomplete left bundle branch block (iLBBB) (Table 2). The rest of the abnormal ECGs were other findings such as ventricular extrasystoles, ST variations, intraventricular conduction disorders and sinus tachycardia. Despite two attempts at matching, data were unavailable for 36 individuals in the control group. No significant differences were found between the frequency of abnormalities of the 420 initial screenings and 2,600 revisions for the cases and controls ($P = 0.342$), which were assessed using the clinical criteria. These results are summarised in Table 3. Among the ECGs that required further investigation, the majority were classified as conduction disorders, including intra-ventricular conduction delay and bundle branch block (Table 4). The remaining ECGs predominantly exhibited rhythm disturbances.

In the control group, three ECGs were identified that required further investigation. Consequently, the application of the new criteria resulted in a 1.0% increase in abnormal ECG findings that were initially overlooked, disregarded or not reported by the examining physician during fitness to dive assessment. These abnormal findings included one instance of intra-ventricular conduction delay of 150 ms, a case with two premature ventricular ectopic beats per 10 s of tracing and a candidate with a prolonged corrected QT interval of 499 ms.

Discussion

This study provides evidence that the implementation of international criteria for interpreting ECGs in athletes appears to be effective in reducing the number of ECGs requiring further investigation and referrals to a cardiologist, while to date, none of the divers whose ECGs were reassessed have presented with any diving-related or other medical issues. This suggests a potential decrease in additional investigations, along with associated costs and

Table 1
Baseline characteristics of the included applicants for all applicants, cases and controls; IQR – interquartile range

Parameter	All applicants *n* = 3,020	Cases *n* = 156	Controls *n* = 312
Initial screening, *n*	420	25	54
Revision, *n*	2,600	131	258
Age (y), median (IQR)	31 (27–39)	30 (26–40)	30 (26–40)
Men, *n* (%)	2,977 (98.6)	156 (100)	312 (100)
Women, *n* (%)	43 (1.4)	–	–
Height (cm), median (IQR)	184 (179–188)	183 (179–189)	184 (180–189)
Weight (kg), median (IQR)	86 (80–92)	85 (79–94)	86 (81–92)
Smoking			
Yes, *n* (%)	472 (15.6)	31 (19.9)	62 (19.9)
No, *n* (%)	2,548 (84.2)	125 (80.1)	249 (80.1)

Figure 1

Classification of ECG findings for cases and controls showing the percentages of cases and controls within the total group, followed by the proportions of normal ECGs, those requiring further investigation, and missing ECGs within the cases and controls

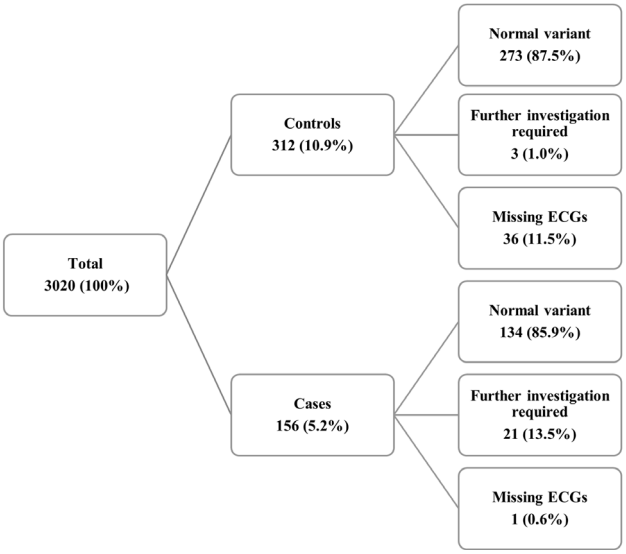

Table 2

Specific electrocardiogram (ECG) findings for the cases at first assessment; *left axis deviation: 30° to -90° in the frontal plane; #right axis deviation: 90° to 180° in the frontal plane; cRBBB – complete right bundle branch block (QRS duration greater than or equal to 120 ms with rsr', rsR' or rSR' pattern in leads V1 or V2); iLBBB – incomplete LBBB (QRS duration between 110 and 119 ms with broad notched or slurred R wave in leads I, aVL, V5, and V6, absent q waves in leads I, V5, and V6)

ECG findings classified as 'abnormal'	Cases *n* (% of total)
cRBBB	74 (55.2)
Left axis deviation*	19 (14.2)
iLBBB	14 (10.4)
Right axis deviation#	5 (3.7)
Other findings	22 (16.4)
Total	134

Table 3

Results of reassessed electrocardiograms for the cases and controls; *P = 0.342

Outcome	Cases: initial screening	Revision	Controls: initial screening	Revision	Total
Normal variant	21	113	48	225	407
Further investigation required	3	18	1	2	24
Total	24	131	49	227	431*

Table 4

Specific electrocardiogram (ECG) findings for the cases and controls; *left axis deviation: 30° to -90° in the frontal plane; #right axis deviation: 90° to 180° in the frontal plane; † ≥ 0.5 mm in depth in two or more contiguous leads; ‡ ≥ 470 ms (male), ≥ 480 ms (female) using Bazett's formula; cLBBB – complete left bundle branch block (QRS ≥ 120 ms with broad notched or slurred R wave in leads I, aVL, V5, and V6, absent q waves in leads I, V5, and V6; cRBBB – complete right bundle branch block (QRS duration greater than or equal to 120 ms with rsr', rsR' or rSR' pattern in leads V1 or V2); PVC – premature ventricular contractions (≥ 2 per 10 s)

ECG findings that required further investigation	Cases	Controls	Total
Profound nonspecific intra-ventricular conduction delay (QRS ≥ 140 ms)	9	1	10
cLBBB	4		4
cRBBB with right axis deviation#	2		2
cRBBB with left axis deviation*	2		2
PVC	2	1	3
ST-segment depression†	1		1
Epsilon wave	1		1
Prolonged QT interval‡		1	1

the risk of potential incidental findings of unknown clinical significance.

This reduced number of ECGs requiring further investigation is the result of major differences between ECG criteria derived from the 'AHA/ACCF/HRS Recommendations for the Standardization and Interpretation of the Electrocardiogram' and the ECG criteria derived from the 'International Recommendations for Electrocardiographic Interpretation in Athletes'. The main differences are the result of the, usually, lower weight and a more active lifestyle of young adults compared to older adults.

This results in ECG manifestations, that may be abnormal in the older population but normal in the young adult population. For instance, the usual voltage criteria for left and right ventricular hypertrophy do not apply to adults under the age of 35 years. High voltages are a normal finding in the young population. In the case of structural heart disease, for instance, a cardiomyopathy, there are usually additional ECG abnormalities like (deep) negative T waves. In addition, due to an increased vagal tone in young people, arrhythmias and conduction disturbances may occur like sinus bradycardia, nodal rhythms, premature atrial complexes (PACs), first degree atrio-ventricular (AV) block and second-degree Mobitz type 1 AV block (Wenckebach). Due to increased strain to the right ventricle caused by sports activities, the right ventricle may enlarge and an (incomplete) RBBB may appear. Also, repolarisation abnormalities like early repolarisation and non-specific ST and T wave abnormalities may appear in active young adults without clinical significance.

However, certain ECG abnormalities are also abnormal in young adults, like a complete LBBB, a QRS duration of > 140 ms, T wave inversion, ST segment depression ≥ 0.5 mm in depth in two or more contiguous leads, ≥ 2 PVCs on the ECG and atrial and ventricular arrhythmias. A left axis deviation, a left atrial enlargement, a right axis deviation, a right atrial enlargement and a complete RBBB are considered 'borderline', and further evaluation is not recommended if it occurs 'in isolation', but when two of more of these abnormalities are present, further evaluation is recommended. These recommendations are based on the finding that in athletes with these ECG abnormalities in isolation no abnormalities were found on echocardiography, especially those who engage in regular and long term participation in intensive exercise.[11] The most important changes in the assessment of ECGs comparing 'old' to 'new' criteria are the assessment of left axis deviation, right axis deviation and cRBBB with a duration < 140 ms in isolation as normal. These major changes together with a few of other findings resulted in a considerable reduction in abnormal ECGs.

To our knowledge, this is the first study to examine the application of these criteria in the context of fitness to dive assessments. A large study involving German military aircrew members analysed 6,284 ECGs and reported a prevalence of 0.21% of ECGs requiring further investigation.[14] This prevalence is approximately four times lower than observed in our study, which could be attributed to differences in physical fitness and exposure to environmental factors between divers and aircrew; for instance, left ventricular hypertrophy or an isolated left axis deviation are less likely to occur in non-athletes and are often a consequence of physiologic adaptation.[16] However, differences in national policy regarding screening and follow-up of findings may have also affected these differences. This could also explain the absence of profound nonspecific intra-ventricular conduction delay (QRS ≥ 140 ms) in the German study, which represented 42% of the abnormalities in the present study. Furthermore, we observed a 1.0% prevalence of ECGs requiring further investigation in the control group, prompting questions about the potential for missed abnormal findings across the entire dataset, even with our valid sample. It is reasonable to argue that ECG findings necessitating further investigation may exhibit low clinical relevance in practice since none of these divers has presented with diving related health issues or other medical problems leading to fatal diving incidents, which may justify the decision not to analyse all ECGs. Furthermore, even after reassessment, the risk of false-negative ECGs remains, as certain abnormalities such as intermittent Wolff-Parkinson-White, Brugada, atrial septal defect and long QT-syndrome, may not always be detectable on an ECG. Additionally, an ECG does not capture all forms of cardiac pathology, such as anomalies in the coronary arteries.

Several recent studies have evaluated the contribution of routinely performed tests, such as spirometry and audiometry, on medical assessment of fitness to dive.[17–19] Collectively, these studies advocate for a more selective approach to additional testing, emphasising the importance of subject history and physical examination in determining the necessity for further evaluation. One potential indicator for conducting a resting ECG is smoking status, as in our study there appeared to be an over-representation of smokers in the cases compared to all applicants. However, in young and fit candidates, smoking status is of little significance as coronary artery disease has not yet developed. Conversely, for divers older than 40 years old this could be very relevant, as smoking is a leading risk factor for cardiovascular diseases and mortality, particularly due to coronary artery disease and cardiac arrhythmias such as atrial fibrillation (AF).[20] Although the current study did not establish a statistically significant effect, a post-hoc power analysis revealed a study power of only 31.5%. Consequently, this study is underpowered to definitively relate smoking status to ECG findings using clinical criteria in healthy adults. Given that the application of sports medicine ECG criteria significantly reduced the number of ECGs requiring further investigation, this power is further diminished. Moreover, identifying cardiovascular risk factors in young athletes based on

history and physical examination may prove challenging, as cardiovascular diseases typically become clinically relevant starting in the fifth decade of life.

As a result, these findings cast further uncertainty on the role of resting ECGs in fitness to dive assessments, particularly with the goal of excluding ischaemia or coronary disease in military divers, though the implications may extend more broadly. While the resting ECG serves as a baseline for an exercise ECG, its added value remains to be determined. Different industries, such as recreational or commercial diving, assign varying levels of importance to resting ECGs. Aside from the prevalence of underlying disease, the decision whether or not to record an ECG at a dive medical assessment, or any other medical investigation for that matter, must also be based on the level of risk that an organisation is willing to accept. In the military diving domain, it may be deemed acceptable to forgo a resting ECG as a screening tool due to the generally fit and healthy population, where unnecessary referrals could leave a diver unfit for duty for extended periods. Conversely, cardiac complaints in operational settings could incapacitate divers, jeopardizing missions, although to our knowledge there have been no incapacitations of divers in the Royal Netherlands Armed Forces that were cardiac related.

For commercial or recreational diving, these considerations may be evaluated differently due to distinct population characteristics and varying costs associated with incidents. Therefore, a more realistic approach to risk assessment and the use of medical screening tools should be carefully considered. Specifically for our military population, we propose that a resting ECG at the start of a diving career may be warranted to exclude disease which can be potentially lethal for divers deployed to locations with limited access to regular medical care, such as underlying arrhythmogenic pathology such as genetic cardiomyopathies, long-QT, Brugada, or Wolff-Parkinson-White syndrome.

Of special importance to diving is the association of a right bundle branch block (RBBB) on the ECG with the presence of an atrial septal defect. In a retrospective study of 104,369 young (sportive) individuals who were analysed, and in whom also a 'selective' echocardiogram was performed, a group of 154 individuals with a complete RBBB was identified, of which seven had cardiac pathology. Four of these individuals had an ASD on echocardiogram (three others had a Brugada syndrome, progressive cardiac conduction disease and atrial fibrillation, respectively). All of the individuals could be identified using the international criteria for ECG interpretation in athletes (six had an axis deviation, one had a QRS duration of 141 ms). The authors suggest that complete RBBB should remain as a 'borderline' finding but only if the QRS duration is < 130 ms. Complete RBBB of ≥ 130 ms should be considered an 'abnormal' finding, warranting secondary evaluation for all with at least an echocardiogram.[21]

Conversely, after ascertaining the presence of an initial normal ECG, routinely performed ECGs, without a clinical indication, seems to be of very little value and could be omitted. Without clinical indications, it seems valid to exclude routine resting ECGs in healthy military divers. However, around the age of 45 years old the risk of cardiovascular disease and cardiac related death in diving increases, which may warrant continuation of ECG screening in older divers.[3,22] Whether this age is appropriate for military divers, who are generally in a better physical condition than the general population and at a lower risk for cardiovascular disease, to commence routine ECG screening remains to be determined.

STRENGTHS AND LIMITATIONS

To our knowledge, this study represents the first retrospective analysis of resting ECGs utilising criteria established in sports medicine during medical assessments of fitness to dive in healthy, relatively young and asymptomatic military divers. A notable strength of this study is the comprehensive analysis of a large sample of resting ECGs over an extended period of time. Furthermore, all examinations and assessments were performed under standardised conditions, employing consistent ECG criteria across multiple independent assessors.

However, this study has several limitations. First, the study population is highly selected, as healthy male and mainly young military divers probably are not representative of female divers and older, commercial and recreational divers. Nonetheless, it is relatively straightforward to ascertain whether divers in other sectors align with these findings or may be at greater risk for cardiac disease based on history and physical examination. We encourage colleagues to conduct and publish similar studies to determine if the results of this study can be applied across different sectors. Secondly, despite two matching attempts, the control group contained 36 missing ECGs, which slightly reduced its size compared to initial expectations. However, as the control group remained substantial and comparable to the overall group, we believe it is still representative and may not have affected the conclusions drawn from this paper. Lastly, and perhaps most importantly, not all cases in this study received a thorough evaluation by a cardiologist, even though referral to a cardiac specialist was deemed appropriate at the time. The reason for this varies from candidates' withdrawal from the process to omissions from the assessing physician. This is unfortunately the case in many retrospective analyses, and may obscure the 'true' presence of cardiac disease and could have affected the prevalence of 'true' cardiac pathology in our group. However, over the past three decades, there have only been two fatal diving accidents in the Royal Netherlands Armed Forces, neither of which was attributed to cardiac pathology.

Conclusion

This study demonstrates that the application of ECG interpretation criteria derived from sports medicine standards effectively reduces the number of ECGs requiring further investigation compared to traditional clinical criteria. This reduction is likely to decrease referrals to a cardiologist and minimise the necessity for additional investigations, along with their associated costs and potential incidental findings. As these findings are often of unknown clinical significance, a more nuanced approach to risk assessment and the utilisation of medical screening tools is warranted. We recommend that a resting ECG can be considered for military divers as part of an initial dive medical assessment, especially when deployed to locations with limited access to routine medical care, to screen for potentially lethal rhythm or conduction disorders and cardiomyopathies, but that subsequent routine ECGs without clinical indication can be omitted. Future research should investigate the generalisability of these findings to other diver populations, particularly females and older male divers. Additionally, studies should aim to determine which risk factors, including age, should prompt recording of an ECG as part of a fitness to dive assessment.

References

1 Mitchell SJ, Bennett MH, Moon RE. Decompression sickness and arterial gas embolism. N Engl J Med. 2022;386(13):1254–64. doi: 10.1056/NEJMra2116554. PMID: 35353963.

2 Bosco G, Rizzato A, Moon RE, Camporesi EM. Environmental physiology and diving medicine. Front Psychol. 2018;9:72. doi: 10.3389/fpsyg.2018.00072. PMID: 29456518. PMCID: PMC5801574.

3 Rienks R, Buwalda M, Bucx J, Dubois E, Wingelaar T, van Hulst R. Cardiovascular risk assessment in divers: toward safer diving. Undersea Hyperb Med. 2022;49:355–65. PMID: 36001568.

4 Marabotti C, Scalzini A, Menicucci D, Passera M, Bedini R, L'Abbate A. Cardiovascular changes during SCUBA diving: an underwater Doppler echocardiographic study. Acta Physiol (Oxf). 2013;209:62–8. doi: 10.1111/apha.12112. PMID: 23638629.

5 Weenink RP, Wingelaar TT. The circulatory effects of increased hydrostatic pressure due to immersion and submersion. Front Physiol. 2021;12:699493. doi: 10.3389/fphys.2021.699493. PMID: 34349668. PMCID: PMC8326965.

6 Wendling J, Vanden Eede R, Elliott D, Meintjes J, Meliet J-L, Nome T, editors. Medical assessment for work under pressure. Fitness to dive standards of European Diving Technology Committee. International Marine Contractors Association; 2024.

7 Maron BJ, Doerer JJ, Haas TS, Tierney DM, Mueller FO. Sudden deaths in young competitive athletes: analysis of 1866 deaths in the United States, 1980-2006. Circulation. 2009;119:1085–92. doi: 10.1161/CIRCULATIONAHA.108.804617. PMID: 19221222.

8 Harskamp RE. Electrocardiographic screening in primary care for cardiovascular disease risk and atrial fibrillation. Prim Health Care Res Dev. 2019;20:e101. doi: 10.1017/s1463423619000355. PMID: 32800007. PMCID: PMC8060828.

9 Chamley RR, Holdsworth DA, Rajappan K, Nicol ED. ECG interpretation. Eur Heart J. 2019;40(32):2663–6. doi: 10.1093/eurheartj/ehz559. PMID: 31433846.

10 Ashley EA, Raxwal V, Froelicher V. An evidence-based review of the resting electrocardiogram as a screening technique for heart disease. Prog Cardiovasc Dis. 2001;44:55–67. doi: 10.1053/pcad.2001.24683. PMID: 11533927.

11 Sharma S, Drezner JA, Baggish A, Papadakis M, Wilson MG, Prutkin JM, et al. International recommendations for electrocardiographic interpretation in athletes. Eur Heart J. 2018;39(16):1466–80. doi: 10.1093/eurheartj/ehw631. PMID: 28329355.

12 Health and Safety Executive. Medical examination and assessment of working divers (MA1); 2023. [cited 2024 Oct 9]. Available from: https://www.hse.gov.uk/pubns/ma1.htm2023.

13 Working Under Pressure Foundation. Guideline occupational health assessment: Working under positive pressure and diving [in Dutch: Keuringsrichtlijn. Arbeidsgezondheidskundig Onderzoek Werken onder Overdruk en Duikarbeid]. Pijnacker, the Netherlands: Working Under Pressure Foundation; 2021. [cited 2024 Oct 9]. Available from: https://www.arbocataloguswoo.nl/images/SWOD/pdf/NL/SWOD-ARBOCAT-WoO-Keuring-CAT003_1-2021-rev4-aug-2021.pdf.

14 Guettler N, Sammito S. Electrocardiographic abnormalities in medically screened German military aircrew. J Occup Med Toxicol. 2021;16(1):37. doi: 10.1186/s12995-021-00327-x. PMID: 34465360. PMCID: PMC8407018.

15 Surawicz B, Childers R, Deal BJ, Gettes LS, Bailey JJ, Gorgels A, et al. AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: part III: intraventricular conduction disturbances: a scientific statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society: endorsed by the International Society for Computerized Electrocardiology. Circulation. 2009;119(10):e235–40. doi: 10.1161/CIRCULATIONAHA.108.191095. PMID: 19228822.

16 Petek BJ, Drezner JA, Churchill TW. The international criteria for electrocardiogram interpretation in athletes: common pitfalls and future directions. Cardiol Clin. 2023;41:35–49. doi: 10.1016/j.ccl.2022.08.003. PMID: 36368810. PMCID: PMC10292923.

17 Sames C, Gorman DF, Mitchell SJ, Zhou L. Long-term changes in spirometry in occupational divers: a 10-25 year audit. Diving Hyperb Med. 2018;48:10–6. doi: 10.28920/dhm48.1.10-16. PMID: 29557096. PMCID: PMC6467824.

18 Canarslan-Demir KC, Ozgok-Kangal K, Kilic S, Genc H. Does diving deteriorate hearing functions? Undersea Hyperb Med. 2023;50:313–8. PMID: 37708065.

19 Melessen A, Wingelaar TT, van Ooij PA. Clinical utility of dipstick urinalysis in assessing fitness to dive in military divers, submariners, and hyperbaric personnel. Diving Hyperb Med. 2024;54:105–9. doi: 10.28920/dhm54.2.105-109. PMID: 38870952. PMCID: PMC11444914.

20 Irfan A, Riggs DW, Koromia GA, Gao H, DeFilippis AP, Soliman EZ, et al. Smoking-associated electrocardiographic abnormalities predict cardiovascular mortality. Sci Rep.

2024;14(1):31189. doi: 10.1038/s41598-024-82503-7. PMID: 39730843. PMCID: PMC11680829.

21 MacLachlan H, Antonakaki A, Bhatia R, Fyazz S, Chatrath N, Androulakis E, et al. Prevalence and clinical significance of electrocardiographic complete right bundle branch block in young individuals. Eur J Prev Cardiol. 2025;32:1054–61. doi: 10.1093/eurjpc/zwae082. PMID: 38412448.

22 Jepson N, Rienks R, Smart D, Bennett MH, Mitchell SJ, Turner M. South Pacific Underwater Medicine Society guidelines for cardiovascular risk assessment of divers. Diving Hyperb Med. 2020;50:273–7. doi: 10.28920/dhm50.3.273-277. PMID: 32957130. PMCID: PMC7819720.

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