Occupational Medicine 2013;**63:**537–543
Advance Access publication 5 November 2013 doi:10.1093/occmed/kqt112

Mortality among professional divers in Norway

Å. Irgens[1], K. Troland[1], E. Thorsen[1,2] and M. Grønning[1,3]

[1]Department of Occupational Medicine, Norwegian Centre for Diving Medicine, Haukeland University Hospital, NO5021 Bergen, Norway, [2]Institute of Medicine, University of Bergen, Box 7804, NO5020 Bergen, Norway, [3]Department of Clinical Medicine, University of Bergen, Box 7804, NO5020 Bergen, Norway.

Correspondence to: Å. Irgens, Norwegian Centre for Diving Medicine, Department of Occupational Medicine, Medicine, Haukeland University Hospital, NO5021 Bergen, Norway. Tel: +47 55973882; fax: +47 55975137; e-mail: agot.irgens@helse-bergen.no

Background	Diving operations are technically complex, and the underwater environment poses a high risk of fatal or near miss accidents. Furthermore, long-term effects of diving on bone, the central nervous system and the lung have been observed in divers who have not experienced any diving-related accidents.
Aims	To compare total and cause-specific mortality among Norwegian professional divers by class of diving certificate, relative to the general population.
Methods	Data on mortality were obtained for divers in the Norwegian Inshore Diving Registry, which comprises data on all divers with a certificate valid for professional diving after 1980. By August 2010, 5526 male divers born between 1950 and 1990 were identified, 3130 of whom were fully certified professional divers. The rest of the Norwegian male population born in the same period (1 604 147) served as referents. Data on mortality were obtained by linkage to the Cause of Death Registry.
Results	Mortality was 23 per 1000 in professional divers and 24 per 1000 in referents. The hazard ratio was 0.79 (confidence interval [CI] 0.63–0.997). Diving-related accidents and suicide were the most common causes of death among divers. Both were significantly more common among divers with the higher level diving certificates.
Conclusions	Overall, mortality in professional divers was lower than that of the general population. However, professional divers had a higher risk of dying from work-related accident or suicide.
Key words	Accidents; mortality registry; occupational diver; professional diver; suicide; violent death.

Introduction

Diving operations are technically complex, and the underwater environment poses a risk of fatal and near-miss accidents [1,2]. In the UK, the work-related fatal accident rate is estimated at 13 deaths per 100 000 divers per year compared with eight and five in construction work and mining, respectively [3].

Apart from the immediate risks associated with technical and operational procedures, including decompression, diving is associated with exposure to hyperoxia, high ambient pressure and increased gas density. Diving may have both immediate and long-term effects on the lungs [4], the central nervous system [5], bone [6,7] and the audiovestibular system [8]. Exposure to life-threatening events may cause serious psychological distress [9]. Several of these factors might cause increased mortality among divers.

Papers addressing mortality in divers are most often case reports or reports on technical and environmental conditions in accidents with fatal outcome [10–12]. To our knowledge, only one previous study has compared mortality in professional divers to that of the general population [13]. At the International Consensus Conference 'Long-term health effects of diving' in 1993, McCallum presented data showing an increased risk of accidental deaths and total deaths in British professional divers compared with the population mortality rates for England and Wales [13].

This study aimed to compare total and cause-specific mortality rates, relative to the general population, among Norwegian professional divers by class of diving certificate.

Methods

Norwegian inshore divers are certified by the Norwegian Labour Inspection Authority, an occupational safety and

health agency of the Ministry of Labour. From 1980 onwards, the Labour Inspection Authority has operated the Norwegian Inshore Diver Registry (Diver Registry) that comprises data on all divers with a certificate valid for professional diving. By August 2010, some 7079 divers were included in the registry. For the first years of the registry, data are incomplete; consequently, we decided to exclude divers born before 1950. Five per cent of all divers registered were women, of whom only 49 were fully certified. Hence women were also excluded from the analyses (Figure 1).

Divers are categorized according to class of certificate. Certificates are graded according to qualification: Class I (Health and Safety Executive part 1 equivalent) requires practical and theoretical training to perform subsea work to a depth of 50 m. Class II (closed bell) requires the same qualifications as class I in addition to theoretical education and practical training in saturation and bell diving. Class III (standard gear) requires the same qualifications as class I in addition to practical training and education in specialized subsea work. Certificate classes R and S have limited validity. Class R is restricted to rescue diving to a maximum of 30 m. Class S is restricted to specific operations such as scientific diving with self-contained underwater breathing apparatus gear to a maximum of 30 m and hyperbaric chamber attendance. Some divers hold more than one class of certificate and some dive both inshore and offshore. The Diver Registry includes inshore divers, while the Norwegian Petroleum Safety Authority manages a separate registry of offshore divers. Those diving both inshore and offshore are recorded in both registries. Based on the age distribution of a subsample of 230 of the 365 offshore divers registered [14], we have estimated that 50% of Norwegian offshore divers born between 1950 and 1990 were included in this study.

For divers holding more than one certificate, we used the highest level in our analyses (II > III > I > R > S). To be able to compare British and Norwegian mortality data, we chose to study fully certified divers, i.e. divers holding class I, II or III certificates (hereafter class I, class II and class III divers). R and S class divers were analysed separately.

The Cause of Death Registry (Death Registry), run by Statistics Norway since 1951, includes data on all deaths certified by medical doctors who are required to report to the registry. One primary cause of death and up to four secondary causes are coded. Causes of death are coded according to the International Classification of

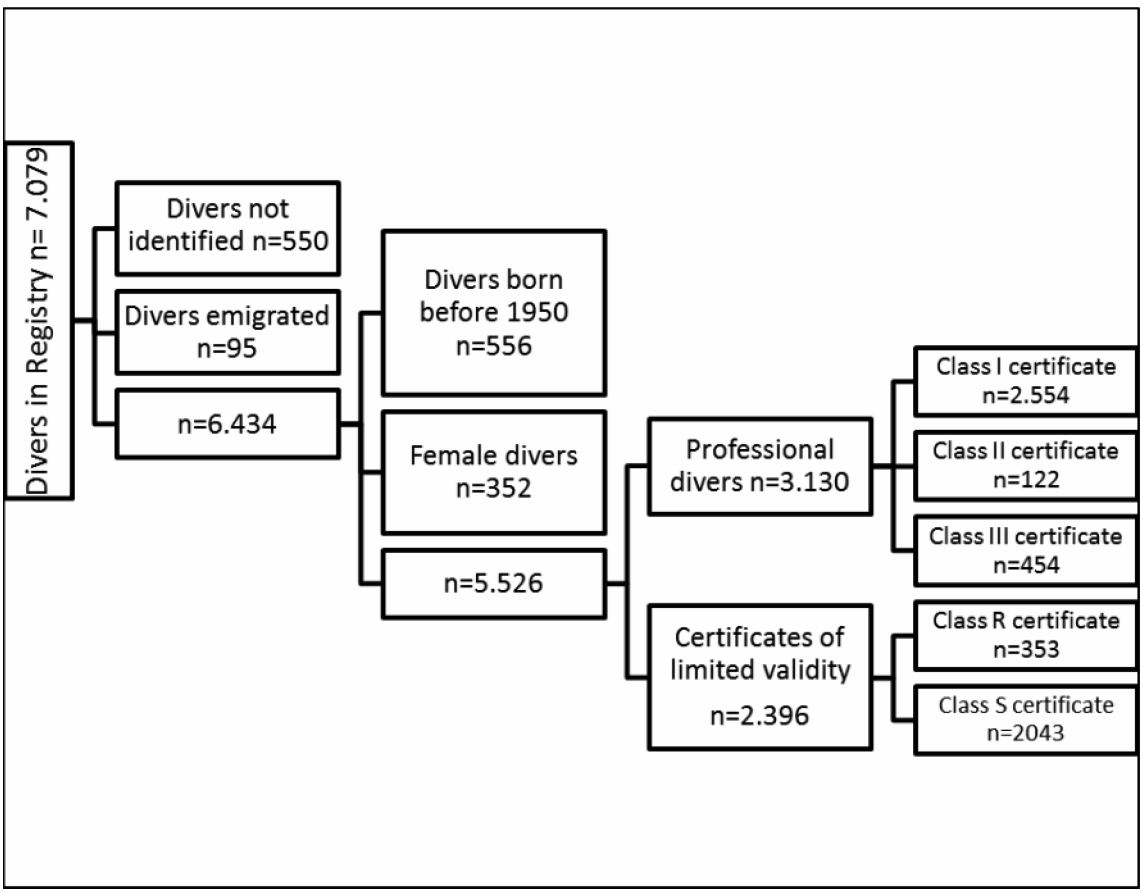

Figure 1. Flow chart showing all divers registered in the Norwegian Inshore Diving Registry by August 2010 and the divers included in the study.

Diseases (ICD). Deaths coded by ICD-7, ICD-8, ICD-9 and ICD-10 were recoded according to the European ICD-10 Causes of Death short list.

The main diagnostic categories are non-violent and violent deaths. Twelve main categories of non-violent causes of death were recorded: neoplasm, endocrine diseases, mental and behavioural disorders, diseases of the nervous system, diseases of the circulatory system, diseases of the respiratory system, diseases of the digestive system, diseases of the skin and subcutaneous tissue, diseases of musculoskeletal and connective tissue and diseases of the genitourinary system, infections and haematological diseases. Violent death is defined as death by external causes of injury, poisoning or accidents. The latter category includes transport accidents, accidental falls and accidental poisoning. Additional violent deaths included are suicide and intentional self-harm, homicide, assault and events of undetermined intent.

The National Population Registry, run by the Directorate of Taxes, issues a personal national identification number (NIN) to all Norwegian citizens as well as to foreigners granted a residence permit. This NIN is a prerequisite for linking registries. Unfortunately, the Diver Registry did not record the NIN. Based on date of birth, first name and surname we identified a NIN for each diver from the National Population Registry. Some divers could not be identified and some had emigrated. We were able to identify 5526 male divers born between 1950 and 1990, 3130 of whom were fully certified professional divers (Figure 1). The rest of the Norwegian male population born in the same period (1 617 660) served as referents. All these records were linked to the Death Registry. Since a professional diving certificate can only be obtained from the age of 18, referents who had died before this age (13 513) were excluded from the study.

Cox regression analyses with adjustment for year of birth were applied to compare overall mortality and cause-specific mortality in divers and referents. For analyses of differences between small subgroups, we used Exact Pearson Chi Square test.

All statistical analyses were performed by SPSS Statistics for Windows, version 20.0 [15].

The study was approved by the Regional committees for medical and health research ethics (2010-01123).

Results

Overall mortality among fully certified professional divers was 23 per 1000, while the mortality among the referents was 24. Adjusted by year of birth, professional divers had a lower mortality compared with the referents, with a hazard ratio of 0.79 (CI 0.63–0.997). Among S and R divers, the overall mortality was 4 per 1000.

There were large differences in mortality between groups of divers holding different certificates (Table 1). Compared with referents, mortality was lower in class I divers ($P < 0.01$) and higher in class II/III divers ($P < 0.01$; Figure 2). Mean age at death was 37.8 years (standard deviation [SD] 9.6) in fully certified divers and 35.5 (SD 11.3) in referents. In S and R divers, mean age at death was 32.6 (SD 10.6).

Violent deaths were 15 and 11 per 1000 in the total population of divers and referents, respectively (non-significant). Violent deaths were more common in divers than in referents ($P < 0.01$). Among the deceased divers, cases of suicide accounted for 24% and diving-related accidents for 17% of the deaths (Table 2). Among fatal accidents, two were due to drowning, four due to high/low ambient pressure and six due to decompression illness. Only class II/III divers had a significantly higher risk of dying from accident or suicide. All cases of suicide appeared in class III divers (Table 3). Survival

Table 1. Total, violent and non-violent deaths among Norwegian professional male divers by class of certificate and referents[a] born between 1950 and 1990

	Total *n*	Deaths *n* (per 1000)	Violent death		Non-violent death	
			n (per 1000)	Age at death mean (SD)	*n* (per 1000)	Age at death mean (SD)
Referents	1 604 147	38 529 (24)	17 824 (11)	30.2 (9.6)	20 705 (13)	40.1 (10.6)
Divers						
Professional	3130	72 (23)	46 (15)		26 (8)	
Class I certificate	2554	47 (18)	29 (11)	34.7 (9.3)	18 (7)	43.9 (8.2)
Class III certificate	454	19 (42)	13 (29)	32.2 (6.3)	6 (13)	50.0 (5.7)
Class II certificate	122	6 (49)	4 (33)	34.3 (3.9)	2 (16)	36.5 (5.0)
Limited validity	2396	10 (4)	7 (3)		3 (1)	
Class S certificate	2043	10 (5)	7 (3)	28.0 (3.2)	3 (1.5)	43.3 (15.0)
Class R certificate	353	0 (0)	0 (0)		0 (0)	

[a]Those deceased before the age of 18 are excluded.

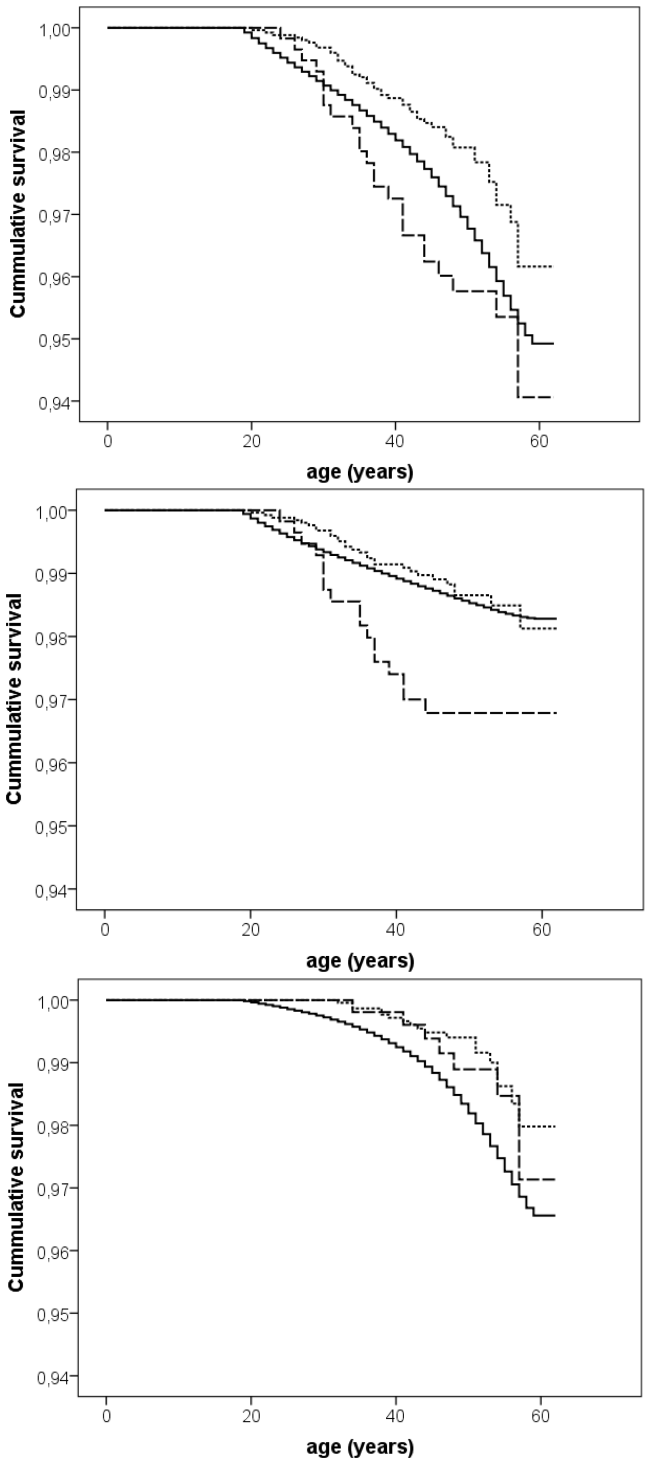

Figure 2. Cumulative survival among Norwegian professional male divers (class I and class II/III diving certificate) and referents born between 1950 and 1990. Lines: referents solid, class I dotted and class II/III broken.

curves for referents, class I divers and class II/III divers, respectively, are shown in Figure 2. Non-violent deaths were less common in divers than referents ($P < 0.05$) due to a lower risk in class I divers. Divers had no increased risk of dying from respiratory, circulatory or neurological diseases or from neoplasms (Tables 2 and 3).

Discussion

Overall, the mortality among fully certified professional divers was lower than that among the referents. However; large differences in mortality were observed between groups of divers holding different certificates. Class II/III divers had an excess mortality due to violent death. Among class I divers, both the overall mortality and the non-violent mortality were lower than among referents. In class R and S divers' total mortality, violent mortality and non-violent mortality were all lower than in referents.

Professional divers selected on the basis of good health would be expected to have a non-violent mortality lower than the general population, provided no excess occupational hazard exists. This held true, however, only for those divers assumed to be the least exposed (i.e. class I divers and class R and S divers). Thus, those with greatest diving exposure had mortality rates similar to the general population, probably due to specific occupational hazards.

In this study, all data had been collected beforehand by Norwegian authorities. Consequently, selection bias was reduced. The unique NIN enables linkage of population-based registries and ensures the completeness of the Death Registry.

Based on data from the Death Registry, we could compare divers to other Norwegian men born in the same period. From the Diver Registry, we had data on all inshore divers with diving certificates valid for professional diving at any point after 1980 and could categorize them according to class of diving certificate.

There are, however, some caveats. The quality of the Diver Registry has never been validated. We had no means to ascertain whether the death certificate data were correct. Since NIN was not included in this registry, not all divers could be traced, due to misspelled or changed names or incorrect dates of birth. However, we managed to identify 92% of the registered divers. Some, but not all, Norwegian offshore divers were included in this study. The Registry comprises only 122 class II divers, whereas 365 Norwegian divers have been reported to have worked offshore [2]. A substantial number of these offshore divers were born before 1950.

The reference population of more than 1.6 million men includes up to 50 000 recreational divers in addition to a few compressed air workers as well as some offshore divers. Thus, pressure, hyperoxia, increased gas density etc. are not hazards absolutely unique to the identified diver population. This fact could underestimate the effects of diving. Considering the size of the reference group, problems due to misclassification of offshore divers as referents should be negligible.

Table 2. Mortality pattern among Norwegian professional male divers (class I, II or III diving certificate) and referents born between 1950 and 1990[a]

	Divers	Referents	Divers	Referents
	n = 3130	*n* = 1 604 147	*n* = 72	*n* = 38 539
	Per 1000 of all		% of the deceased	
Violent deaths	15	11	64	46
Suicide	5	4	24	16
Traffic accidents	3	4	14	15
Diving-related accidents	4	na	17	na
Other accidents	2	4	10	15
Non-violent deaths	8	13	36	54
Circulatory system	2	3	7	13
Respiratory system	<1	<1	1	1
Neoplasms	4	4	15	16
Central nervous system	0	1	0	3
Other	3	5	12	21

na = not applicable.
[a]Those deceased before the age of 18 are excluded.

Table 3. Mortality risk among Norwegian professional male divers (class I and II/III diving certificate) and referents born between 1950 and 1990

	Group	*n* (per 1000)	Crude HR (95% CI)	Adjusted HR[a] (95% CI)
Death	Referents	38 529 (24)	1	1
	Class I certificate	47 (18)	**0.66 (0.50–0.88)**	**0.66 (0.49–0.87)**
	Class II/III certificate	25 (43)	1.26 (0.85–1.86)	1.17 (0.79–1.73)
Violent	Referents	17 824 (11)	1	1
	Class I certificate	29 (11)	0.89 (0.62–1.29)	0.87 (0.60–1.25)
	Class II/III certificate	17 (30)	**2.11 (1.31–3.39)**	**1.92 (1.20–3.09)**
Non-violent	Referents	20 705 (13)	1	1
	Class I certificate	18 (7)	**0.46 (0.29–0.73)**	**0.46 (0.29–0.73)**
	Class II/III certificate	8 (14)	0.68 (0.34–1.36)	0.64 (0.32–1.28)
		n (%)	Crude RR (95% CI)[b]	*P*-value Pearson chi-square[b]
Accidents[b]	Referents	10 788 (7)	1	
	Class I certificate	18 (7)	1.04 (0.66–1.65)	NS
	Class II/III certificate	11 (20)	**2.86 (1.59–5.14)**	**< 0.01**
Suicide[b]	Referents	6326 (4)	1	
	Class I certificate	11 (4)	1.09 (0.61–1.97)	NS
	Class II/III certificate	6 (11)	**2.64 (1.19–5.86)**	**< 0.05**

HR = hazards ratio; NS = not significant.
[a]Adjusted for year of birth.
[b]Exact calculation from 2 × 2 tables.

The Diver Registry holds no detailed data on diving activity and exposure, hence possible relationships between such exposure and mortality could not be studied.

The quality of the cause of death registries in Scandinavia has been under debate [16,17]. A Norwegian diabetes study [18] presented causes of death codes together with all available data on each case for a clinical review committee. The coding varied, depending upon whether the deceased was hospitalized or not. The review committee reclassified 10% of all cases of accident to suicide. Misclassification of causes of death might be an issue in our study as well but is most likely to be non-differential in its impact.

In contrast to McCallum's study of British divers [13] we saw no increase in overall mortality in Norwegian divers. Among all deceased, the prevalence of violent deaths, including suicide, was similar, while the

prevalence of drowning was higher and traffic accidents lower in the British study. The sizes of the two diving populations were comparable, while the mean age of the British divers was lower. The divers included in the British study were active at an earlier time period (1972–81) when diving conditions were probably worse.

There is some discrepancy in the design of McCallum's [13] and our study. The British study included inshore and all offshore divers with an annual medical examination at least twice, which might make them more comparable to our class II/III divers. McCallum estimated expected total mortality and accidental death based on mortality rates for England and Wales. We were able to compare actual death rates in divers to the rest of the male Norwegian population of the same age. The population mortality rates quoted in McCallum's study were lower than the Norwegian rates, most likely due to the differences in age. Violent deaths were most prevalent in class II/III divers due to an increase in cases of suicide and diving-related accidents. The safety of divers depends on several critical factors related to equipment, diving procedures and human factors [1,10,11]. In the underwater environment, even minor technical or human failures may have serious consequences. Work-related risks and accidents may cause serious psychological distress [9,19], which in turn might increase the suicide risk [20,21].

The proportion of suicide in our study was similar to that of the British study. However, the suicide rate among Norwegian divers might be underestimated. In their report to the Ministry of Labour, Lossius *et al.* [2] reported that 11 out of the cohort of 365 offshore divers had committed suicide. In our data, however, there are no cases of suicide among the 122 divers with class II certificates (Table 2). This discrepancy might be attributable to the fact that a substantial number of the offshore divers were born before 1950.

Prospective studies on mortality and morbidity in divers are limited and should be prioritized with greater emphasis on accurate assessment of the diving job-specific exposure factors. The fact that the work as a diver is risky and stressful should be recognized by divers, employers, diving schools and diving medics/medical doctors, as well as by the authorities.

Systematic registration and investigation of fatal as well as non-fatal diving injuries may help identify preventive measures. Such measures may include training and improvements in technical performance of diving equipment, diving procedures and workplace organization, including surface support. The authorities as well as the diving industry, both inshore and offshore, need to uphold their focus on health and safety issues and monitor the impacts of changes in procedures, equipment and regulations.

For divers involved in adverse events, an emergency care system and a follow-up programme for subsequent health problems, particularly post-traumatic stress symptoms, should be accessible.

Key points

- Diving is a dangerous occupation. This study addresses the overall mortality rate among Norwegian divers compared with that of the general population.
- Professional divers holding the higher class certificates had an increased risk of dying a violent death although overall mortality was not increased.
- The increase in violent deaths was largely attributable to an increase in cases of suicide and diving-related accidents. Suitably targeted precautionary measures might reduce these numbers.

Funding

The Norwegian Centre for Diving Medicine.

Acknowledgements

We wish to thank the Norwegian Labour Inspection Authority who allowed us to use the Diving Registry, the staff at the Diving School at Bergen University College for practical assistance, Berit Johannessen at the Department of Occupational Medicine, the IT-Department at Haukeland University Hospital for identifying divers and Professor Lorentz M. Irgens for help with the final version of the manuscript.

Conflicts of interest

None declared.

References

1. Sagvolden T, Olshausen KD, Jørgensen R. Analysis of risk in manned underwater operation. SPE 98460. Proceedings of the Conference on Health, Safety, and Environment in Oil and Gas Exploration. Abu Dhabi, U.A.E., 2–4 April 2006. http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-98460-MS# (1 February 2013, date last accessed).
2. NOU. Pionerdykkerne i Nordsjøen.Oslo: Ministry of Government Administration, Reform and Church Affairs, NOU 2003:5 [Commission of Enquiry to investigate all circumstances related to diving in the North Sea in the pioneer period]. http://www.regjeringen.no/nb/dep/fad/dok/nouer/2003/nou-2003–5.html?id=381525 (1 February 2013, date last accessed).
3. Lusby N. Diving Statistics – a tool for improvement. Proceedings of the Norwegian Underwater Intervention, Diving Seminar. Bergen, 2011. http://www.nui.no/sitefiles/22/Dykkeseminar/2011/pdf/NLustbyesesjon1.pdf (1 February 2013, date last accessed).

4. Thorsen E, Segadal K, Kambestad BK. Mechanisms of reduced pulmonary function after a saturation dive. *Eur Respir J* 1994;**7:**4–10.
5. Grønning M, Aarli JA. Neurological effects of deep diving. *J Neurol Sci* 2011;**304:**17–21.
6. Jiang CQ, Wang B, Yu CF *et al.* Dysbaric osteonecrosis by X-ray and CT scan in Chinese divers. *Undersea Hyperb Med* 2005;**32:**169–174.
7. Uzun G, Toklu AS, Yildiz S *et al.* Dysbaric osteonecrosis screening in Turkish Navy divers. *Aviat Space Environ Med* 2008;**79:**44–46.
8. Goplen FK, Grønning M, Irgens A, Sundal E, Nordahl SH. Vestibular symptoms and otoneurological findings in retired offshore divers. *Aviat Space Environ Med* 2007;**78:**414–419.
9. Troland K, Sundal E, Irgens A, Gronning M, Thorsen E. Potentially traumatic events and posttraumatic stress reaction in retired North Sea divers. Proceedings of the XXVIIth Annual Meeting of the European Underwater Biomedical Society (EUBS). Gdansk, Poland: EUBS, 2011; 22. http://www.eubs2011.org/media/files/downloads/download_01.pdf (01 February 2013, date last accessed).
10. Bradley ME. Commercial diving fatalities. *Aviat Space Environ Med* 1984;**55:**721–724.
11. Denoble PJ, Caruso JL, Dear Gde L, Pieper CF, Vann RD. Common causes of open-circuit recreational diving fatalities. *Undersea Hyperb Med* 2008;**35:**393–406.
12. Lippmann J, Lawrence C. Diving-related deaths in Hong Kong waters, 2006–2009. *Undersea Hyperb Med* 2012;**39:**891–900.
13. McCallum RI. A study of the mortality of professional divers. In: Hope A, Lund T, Elliot DG, Halsey MJ, Wiig H, eds. *Long Term Health Effects of Diving. Proceedings of International Consensus Conference*. Godoysund, Bergen: Norwegian Underwater Technology Centre, 1993; 179–185.
14. Irgens A, Grønning M, Troland K, Sundal E, Nyland H, Thorsen E. Reduced health-related quality of life in former North Sea divers is associated with decompression sickness. *Occup Med (Lond)* 2007;**57:**349–354.
15. IBM Corp. *IBM SPSS Statistics for Windows, Version 20.0. Released 2011*. Armonk, NY: IBM Corp.
16. Reseland S. [Bad quality of the Cause of Death Registry]. *Tidsskr Nor Laegeforen* 2009;**129:**894.
17. Gjersøe P, Andersen SE, Mølbak AG, Wulff HR, Thomsen OO. [Reliability of death certificates. The reproducibility of the recorded causes of death in patients admitted to departments of internal medicine]. *Ugeskr Laeger* 1998;**160:**5030–5034.
18. Skrivarhaug T, Bangstad HJ, Stene LC, Sandvik L, Hanssen KF, Joner G. Long-term mortality in a nationwide cohort of childhood-onset type 1 diabetic patients in Norway. *Diabetologia* 2006;**49:**298–305.
19. Asmundson GJ, Norton GR, Allerdings MD, Norton PJ, Larsen DK. Posttraumatic stress disorder and work-related injury. *J Anxiety Disord* 1998;**12:**57–69.
20. Cougle JR, Resnick H, Kilpatrick DG. PTSD, depression, and their comorbidity in relation to suicidality: cross-sectional and prospective analyses of a national probability sample of women. *Depress Anxiety* 2009;**26:**1151–1157.
21. Bernal M, Haro JM, Bernert S *et al.*; ESEMED/MHEDEA Investigators. Risk factors for suicidality in Europe: results from the ESEMED study. *J Affect Disord* 2007;**101:**27–34.