Original articles

The predictive power of initial fitness-to-dive certification procedures for occupational divers in New Zealand

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Key Words
Health surveillance, occupational diving, medicals diving, research

Abstract
(Greig P, Gorman D, Drewry A, Gamble G. The predictive power of initial fitness-to-dive certification procedures for occupational divers in New Zealand. *SPUMS J* 2003; 33:182-187)
Objective: To determine which aspects of the initial medical assessment of New Zealand occupational divers influence the 'diving fitness' certification outcome.
Methods: The assessment process and the final certification outcome were analysed by calculation of sensitivities and specificities, positive and negative predictive powers, and the areas under the respective receiver operator characteristic curves for a random selection of 300 occupational divers.
Results: Logistic regression revealed only three independent predictors of outcome: a past history of asthma ($p < 0.0001$), abnormal cardiac auscultation ($p < 0.0005$) and abnormal respiratory function tests ($p < 0.0001$).
Conclusion: The certification outcome of medical assessments of occupational diver fitness in New Zealand, which is based on Australian and New Zealand Standard AS/NZ 2299, is largely determined by free text written on the questionnaire by the medical assessor and by respiratory system assessment. The predictive power of the survey elements would be more useful in diagnosis than a health survey, which is consistent with the origin of AS/NZ 2299. This is a strong argument for both reform of the process and for the ongoing restriction of such assessments to specifically trained medical practitioners.

Introduction

Occupational diving can be physically and psychologically demanding and occurs in an unpredictable, mobile, dense, irrespirable environment.[1] Although human error is primarily responsible for most diving incidents and accidents, it is essential that a person be 'fit to dive' if risks are to be managed adequately.[2-4] The issue then is how to assess this 'fitness' and to what extent this can be done by a physician.

In New Zealand, subcontractors to the Department of Labour (DoL) oversee occupational diving health assessments.[5,6] The process is based on an Australian and New Zealand Standard (AS/NZ 2299),[7] which is a derivative of Royal Australian Navy regulations (ABR 155).[8] Accredited diving medical examiners assess candidates using the AS/NZ 2299 questionnaire, examine the candidate and complete a standard record, and similarly record the findings of both required (e.g., air audiogram, lung function tests) and discretionary investigations (e.g., chest X-ray in a candidate with a history of respiratory disease). This questionnaire and these records are then audited, further information is obtained as necessary and an appropriate certificate is issued. A trial of discretionary certification and of only periodic (five-yearly) clinical assessment is underway, but a test of the efficacy of these modalities will not occur until sufficient occupational divers have completed a five-year cycle.

This analysis is of the predictive power[9,10] of the specific items of the initial assessment of fitness for occupational diving with respect to certification outcome. The AS/NZ 2299 questionnaire has never been tested in this regard. Anecdotal experience in employed divers suggests that a clinical assessment in the absence of a positive questionnaire response is poorly predictive and that similarly poor predictive power exists for investigations generally. Specifically, there is no diving-relevant test of cardiovascular fitness, and lung function tests are poorly predictive of risk for lung injury due to decompression barotrauma.[11]

A longitudinal study involving very large numbers of divers is needed to assess the quality of certification decisions in the context of long-term diver health and performance. Here, we will accept the certification response outcome as such and will determine what features of the assessment process are influential as a preface to reform if necessary.

Methods

POPULATION

The medical and dive records of all New Zealand occupational divers are kept in a confidential database at the Naval Hospital in Auckland. The subject population was the 1,790 occupational divers who had undergone an initial assessment of their fitness to dive up to and during the calendar year 2002 and remained registered as an occupational diver with the DoL.

SAMPLE SIZE

The study design was piloted using a random sample of 30 divers. Questionnaire responses, examination and investigation findings were independently grouped into organ systems by two observers. Kappa coefficient values were calculated to test internal agreement. Subsequently, each diver's medical record was categorised as follows:

1 positive questionnaire responses only;
2 positive clinical and or investigation findings only;
3 positive questionnaire responses and positive clinical and or investigation findings;
4 positive questionnaire responses or positive clinical and or investigation findings.

The proportion in each category enabled calculation of sensitivity, specificity, the positive predictive value (PPV), the negative predictive value (NPV), and receiver operator characteristic (ROC) values.[9,10]

Outcomes for the pilot and main study were categorised as follows:

1 accepted for certification without further action (category one pass);
2 accepted for certification after further action (category two pass);
3 not accepted for certification (fail).

A ROC plot was then determined for each organ system and for a positive screen being determined for a category two pass and or a fail by successively setting the positive screen threshold at one, two, three, four or more positive responses or findings.

From the pilot study, data estimates of the precision (width of the 95% confidence intervals) of sensitivity and specificity measures with various sample sizes could be calculated. The final study sample size of 300 was selected to give the optimal balance of tight confidence intervals and practicability.

For the main study, the methods described above for the pilot study were employed for a randomly selected sample of 300 divers, analysing the following organ systems. The organ systems not listed are those for which there were no positive responses:

1 respiratory system: positive questionnaire responses, positive examination findings, abnormal lung function spirometry (RFTs) results, abnormal chest X-ray findings;
2 cardiovascular system: positive questionnaire responses, positive examination findings, abnormal chest X-ray findings, abnormal resting and exercise ECGs (ETT);
3 neurological system: positive questionnaire responses, positive examination findings, abnormal audiometry results;
4 otorhinolaryngological system: positive questionnaire responses, positive examination findings, abnormal audiometry results, abnormal tympanometry results.

In addition to the statistical analysis described above, the frequencies of positive questionnaire responses and examination and investigation results were considered independently of outcome.

Results

The demographical data for the main study sample are listed in Table 1. There were 32 divers who had a category two pass. One diver with severe obstructive airways disease was determined unfit for occupational diving. Five of the 32 category two passes occurred only after a case conference involving the medical assessor, the diver, their employer, the dive school manager if appropriate, and DOL representatives. Such a discretionary outcome is not a subject for discussion in this report.

The AS/NZ 2299 questionnaire has 89 items requiring a yes/no answer, with free space for the medical assessor's

TABLE 1
DEMOGRAPHIC DATA FOR THE MAIN STUDY SUBJECTS

Sex	254 males 46 females
Age (years)	Median = 35 Range = 17 - 66
Previous diving experience	
Number of dives	Median = 200 Range = 0 - 10,000 Interquartile range = 100 - 500
Level of training	SCUBA (air) only = 235 SCUBA (mixed gases) = 56 SSBA = 10 Saturation diving = 9
Year of first dive	Mode = 2000 Range = 1960 - 2002

TABLE 2
CLASSIFICATION OF QUESTIONS AND POSITIVE RESPONSE RATES BY ORGAN SYSTEM

System	Number of Questions	PRR (per 1,000 questions)	Most frequently positive question	
Otolarnygological	14	57	"Do you suffer severe motion sickness"	(n=33)
Respiratory (RS)	13	40	"Do any of your relatives suffer from asthma"	(n=53)
(Co-categorised with CVS)	*3*			
Cardiovascular (CVS)	10	13	"Have you ever had an abnormal ECG test?"	(n=9)
(Co-categorised with RS)	*3*			
Neurological (CNS)	13	52	"Do you require prescription spectacles?"	(n=73)
(Co-categorised with MS)	*1*			
Musculoskeletal (MS)	5	193	"Have you ever sustained a fracture?"	(n=122)
(Co-categorised with CNS)	*1*			
Haematological	3	3	"Have you ever had an abnormal blood test?"	(n=2)
Gastrointestinal	3	38	"Have you ever suffered a hernia/rupture?"	(n=18)
Genitourinary	1	3	"Do you suffer from kidney or bladder disease?"	(n=1)
Endocrine	1	0	N/A	
Others	30	60	"Have you ever been admitted to hospital for any reason?"	(n=173)

PRR: Positive Response Rate

TABLE 3
SENSITIVITY, SPECIFICITY, POSITIVE (PPV) AND NEGATIVE (NPV) PREDICTIVE VALUES FOR POSITIVE QUESTIONNAIRE RESPONSES BY ORGAN SYSTEM AND FOR EXAMINATION FINDINGS VERSUS OUTCOME OF CERTIFICATION

	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Questionnaire only	0.97 (0.9, 1)	0.21 (0.16, 0.25)	0.13 (0.09, 0.17)	0.98 (0.95, 1)
Respiratory and CVS exam	0	1	undefined	0.89 (0.85, 0.93)
Neurological exam	0.06 (0, 0.14)	0.92 (0.89, 0.95)	0.09 (0, 0.2)	0.89 (0.85, 0.93)
ENT exam	0.21 (0.07, 0.35)	0.88 (0.84, 0.92)	0.18 (0.06, 0.3)	0.9 (0.86, 0.94)
RFT	0.67 (0.51, 0.83)	0.66 (0.6, 0.72)	0.19 (0.12, 0.27)	0.94 (0.91, 0.97)
Tympanometry	0.52 (0.34, 0.69)	0.55 (0.49, 0.61)	0.12 (0.07, 0.18)	0.9 (0.86, 0.95)
Audiometry	0	1	undefined	0.89 (0.95, 1)
Questionnaire or				
RFT	1	0.21 (0.16, 0.25)	0.13 (0.09, 0.18)	1
Audiology	0.97 (0.91, 1)	0.19 (0.14, 0.24)	0.13 (0.09, 0.17)	0.98 (0.94, 1)
Tympanometry	0.97 (0.91, 1)	0.21 (0.16, 0.25)	0.13 (0.09, 0.17)	10.98 (0.95, 1)

RFT: respiratory function tests

comments. The organ system categorisation of the 89 questionnaire items was internally valid, with a 93% concordance (kappa coefficient 0.92, 95% CI = 0.87 to 0.97). The positive response rate per 1000 questions for each organ system is shown in Table 2. Only 56 (19%) questionnaires contained no positive responses (median number of positive responses = 2; range 0 to 14). Of the 300 divers, 102 responded positively to questions about previous diving-related problems, most commonly nitrogen narcosis, ear and sinus barotrauma and decompression illness.

TABLE 4
THE NUMBER OF POSITIVE FINDINGS FROM EACH QUESTIONNAIRE OR EXAMINATION VERSUS RELEVANT TEST OUTCOME

	No. +ve	Sensitivity (95%CI)	Specificity (95%CI)	PPV (95%CI)	NPV (95%CI)
ETT	1	Undefined	0.53 (0.48-0.49)	0 (0-0)	1 (1-1)
	2	Undefined	0.88 (0.84-0.92)	0 (0-0)	1 (1-1)
	3	Undefined	0.96 (0.94-0.98)	0 (0-0)	1 (1-1)
	4+	Undefined	0.98 (0.97-1)	0 (0-0)	1 (1-1)
Audio	1	0.78 (0.65-0.9)	0.29 (0.23-0.34)	0.14 (0.1-0.19)	0.89 (0.83-0.96)
	2	0.4 (0.25-0.55)	0.63 (0.57-0.69)	0.14 (0.08-0.21)	0.87 (0.82-0.92)
	3	0.15 (0.04-0.26)	0.83 (0.78-0.87)	0.12 (0.03-0.21)	0.86 (0.82-0.91)
	4+	0.05 (0-0.12)	0.93 (0.9-0.96)	0.1 (0.03-0.22)	0.86 (0.82-0.9)
Tymp	1	1 (1-1)	0.49 (0.43-0.54)	0.01(0.00-0.02)	1 (1-1)
	2	1 (1-1)	0.76 (0.71-0.81)	0.01 (0.00-0.04)	1 (1-1)
	3	1 (1-1)	0.89 (0.85-0.92)	0.03 (0.00-0.08)	1 (1-1)
	4+	0 (0-0)	0.95 (0.93-0.97)	0 (0-0)	1 (0.99-1)
RFT	1	0.6 (0.3-0.9)	0.63 (0.58-0.69)	0.05 (0.01-0.09)	0.98 (0.96-1)
	2	0.4 (0.1-0.7)	0.9 (0.87-0.94)	0.13 (0.01-0.24)	0.98 (0.96-1)
	3	0.2 (0-0.45)	0.97 (0.95-0.99)	0.2 (-0.05-0.45)	0.97 (0.95-0.99)
	4+	0 (0-0)	0.99 (0.97-1)	0 (0-0)	0.97 (0.95-0.99)
CXR	1	1 (1-1)	0.54 (0.48-0.59)	0.01 (0-0.03)	1 (1-1)
	2	0 (0-0)	0.88 (0.84-0.92)	0 (0-0)	0.99 (0.98-1)
	3	0 (0-0)	0.96 (0.94-0.98)	0 (0-0)	0.99 (0.98-1)
	4+	0 (0-0)	0.98 (0.97-1)	0 (0-0)	0.99 (0.98-1)

ETT: Exercise Tolerance Test; **Audio**: Audiometry; **Tymp**: Tympanometry; **RFT**: Respiratory Function Test
CXR: Chest X-ray

The AS/NZ 2299 examination form has 48 items, some for observed values (e.g. height, weight) and others for normal/abnormal notation.

All divers had audiometry (40 abnormal, 13%), RFTs (10 abnormal, 3%) and tympanometry (one abnormal) performed. An exercise tolerance test was performed on three of the divers; none were abnormal. Two out of 295 chest X-rays performed were abnormal.

Specificity, sensitivity, PPV and NPV data with respect to certification outcome (category one passes versus category two passes and failures) are shown in Tables 3 and 4.

The area under the curve (AUC) of the ROC curves for all single and aggregated common organ system indices are shown in Table 5. Any AUC determination for which a 95% confidence interval approximates 0.5 has little predictive value.

Predictors of certification outcome were sought from all recorded items, with the exception of free-text comments, which could not be standardised. Stepwise logistic regression determined the following three independent predictors of outcome, which were then confirmed by forward logistic regression analysis:

1 past history of asthma ($p < 0.0001$);
2 abnormal cardiac auscultation findings ($p < 0.0005$);
3 abnormal RFTs ($p < 0.0001$).

TABLE 5
AUC DATA FOR ROC PLOTS FOR AGGREGATED ORGAN SYSTEM INDICES

Organ system	AUC value	(95% CI)
Respiratory	0.67	(0.54, 0.8)
Gastrointestinal	0.65	(0.52, 0.79)
ENT	0.63	(0.50, 0.76)
Neurological	0.6	(0.47, 0.73)
Other	0.6	(0.47, 0.73)
Cardiovascular	0.6	(0.47, 0.73)
Musculoskeletal	0.56	(0.43, 0.69)
Genitourinary	Insufficient positive findings	
Haematological	Insufficient positive findings	
OVERALL	0.6	(0.47, 0.73)

Discussion

The AS/NZ 2299 questionnaire used to screen occupational

divers in New Zealand, in isolation and in the context of certification outcome, has high sensitivity and NPV's, but low specificity and PPV's. Of the organ system examinations and required investigations, only RFTs possessed both high PPV and NPV. The AUC data similarly produced significant results only for the respiratory system items. Combinations of questions and findings in other organ systems did not cause an improvement in the NPV/PPV profiles. Three independent predictors of outcome, a past history of asthma, abnormal cardiac auscultation and abnormal RFTs, were identified in multivariate analysis. All three are clinically plausible.[1]

Many questions failed to generate any positive answers. However, not all of these questions warrant exclusion. This highlights the difference between clinical and statistical significance. Some conditions may be unusual in such a (potential) worker cohort, but of great significance to diving, e.g., epilepsy, such that concerns regarding statistical validity are superseded by the necessity of detection. The same comments apply to some items of the examination and investigations. Some others need to be included for purposes of baseline data collection. An example of the latter is audiology, where many (13%) of those undergoing this initial fitness assessment for diving were noted to have pre-existing hearing loss.

The optimal balance of sensitivity and specificity depends on the significance of false positive and negative results.[9] In this analysis, none of the questionnaire, examination and investigation items, alone or in combination, offer an acceptable balance. In general, the profile here of low PPV and high NPV would be more useful in diagnosis than in health surveillance. This conclusion is supported by the ROC-AUC analyses, in which, as cited above, the closer an AUC value lies to 0.5, the less statistically significant is the factor. This result is predictable given the genesis of AS/NZ 2299; a list of diseases that were considered relative and absolute contra-indications to diving was used as the basis for the standard. Consequently, the survey has some diagnostic utility. However, this should be an exercise in determining the level of health-related risk for someone who wishes to become an occupational diver. A high-utility occupational health survey would then be based on a list of determined functional competencies and not on a list of diseases.

These data suggest that decisions regarding 'fitness to dive' are not based so much on the questionnaire response, but more so on the free-text component. It follows that, if the AS/NZ 2299 questionnaire is to be used, review of the yes/no responses and free-text clarification by the medical assessor and a subsequent clinical audit are critical components. It is also apparent that such an assessor must not be naive in the context of diving medicine. The real conclusion here, however, is that the AS/NZ 2299 questionnaire is of low utility and needs to be replaced.

It is not clear from this analysis as to the merit of clinical examination and investigation in the absence of positive questionnaire responses, in part due to the poor predictive power of the questionnaire. Nevertheless, it is noteworthy that both abnormal cardiac auscultation and RFTs were predictive of certification outcome, independent of cardiovascular and respiratory system questionnaire responses. It is highly likely that this observation would apply only to initial assessments, but this will be tested subsequently. Again, the conclusion here is that reform of the health surveillance of occupational divers is justifiable.

The relatively small number of fails within each organ system limits this study. However, by focussing on the data that can be objectively collected rather than the process of finally passing or failing a diver, the possibility was raised for an objective audit of the utility of the questionnaire component.

Although not tested here, our hypothesis is that assessment of diver 'fitness' will be best served by way of functional capacity (competency) tests and physicians may have little role in this process.

References

1 Bevan J. Commercial diving practice and equipment. In: Bennett PB, Elliott DH, editors. *The Physiology and Medicine of Diving*. 3rd ed. San Pedro: Best Publishing Co, 1982

2 Acott CJ. Scuba diving incident reporting, the first 125 reports. *SPUMS J* 1992; 22: 218-221

3 Acott CJ. Diving incident monitoring, an update. *SPUMS J* 1994; 24: 42-49

4 Acott CJ. 457 equipment incident reports. *SPUMS J* 2001; 31: 182-195

5 Occupational Health and Safety Service. *Guidelines to occupational diving 2001*. Wellington: Occupational Health and Safety Service, 2001

6 White B. *A guide to the Health and Safety in Employment Act 1992*. Wellington: Occupational Health and Safety Service, 2000

7 Australian and New Standard AS/NZ 2299.1 Supp 1: 1999: *Occupational diving operations - Standard Operational Practice*

8 *Royal Australian Navy Diving Manual*, Australian Book of Regulations, ABR 155

9 Beaglehole R, Bonita R, Kjellstrom T. *Basic epidemiology*. Geneva: World Health Organisation, 1993

10 Knottnerus JA, van Weel C, Muris JWM. Evidence base of clinical diagnosis: Evaluation of diagnostic procedures. *BMJ* 2002; 324: 477-480

11 Brooks GJ, Pethybridge RJ, Pearson RR. Lung function reference values for FEV1, FEV1/FVC ratio and FEF75-85 derived from the results of screening 3788 Royal Navy submariners and submarine candidates by spirometry. *EUBS Paper No. 13*, Aberdeen, 1988

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