DEVELOPMENT OF A HIGH-UTILITY, EVIDENCE-BASED SYSTEM OF OCCUPATIONAL HEALTH SURVEILLANCE FOR DIVERS

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“People don’t resist change. They resist being changed.” … Peter Senge

Abstract

Routine health surveillance, and specifically routine occupational health surveillance in the form of a medical examination, is commonplace, and for many workers is mandatory. Perpetuation of workplace policies that mandate testing such as 'the annual medical' is influenced by a variety of 'stakeholder' agendas. However, evidence of the utility of such testing is lacking.

The primary aim of this research was to find evidence to clarify whether widely accepted basic components of the current occupational diver health surveillance programme are 'fit for purpose' and actually enable an appropriate determination of fitness to work. The working hypothesis underlying the studies that comprise this thesis was that there is no evidence to support many of the current mandatory requirements of occupational health surveillance or fitness-to-work determination. A secondary aim was to propose a justifiable and logical health surveillance system for this particular group of workers, professional divers, with possible broader applicability to other categories of workers.

Using the case of professional divers as an exemplar, the various components of the routine health surveillance and certification process were examined for their contribution to determining fitness to dive. First, the only two mandatory investigations of the physical examination are tests of lung function and hearing. The value of these investigations was assessed using three longitudinal studies seeking evidence of any correlation between professional diving and clinically significant deterioration in either lung function or hearing. Second, a postal survey was conducted to determine whether the doctors who perform dive medical examinations were able to accurately determine fitness to dive based on vital health information. Third, diver satisfaction with the current certification system was determined using an internet-based survey of registered divers over a 12-month period. Fourth, a qualitative study examined diver interpretations and the value of the individual component questions in the current annual health questionnaire. Fifth, the utility of the current surveillance system was examined using two audits spanning different 5-year intervals. These audits involved analysis of divers' health records to determine whether the vital information leading to diver disqualification came from the annual health questionnaire or from the medical examination. Finally, an audit of ex-divers was conducted to determine whether health-related issues were a significant factor in the high rate of attrition of professional divers.

The results demonstrated that neither lung function nor hearing was significantly affected by long-term professional diving activity. The doctors who conduct medical assessments of divers were found to perform little better than chance in determining fitness to dive. Most divers were satisfied with the current health certification/surveillance system. Dissatisfaction was mainly related to cost and a limited understanding of the reasons for the various facets of the system. All questions comprising the annual health questionnaire were correctly interpreted by divers, although some questions were considered of low value by experts. Audits of the current system concluded that routine physical examination or investigations did not add significantly to the value of the health questionnaire in uncovering those conditions incompatible with, or requiring modification of, ongoing professional diving. Finally, health-related factors did not appear to be a significant determinant of diver attrition, strongly validating the modifications thus far to the health surveillance system.

The over-all conclusion to be drawn from this body of research is that routine medical examinations of professional divers are unreliable and unnecessary. A modified surveillance programme, centred on a health questionnaire, has been proposed for this specialised group of workers, with the aim of providing considerable savings of time and money, but no increase in health risk. Other groups of workers are likely to be similarly affected by health surveillance protocols in need of revision for lack of a reliable supporting evidence base.

Preface and Acknowledgements

My initial research into the health of professional divers began in 2008 while employed as a medical officer with the Royal New Zealand Navy (RNZN). The earliest studies (see Chapters Three and Eight) were prompted by a modification to the divers' routine health surveillance programme introduced five years earlier, and one of the aims was to validate that change. The repository of medical records for all of New Zealand's professional divers was located at the naval base, and easily accessible. Subsequent research has been facilitated by the computerisation of divers' medical records since 2010, and has focused on the value of existing health surveillance requirements.

The data presented in this thesis have mostly been published in the peer-reviewed literature. Most of the studies were published in *Diving and Hyperbaric Medicine* which is arguably the pre-eminent academic publication for this relatively small medical sub-specialty. The exceptions are the two audits presented in Chapter Eight which were submitted to, and published in, *Internal Medicine Journal,* because they were felt to be of interest to the broader medical community. None of the data have previously been presented to this or any other university for any purpose, with the exception of Tables Three to Six and Figures One and Two in Chapter Three, which were presented to the University of Auckland as a part of my dissertation for the Master of Medical Science degree. However, these data have been reviewed for presentation within this thesis and provided context for subsequent work in the same area, namely, divers' respiratory function. The reference data set used in the initial study was superseded, and absorbed, by the set used in the subsequent study. The intellectual property of all original work is mine.

I am especially indebted to Professor Des Gorman for inspiring and initiating this line of research, and to both him and Professor Simon Mitchell for their invaluable mentorship and contribution to the studies described herein. Others have also provided crucial input, and their specific roles in each study cited have been acknowledged (see Table One). I acknowledge the New Zealand (NZ) professional diving community, the main subject of this thesis, for allowing access to its data, without which, most of the included studies would not have been possible. I am grateful for the forbearance of my work colleagues, past and present, at the Royal New Zealand Navy and the Waitemata District Health Board Hyperbaric Unit. Most importantly, I acknowledge the unwavering, ever-present support from my wife, Sandra, and our two children, Hannah and Alex.

Table One	**Major publications of the research work cited in this thesis**
<u>Chapter Three Citations</u>	<u>Comments</u>
Sames, C., Gorman, D. F., Mitchell, S. J., & Gamble, G. (2009a). *Diving Hyperb Med, 39*(3), 133-7	This is a description of an audit of professional diver lung function data over a five year period. Professors Gorman and Mitchell assisted in the study and helped write the manuscript. Mr Gamble is a University of Auckland biostatistician who assisted with statistical advice and analysis.
Sames, C., Gorman, D. F., Mitchell, S. J., & Zhou, L. (2018). *Diving Hyperb Med, 48*(1), 10-16	This is a description of a longitudinal audit of professional diver lung function data over a 10-25 year period. Professors Gorman and Mitchell assisted with study design and manuscript writing. Dr Zhou is an epidemiologist who provided statistical advice and analysis.
<u>Chapters Four to Six inclusive Citations</u>	<u>Comments</u>
Sames, C., Gorman, D. F., Mitchell, S. J., & Zhou, L. (2019a). *Diving Hyperb Med, 49*(1), 2-8	This is a description of an audit of the audiometric data of professional divers spanning careers of 10-25 years. Professors Gorman and Mitchell assisted with study design and manuscript writing. Dr Zhou is an epidemiologist who provided statistical advice and analysis.
Sames, C., Gorman, D., & Mitchell, S. (2012). *Diving Hyperb Med, 42*(1), 24-9	This is a description of a postal survey of diving doctors and general practitioners to determine and compare their accuracy in assessing medical fitness to dive. Professors Gorman and Mitchell assisted with study design and manuscript writing.
Sames, C., Gorman, D. F., Mitchell, S. J., & Zhou, L. (2020). *Diving Hyperb Med, 50*(1), 28-33	This is a description of an internet-based survey of professional divers to determine their level of satisfaction with the current system of certification and health surveillance. Professors Gorman and Mitchell assisted with study design and manuscript writing. Dr Zhou provided statistical advice and analysis.

Chapter Eight Citations	Comments
Sames, C., Gorman, D., Mitchell, S. J., & Gamble, G. (2009b). *Intern Med J, 39*, 763-70	This is a description of an audit, spanning five years, of the utility of routine medical examinations of occupational divers. Professors Gorman and Mitchell assisted with the study and writing of the manuscript. Mr Gamble is a University of Auckland biostatistician who provided statistical advice and analysis.
Sames, C., Gorman, D., Mitchell, S., & Sandiford, P. (2016). *Intern Med J, 46*, 1146-52	This is a description of a further audit of the value of various components of the routine certification and health surveillance of professional divers, spanning a different five-year period than the above study. Professors Gorman and Mitchell assisted with the study and writing of the manuscript. Dr Sandiford is an epidemiologist who assisted with statistical advice and analysis.
Chapter Nine Citation	
Sames, C., Gorman, D. F., Mitchell, S. J., & Zhou, L. (2019b). *Diving Hyperb Med, 49*(2), 107-111	This is a description of a survey of ex-professional divers to determine the impact of health status on their decision to leave the industry. Professors Gorman and Mitchell assisted with study design and manuscript writing. Dr Zhou is an epidemiologist who provided statistical advice and analysis.

Interest in occupational medicine was the main motivation for my joining the RNZN as a medical officer. Naval medical service was, at that time, the most feasible entry to the field of diving and hyperbaric medicine, a field closely associated with navies since its earliest days. Frequent encounters with navy divers led me to question the value of persisting with annual full medical examinations for this notoriously fit occupational group, as the New Zealand Defence Force retained the annual requirement even after it had been reduced to five-yearly for the New Zealand diving industry in general. In parallel with my experience with naval divers, I also questioned the justification for similar routine examinations of the other mariners and oil and gas industry ‘topside’ workers I often encountered, many of whom are required to undergo frequent and extensive medical examinations as a condition of employment. The focus of this thesis, however, is the NZ professional diving cohort, which will serve as an exemplar, to demonstrate a process by which health surveillance of an occupational group can be modified and then implemented on a rational, evidential basis.

The outline of this thesis is as follows: Chapter One is an introduction to the health surveillance and fitness-for-work concepts underlying this thesis. Specifically, it provides an overview of the history and development of, and evidence for and against, both primary health surveillance in the asymptomatic general population, and routine occupational health and fitness-for-work screening. Chapter Two outlines the development of the current system of surveillance of New Zealand (NZ) professional divers. Studies relating to the NZ cohort of professional divers are then described in Chapters Three to Nine. These studies, most of which have been published in peer-reviewed literature, comprise the body of evidence supporting my hypothesis that routine occupational medical examinations are of little value, and that the process of professional diver certification needed modifying to be fit for purpose. The published studies are presented essentially in the form that they were published, with minor amendments only to allow sequential numbering of tables and figures, and forward and backward referencing to improve cohesion throughout the thesis. Each of the following chapters includes review of the relevant literature. Chapters Three and Four describe longitudinal studies of diver lung function and hearing. Chapter Five describes a postal survey soliciting opinions on what constitutes 'fitness-to-dive' from doctors who undertake divers' medical examinations. Chapter Six describes an audit of divers' satisfaction with the current certification system, while Chapter Seven describes a qualitative survey of experts' and divers' opinions of the value and interpretation of components of the current health questionnaire completed by divers annually. Chapter Eight describes two audits of the NZ diver certification system, undertaken and published seven years apart. These two studies are pivotal to my thesis. Chapter Nine describes an audit of the reasons for the high rate of attrition of professional divers, specifically searching for health-related reasons. Chapter Ten is a summary of the findings of the original studies comprising this thesis, and in Chapter Eleven I draw conclusions, make suggestions for, or comment on, already initiated modifications to the certification and health surveillance system for professional divers, and discuss possible implications of this body of work for the wider working community.

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Abbreviations

Abbreviation	Expansion
ADC	Association of Diving Contractors
ACC	Accident Compensation Corporation
ACP	American College of Physicians
AMA	American Medical Association
ASMS	Association of Salaried Medical Specialists
BMI	Body mass index
BP	Blood pressure
CAA	Civil Aviation Authority
CI	Confidence interval
CL	Confidence limit
CMC	Council of Medical Colleges
CME	Continuing medical education
CoC	Certificate of competence
CT	Computerised Tomography
CXR	Chest X-ray
DDD	Designated diving doctor
DHMS	Diving and Hyperbaric Medical Services
DIAG	Diving Industry Advisory Group
DIRG	Diving Industry Reference Group
DMAC	Diving Medical Advisory Committee
DoL	Department of Labour
EBM	Evidence-based medicine
ECG	Electrocardiogram
EEG	Electroencephalogram
ENT	Ear, Nose and Throat
FEF_{25}	Forced expiratory flow rate at 25% FVC
FEF_{50}	Forced expiratory flow rate at 50% FVC
FEF_{75}	Forced expiratory flow rate at 75% FVC
FEF_{25-75}	Mean forced expiratory flow rate from 25-75% FVC
FEV_1	Forced expiratory volume in 1 second
FN	False negative

Abbreviation	Expansion
FP	False positive
FVC	Forced vital capacity
GLI	Global Lung function Initiative
GP	General Practitioner
HDEC	Health and Disability Ethics Committee
HIPC	Health Information Privacy Code 1994
HRA	Human Rights Act 1993
HSCT	Hypertonic saline challenge test
HSWA	Health and Safety at Work Act 2015
Hz	Hertz (cycles/second)
ISO	International Standards Organisation
kHz	kilohertz
MBIE	Ministry of Business Innovation and Employment
MEBt	Middle ear barotrauma
MRI	Magnetic resonance imaging
NHANES III	3rd National Health and Nutrition Evaluation Study
NIHL	Noise-induced hearing loss
NNH	Number needed to harm
NNS	Number needed to survey
NPV	Negative predictive value
NZ	New Zealand
NZMA	New Zealand Medical Association
OSH	Occupational Safety and Health
PBt	Pulmonary barotrauma
PEF	Peak expiratory flow rate
PPV	Positive predictive value
RCT	Randomised controlled trial
RNZCGP	Royal New Zealand College of General Practitioners
RNZN	Royal New Zealand Navy
SAS	Statistical analysis system
SPSS	Statistical package for the social sciences
SPUMS	South Pacific Underwater Medicine Society

Abbreviation	Expansion
TN	True negative
TP	True positive
USA	United States of America
WHO	World Health Organisation
WRS	Wellington Respiratory Study

CHAPTER ONE

INTRODUCTION: Routine health screening

Prelude

The focus of this thesis is the process of screening professional divers for their initial and ongoing fitness for work. More generally, I question the value of the widely-practiced tradition of routine, annual, detailed medical examinations and investigations for asymptomatic workers, using professional divers as an exemplar. It is pertinent, therefore, before proceeding with the specific case of professional divers, to provide background information relevant not only to the even broader question of health screening of an asymptomatic general population, but also of routine occupational health screening. The distinctions between the two types of screening, a review of the evidence of their value, and the factors that may detract from underlying ethical intentions, are the subject of this chapter.

ROUTINE HEALTH SCREENING OF THE ASYMPTOMATIC GENERAL POPULATION

The aim of primary health surveillance of the general population is to improve health outcomes by early detection and treatment of health conditions. Test outcomes are dichotomous (a person either has the condition and needs treatment, or does not have the condition). Criteria for appropriate screening are discussed later in this chapter, but essentially, screening tests must have high sensitivity, to obviate the need for multiple confirmatory tests, but also high specificity, to reassure those with negative tests that they do not have the condition. This differs from routine occupational health screening/surveillance for reasons discussed below.

Historical overview

Since the often-quoted, but uncertain, instigation of routine (periodic) medical examinations by renowned British chest physician, Horace Dobell (1862), both the content and legitimacy of such examinations have been questioned. Variations have evolved through the intervening years as a result of reviews of their costs and benefits as well as their utility, and the expectations placed on them by the various interested parties. Dobell argued that early detection of disease in apparently healthy people would lead to more effective therapeutic intervention (Dobell, 1862). He advocated routine comprehensive history and head-to-toe examination, with the premise that detection of even a slight deviation from 'normal' would improve therapeutic outcome. Early comprehensive routine examinations of school children sought specific conditions such as vision, hearing or growth defects or contagious diseases such as tuberculosis (Medical Inspection of School Children. 1906, as cited in Han, 1997).

The content of these early versions of the routine examination was all-inclusive because early proponents of this form of screening were guided by scientific and humanitarian motives, with the aim of preventing poorly-understood diseases and expanding knowledge. Uptake of this practice was initially more popular with clinicians than with the general public, but even from the mid-1800s, in the United States of America (USA), the concept was adopted by non-clinicians from the life insurance industry, and by 1900 most major life insurance companies employed doctors to carry out examinations to assess financial risk (Davis, 1981). But the medical establishment in the USA had its own motives for promoting routine examinations, not least of which was to enhance the physician's standing in the community through improving the physician-patient relationship (Rosen, 1975; Edie, 1925; Shillito, 1953). Control of the practice of routine physical examinations strengthened the position of doctors in disputes with public health organisations or the government, to the extent that the medical establishment often opposed government-run health examination programmes in workplaces and schools unless private physicians were employed (Duffy, 1992).

In the early 1900s life insurance executives promoted routine comprehensive medical examinations not only for those joining, but for existing clients, believing this would reduce the risk of death (and the associated cost to the company). Although there was similar activity in Britain and Europe, the magnitude of the insurance industry in the USA and its interface with the health sector meant that most of the published research on this subject originated there. However, despite growing enthusiasm, there was very little published evidence of the effectiveness of routine medical examination programmes until 1916, when life insurance company medical directors, Fisk and Crawford (1927, as cited in Han, 1997) reported mortality rate reductions of 18% with a 9-year follow-up, and 53% with 5-year follow-up. An earlier study by Knight, also an insurance company medical director (1921, as cited in Han, 1997), reported a 28% mortality rate reduction over 5 years, and a 200% profit on investment over that period. These results, although biased, stimulated other companies to adopt the practice of extremely comprehensive routine health examinations, with emphasis on the slightest deviation from normal, which was seen as an indicator of disease (unless proven otherwise).

The drive for profit was clearly the principal motivation underpinning the widespread uptake of routine health examinations, further justified by the finding that nearly all 'healthy' people examined had some defect, and over 50% were deemed to need medical/surgical intervention. Draft examinations in the USA during World War 1 estimated that 30-40% of candidates, even in the most favourable age group of 19-45 years old, were rejected for military service for physical reasons (Fisk, 1918). The high rate of positive findings provided stimulus to pursue the search for a method of assessing and reducing risk of death, and was further endorsement of policies comprising all-inclusive routine examinations.

The potential profit to be derived from routine examinations appealed as much to, and was taken up with as much alacrity by, private industry, as to the insurance sector, because it linked its economic goals to employee health, and most published reports from the USA since 1940 come from this sector. Unfortunately, most reports through to the mid-1960s paid scant attention to the impact of routine examinations on employee disability, hospitalisation, absenteeism or morbidity and mortality, but instead, only highlighted the conditions revealed by the examinations (Cronin, 1916; Siegel, 1966).

Routine examinations were not popular among the American public, nor even among many physicians, in the first half of the twentieth century, especially at times of increased stress such as during the first and second World Wars and the Great Depression of the 1930s (Reiser, 1978; Rosen, 1975; Dodson, 1925; Levin &

Brightman, 1952). But interest increased after World War II with the introduction of new technology that enabled mass screening, and also with the 'pre-paid' health care plans introduced by American insurance companies (Thorner, 1969; Breslow, 1973). The influence of the insurance sector in promoting routine examinations was most aggressively debated and implemented in North America (Han, 1997).

The impact of critical analysis

The growing influence of evidence-based medicine (EBM) on modern medical practice has helped shed light on, or at least positively contributed to our understanding of, the value of routine medical examinations. The general principles of EBM were recognised long before the term was coined in the 1980s. The variable that accounts for the diversity of activity accepted by the disparate groups of 'healers', such as naturopaths, homeopaths, acupuncturists, etc., who believe their practice is evidence-based, is the definition of the term 'evidence'. Modern science accepts that evidence is a continuum, composed of different elements, which can be ranked from low to high value, from anecdote through to the double-blinded, randomised, controlled trial (RCT) or systematic review of RCTs. Evidence of varying value is variably accepted by the myriad varieties of practitioners of the 'healing art' and the patients/clients they treat. Of note, there are many situations for which an RCT may be impractical or simply unethical. An obvious, if amusing, example is the use of parachutes to prevent gravity-induced injury (Smith & Pell, 2003). Perhaps a more pertinent example of the appropriateness of forms of evidence other than the RCT, is the universally accepted use of recompression with oxygen to treat divers with decompression sickness, based not on any RCT evidence but on cohort evidence of an almost 'all-or-nothing' response (Bennett et al., 2012). It is now widely accepted that the best available hard evidence alone is not sufficient, any more than is clinical expertise alone, but that ideally, clinicians should combine the two to be optimally effective (Sackett et al., 1996).

The application of the then relatively new science of clinical epidemiology, to the question of routine screening, began in the 1960s, with various groups proposing sets of criteria for the evaluation of such programmes. The result was a set of ten principles, published by the World Health Organisation (WHO) in 1968 (Wilson &

Junger, 1968). These criteria/principles have remained influential ever since, with only minor additions and adaptations proposed over the intervening years, as discussed in a recent systematic review (Andermann et al., 2008). The main problem, and what may account for the apparent lack of effectiveness of many screening programmes, is that few meet all ten criteria (Hickman, 2002). Introduction of these criteria appears to have instigated a necessary tempering of the initial enthusiasm that led to an indiscriminate proliferation of screening programmes.

Initial major RCTs assessing the effectiveness of routine examinations to not only detect, but also alter the course of various medical conditions, were undertaken in the 1960s and 70s (Friedman et al., 1986; Holland et al., 1977). Neither these studies, nor many smaller ones (Olson et al., 1976), produced evidence that routine examinations were effective in reducing morbidity or overall mortality. Major reassessments conducted since the 1970s have come to the same conclusions, but most of these have gone further, in abandoning the ‘one size fits all’ concept, and recommending only specific aspects of the examination be retained, targeted to specific patient groups, and only at specified intervals, rather than, for example, annually for everyone (Frame, 1995; Canadian Task Force on the periodic health examination, 1986; US Preventive Services Task Force, 1996; Bloomfield & Wilt, 2011).

The emergence, in the 1980s and 90s, of yet more disappointing reports on the effectiveness of screening programmes, prompted one prominent researcher to say: “…we have said that screening is simple, effective and inexpensive. In truth, it is complex, of limited effectiveness and very expensive” (Raffle, 1998). The conclusions of the above extensive research, and the endorsement of them by the American College of Physicians (ACP) and the American Medical Association (AMA), has led many physicians to abandon their long-held beliefs about the importance of ritualistic, routine, head-to-toe examinations (Breslow & Somers, 1977; Oboler & LaForce, 1989). The findings of the above reviews apply not only to the physical examination, but also to the investigations that often accompany a ‘thorough’ medical examination.

In addressing cost-effectiveness and appropriate use of screening, a recent ACP workgroup reported that they had identified a list of 37 medical investigations that, rather than benefit, may even be harmful to patients (Qaseem et al., 2012). The list included: performing echocardiography in patients with innocent-sounding heart murmurs; performing exercise ECGs in low-risk asymptomatic adults; annual lipid screening in patients not on lipid-lowering drugs or diet therapy; screening for prostate cancer in men older than 75 years; and, performing imaging studies in patients with non-specific low back pain. Similarly, 20 Australian and New Zealand colleges and specialist societies have endorsed over 100 evidence-based recommendations that doctors and patients should question (Choosing Wisely, 2017).

A survey conducted by the Council of Medical Colleges (CMC) together with the New Zealand Medical Association (NZMA) and the Association of Salaried Medical Specialists (ASMS) found that most doctors (61.6%) thought that unnecessary tests, treatments and procedures were a serious, or very serious, health sector issue (CMC survey, 2017). The survey also concluded that the principal factor for NZ doctors in determining the appropriateness of examinations, tests or treatments, was the quality of care. Cost was a secondary consideration. In the context of this thesis, it is noteworthy that doctors are still required to perform exhaustive routine examinations on asymptomatic divers, as well as workers in other industries, simply to comply with industry policies.

<u>A balanced view?</u>

One might expect, in the face of the overwhelming evidence of lack of effectiveness of routine screening/examinations, apart from some components of the physical examination such as blood pressure, vision, weight and height (Bloomfield & Wilt, 2011), there would be little remaining enthusiasm for them. However, there are still many adherents who believe routine medicals have an important role, and that preventive screening should not be relegated to opportunistic additions to other consultations. Despite the recent conclusions of a Cochrane systematic review comprising 14 RCTs, that general health checks were ‘unlikely to be beneficial’, and had no effect on risk of death (including from cardiovascular disease or cancer), nor on admissions to hospital, disability worry, additional doctor visits or work absence, debate is ongoing about other, less tangible, benefits from such examinations (Krogsball et al., 2012). Just as the early reports, especially from the insurance companies, on the efficacy of routine examinations, were biased in favour of them, some of the more recent reviews, including the Cochrane meta-analysis, have been criticised for methodological flaws that could cause bias against justification for routine examinations. For example, some studies used an affluent control group, more likely to access health services (Himmelstein, 2016). A 2007 systematic review that avoided the flaws of some of the other studies, such as under-representation of poorer patients, and using non-representative batteries of tests, concluded that the evidence justified the implementation of (targeted) routine examinations (Boulware et al., 2007).

Mammographic screening of asymptomatic women for breast cancer is a good example of a well-established screening programme, widely adopted in developed countries, and still strongly promoted despite ongoing debate over inconsistency in reports of its efficacy. The efficacy of any screening programme can be characterised by the balance of two statistical properties; the number needed to screen (NNS), and the number needed to harm (NNH). The NNS is the number of people who need to be screened in order to save a single life, while the NNH is the number of people screened resulting in a single death secondary to the screening (if life and death are the agreed outcomes). The lower the NNS, and the higher the NNH, the better. If the two values are equal, the screening programme is as likely to cause harm as benefit, and would be hard to justify. Uncertainty can arise when some studies report only cause-specific mortality, while others are more broadly focused and report all-cause mortality, reasoning that over-diagnosis and over-treatment can increase all-cause mortality, as reported in prostate cancer screening (Lane et al., 2010).

In the case of breast cancer screening with mammography, the intuitive reasoning, and the predominant message to the public, has been that earlier detection of cancer allows earlier treatment, and therefore saves lives. However, several recent reviews have found that when deaths due to treatment (such as surgery or radiotherapy) are included, the NNH may be lower than the NNS (Gotzsche & Nielsen, 2011; Marmot et al., 2013; Baum, 2013). It has been estimated that there may be an additional one to three deaths from other causes for every breast cancer death avoided by mammography screening (Baum, 2013). Importantly, the positive and negative predictive values of a test (PPV and NPV), along with the NNS, are highly dependent on the pre-test probability (often referred to as the 'prevalence') of a disease in a given population. The PPV is the proportion of those who test positive and who actually have the disease, while the NPV is proportion who test negative and do not have the disease. Ideally a screening test will produce both a high PPV and NPV for the population to which it is applied. Mammography has been reported to have a sensitivity of 87% and a specificity of 89% (Breast Cancer Screening Consortium, 2017) although reports range from 75%-90% for sensitivity and 85%-95% for specificity depending on the study population. If, for the purpose of demonstration, we use a sensitivity of 80% and a specificity of 94%, then, given two populations where breast cancer has a prevalence of 60% and 5% respectively, a positive mammography result has a PPV of 96% in the high-prevalence group and only 40% in the low-prevalence group. The NPVs would be 76% and 99% respectively. In other words, the lower the prevalence, the less likely a positive test indicates disease, and the more likely a negative test indicates absence of disease (Akobeng, 2007). So, for mammographic screening for breast cancer in younger age groups, where the prevalence is low, the PPV of screening is also low, and the ratio of NNS to NNH is unacceptably high.

Proponents of the value of routine examinations point to evidence that patients feel better about their health, and their doctors, the more physical examinations and investigations they perform, which is equated with 'thoroughness' (Martin et al., 1982). Patients may feel better even having laboratory tests that are not indicated, and they are less trusting of their doctor if they don't get the tests or referrals they expect (Sox et al., 1981; Keating et al., 2002). Unsurprisingly, NZMA doctors in primary care felt more pressure from patients to provide 'unnecessary' tests or procedures, and were also more likely than their ASMS specialist colleagues to submit to this pressure (CMC survey, 2017).

The principal argument proffered by routine examination proponents is that such practice may offer difficult-to-quantify, or intangible, benefits, such as improved receipt of guideline-sanctioned preventive measures, and changes in health behaviour and perception, particularly for the more vulnerable groups of patients. The concept of compassion, or 'the laying on of hands', and its possible contribution to health, has received considerable attention in the literature, but a recent systematic review concluded that most studies were of low quality and there was little consensus about both the definition of the term 'compassion' and also the methods for measuring it (Strauss et al., 2016). Neither the Canadian nor the American Preventive Services Task Force reports evaluated these intangible objectives, or the possible value of nurturing the doctor-patient relationship (Fletcher & Spitzer, 1980; Laine, 2002). However, with ever-increasing healthcare costs, the expense of what some might characterise as a 'placebo effect' requires justification. Further study is needed to accurately determine the rather vague impact of actual or perceived compassion during routine examinations, on mental and physical health outcomes.

ROUTINE OCCUPATIONAL HEALTH SCREENING

The arguments alluded to above, for maintaining the practice of annual medical examinations of asymptomatic people in the general population, such as fostering the doctor-patient relationship, etc., are not as obviously applicable to healthy workers. Anecdotally, many, if not most such workers, seen for 'annual medicals', only attend grudgingly at the behest of their employer, and they see little point in the exercise, particularly those who are self-funding. There may be some who feel a sense of 'wellness' from being assured if there were no abnormal findings, and who may also derive some intangible benefit from the interaction with a physician. But the key subjective distinctions between the asymptomatic member of the general population who voluntarily attends their usual physician for a 'routine medical', and the employee who is obliged to attend a possibly unfamiliar physician for an occupational health surveillance examination, are likely, in my opinion, to be 'motivation' and 'mindset'. It seems intuitive that low motivation and a negative mindset will reduce perceived benefit for the asymptomatic worker subjected to an enforced physician interaction.

Key distinctions between diagnostic testing, routine screening of the general population and occupational health surveillance are summarised in Table Two. Notably, the objectives of occupational health surveillance are to assess fitness for specific duties, reduce work-related injuries or illness, and maintain wellness, and thereby increase productivity. Such surveillance exists in the context of a complex legislative/regulatory milieu comprising a large number of interested parties who, while they may have the same goal, usually have different approaches to achieving it.

Occupational health screening/surveillance does not have a dichotomous outcome, as general population screening does, because it may be possible to modify the workplace or the job or the worker themselves, to transform someone from being deemed unfit, to being fit for work. In this context, screening that maximises sensitivity (the ability of a test to detect a condition when it really is present) will minimise false negative outcomes (or type 2 error) where an 'unfit' worker is advised that they are fit to work, with the inherent increased risk of harm to them or others. But, for the sake of fairness, it is also important to concurrently maximise specificity (the ability of a test to detect the absence of a condition when it really is absent), thereby minimising false positive outcomes (type 1 error) where a 'fit' worker is denied work.

The term 'fitness to dive' may seem an odd concept to those not involved with diving as a profession or recreation. It is an often-quoted truism that no human can really be fit to dive because we have not evolved to survive in a non-respirable environment (without the aid of technology). However, for practical purposes, an assessment must be made of an individual's likely risk of diving injury based on health information and the nature of the anticipated diving. As will be seen in the following chapters, the risk assessment is normally based on information gathered from a health questionnaire, a physical examination and various health investigations. Unfortunately, any such determination of risk does not take into account the main contributors to diving injuries, namely, human error, gear failure and environmental conditions. Consequently, the assessment of 'fitness to dive' by a suitably qualified medical practitioner can only ever give the diver (or his employer or other interested parties) an incomplete indication of risk. In most countries the process of certification of a diver as ‘fit to dive’ is entirely prescriptive based on the medical assessment, but, as will be described in this thesis, there are sound arguments for adopting a more discretionary approach to this issue, with the most invested parties (the diver, employer and insurer) taking ultimate responsibility for the fitness to work decision.

Table Two **Comparisons between diagnostic testing, health screening of the asymptomatic general population and health surveillance of asymptomatic workers**

	Diagnostic testing	Screening	Worker surveillance
Aim	Confirm disease	Detect indicators of disease	Detect conditions relevant to fitness for work. Reduce work-related injuries/illness. Maintain wellness.
Target group	Symptomatic needing diagnostic certainty, or asymptomatic but with positive screening test	Asymptomatic population possibly at increased risk	Selected workforce
Method	Possibly expensive and/or invasive, but justifiable	Large numbers, so should be cheap, simple, acceptable to all	Should be cheap, non-invasive and justifiable if compulsory
Sensitivity/Specificity	High specificity important to reassure those with negative results. Precision and accuracy most important.	High sensitivity important to avoid missing any with disease. Expect high false positives.	High sensitivity for safety. High specificity for fairness.
NNS	As low as possible	As low as possible	N/A
NNH	As high as possible	As high as possible	N/A
Positive result meaning	Definitive diagnosis	Disease indicated but requires confirmation	Work-relevant health condition detected. Worker may be unfit for work, or, job or work environment may need adjustment

Historical overview

The practice of screening asymptomatic workers to determine fitness for work is certainly not novel, but has blossomed over the past several decades to become a global multi-billion-dollar ‘industry’, driven more by modern legislation and insurance company policies than by evidence of health benefit (as discussed above). This, in many ways, reflects the pattern of enthusiasm for routine examinations, by interested parties, seen a century ago. In the modern setting though, the environment is more one of fear of non-compliance and consequent medico-legal repercussions (Carter, 2000).

The origins of the pre-employment medical examination undoubtedly extend far into antiquity, when its most rudimentary form may have consisted of an employer or his foreman performing some cursory check of a potential employee prior to offering employment. Little consideration would be given to those who were injured or became unwell at work. Knowledge of an association between certain occupations and illness was recorded in ancient Greece by Hippocrates who noted an association between mining and lead poisoning, and in ancient Rome by Pliny the Elder, who recommended that miners should wear breathing protection. Medieval records show that there were regulations affecting certain occupations such as bakers, inn-keepers, butchers and tanners, and some groups formed guilds with their own rudimentary forms of insurance against illness and death, precursors of today’s health insurance. Early statutes, however, were more for the benefit of the community than the worker. In 1556, the German mineralogist, Georgius Agricola’s publication, De Re Metallica (On the Nature of Metals) (Agricola, 1556/1950), although dismissive of the dangers, still recommended that miners be provided with good ventilation and respiratory protection. In 1713, the Italian physician, Bernardino Ramazzini, commonly regarded as the ‘father of occupational medicine’, published the latin text De Morbis Artificum Diatriba (On Diseases of Workers) (Ramazzini, 1713/1940) which detailed the potential health hazards of over fifty occupations, and provided important groundwork for the development of modern occupational medicine. He was a strong advocate of the notion that ‘prevention is better than cure’. However, care for workers’ health remained largely *ad hoc*, at the whim of the employer, at least in Britain, until towards the end of the Industrial Revolution, with the introduction of the first iteration of the Factory Act in 1833, to place restrictions on child labour in the textile industry. This came only a year after publication of the second edition of Charles Thackrah's book on industrial illnesses (the full title of which was: 'The Effects of Arts, Trades and Professions, and of Civic States and Habits of Living on Health and Longevity: with suggestions for the removal of many of the agents, which produce disease and shorten the duration of life') (Thackrah, 1832). Charles Thackrah shares the epithet 'father of occupational medicine' with Ramazzini. The industrial revolution, with its insatiable demand for a workforce drawn largely from what was an agrarian or artisan community, recruited anyone considered able to work, including young children. These workers were suddenly required to perform unfamiliar tasks in dangerous, mechanised surroundings, resulting in a predictable rise in workplace fatalities, injuries and illnesses, and highlighting the need for legally enforceable controls.

The subsequent long struggle for improved workers' rights has essentially been a movement towards improved occupational health, as issues such as work hazards, hours of work, shift work, remuneration, etc., are inextricably linked to both physical and mental health. The previously mentioned examples are just some of the more notable early milestones towards formally redressing unsatisfactory workplace conditions, but the twentieth century saw a large number of significant changes to workplace legislation, in developed countries anyway, to further benefit the working community. Among many other factors, the introduction of Health and Safety regulations and specific safety measures, such as use of personal protective equipment and identification and elimination of hazards, led to a sharp decline in workplace mortality over the past century. In the early 1900s, the introduction of workers' compensation legislation in the USA also led to an increase in monitoring for health conditions that could increase the risk of workplace injury (Rosen, 1975; Cronin, 1916). This resulted in a rapid uptake in the practice of routine health examinations, which were credited, by the proponents of this practice, for producing the observed reduction in workplace morbidity and mortality rates many decades later.

For example, in the USA, the workplace mortality rate due to accidents fell by 90% between 1933 and 1997, while the workforce more than trebled (National Safety

Council, 1998, as cited in Centre for Disease Control and Prevention, 1999). Similarly, in Great Britain there have been significant declines in both non-fatal and fatal workplace injuries over recent decades (Health and Safety Executive, 2018). This is a global trend (Hamalainen et al., 2009), but, as discussed below, and in relation to the main tenet of this thesis, there is a lack of evidence that medical screening of employees has contributed significantly to this decline in mortality and morbidity rates.

In New Zealand, the principal legal framework relevant to workers, in the context of screening for fitness for work, comprises: The Human Rights Act 1993 (HRA) (Ministry of Justice, 1993); The Health Information Privacy Code 1994 (HIPC) (Ministry of Justice, 1994); and the Health and Safety at Work Act 2015 (HSWA) (Ministry of Business, Innovation and Employment, 2015). There is potential for these regulations to work antagonistically from the viewpoint of both of the most interested parties, the employer and the employee. For example, an employer may demand disclosure of an unnecessary level of personal health information, mistakenly claiming it is required to fulfil an obligation to adhere to the HSWA and determine workplace risk, but they may be using arbitrary or irrelevant measures. The employee would be justified in feeling that provision of such information could breach their rights under the HRA and/or the HIPC and lead to unfair discrimination.

The introduction of legal requirements obligating employers to provide at least a minimum set of work conditions, and take all practicable precautions to avoid harm to their employees, has been accompanied by a growth in the activities of third parties whose role is to act either as agents for the employer, or the state or funder, to ensure regulatory compliance. Regardless of health outcomes, the consequence of employer non-compliance can be financially severe, which has resulted in health and safety compliance becoming an industry in its own right, and 'funder capture' has become a significant phenomenon. Funder capture occurs when a third party that provides funding, such as an insurance company or government department, possibly without medical expertise, dictates health policy based on a perceived potential reduction of their exposure, echoing the activities of life insurance companies' promotion of routine health examinations in the USA a century ago. This can result in exhaustive, sometimes even invasive, medical examinations and investigations, being required of asymptomatic employees. In many cases, these requirements must be met at regular, relatively short intervals, as, for example, with offshore workers (eg. oil rig workers and mariners) and professional divers. The funder justifies this on the basis of a perceived reduction in the risk of an adverse health event at work (or for which the work could be considered contributory), and thus a reduced risk of a financial claim being lodged. Significant financial gain can result for other third parties, such as medical clinics, that provide the 'unnecessary' medical examinations and investigations. Evidence of validity of policies involving routine examination of healthy workers is lacking, as will be seen from the studies discussed below.

The purported value of routine assessments of fitness for work is in their ability to assess the capacity of a worker to work safely, both for him/her and co-workers, or to evaluate the risk to the worker or others (Cox et al., 2000; McGregor, 2003). The utility of this process has long been questioned, and the methods used to predict the future health of workers are disparate and of dubious value (McGregor, 2003; De Kort & Van Dijk, 1997). As mentioned above, early evaluations of routine fitness-for-work assessments focused on their ability to detect medical or physical abnormalities, but failed to critically evaluate correlation with absenteeism, loss of productivity, morbidity and mortality (Cronin, 1916; Siegel, 1966).

More recent studies have specifically addressed the impact of fitness-for-work evaluations on worker health and safety and prevention of future risks, and concluded that there is 'scant evidence' of their effectiveness (Shepherd, 1992). There is, however, evidence that prospective workers are unfairly excluded because of ill-informed decisions based on anecdotal evidence or erroneous assumptions about the correlation of certain health conditions and increased risk (Mohr et al., 1999). For example, discrimination on the grounds of increasing age has been found in the aviation industry, yet there is evidence of a decrease in accident risk with increasing pilot age, at least until age 60, so that displacement of middle-aged with younger pilots is unjustified regarding air safety (Bennett, 1992). Experience, rather than age, is the critical factor. In the case of professional divers, there are a number of medical conditions widely recognised as posing an increased diving risk. An example is asthma, which, some years ago, would have resulted in an automatic denial of fitness-for-work certification. This prescriptive approach has been replaced, in some countries, with a discretionary practice that bases such a decision, for a diver with a history of asthma, on evidence of control of the condition. Similarly for divers with treated heart disease, whose risk can be minimised by restricting their work practice. In such cases, provided the diver and other interested parties are fully informed and accept the likely risks, the diver can be issued with a 'restricted' medical clearance certificate.

The role of the occupational physician

One of the principal initial drivers of routine occupational health screening was the potential for financial gain through increased productivity, reduced absenteeism and fewer insurance claims for work-related morbidity or mortality. This motive explains the ready acceptance of such practice by employers, and insistence on it by insurers. Considering that the little available evidence suggests a lack of effectiveness of routine occupational health screening in preventing either future health-related risks or potential financial loss (Shepherd, 1992; Cox et al., 2000), there are clearly still mechanisms at play that result in its widespread prevalence.

In response to the external influence of legislation, insurance company directives and industry management's reaction to both of those, the occupational physician working 'at the coal face' should provide active leadership in guiding the future direction of occupational health surveillance and fitness-for-work determination. As mentioned above, the ideal stance for clinicians is to find a balance that embraces the principals of EBM, combining published evidence with clinical acumen/expertise. However, occupational medicine provides some unique challenges absent from typical clinical research. For example, there are industry-imposed barriers to implementation, and there is a dearth of randomised controlled studies (Franco, 2005). Although undoubtedly influenced by their funders, occupational physicians seem inclined to perpetuate the status quo, based more on tradition than evidence. Admittedly, they are often operating within a system of externally imposed accountability that may demand, for example, conducting batteries of tests that have no evidence base. The pragmatic approach is to not 'rock the boat', and some clinicians may be displaying a variation of 'practice drift' involving the inclusion rather than exclusion of unnecessary components of health surveillance, and in the absence of any perceptible harm, may not feel conflicted. In this case, conducting unnecessary, evidence-free testing, is just the easy option that satisfies bureaucrat-generated protocols. The commonly accepted meaning of 'practice drift' is slightly different, and is an adaptation to inefficiencies, where doctors find more efficient ways of doing things by 'short-circuiting' a previously adopted protocol/procedure. This eventually becomes their new norm, and further short-cuts (or 'violations') can gradually lead further from the agreed protocols until a 'reset' has to occur in response to an adverse outcome. Dramatic examples of this 'normalisation of deviance' in a non-medical setting are the 1999 Tokai-Mura nuclear power plant disaster in Japan and the 1987 Zeebrugge ferry tragedy (Amalberti et al., 2006). The involvement of doctors with the Nazi regime in World War II is an extreme medical example. More often than not, such departures from agreed practice are rationalised as well-intentioned, and it is not surprising that occupational physicians behave like many doctors who continue to order unnecessary tests and examinations, driven by the need to 'do something rather than nothing'. Perhaps it is societal opinion that 'errors of omission are far more reprehensible than errors of commission', and the medical profession's sensitivity to it, that perpetuates the ritualism of routine occupational screening (Doust & Del Mar, 2004). Alternatively, busy occupational physicians may simply feel powerless to bring an end to this unjustifiable component of the health and safety 'compliance industry'. It has been suggested that the appropriate role of the occupational physician is as a health advisor rather than a 'policeman' (Gorman, 2003), such that the ultimate decision about the fitness of a particular person for a particular job is the shared responsibility of those with most at stake (the employee, employer and insurer) based on a risk assessment by the occupational physician. How practicable such a system would be, is unknown.

It is apparent, from a review of the literature, that none of the three crucial steps involved in modern health surveillance is reliably achieved in most settings. Those steps are: identification of relevant conditions for survey, selection of appropriate survey tools and methods, and audit of survey efficacy (Gorman, 2003). A systematic review of the criteria and methods used for determining fitness for work, spanning a 40-year period, concluded that there are few studies that evaluate the effectiveness of such criteria and examinations (Serra et al., 2007), and, as mentioned above, those that address this issue have found little evidence of effectiveness (Shepherd, 1992). There is consensus that fitness-for-work examinations are indicated for specific, safety-sensitive, occupations such as airline pilots, military personnel, firefighters, etc., at both the selection stage and periodically, but for most workers, the responsibility for reporting changes in health status that could impact safety should rest with the employee (Hainer, 1994; Szeinuk et al., 2000; McGregor, 2003).

A recent review of the evidence base for pre-employment medical screening suggested: 1) elimination of pre-employment physical examinations; 2) elimination of pre-employment drug screening, and 3) development of a set of consensus- and evidence-based recommendations regarding pre-employment best practice (Pachman, 2009). In most work situations it is likely that a health assessment using a job-relevant questionnaire will be sufficient to trigger any further enquiry or investigation. Case-specific risk assessment should be determined by an occupational physician with knowledge not only of an employee's medical history, but also of the risks specific to the job and workplace.

<u>Summary</u>

In summary, after many decades, and some might argue, many hundreds of years, the practice of conducting routine screening medical examinations remains poorly done, and in most cases, unjustified. In the case of screening of the asymptomatic general population, high costs and poor quality results, sometimes causing more harm than good, largely stems from failure to comply with a widely accepted set of efficacy criteria. In this group, there is very little evidence to justify evaluation of more than a small number of health parameters. For occupational health surveillance and fitness for work screening there is little evidence for consensus on what should be screened for, how it should be screened, and whether such screening has value in terms of reduced absenteeism, morbidity and mortality, and increased productivity. There is evidence that current systems are ad hoc, and could be variously described as sexist, racist, ageist, or unjustifiably discriminatory in other ways. Legislation requires employers to do whatever is reasonably practicable to minimise harm to employees, but many employers and/or their insurers/legal advisors interpret this as ‘the more tests, the better’ and the less the likelihood of adverse financial repercussions. There is no legislation that limits fitness-for-work screening or health surveillance to that which is evidence-based. Until this discrepancy is adequately addressed, routine occupational health screening will remain discriminatory, expensive, illogical, and effected at the whim of funding agencies.

CHAPTER TWO

Development of the system of health surveillance of NZ professional divers

Prelude

This chapter describes details of the current system of health surveillance and certification of professional divers in New Zealand. As development of this system is the primary focus of my thesis, an historical perspective is appropriate and is outlined, together with a description of changes made based largely on evidence gathered from the research presented in the following chapters.

Background

New Zealand has a temperate climate, many lakes and rivers and an extensive coastline. It is not surprising, therefore, that aquatic activity, and specifically diving, is popular both as a recreational pursuit and as an occupation. Prior to the arrival of Europeans, for many centuries the indigenous Maori population, although mostly employing nets, traps, hooks and spears, also used breath-hold diving techniques to harvest kai moana (seafood) such as crayfish and certain shellfish, and continues to do so today. However, the introduction of various forms of compressed gas diving over the past century stimulated the development of an occupational diving industry comprising a much wider variety of diving activities than the gathering of seafood. Two of the most common categories of the modern diver are scientific/research divers and diving instructors (mainly training tourists and recreational divers). Other categories include: military, police and customs divers; construction divers, including those who work from saturation habitats; commercial divers; aquaculture workers; and divers involved primarily with photography and videography. For at least the past decade the number of divers registered (with WorkSafe NZ, formerly with the Department of Labour) as active 'occupational divers' has remained fairly stable at approximately 1000.

Since the 1970s professional diving in New Zealand has been a 'regulated' occupation, meaning that these divers are legally required to be registered and regularly renew their medical fitness certification according to the current industry standard (AS/NZS 2299.1.2015) under the auspices of the regulating authority, WorkSafe NZ (Australian and New Zealand Standard, 2015). Although the standard is the same for both Australia and New Zealand, there have been significant differences in the evolution of the respective diver medical certification and surveillance processes, likely due, at least in part, to the organisation and size of the various jurisdictions. For example, while New Zealand is a single jurisdiction, Australia comprises six states and two self-governing territories. This fact alone may render impractical, in Australia, the principal distinguishing feature of the New Zealand system since its inception, namely, a central audit process and record repository. This 'hub and spoke' model has previously been described in reference to medical certification of both pilots and divers (D. Gorman, personal communication, 2018) and is discussed in more detail below, but in essence, it means that after routine examination by a Designated Diving Doctor (DDD), the health of a professional diver is audited by a diving medicine specialist before medical certification is issued. The DDD is usually a General Practitioner (GP) who has completed a specified short course in diving medicine. The 'hub and spoke' model recognises the importance of specialist review, and it also provides a mechanism of reasonable access to such for all professional divers.

In its early years, the system of diver certification was overseen by the Department of Labour (DoL), and the only doctors with specialist status in diving medicine were a small number of naval medical officers who acted as contractors to the DoL. Eventually, because of the possible perception of a conflict of interest, the Royal New Zealand Navy (RNZN) withdrew from any formal connection with the certification process, and the DoL (and its subsequent incarnations as departments of the Ministry of Business Innovation and Employment (MBIE), namely Occupational Safety and Health (OSH) and WorkSafe NZ) then contracted the services of a private company, Diving and Hyperbaric Medical Services (DHMS), which engaged the only diving medicine specialists in New Zealand.

In all other countries, apart from New Zealand, the responsibility of issuing medical fitness certificates has been delegated to the DDDs (or their local equivalents). However, the importance of retaining the 'hub and spoke' model, with its objective centralised audit of health data and a single record repository, has been emphasised by three relevant studies. The first was a review of the New Zealand Civil Aviation Authority's (CAA) revised system of certification of pilots' fitness to fly. The existing process allowed some suitably qualified doctors to directly issue the fitness certificates without audit (Gorman & Scott, 2001). The review showed significant shortcomings in the quality of the records, and that an alarming 10% of the audited pilots should have been denied fitness-to-fly certification on medical grounds. In addition to highlighting the importance of the expertise of the designated examiner, the review also exposed examples of two concepts alluded to in Chapter One, namely, funder capture and practice drift. A pilot paying a designated examiner essentially to provide a fitness certificate is a classic example of 'funder capture'. It was also reported that designated examiners' behaviour deteriorated dramatically, in this regard, over a number of years, in the absence of independent central audit and in the presence of collegial support (practice drift). This review led to legislative changes that reinstated central audit, and a subsequent review after two years confirmed restoration of reliability to the system (Gorman & Scott, 2003).

It is not surprising, then, that the NZ system for surveillance of professional divers has retained the central audit facility. The second and third relevant studies were both postal surveys of the doctors who perform fitness-to-dive medical examinations. One study surveyed dive doctors in Queensland, Australia (Simpson & Roomes, 1999), and the other, dive doctors from throughout New Zealand and GPs from the Auckland area (Sames et al., 2012). Both presented the participating doctors with vignettes of prospective divers and asked for them to be graded as either fit or unfit to dive. The results of both studies showed that not only GPs, but even DDDs (and their Australian equivalent) were poor at determining fitness to dive, reinforcing the value of the hub-and-spoke model in providing a consistent, expert and objective audit of fitness-to-dive determinations. It is likely that the infrequency with which DDDs perform dive medical examinations is a significant reason for diminishing expertise, and such a correlation has been demonstrated. Similarly, accuracy was shown to diminish with time since completing dive medicine training (Sames et al., 2012). DDDs have subsequently shown an improvement in their performance (unpublished observation) after engaging in 'refresher course' activity. The survey of

New Zealand dive doctors and Auckland-based GPs is presented in full in Chapter Five.

<u>Development of the system of health surveillance and medical fitness-to-dive certification for New Zealand professional divers</u>

The globally accepted mechanism for certification of professional divers as 'fit to dive' is annual completion of a health questionnaire, a comprehensive physical examination and certain investigations. The investigations often include a wide variety of tests, such as blood tests, resting and/or exercise electrocardiogram (ECG), electroencephalogram (EEG), chest x-ray (CXR), chest computerised tomography (CT) scan, hypertonic saline challenge test (HSCT) or other bronchial challenge tests, plethysmography and psychometric tests. In New Zealand the only mandatory tests currently are spirometry and audiometry on a five-yearly basis, with additional tests or increased examination frequency instigated only on the basis of clinical indication. That was not always the case, and, in contrast to all other countries, the New Zealand system has evolved over the last two decades in response to detailed examination of the various elements of the certification process. The first of these studies questioned the predictive power of the initial fitness-to-dive procedures (Greig et al., 2003) and concluded that there was little value in the prevailing Australian and New Zealand Standard (AS/NZS 2299) health questionnaire (Australian and New Zealand Standard, 1999). This questionnaire, comprising 89 health questions requiring a yes/no response, originated with the Royal Navy based on a list of diseases considered relative and absolute diving contra-indications and was subsequently adopted by the Royal Australian Navy and Royal New Zealand Navy. An unpublished audit of RNZN divers revealed that it was poorly understood by many, and the finding by Greig et al. (2003) of low PPV and high NPV suggested that the questionnaire was, in any case, more appropriate as a diagnostic than a health survey tool. The importance of the examiner being appropriately trained in diving medicine was highlighted when responses to the dichotomous questions were found to be useful, in determining fitness to dive, mainly in the context of additional explanatory text from the examining physician. These findings prompted modification of the questionnaire, including a reduction in the number of questions from 89 to 39. The finding that in the absence of positive questionnaire responses there was no obvious additional health benefit in undergoing examination or investigations, led to relaxation of the frequency of examination requirement, on a case-by-case basis, from annually to five-yearly. Several subsequent studies, that constitute the main body of this thesis, have validated the reduction in examination frequency and other reforms to this process, such as further refinement of the questionnaire and elimination of the requirements for routine spirometry and audiometry (Sames et al., 2009a, 2009b, 2012, 2016, 2018, 2019a, 2019b, 2020).

The process of reform of the New Zealand 'system' was overseen by a consumer group, subsequently called the Diving Industry Reference Group, formed by DHMS at the instigation of the Association of Diving Contractors (ADC). This Diving Industry Reference Group (DIRG) comprised representatives of all branches of the occupational diving industry (recreational, scientific, construction, commercial, military/police/customs, etc.) and met on a regular basis to discuss proposed changes to the diver health surveillance and certification system as well as many other practical concerns raised by divers. Among the issues unanimously agreed upon by the group (together with DHMS and OSH/WorkSafeNZ) was the setting of a processing fee to cover the administration costs of the process, including, among many other functions, the establishment and maintenance of a user-friendly website exclusively for New Zealand occupational divers. This website is used by divers annually to complete their health questionnaire online, and it also functions as the central record repository. Each diver can upload their health information (scans of the medical examination and any letters or investigation results) which remains accessible to the individual diver, along with their current and past medical certificates.

With a transfer in activity from involvement in the reforms of the medical surveillance and certification process to more general provision of advice about various diving practices in response to queries from the industry, the DIRG transformed into a new entity named the Diving Industry Advisory Group (DIAG) which is responsive to WorkSafe NZ rather than DHMS. As well as providing advice to WorkSafe NZ, the diver medical assessment process is now also overseen by the DIAG.

The current system of certification of fitness to dive for New Zealand professional divers

As outlined above, the New Zealand professional diver certification process involves two mandatory components; the health questionnaire and the medical examination. Additional components may be included if clinically indicated. After successful completion of medical certification, additional training and experience-based certification (the Certificate of Competence (or CoC)) is required for the diver to comply with WorkSafe NZ regulations and be deemed fully certified for occupational diving in this jurisdiction.

The health questionnaire

Each diver must complete the questionnaire annually to remain medically 'in date'. This is normally done online using the professional diver-dedicated website (maintained by DHMS under contract to WorkSafeNZ), or can be completed manually and then uploaded to the website, making it convenient for divers anywhere in the world (with internet service) to renew their certification. The completed questionnaire is audited centrally by the DHMS diving medicine expert, and when there are no health issues of note, requirement for a full medical examination is waived, and certification, valid for a further year, is renewed within a few days, and the diver is informed by email. The DHMS diving medicine expert has the appropriate qualification and experience in diving medicine and is appointed to the role and contracted by WorkSafeNZ. Regardless of questionnaire responses, a full medical examination is required at least every five years. If any health concerns are highlighted by the questionnaire, the diver is contacted by email and clarification is sought. This may involve a request for medical examination or investigations to be conducted.

As mentioned above, the current format of the NZ questionnaire has been modified from its original form that is still part of the most recently published Australian and New Zealand Standard (2015). The changes made to the questionnaire used by New Zealand divers are the result of detailed examination of the value of each question in determining fitness to dive, and the likelihood of diver misinterpretation. The most recent review of the questionnaire is presented in full in Chapter Seven.

The medical examination

As noted above, the previous annual medical examination requirement was relaxed in 2003 on the basis of the findings of a review of the initial fitness-to-dive procedures (Greig et al., 2003). This move has since been validated by two further reviews that are discussed in detail in Chapter Eight (Sames et al., 2009b, 2016). Also as mentioned above, currently, a full medical examination including spirometry and audiometry, must be completed at least every five years. The medical examination is conducted by a DDD and all of the records are uploaded to the DHMS website and reviewed by the expert auditor. Any irregularities may result in a request for further investigations before certification can be issued. In some cases, divers are requested to submit to a full medical examination on a more frequent basis than five-yearly, if deemed appropriate. In all countries, apart from New Zealand, the routine full medical examination is required of most divers annually, and, as previously mentioned, may include many additional components (CXR, ECG, bloods, etc.) that have been methodically eliminated from the New Zealand requirements because of lack of evidence of utility, in the sense that those investigations that have been eliminated do not lead to an increase in safety for the diver unless there is a clinical indication for conducting them. Some unnecessary investigations conducted on a routine, rather than 'as indicated' basis, could even be harmful (eg. CXR).

There are now only two remaining mandatory investigations included in the New Zealand full medical examination, namely, spirometry and audiometry. Even on a five-yearly basis, let alone annually, neither of these tests has been demonstrated to be useful in improving the health or safety of divers. Two audits of New Zealand professional divers, spanning diving activity from five to 25 years, have shown no significant diving-related deterioration in lung function (Sames et al., 2009a, 2018), and similarly, an audit of divers' hearing over careers spanning 10-25 years also showed no significant deterioration (Sames et al., 2019a). These studies are discussed in detail in Chapters Three and Four. Further reduction in the requirements of medical surveillance will follow because of these audits, so that spirometry and audiometry will be required at the initial full medical, but subsequently only if clinically indicated, or on exit from the diving industry.

Conditional / Restricted certification

A common criticism of surveillance systems largely reliant on self-administered questionnaires is that respondents may be 'economical' with the truth if they perceive that admitting to a health condition may negatively impact their certification, and consequently their livelihood. It could be claimed with some confidence that systems that are wholly, or even largely, prescriptive, may in fact be punitive. Such systems are likely to foster deceit, inaccurate assessment and potentially serious adverse health and safety outcomes for the diver. To avoid this, the system adopted in New Zealand is largely discretionary, and specifically encourages 'end-user buy-in' by emphasising that honest provision of health information is not only the safest thing to do, but is likely to lead to outright denial of certification only in a small minority of cases. Instead, depending on the specific details, the diver can, at no additional expense, attend an interview with the DHMS diving medicine expert to discuss possible modifications of diving practice that will allow continuation of diving, but with conditions/restrictions applied to minimise future risk to the diver. Such meetings are instigated and convened by the DHMS diving medicine expert, but other interested parties, such as those who may also be accepting an increased risk burden (the employer, WorkSafe and/or ACC or dive school representatives), will be invited to attend, and any resolutions must be unanimous. In all other countries, to my knowledge, the system is prescriptive, and the outcome for the diver is dichotomous (either fit or not fit to dive) with no allowance for modification of diving practice or working environment to reduce risk to a level acceptable to all. Several of these 'conditional' certificates are issued each month in New Zealand.

Summary

In the past two decades the NZ professional diver certification system has undergone several modifications that have made it safe, equitable and responsive to the requirements of the divers. Although the 'default' for the NZ system is annual review of divers' health, the requirement for review of various components of the assessment has been relaxed, on a case-by-case basis, to being as infrequently as five-yearly for the medical examination and possibly only on entry to and exit from the industry for spirometry and audiometry. It has always had the central audit facility that is a significant point of difference from certification systems in other countries, but changes have been made to the previous, and widely accepted, requirements for routine physical examinations, investigations and health questionnaires to make every aspect of it justifiable on the basis of the evidence presented in this thesis.

CHAPTER THREE

The long-term effects of professional diving on lung function

Prelude

This chapter, and those following, presents original studies that were referred to briefly in the previous chapter. The two studies cited in this chapter have been published in the peer-reviewed literature, and are presented here with only minor modifications for cohesion within this thesis (Sames et al., 2009a, 2018). The first study audited lung function changes in professional divers over a 5.6 year mean observation period and also compared four normative datasets produced by their respective prediction equations. In an attempt to address some of the limitations of that study, and accommodate the introduction of a new, more comprehensive, normative dataset, the second study audited lung function changes over diving careers spanning 10-25 years.

THE LONG-TERM EFFECTS OF COMPRESSED GAS DIVING ON LUNG FUNCTION IN NEW ZEALAND OCCUPATIONAL DIVERS – A RETROSPECTIVE ANALYSIS

Introduction

Lung function is arguably most important in determining health risk for divers. Disparate results from a small number of studies of the long-term effects of diving on the lung have led to ongoing uncertainty (see Table Three).

A literature search of the PubMed database seeking the MeSH terms ‘Diving’ and ‘Respiratory function tests’ found 438 articles, eight of which were longitudinal studies of professional divers’ lung function, plus one preliminary report (Watt, 1985; Skogstad et al., 2000; Skogstad et al., 2002; Davey et al., 1984; Bermon et al., 1994; Fitzpatrick & Conkin, 2003; Tetzlaff et al., 2005; Tetzlaff et al., 2006; Chong et al., 2008).

Table Three Comparison of longitudinal studies on lung function of divers

Author(s)	Study Design	Sample Size (N=)	Time Period (years)	Outcome
Davey IS, et al. 1984	Retrospective Epidemiological	255	5+	Change in FVC (but not FEV_1) related to max depth. Decreased FEF_{75} compared with controls. Evidence of airway narrowing possibly related to loss of elastic tissue.
Watt SJ, 1985	Retrospective Epidemiological	224 123	3 – 4 5 – 9	Decrease in FVC > decrease in FEV_1. Reduction in FVC significant compared with predicted norms, correlated with initial FVC (mostly above predicted norms). Not correlated with age, max depth, years diving or weight change. No difference between smokers and non-smokers. Indicated either gradual return to normal values or pathological decrease in lung volume.
Bermon S, et al. 1994	Retrospective Epidemiological	20	8 – 9	Decrease in VC < decrease in FEV_1 so decrease in FEV_1/VC% over time. Pronounced decrease in MMEF and MMEF/VC suggested chronic effect on small airways.
Skogstad M, et al. 2002	Prospective Controlled Cohort	77	6	Significant decrease in FVC, FEV_1, MEFRs and Tl_{co} compared with reference group (policemen). Reduction in FEF_{25} and FEF_{75} greater than in reference group and related to cumulative number of dives. No difference between smoking and non-smoking divers.
Fitzpatrick DT, et al. 2003	Retrospective Epidemiological	43 (shallow nitrox divers)	3	Initial FVC and FEV_1 greater than predicted. FVC and FEV_1 significantly increased after 3y associated only with cumulative dive hours. No significant change in other parameters. Likely training effect.
Tetzlaff K, et al. 2005	Retrospective Epidemiological	39 (oxygen rebreathers)	5.8	No significant change in FVC or FEV_1. Hyperoxia not associated with decline in lung function.

Author(s)	Study Design	Sample Size (N=)	Time period (years)	Outcome
Tetzlaff K, et al. 2006	Prospective Controlled Cohort	468	5	Baseline lung function of divers and controls (submariners) greater than predicted. Decrease in FEV_1 faster if older, smoker or initially higher FEV_1. No difference in decline in FEV_1 between divers and controls.
Chong SJ, et al. 2008	Retrospective Epidemiological	116	5	Increase in % predicted FVC, FEV_1 and PEF. Decrease in FEV_1/FVC ratio. No significant difference with age, smoking or years Naval service

Neither the references quoted in these articles nor the 84 articles cited in the British Thoracic Society guidelines on respiratory aspects of fitness for diving revealed any further relevant longitudinal studies (Godden et al., 2003).

Regulations introduced by the Department of Labour in 1999 required occupational divers in New Zealand to undergo annual surveillance of their medical fitness to dive by completing, and submitting to the central medical directorate, a health questionnaire, which is augmented by a comprehensive medical examination that may be deferred for up to five years in the absence of health concerns (see Chapter two). Audit of these diver health surveillance data is facilitated by New Zealand's relatively small population and the collection and scrutiny of the data centrally and by an expert censor panel that certifies occupational diver medical fitness.

The aim of this retrospective longitudinal cohort study was to audit lung function data collected from occupational divers over the past five to 15 years (minimum of five), and to examine any relationships with gender, smoking status and years of occupational diving experience.

Method

The inclusion criteria were that the diver was currently registered with the regulator, the New Zealand Department of Labour (now WorkSafe NZ), and that the diver had completed at least two ‘full’ dive medical examinations, including spirometry, with an interim period of at least five years. The annual questionnaire and five-yearly medical examination data were uploaded to a customised database for analysis.

Lung function parameters: forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), peak expiratory flow (PEF), forced expiratory flow rates at 25%, 50% and 75% FVC ($FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$) and mean forced expiratory flow rate in the range 25%-75% FVC ($FEF_{25\%-75\%}$) were analysed for changes over time and against gender, smoking status and duration of diving experience.

Comparison was made with matched normative data derived from four sets of published spirometry prediction equations (Knudson et al., 1983; Gore et al., 1995; Marsh et al., 2006; Hankinson et al., 1999) (see Appendix One). The results were expressed as the percentage change of these predicted values, which controlled for advancing diver age between measurements, as all equations are based on diver age, height and gender.

Two of the sets of prediction equations (Knudson and NHANES III) were chosen because of their popularity worldwide, and two sets (Gore and WRS) because of their local relevance (Knudson et al., 1983; Gore et al., 1995; Marsh et al., 2006; Hankinson et al., 1999). Knudson’s 1983 equations improved on the previous 1976 set and were derived from 697 non-smoking, healthy, white, non-Mexican-American residents of Tucson, Arizona (Knudson et al., 1983). The NHANES III (Third National Health and Nutrition Examination Survey) equations were based on data collected across the USA from a total of 20,627 subjects divided into three ethnic groups (Hankinson et al., 1999). However, after selecting only those who were life-long non-smokers who could provide at least two acceptable FVC manoeuvres, the equations were derived from 7,429 subjects. For use in our study, only the equations derived from the data for Caucasian subjects older than 20 years (*n* = 1,349) were used.

The Australian set of equations was derived from 414 asymptomatic, non-smoking Caucasian adults from metropolitan Adelaide, South Australia, while the New Zealand set, the Wellington Respiratory Survey (WRS), was derived from 212 healthy, non-smoking Caucasian adults (Gore et al., 1995; Marsh et al., 2006). Comparable reference equations for Maori and Pacific Island populations are not yet available.

Student's paired t-test was used to test the hypothesis that there was no change in function over five years. The same test was used to find whether the baseline values of lung function tests differed from the normative means.

The relationship between dependent variables (recorded lung function) and several predictor variables (covariates such as gender, age, weight, smoking status and number of years' diving experience) was tested by univariate Pearson correlation coefficients and multiple linear regression analyses ($P < 0.15$ was considered necessary for inclusion in the multiple regression model). A variety of iterative procedures was used (stepwise regression, forward and backward selection and MaxR). The final model was chosen on the basis of goodness-of-fit and biological plausibility. All analyses were conducted using procedures of SAS (SAS Institute Inc. v 9.1). A *P*-value of less than 0.05 was considered significant and all tests were two-tailed.

Results

Of the 1,475 currently registered occupational divers in New Zealand, only 336 (23%) satisfied the inclusion criteria by having two sets of spirometric data separated by five years. Their demographic details are summarised in Table Four.

The divers' occupational grouping was broadly categorised as commercial (148), scientific (122), sports and recreation industry (30) and military (15). At baseline, females (7.4% of the group) were, on average, six years younger and had 7.6 years less diving experience than males. The comparative gender/age distribution is shown in Figure One. Only 15% and 7% respectively of the divers reported their total number of dives, and dives beyond 30msw, in the past year; compared to 96% who reported their total number of years' compressed gas diving.

Frequency of paired data varied according to spirometric parameter as shown in Table Five. The only significant difference over 5.6 years between smokers (defined as current and ex-smokers) and non-smokers (72.6% of the group) was a decrease of 3% in the % predicted FEV_1 in non-smokers according to the Knudson equations.

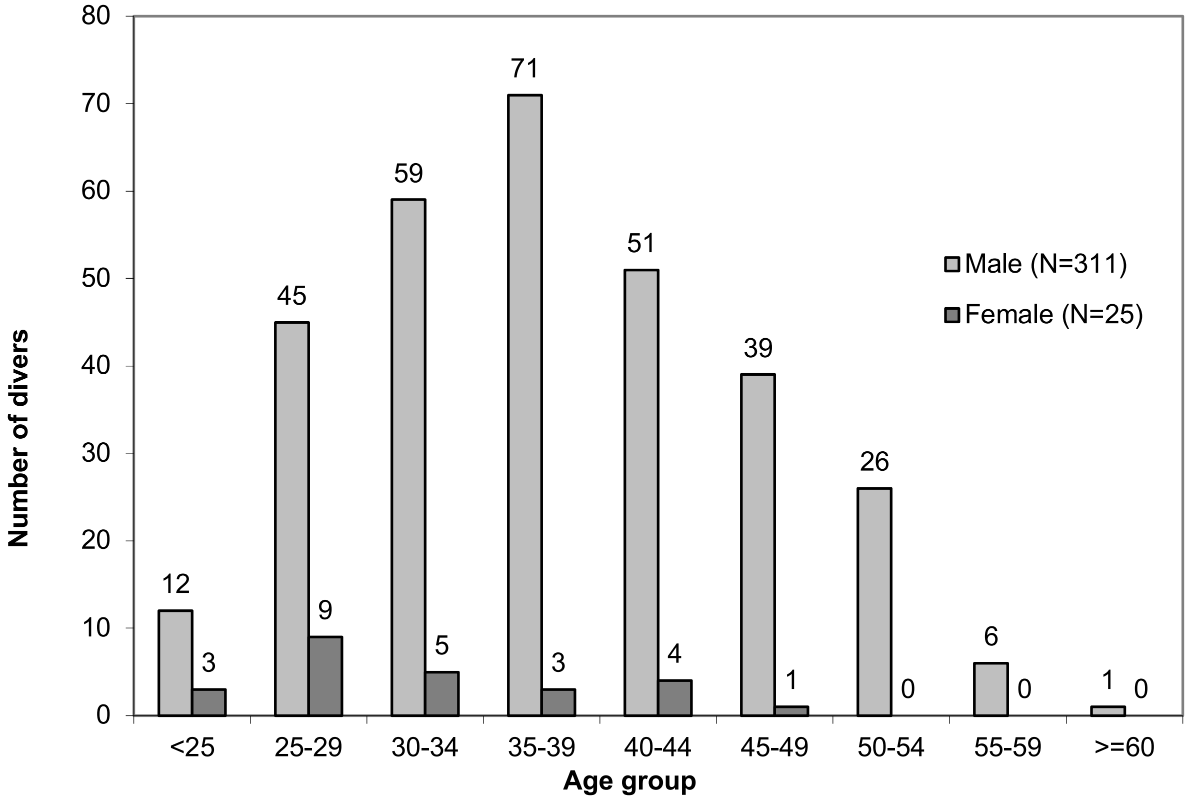
Table Four **Demographic characteristics of 336 New Zealand occupational divers at initial assessment of medical fitness for diving**

	N or mean (std deviation)	Range
Male	311	
Female	25	
Height (cm)	177.9 (7.1)	158 – 196
Weight (kg)	82.3 (12.8)	50 – 116
BMI (kg/m^2)	26 (3.4)	20 – 36
Age (y)	35.6 (8.6)	18 – 65
Ex-smoker	25	
Smoker	33	
Non-smoker	278	
Years occupational diving	13.8 (8.8)	0 – 42
No. dives in past year (N=52)	97 (117)	0 – 600
No. dives >30m in past year (N=25)	5 (14)	0 – 50
Time to second examination (y)	5.6	4.8 - 12

Table Five **Frequency of divers' paired data by spirometric parameter**

Spirometric parameter	N	Percent of sample
FVC	328	98
FEV_1	330	98
FEV_1 / FVC	325	97
PEF	174	52
FEF_{25}	54	16
FEF_{50}	77	23
FEF_{75}	63	19
FEF_{25-75}	70	21

Figure One **Bar graph of age / gender distribution of 336 New Zealand professional divers**



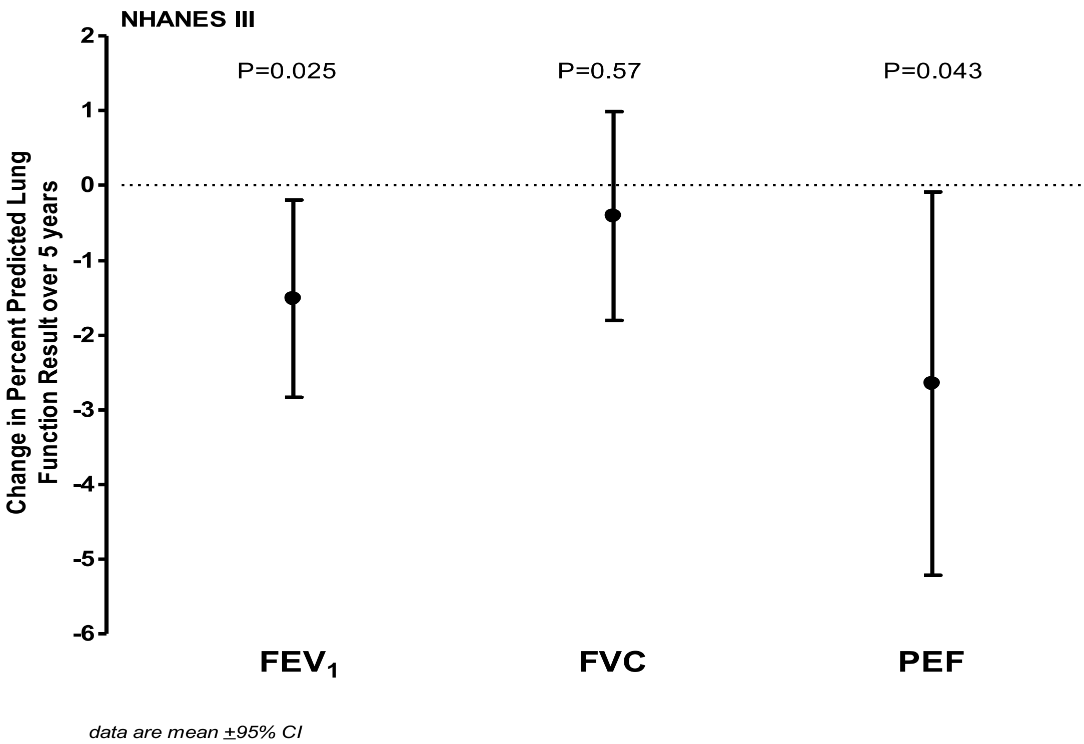
Three sets of normative value equations (Gore, Knudson and WRS) showed a 6% increase in % predicted FVC in females over the observation period. The WRS equations also showed that females had lower than predicted baseline FVC and FEV_1 values (7.4% and 8.5% respectively).

Student's paired t-testing revealed no significant differences in lung function parameters when the group was stratified for age and years of diving experience (using the median value as the dividing point for young versus old and low versus high experience).

The NHANES III equations most accurately predicted the recorded values for FVC, FEV_1 and PEF and were the only equations to demonstrate significant change (for % predicted FEV_1 and % predicted PEF) for the group as a whole over the observation period. The mean changes in % predicted FEV_1, FVC and PEF, 95% confidence intervals and *P*-values are presented in Figure Two.

A comparison of changes in lung function over time employing all four prediction methods is shown in Table Six.

Figure Two **Change in % predicted FEV_1, FVC, and PEF over 5.6y (mean) using NHANES III prediction equations***



* Dots are the mean values and the arms represent the 95% confidence intervals

Table Six **Comparison of mean change in % predicted FVC, FEV_1, and PEF over 5.6y using various prediction methods**

	Change in % predicted lung function over 5.6 years*		
Method	FVC (N=328)	FEV_1 (N=330)	PEF (N=174)
NHANES III	-0.407, 12.838, 0.566	-1.510, 12.142, 0.042	-2.645, 17.098, 0.043
Knudson	0.794, 13.628, 0.292	-1.064, 12.498, 0.123	-1.753, 18.557, 0.214
WRS	0.508, 12.195, 0.451	-1.054, 11.173, 0.087	-0.199, 2.630, 0.552
Gore	-0.269, 12.989, 0.707	-1.239, 12.022, 0.062	-2.085, 16.324, 0.094

*Values are presented as mean, standard deviation, *P*-value

Discussion

With few exceptions, both epidemiologic and experimental studies have concluded that compressed gas diving is detrimental to divers' lung function (Thorsen, 2003). The mechanism for the deterioration in lung function is not completely understood, but several factors have been implicated both independently and in combination. However, the small changes in lung function found in this study and in others, suggest a low likelihood of clinical significance and raise the question of the value of regular lung function testing. The two relevant and controlled prospective studies showed similarly small and probably clinically insignificant changes over a similar timeframe (Skogstad et al., 2002; Tetzlaff et al., 2006). The clinical significance of respiratory function changes in terms of divers' careers, quality of life and morbidity after retirement from diving consequently remains unknown. This contrasts with the recommendations for such studies in response to the international consensus conference in Norway in 1993 (Hope et al., 1993).

The four prediction methods used here were chosen because of their relevance to New Zealand divers and their local and global popularity (Knudson et al., 1983; Gore et al., 1995; Marsh et al., 2006, 2007; Hankinson et al., 1999). However, the variable results (*P*-values ranging from 0.02 to 0.97) suggested a poor fit of at least some of these equations with this data set. The accuracy of the NHANES III equations in predicting the FVC, FEV_1 and PEF values, together with their demonstration of significant change in % predicted FEV_1 and PEF values over the observation period, implied greater accuracy but less precision than the other sets of predictive equations for this data set.

Divers' lung function is measured on a variety of equipment and is calibrated against different sets of reference algorithms. This study showed that the most appropriate data set for deriving normative values with which to compare New Zealand occupational divers is the NHANES III equations; it is reassuring that these equations are the most commonly used in New Zealand (Marsh et al., 2007).

The small, mostly insignificant changes, and the lack of correlation with reported number of years' diving, suggested a 'healthy worker effect', which is a form of sampling bias recognised since 1885. Put simply, the working population is likely to be healthier than the general population, which includes those who are not working for health reasons. Erroneous conclusions can be drawn if this is not taken into account. In the current study, the sets of 'normative' lung function prediction equations were based on groups of healthy Caucasian non-smokers with no clinical evidence of respiratory disease. No information was available on participants' occupation. Retired divers' files were not included in this audit, and it was thought that some divers might retire early for respiratory health reasons, compounding any 'healthy worker' bias. In fact, subsequent research (see Chapter Six) found that no divers had retired for respiratory reasons.

Previous studies such as those of Skogstad and Tetzlaff which used control groups of occupations of similar physical nature but without any diving (such as policemen or submariners) are more likely to reach valid conclusions than those based on more heterogeneous groups (Skogstad et al., 2002; Tetzlaff et al., 2006).

Recent research on New Zealand occupational divers (see Chapter Eight) found that regular five-yearly medical examinations resulted in very few divers having their certificates of medical fitness changed (Sames et al., 2009b). The observation that only 22.8% of registered occupational divers met the inclusion criteria for this study suggested that few divers continue occupational diving for longer than five to ten years. The possibility of premature health-related retirement was considered a subject worthy of further research, and a study investigating the effect of divers' health on the rate of attrition from the industry was conducted and is described in Chapter Nine.

Conclusions

Decreases in occupational divers' lung function over a period of 5.6y were minimal and of doubtful clinical significance, but, any changes were thought to possibly be obscured due to a 'healthy worker effect'. However, the subsequent study described in Chapter Nine found that the healthy worker effect appears to be of minimal significance for professional divers.

The mean 5.6-year observation period for this study may have been too short to observe clinically significant changes in lung function, but does reflect the relatively short mean duration of occupational diving careers. The follow-up study described below addressed this issue of the relatively short observation period by examining divers' lung function changes over careers spanning 10-25 years. Future study should also involve the long-term follow-up of retired divers.

Apart from anatomic lung abnormalities, or a history of previous pulmonary barotrauma (PBt), the only factor reported to be associated with an increased risk of PBt or cerebral artery gas embolism is a small FVC, and, in most cases of PBt, none of the many commonly recognised risk factors is present (Benton et al., 1999; Elliott et al., 1978; Gorman, 1984). Given this, and the results of the current and previous audit on the NZ occupational diver population it is hard to justify annual comprehensive lung function testing (Sames et al., 2009b).

LONG-TERM CHANGES IN SPIROMETRY IN OCCUPATIONAL DIVERS: A 10-25 YEAR AUDIT

Introduction

The lung function of professional divers is important to performance of their role. The question of whether diving causes lung function deterioration in the long-term has been previously investigated, and changes such as blunted respiratory response to carbon dioxide (Earing et al., 2014), airway inflammation, airway hyper-reactivity (Thorsen et al., 1990; Thom et al., 2012) and reduced diffusion capacity for carbon monoxide have been reported (Cotes et al., 1987; Dujic et al., 1993; Thorsen et al., 1994; Thorsen et al., 1995). Various pathophysiological theories have been advanced to account for these changes including: repeated exposures to the pulmonary effects of inert gas microemboli, and to hyperoxia leading to pulmonary oxygen toxicity (Thorsen et al., 1990; Thom et al., 2012).

However, a 1994 consensus recognised that the various published investigations of changes in lung function among occupational divers were of limited quality and often produced conflicting results. The consensus included a plea for further research, particularly longitudinal studies, to further characterise any correlation with diving and any long-term impact on health (Hope et al., 2003). Since then, studies have continued to produce inconsistent results based on small sample sizes and variable methods (Pougnet et al., 2014; Watt, 1985; Thorsen et al., 1993; Skogstad et al., 2000; Fitzpatrick & Conkin, 2003; Lucas et al., 2005; Tetzlaff et al., 2006; Chong et al., 2008; Skogstad & Skare, 2008; Sames et al., 2009a). The ongoing limitations of research in this area are evident from two recently published literature reviews.

The first, comparing relevant papers over a 30 year period to 2014 found fourteen such studies (Pougnet et al., 2014), seven of which followed divers for an average of five years or less (Watt, 1985; Thorsen et al., 1993; Skogstad et al., 2000; Fitzpatrick & Conkin, 2003; Lucas et al., 2005; Tetzlaff et al., 2006; Chong et al., 2008), and only one for longer than 10 years (Skogstad & Skare, 2008). Seven studies involved fewer than 50 divers. Prospective studies used appropriately matched control groups, while the retrospective studies used different normative datasets for comparison with the divers. Only three longitudinal studies reported changes as percentages of the reference values (Thorsen et al., 1993; Chong et al., 2008; Sames et al., 2009a).

The second is the most recent and comprehensive review of both short and long-term effects of diving on lung function (Tetzlaff & Thomas, 2017). This included commentary on all published longitudinal studies, including recreational divers, and a large 30-year study of Dutch naval divers (Voortman et al., 2016) over a 70 year period to 2017. It emphasised that although past studies have provided disparate results, most agree that lung function changes are of minimal clinical significance. The exception is for the small number of individuals who may be adversely affected in the long-term, but are likely to be identifiable based on their particular diving history or exposure and physiological predisposition to lung function impairment.

Using a large database containing serial spirometry measurements on occupational divers over periods ranging from 10 to 25 years, we sought evidence for any deterioration in lung function that was disproportional to changes predicted by age-adjusted normative values. The null hypothesis was that there would be no difference between age-adjusted predicted values for spirometric indices and the values obtained from long-term occupational divers.

Method

Ethical approval for this study was granted by the Waitemata District Health Board Human Ethics Committee (reference number RM 13630).
The New Zealand national occupational divers' database was searched for all divers registered for 10 years or longer, whether currently registered or not. The identified divers' medical records were searched for spirometric data. Inclusion in this study required the diver to have two adequate spirometry records, including at least forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1), but preferably also peak expiratory flow (PEF), separated by at least 10 years. For each diver the most recent and the earliest suitable recordings were selected. De-identified demographic data were collated for stratification and comparison.
Changes in FVC, FEV_1, FEV_1% and PEF between the first and most recent suitable

recordings were calculated and expressed as medians for the entire cohort combined, and with subjects stratified into groups with 10 – 15 years and > 15 years diving activity between observations. In parallel, two sets of algorithms, the Global Lung Function Initiative (GLI-2012) and the third National Health and Nutrition Examination Survey (NHANES III) (see Appendices One and Two), were used to calculate the age–related changes in these parameters expected for each subject's gender, height and age at the first measurement, and subsequent period of observation. These changes were also expressed as medians for the entire cohort combined, and with subjects stratified into groups with either 10 – 15 years or > 15 years diving activity between observations.

The primary outcome of this study was a comparison of the changes in spirometric indices over the period of observation to those predicted on the basis of ageing alone, in order to deduce any independent effect of occupational diving. Predicted values and z-values for FVC, FEV_1 and the FEV_1/FVC ratio were generated using software downloaded from the GLI website (Quanjer et al., 2012). Similarly, the predicted values for the same parameters, as well as those for PEF, derived using the NHANES III equations, were extracted from published data for the appropriate ethnic group, gender, height and age (Hankinson et al., 1999). Correlations were also sought between changes in lung function and age of the diver, smoking status, gender and BMI.

Statistical analysis was performed using SAS® v9.4 software (SAS Institute Inc., Cary, North Carolina, USA). Frequency and proportion (%) were used for describing categorical variables, such as gender, smoking status and type of diving. Median with minimum and maximum were used for describing the continuous variables including age and BMI as they did not follow normal distribution. Duration of diving experience was categorical in some comparison analyses and continuous in the regression models. Median, and its distribution-free 95% confidence intervals, was used to present the study outcomes including observed values, predicted values, percent predicted values and z values of FVC, FEV_1, FEV_1/FVC and PEF. Spearman correlation was used for simple correlation analysis. Robust regression models (an alternative to least squares regression when data are contaminated with outliers, or for detecting influential observations) and analysis of co-variance with general linear models, were used in multiple regression analyses. A *P*-value of <0.05 was considered to be statistically significant. To account for outliers and avoid the possibility of missing important information, type 1 error was not adjusted for multiple comparisons.

Results

232 divers satisfied the entry criteria. The mean interval between recordings was 13.6 years. The group was stratified into those with 10-15 years (*n* = 159, mean = 11.6y), and those with greater than 15 years (*n* = 73, mean 18.1y) between spirometric recordings. Demographic characteristics, including breakdown into the various occupational diving categories, are represented in Table Seven. Of note, the commonest type of diving was 'scientific', comprising over one third of the group. The group was predominantly male and exclusively so for the more experienced group. It should be noted that the group comprised divers using a variety of breathing apparatus, including scuba (open and closed circuit), surface-supplied gas and saturation systems. Non-smokers (never smoked) comprised three quarters of the group, while the vast majority of the remainder were ex-smokers. The entry criteria dictated that this was a relatively old group of divers, with an average age of 48y at the time of the second assessment. There was a small mean increase in BMI (1.6 kg/m^2) over the assessment period.

Initial FVC measurements among our divers were not significantly different from the age-adjusted norms. Comparisons of subsequent observed and predicted changes in spirometric indices over the period of observation are presented in Table Eight. These data showed a reduction in FVC and FEV_1 with increasing duration of diving career, but this was less than predicted on the basis of increasing age by either prediction method. Similarly, the FEV_1/FVC ratio decreased in longer-term divers, but essentially as predicted on the basis of increasing age. PEF decreased as predicted by NHANES III for the group overall, but statistically significantly more than predicted for age for the longer career group, and less than predicted for the shorter career group. The overall reduction in observed PEF values together with an increase in percentage of predicted values is explained by the slower rate of decline in observed relative to predicted values.

Table Seven **Characteristics of 232 professional divers stratified by duration of career**

	All (*n* =232)	>15 years (*n* =73)	10-15 years (*n* =159)
Male (%)	90	100	86
Female (%)	10	0	14
Non-smoker (%)	74	70	75
Smoker and ex-smoker (%)	26	30	25
No. dives/yr (at 2nd med*)	60 (0-350)	55 (0-272)	62 (0-350)
Age (at 2nd medical)	48 (31-75)	52 (38-75)	46 (31-73)
ΔBMI (kg/m^2)	1.6 (-6.3-12.2)	2 (-4.1-9.0)	1.4 (-6.3-12.2)
Δ Age (years)	13.6 (10-25)	18.1 (15-25)	11.6 (10-14)
Scientific (%)	35	30	36
Commercial (%)	19	24	17
Instructor (%)	17	9	21
Construction (%)	14	14	14
Aquaculture (%)	7	9	6
Mil/Police/Customs (%)	4	4	4
Film (%)	3	10	1
HBU attendant (%)	1	0	1

* 2nd medical refers to data collected from the divers' most recent medical examinations

Table Eight **Long-term changes in observed and predicted values of diver lung function**

Diving duration group	Lung function parameter			
	FVC (L)	FEV_1 (L)	FEV_1 / FVC	PEF* (L/s)
All (*n*=232)				
Observed	-0.16 (-0.22,-0.07)	-0.30 (-0.36,-0.21)	-0.04 (-0.04,-0.03)	-0.31 (-0.68,-0.08)
Predicted (NHANES III)	-0.28 (-0.32,-0.25)	-0.35 (-0.39,-0.32)	-0.03 (-0.03,-0.03)	-0.29 (-0.37,-0.23)
Predicted (GLI)	-0.32 (-0.35,-0.29)	-0.37 (-0.35,-0.40)	-0.02 (-0.03,-0.02)	x
>15 years (*n*=73)				
Observed	-0.36 (-0.60,-0.20)	-0.52 (-0.69,-0.36)	-0.03 (-0.05,-0.02)	-0.79 (-1.41,-0.17)
Predicted (NHANES III)	-0.41 (-0.45,-0.37)	-0.50 (-0.55,-0.46)	-0.04 (-0.04,-0.03)	-0.50 (-0.60,-0.42)
Predicted (GLI)	-0.47 (-0.52,-0.40)	-0.55 (-0.58,-0.51)	-0.03 (-0.03,-0.03)	x
10-15 years (*n*=159)				
Observed	-0.07 (-0.16,0.04)	-0.22 (-0.31,-0.15)	-0.04 (-0.05,-0.03)	-0.10 (-0.55,0.16)
Predicted (NHANES III)	-0.23 (-0.25,-0.19)	-0.29 (-0.31,-0.27)	-0.02 (-0.02,-0.02)	-0.22 (-0.28,-0.15)
Predicted (GLI)	-0.27 (-0.29,-0.23)	-0.32 (-0.35,-0.30)	-0.02 (-0.02,-0.02)	x

Data are presented as: medians (95% confidence limits)

* For PEF, *n*(All)=195, *n*(>15y)=56, *n*(10-15y)=139

The annual changes in observed values of FVC, FEV_1 and PEF are presented in Table Nine. However, these data do not discriminate between any effect of diving exposure and changes expected with ageing. Therefore, we present the observed changes as deviations in percentage of predicted values (see Table Ten) and as changes in z-values (see Table Eleven, GLI comparison only).

Table Nine **Annual observed change in occupational diver lung function**

Lung function	Diving duration group		
	All (*n*=232)	>15 yrs (*n*=73)	10-15yrs (*n*=159)
FVC (mls)	-10.3 (-16.7,-5.8)	-21.3 (-33.3,-10.5)	-5.8 (-13.3,-3.3)
FEV_1 (mls)	-23.2 (-28.3,-17.3)	-29.6 (-37.5,-19.3)	-20.0 (-26.0,-12.9)
PEF*(mls/sec)	-21.9 (-46.4,-6.7)	-43.7 (-73.7,-8.3)	-9.0 (-45.8,14.0)

Data are presented as: medians (95% confidence limits)

* For PEF, *n*(All)=195, *n*(>15y)=56, *n*(10-15y)=139

Table Ten **Long-term changes in % predicted values of diver lung function using GLI-2012 and NHANES III values**

Lung function	Diving duration group					
	ALL (*n* =232)		>15y (*n* =73)		10-15y (*n* =159)	
	GLI	NHANES III	GLI	NHANES III	GLI	NHANES III
FVC	3.1 (1.8,5.2)	2.6 (1.0,4.5)	0.5 (-2.0,5.2)	0.5 (-2.4,3.7)	3.6 (2.4,6.7)	4.1 (1.8,5.9)
FEV_1	2.5 (0.6,3.8)	2 (0.2,3.1)	2.4 (-3.0,4.0)	0.5 (-3.6,4.4)	2.5 (0.6,4.4)	2.3 (0.6,4.0)
FEV_1/FVC	-1.35 (-2.5,-0.1)	-1.3 (-2.3,-0.1)	0 (-2.6,1.5)	-0.1 (-1.6,2.4)	-2.5 (-2.7,-0.2)	-1.4 (-2.6,-1.2)
PEF*	x	0.4 (-3.6,3.3)	x	-1.95 (-8.4,3.6)	x	0.5 (-3.1,5.5)

Data are presented as: medians (95% confidence limits)

* For PEF, *n*(All)=195, *n*(>15y)=56, *n*(10-15y)=139

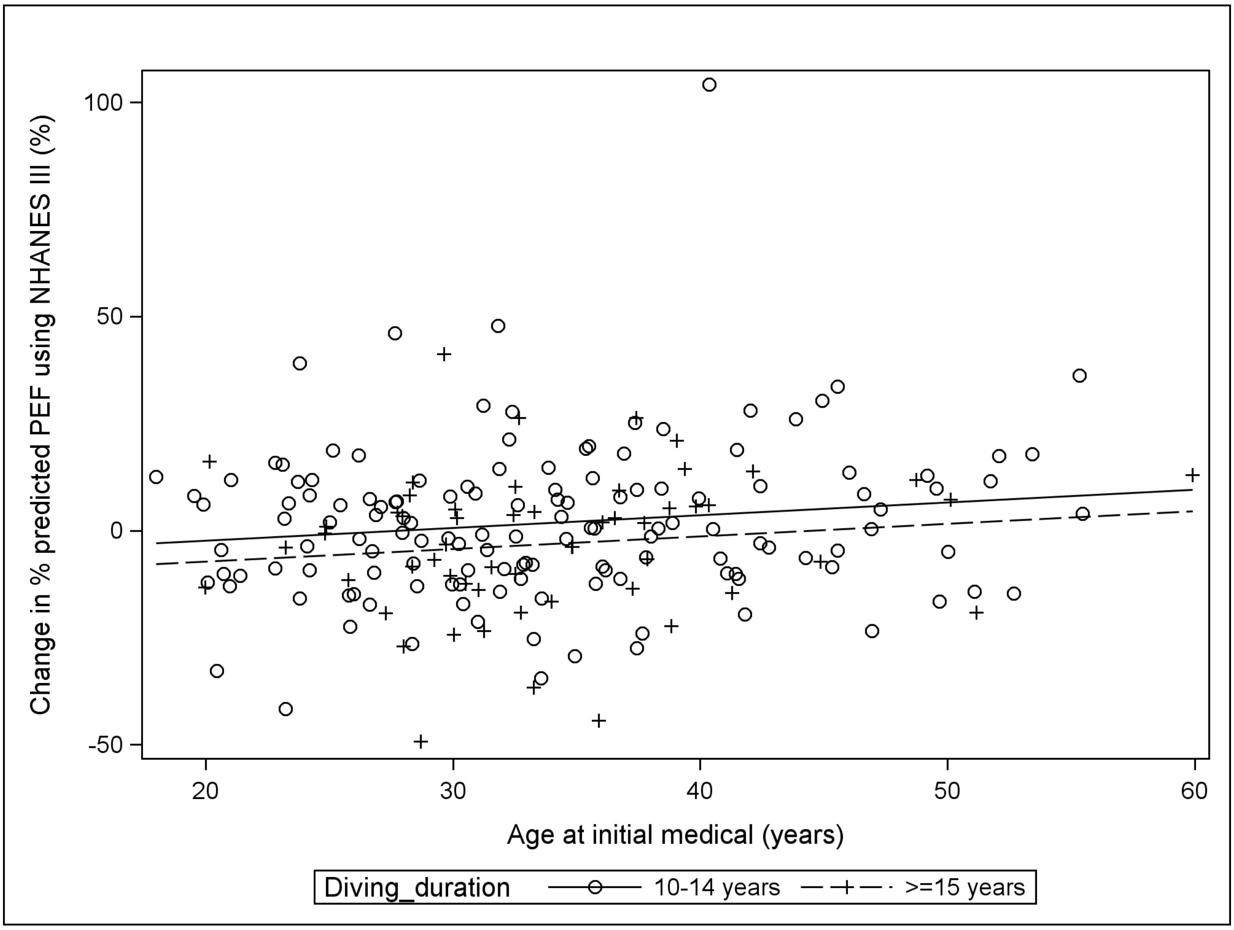
Table Eleven **Long-term changes in z-values of diver lung function using GLI-2012 values**

Lung function	Diving duration group		
	All (*n* = 232)	>15 yrs (*n* = 73)	10-15yrs (*n* = 159)
FVC (Δz)	0.25 (0.11,0.43)	0.04 (-0.24,0.39)	0.34 (0.18,0.52)
FEV1 (Δz)	0.18 (0.05,0.34)	0.08 (-0.21,0.36)	0.19 (0.05,0.38)
FEV1/FVC (Δz)	-0.18 (-0.32,-0.07)	-0.03 (-0.31,0.19)	-0.23 (-0.35,-0.14)

Data are presented as: medians (95% confidence limits)

There was a minor rise in percentage of predicted value and z-value of FVC (3.1%, 0.25 respectively), a smaller rise for FEV_1 (2.5%, 0.18 respectively), and a consequent reduction in the values for the FEV_1/FVC ratio (-1.35%, -0.18 respectively). These changes were greater for the less experienced sub-group, so there was a trend towards zero change with increasing duration of occupational diving. The magnitude of PEF changes was greater for the more experienced sub-group, with a significant median reduction in percentage of predicted value (-1.95%). The analysis of covariance plot represented by Figure Three demonstrates the small but significant difference between the increase in percent predicted values of PEF (using NHANES III data) for the two groups of divers based on their age at initial examination.

Figure Three Relationship between age at the earliest spirometry test, diving exposure and long-term changes in % predicted values of divers' peak expiratory flow (PEF) based on NHANES III prediction equations



Multiple regression analysis showed that the change in percent of predicted value of PEF correlated significantly with the age of the diver at initial assessment (P = 0.002), the duration of diving exposure (P = 0.037) and the BMI at second assessment (P = 0.035). The only other significant correlation was between the BMI at second assessment and changes in z-values and % predicted values of FVC (P = 0.04 and P = 0.025 respectively) and FEV_1/FVC (P = 0.017 and P = 0.009 respectively). No significant correlations were apparent between changes in any of the lung function parameters and smoking status. Diver age and gender were controlled for in the comparison data and no additional correlation was found with these parameters.

Discussion

From the very early days of occupational diving it has been widely accepted that detailed physical examination, with a strong focus on respiratory function, was mandatory for screening of prospective occupational divers and for routine surveillance of experienced divers. Traditionally, routine surveillance entailed annual measurement of spirometric indices, and this practice has prevailed in most countries despite lack of evidence of its utility.

This study was undertaken because of inconsistent findings from small studies of divers' lung function, variable control methods and a lack of studies extending as far as 25 years of diving activity. Our database contained 232 occupational divers with adequate spirometric recordings covering a period of 10-25 years of diving activity. We compared changes in the principal spirometric parameters with normative data and found no significant difference that could be attributed to diving experience rather than increasing age. Therefore, the main finding of this study relevant to working divers is that while small changes in some spirometric parameters may reach statistical significance, there is no evidence of change attributable to diving that is likely to be of clinical significance in the long-term. Prospective occupational divers, and those who remain in the industry for many years, should be encouraged by this further evidence of the relative lack of harm to the respiratory system due to diving.

These results were confluent with our previous study of a cohort of 336 divers over a mean period of 5.6 years (see above), except that in that study we found small but statistically significant reductions in the percent of predicted values for FEV_1 and PEF using NHANES III normative data (Hankinson et al., 1999). The current study found no significant change for FEV_1 and a small but statistically significant rise in percent of predicted PEF. Our results also support those of Skogstad and Skare (2008) whose prospective study of 37 Norwegian professional divers over 12 years showed no correlation between diving exposure (total number of dives) and FVC and FEV_1.

These findings, like those of our previous study, also cast doubt on the utility of routine annual spirometric measurement in all occupational divers. There seems little point in conducting serial investigation for changing spirometry over a diving career in the absence of convincing evidence that such change is a feature of long-term diving. However, we recognise that spirometry would be indicated if some other aspect of a diver's medical history, likely to be detected on their annual health questionnaire, implied that significant change was plausible (such as a diving accident or a significant respiratory illness in the preceding year).

This study has a number of limitations that must be acknowledged.
First, and most significantly, as with the previous study (above) we used years of occupational diving as a surrogate for diving exposure. Clearly, this is a blunt measure of exposure, but we had no access to more precise data. The ideal would have been to record number of dives with times, depths and gases used, but we lacked such records over the long period of observation involved. Even the number of dives per year was not consistently recorded, and most likely inaccurate. Such detail may only be available in the setting of a prospective study. With this limitation acknowledged, it nevertheless seems implausible that divers would maintain medical fitness certification for occupational diving over a prolonged period in the absence of moderate diving activity.

Secondly, we cannot exclude some degree of selection bias, where divers may have quit with less than 10 years' experience due to deteriorating lung function. We know from a previous study (see Chapter Eight) that there is an attrition rate of nearly 80%

over a five-year period for NZ occupational divers, suggesting the possibility of a significant 'healthy worker effect'. However, we think this is unlikely to have influenced our findings in relation to spirometric changes (see Chapter Nine). The collective qualitative experience of the medical authors among our group is that occupational diver attrition due to deterioration in lung health in the absence of a discrete accident (such as pulmonary barotrauma) or a non-diving medical explanation is virtually unheard of. For example, in the current study, no diver was found to have clinically significant lung function deterioration. From our previous study of those remaining in the job for a mean of 5.6 years, only two out of 336 divers were found to have abnormal spirometry, but after further investigation neither was considered unfit for diving (Sames et al., 2009b).

Thirdly, we restricted this study to what we considered to be the principal spirometric parameters, namely FVC, FEV_1, FEV_1/FVC ratio and PEF, to avoid erosion of the sample size, since the other parameters were far less consistently recorded, especially in the older clinical records. We don't believe this detracts from our findings, but it does make this study a less than complete survey of lung function.

Fourthly, as with most retrospective studies, the quality of spirometric data was beyond our control, and likely to have varied widely.

Finally, we chose to compare our data with the NHANES III and GLI normative data because these sets of prediction equations are widely accepted internationally, despite the fact that neither set is based on data drawn from the NZ population. An argument against using such 'normal' population data is that, with a cohort comprising only divers, we are not dealing with a 'normal' population, so they would more appropriately be compared with a control group of similar fitness engaged in equally strenuous activity. Previous studies have used such occupations as submariners (Tetzlaff et al., 2006), policemen (Skogstad et al., 2002) and non-diving offshore workers (Macdiarmid et al., 2004) for comparison. However, any error introduced because of our selection of comparative data is not likely to be significant, and we have previously demonstrated close alignment of the NHANES III data with data from NZ divers (Sames et al., 2009a).

Conclusion

The small changes in lung function found in divers with a 10 - 25 year occupational diving history are generally confluent with predictions based on aging, and not likely to be clinically significant. There appears to be no justification for routine spirometry in asymptomatic divers.

CHAPTER FOUR

The long-term effects of professional diving on hearing

Prelude

The following study has been published in peer-reviewed literature and examined changes in divers' hearing over a 10-25 year period (Sames et al., 2019a). Minor modifications have been made for incorporation within this thesis. This chapter addresses the second of two mandatory physical investigations included in the routine medical examination, the first being lung function, discussed in the previous chapter.

Introduction

Hearing loss is recognised as an important and preventable occupational injury. In most industries, exposure to excessive noise is the responsible mechanism, and where all other measures to reduce noise levels have been exhausted, employers are obligated to provide hearing protection and appropriate staff education. For working divers, however, hearing can be adversely affected by several mechanisms that are independent of noise exposure. These include: conductive loss due to middle ear barotrauma (MEBt) which impairs transduction of sound by the tympanic membrane and ossicular chain (Money et al., 1985); and sensorineural deficit due to noise-induced hearing loss (NIHL), barotraumatic damage to the inner ear structures (Elliott & Smart, 2014; Freeman & Edmonds, 1972), and inner ear decompression sickness (DCS) (Farmer et al., 1976; Mitchell & Doolette, 2016). Apart from these discrete barotraumatic and DCS events, doubt remains as to whether diving *per se* has a clinically significant negative impact on hearing over the long term. Controlling for the effects of increasing age and discrete injurious events remains a confounding factor for research in this area. The value of such research, for divers and employers, is that after identifying and either eliminating or minimising any preventable causes of hearing loss, including high-risk diving practice, they could have realistic, evidence-based, expectations about the impact of diving on hearing.

The objective of the current study was to identify evidence of hearing loss that appears related to long term occupational diving, with the intention of informing auditory surveillance policy for divers.

Reviews of diving-related hearing loss suggest that long-term changes are not clinically significant, and that, after correcting for age, any deterioration is likely due to noise exposure or trauma (Livingstone et al., 2017; Evens et al., 2012). However, results of individual studies are variable, with some studies reporting significant hearing loss and a correlation with diving experience, and others reporting no such loss or correlation. For example, Molvaer and Lehmann (1985), and Molvaer and Albrektsen (1990) found that at most frequencies, divers had poorer hearing than age-matched, otologically normal subjects at both the initial and final examination six years later. They also found a significant correlation between hearing loss and both diving experience and smoking. Similarly, a prospective series of studies of professional divers over a twelve year period (Skogstad et al., 2000, 2005, 2009) reported that although divers had better hearing than the general population at both initial and final examinations (in contrast to the above findings of Molvaer), minor reduction in hearing seemed related to diving exposure. Similar results were reported in a five year prospective study of Japanese fishery divers (Haraguchi et al., 1999), and in a cross-sectional study of Malaysian Navy divers whose hearing deteriorated at a faster rate than controls (Zulkaflay et al., 1996). However, in a previous cross-sectional study, Skogstad et al. (1999) had found no difference between the hearing of a group of construction divers with a mean of 20 years' diving experience and a matched control group of workshop workers. Another prospective study of professional divers over six years reported no correlation between hearing loss and diving frequency or history of middle ear barotrauma (Goplen et al., 2011). Other studies of professional divers have also found no significant difference in hearing between divers and control subjects or a relationship between hearing loss and diving experience (Macdiarmid et al., 2004; Brady et al., 1976; Chng et al., 2014). Most studies of recreational divers have reported no significant hearing impairment compared with control subjects (Taylor et al., 2006; Hausmann et al., 2011b; Klingmann et al., 2004; Hizel et al., 2007). This suggests that increased noise exposure, more likely to be encountered by professional divers, is the most plausible explanation for any finding of increased hearing loss in that group. A comparison of professional divers and offshore workers found that these divers were indeed more likely to suffer noise-induced hearing loss (Ross et al., 2010).

As one of only two mandatory physical investigations routinely required of professional divers, the other being assessment of lung function, investigation of the evidence underlying the requirement for audiometry, repeated annually in most countries, is both apposite and overdue.

Method

This study was reviewed and authorised by the Waitemata District Health Board Research and Knowledge Centre and did not require review by a Health and Disability Ethics Committee (reference No. RM13630).

The New Zealand occupational divers' database was audited for all divers with two hearing assessments separated by at least 10 years. We used the earliest hearing assessment available on our database as their baseline, but this was not invariably the first hearing assessment in the diver's career. To clarify, the duration of occupational diving between assessments was not necessarily equivalent to the total occupational diving experience of any diver. Qualifying divers' records were also audited for a history of middle or inner ear barotrauma, inner ear DCS, pre-existing hearing loss or tinnitus. Initial and follow-up recordings of pure tone air conduction hearing thresholds, in decibels (dB), were collated for each ear for the following frequencies: 500Hz, 1, 2, 4, 6 and 8kHz. For each of these recordings, a corresponding age-adjusted value was calculated by subtracting from the observed value, the median normal hearing threshold, derived from the appropriate ISO 7029:2017 prediction equation for otologically normal subjects, based on age and gender (International Organisation for Standardisation, 2017). This model uses, as the reference zero level, the median hearing threshold of the 18-year old population. So, for example, the recorded thresholds for an 18-year old would require no adjustment. The changes in both recorded and adjusted values were calculated between the initial dataset and the paired dataset recorded after a period of 10-25 years of occupational diving. Correlations were sought between changes in hearing and duration of professional diving experience, intensity of diving (as described below), smoking status (categorised as non-smokers, ex-smokers and current smokers) and body mass index (BMI).

Statistical analysis used SAS® v9.4 software (SAS Institute Inc., Cary, North Carolina, USA). Frequency and proportion (%) were used for describing categorical variables, such as gender, smoking status and type of diving. Median with minimum and maximum were used for describing the continuous variables including age (and change in age used to represent duration of diving experience), BMI and number of dives per year, as they did not follow a normal distribution. Median, and its distribution-free 95% confidence intervals, was used to present the study outcomes including observed, predicted and age/gender-adjusted values of hearing thresholds. Robust regression models (using the Robustreg procedure, an alternative to least squares regression, that provides stable results in the presence of outliers, and limits their influence) and analysis of co-variance with general linear models, were used in multiple regression analyses. A *P*-value of <0.05 was considered to be statistically significant. Type 1 error was not adjusted for multiple comparisons, in order to allow for outliers and include all possible important information.

Results

Two hundred and twenty seven divers satisfied the entry criterion of having adequate records spanning periods of 10-25 years (median=12 years). Demographic data for the divers are presented in Table Twelve.

None of the divers had a recorded history of either inner ear barotrauma or DCS, but two had a history of MEBt, and 44 (19.4%) had record of either pre-existing hearing loss and/or chronic tinnitus. Both initial and final hearing thresholds for the group were higher than normal values, meaning that sounds were detected at a higher sound intensity, indicating that hearing was slightly worse than predicted for age throughout the recording period. However, changes over the recording period were smaller than predicted by the relevant ISO Standard (International Organisation for Standardisation, 2017). Both age-adjusted and observed hearing thresholds for right and left ears were compared with predicted (normal) values for initial (see Figure Four) and final recordings (see Figure Five).

The median values and 95% confidence limits of changes in observed and predicted thresholds are shown in Table Thirteen, together with 25 and 75 percentiles and interquartile ranges.

Despite more than half of the group showing a significant hearing reduction in at least one ear and at one frequency, more notable at the higher frequencies (see Figure Six), median values for the group showed no change in the hearing thresholds at lower frequencies (500Hz, 1kHz, 2kHz) in either ear, and only minor changes at the higher frequencies (4kHz, 6kHz, 8kHz) that were less than predicted for increasing age (see Figure Seven).

The reduction, over time, in the difference between age-adjusted recordings and predicted thresholds is further demonstrated by comparison of the ratio of median age-adjusted observations and predicted thresholds at initial and subsequent testing after 10-25 years of occupational diving (see Figure Eight).

This reduction in difference (approaching the predicted values) of thresholds is significantly more pronounced at the low frequencies (500 and 1000Hz). Multiple regression analysis, using the models described above, found no significant correlation between hearing change and intensity of diving or smoking status, but at most frequencies there was a statistically significant association with BMI ($P<0.05$).

No correlation was found between hearing change and duration of diving apart from at 4kHz in the left ear ($P = 0.0342$) and 8kHz in the right ear ($P = 0.0384$).

Table Twelve **Characteristics of 227 occupational divers undergoing audiological testing after periods of between 10 and 25 years of diving**

Characteristic	%/number/value
Male n(%)	90
Female n(%)	10
Non-smoker n(%)	73
Smoker and ex-smoker n(%)	27
Dives/year (median at 2nd medical*)	39 (0-350)
Age (median at 2nd medical*)	47 (31-75)
BMI (median at 2nd medical* kg/m^2)	27.1 (18.8-40.8)
Age change (median, yrs)	12 (10-25)
Scientific n(%)	35
Commercial n(%)	20
Instructor n(%)	17
Construction n(%)	14
Aquaculture n(%)	7
Military/Police/Customs n(%)	3
Film n(%)	3
HBU attendant n(%)	1

* '2nd medical' refers to data collected from the divers' most recent medical examinations.

Figure Four **Median age-adjusted, initial observed and predicted* hearing thresholds of 227 divers** (* derived from ISO Standard 7029.)

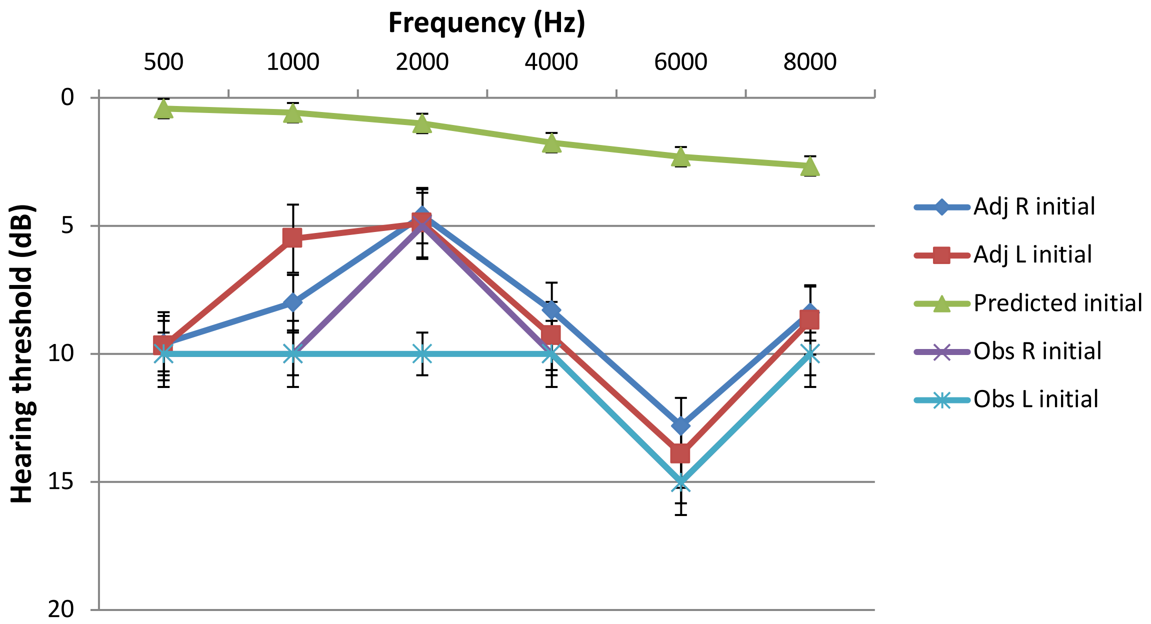


Figure Five **Median age-adjusted, observed and predicted* hearing thresholds of 227 divers after 10-25 years of diving** (* derived from ISO Standard 7029.)

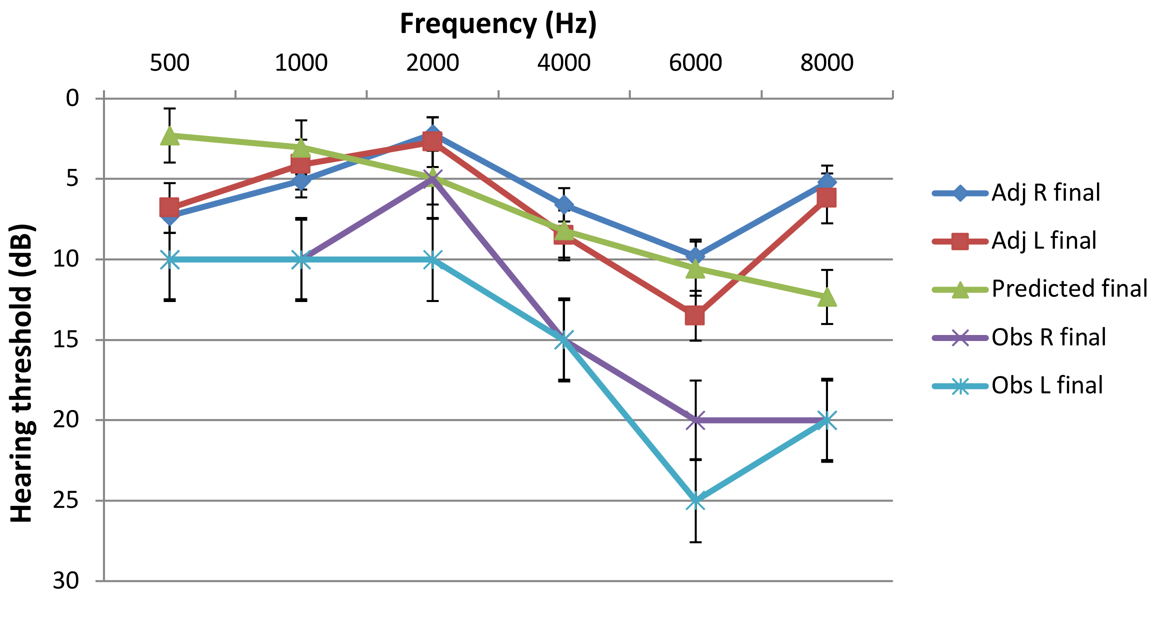


Table Thirteen **Changes of the observed, age-gender-adjusted and predicted hearing threshold values of 227 occupational divers over 10-25 years of diving**

	Freq, Side	Median	95% CI of median		Q1*	Q3**	Q3-Q1 range
			Lower	Upper			
Change in observed values	500Hz, R	0	0	0	-5	5	10
	500Hz, L	0	0	0	-5	5	10
	1kHz, R	0	0	0	-5	5	10
	1kHz, L	0	0	0	-5	5	10
	2kHz, R	0	0	0	-5	5	10
	2kHz, L	0	0	0	-5	5	10
	4kHz, R	5	5	5	0	15	15
	4kHz, L	5	5	5	0	15	15
	6kHz, R	5	5	10	-5	15	20
	6kHz, L	5	5	10	0	15	15
	8kHz, R	5	5	10	0	15	15
	8kHz, L	10	5	10	0	20	20
Change in age/gender-adjusted values	500Hz, R	-1.8	-2.8	-1.2	-7.9	3.6	11.5
	500Hz, L	-2.4	-3.8	-1.4	-7.7	3.3	11.0
	1kHz, R	-2.0	-3.6	-1.2	-7.0	3.2	10.3
	1kHz, L	-2.3	-3.4	-1.6	-7.4	2.5	9.9
	2kHz, R	-2.9	-3.9	-2.0	-8.0	2.4	10.4
	2kHz, L	-2.4	-3.7	-1.7	-7.8	2.0	9.8
	4kHz, R	0.1	-1.9	1.1	-7.3	5.3	12.5
	4kHz, L	-1.2	-2.9	0.9	-8.5	6.1	14.7
	6kHz, R	-3.3	-4.6	-1.1	-10.5	6.1	16.7
	6kHz, L	-1.5	-3.1	0.4	-8.9	5.8	14.7
	8kHz, R	-3.1	-5.3	-0.8	-10.0	7.5	17.4
	8kHz, L	-1.9	-3.5	0.4	-9.8	8.7	18.5
Change in predicted values	500Hz	1.8	1.6	2.0	1.1	3.0	1.9
	1kHz	2.4	2.1	2.6	1.4	3.9	2.5
	2kHz	3.8	3.1	4.1	2.3	6.1	3.8
	4kHz	6.3	5.5	6.7	3.8	9.6	5.8
	6kHz	8.0	7.1	8.5	4.9	12.2	7.3
	8kHz	9.4	8.2	10.0	5.7	14.4	8.7

* 25 percentile; ** 75 percentile
All values in Table 13 are expressed in decibels (dB).

Figure Six **Degree of hearing loss at certain frequencies in 227 divers over 10-25 years**

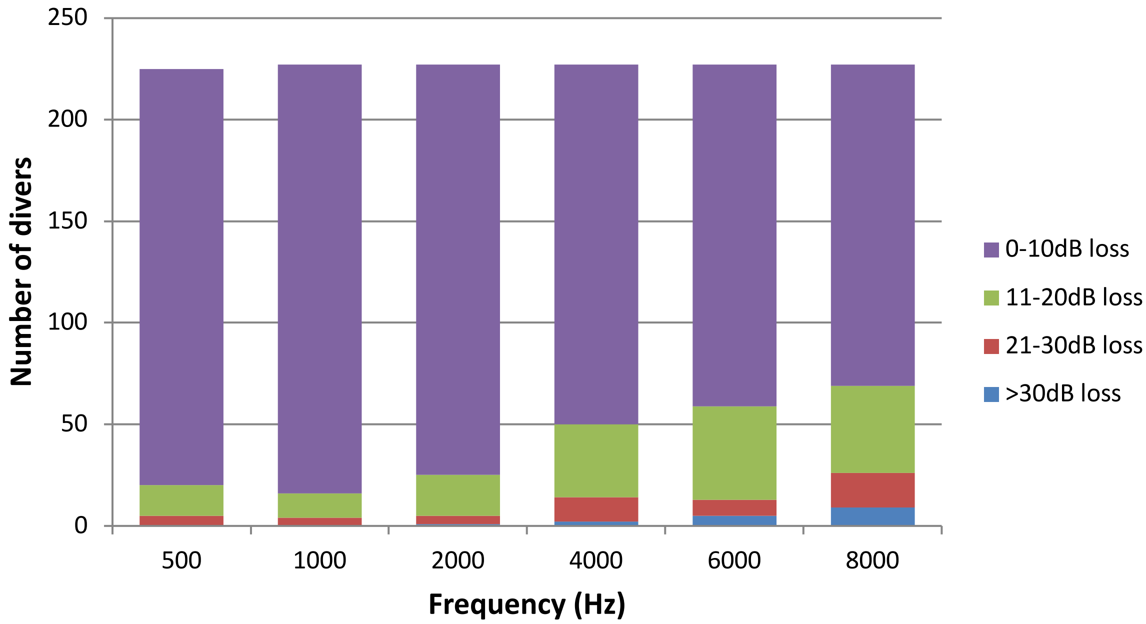


Figure Seven **Change in observed and age-adjusted hearing thresholds over 10-25 years of diving compared with predicted* change**
(* derived from ISO Standard 7029.)

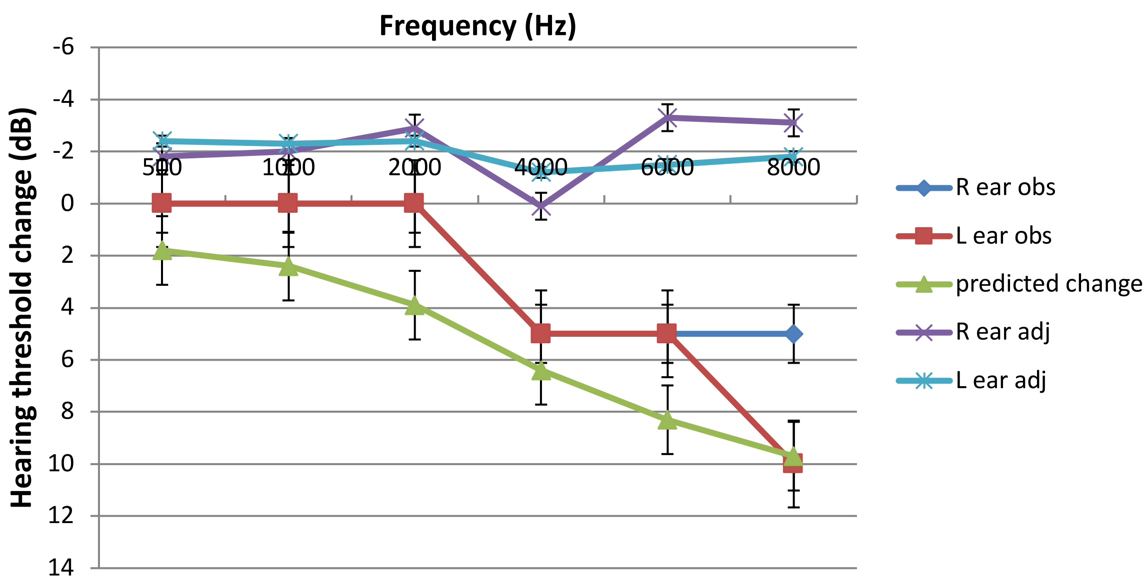
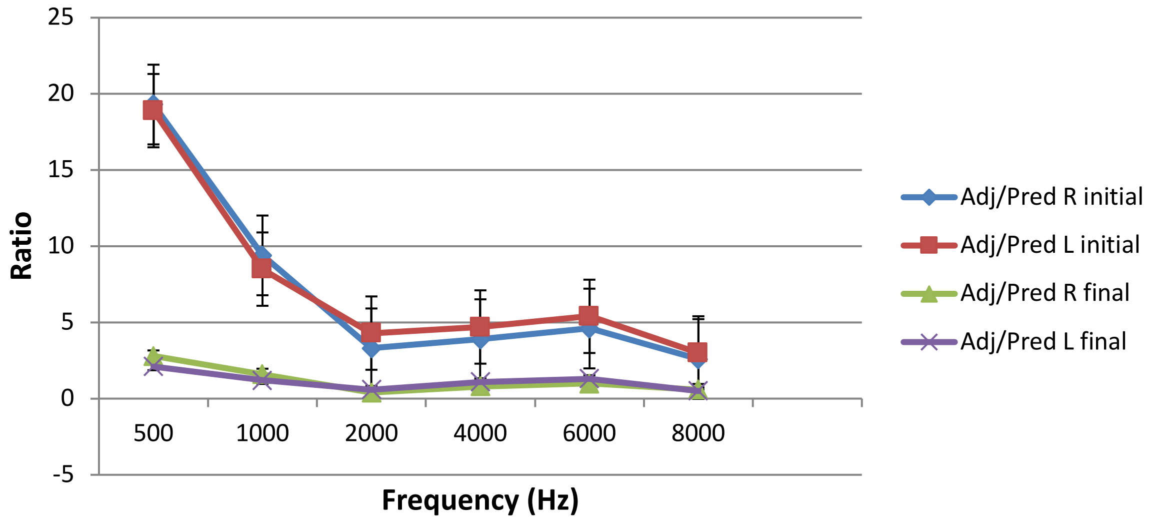


Figure Eight **Ratio of age-adjusted and predicted* hearing thresholds of divers before and after 10-25 years of diving** (* derived from ISO Standard 7029.)



<u>Discussion</u>

Our data showed that, for this sample of 227 professional divers, there was less deterioration in hearing after 10-25 years of professional diving than would be expected in the age-matched general population. However, we do not suggest that diving confers a degree of hearing protection, as most of the demonstrated changes are too small to be clinically relevant, and fall within the margin of error of many commonly used audiometers. Our finding of a correlation between hearing loss and BMI at most of the tested frequencies was unexpected, and of unlikely clinical significance, although previous studies have shown an association between high BMI and increased risk of hearing loss in adolescents (Lalwani et al., 2013) and adult women (Curhan et al., 2013), but not in adult men (Shargorodsky et al., 2010).

Valid reasons for testing divers' hearing include determination of fitness for work (ie. communication issues), tracking of hearing loss with the aim of prevention of further damage, and documentation of existing damage for possible future compensation claims. But whether the results of such tests are usually acted upon, and/or have a role in the prevention of further deterioration of hearing, is debatable. Abnormal results mean that damage is already done or may imply a pre-existing condition. They could certainly point to modifiable causes, but post-hoc rationalisation is an unsound basis on which to mandate formal routine audiological examinations. For example, while abnormal results do not imply an unsafe environment, normal results do not imply an audiologically safe working environment, that should ideally be provided, regardless of test results, by adherence to all practicable safety measures.

Our results concur with the majority of previous studies and suggest that while professional divers are always at increased risk of hearing damage due to a specific traumatic incident, they are at no greater risk of hearing loss than the general public in the absence of such an incident. Of particular note, in the past fifteen years, since the introduction, in New Zealand, of five-yearly rather than mandatory annual full medical evaluations in the absence of health concerns, not a single diver has been found, on routine audiological testing, to have a hearing condition that has resulted in any restriction on their certification. Employers, and divers themselves, are responsible for minimising exposure to excessive noise and other potential causes of hearing damage, such as barotrauma and DCS.

Consequently, we believe that a reasonable approach to surveillance of divers' health in this regard would be to perform formal audiological testing on entry to the industry, as a screening test and baseline, followed by further testing only if clinically indicated (for example, after a barotraumatic or inner ear DCS event), and then final testing on exit from the industry.

LIMITATIONS

There are a number of limitations of this study which must be acknowledged. Firstly, we did not have an objective measure of actual diving exposure, and our first audiometric recordings did not invariably represent the beginning of that exposure. The number of years of occupational diving between assessments, although a blunt measure, was adopted as a surrogate for diving exposure, as was done in both of the previously described studies of lung function (see Chapter Three). In addition, as mentioned above, the number of years of occupational diving used in this study is not necessarily representative of an individual diver's complete diving career, as many divers had already been diving for several years before the earliest of our usable audiological records. We have reported the change in hearing over periods of occupational diving ranging from 10 to 25 years. However, the initial recordings represent the divers' hearing at various points in their diving careers. So, we cannot exclude the possibility that our initial recordings may have been influenced by existing damage which could, in turn, influence later changes. Divers with an initial history of MEBt, hearing loss or tinnitus were not excluded from this study, because they were still considered to be fit to dive, and including them produced a more complete record of the real-world situation for working divers. For the multiple regression analysis, diver occupational groups were stratified into 'high intensity' and 'low intensity' groups on the basis that the high intensity group, consisting of construction, commercial, and military divers, was more likely to be exposed to deeper and more exertional diving with greater likelihood of noise pollution from in-helmet communications or equipment, than the low intensity group. Again, we acknowledge that this classification may be subject to inaccuracies.

Another limitation of this study is the possibility that a selection or attrition bias (healthy worker effect), based on divers leaving the industry because of hearing problems, may have influenced our findings. The only way to resolve this question would be to compare the audiograms of all divers on entry to, and exit from the industry, a topic for ongoing study. However, the results of a study into health reasons for diver attrition (Sames et al., 2019b) demonstrated no evidence of hearing loss as a reason for quitting diving (see Chapter Nine).

As with all such audits, data gathered over many years and from many sources are subject to the vagaries of variable equipment quality and the technical competence of operators. We were limited to using pure tone air conduction data when a more complete data set would have included bone conduction and speech discrimination data.

Finally, we used the latest ISO Standard data set as the normative data for comparison. An appropriate alternative may have been to use a matched group with similar occupational noise exposure to divers, such as firefighters, a consideration for future study.

Conclusions

Audiological changes over 10-25 years of professional diving were not found to be significantly different from the changes expected due to ageing. Development of policies for health and safety surveillance of occupational divers should be guided by the best available evidence of benefit when determining the frequency and type of screening examinations required. The results of this study suggest that routine annual audiological testing of occupational divers is not justifiable.

CHAPTER FIVE

Postal survey of fitness-to-dive opinions of diving doctors and general practitioners

Prelude

The ability of those with the responsibility of determination and certification of divers' fitness-to-dive status to operate with a reasonable degree of accuracy is ultimately a key determinant of the health and safety of both professional and recreational divers. The study described in this chapter has been published in peer-reviewed literature (Sames et al., 2012), and demonstrated a significant and potentially dangerous deficit in certification systems that are not routinely audited.

Introduction

In New Zealand, the estimated compressed-gas diver fatality rate was 5.8 deaths per 100,000 divers per year during 1996-2000, or a mean death rate of 6 per year from 1980-2006 (Davis et al., 2002; McClelland, 2007). This figure represents only about 5% of drowning fatalities and suggests that diving is a relatively safe occupation or pastime. However, of the 40 diver deaths in New Zealand from 2000-2006, 12 (33%) could have been disqualified from diving on medical grounds and, although the relationship between the medical condition and the accident was often unclear, these pre-existing medical conditions were considered by the coroner to be either causative or contributory to their deaths (McClelland, 2007).

Recreational divers in New Zealand are required to undergo a medical examination conducted by a medical practitioner prior to concluding training. There is no requirement for the examining doctor to have undergone training in diving medicine, and there is no ongoing health surveillance for these divers. In contrast, occupational divers undergo annual health evaluation comprising a questionnaire and a medical examination conducted by a 'designated diving doctor' (DDD) who has undertaken post-graduate training in diving medicine recognised in Australasia by the South Pacific Underwater Medicine Society (SPUMS). As noted previously, the obligation for the medical examination can be reduced to five-yearly in the absence of health concerns revealed by the annual health questionnaire (see Chapter Two). Both the medical examination documentation and the annual health questionnaires are independently reviewed by an expert medical panel. This system has been shown to be reliable, but controversy periodically arises about the justification for expert and independent review of the medical documentation (Sames et al., 2009b).

One reason for such a review is the potential for inconsistency in decision making, even between doctors trained in diving medicine. A previous study of doctors in Queensland, Australia, who had training in diving medicine, showed a low level of consensus in regard to the impact of certain medical conditions on 'fitness' to dive (Simpson & Roomes, 1999). Similar problems were found in a review of the process used to certify civil pilots fit to fly in New Zealand (Gorman & Scott, 2001, 2003).

The present study re-examined this issue in New Zealand; the aim was to determine consensus and concordance with expert opinion among New Zealand's designated diving doctors (DDDs) and general practitioners (GPs) regarding fitness for diving (both occupational and recreational); to consequently see if there is an ongoing need for independent review or arbitration of occupational diving medical evaluations; and, to identify possible improvements to recreational diving medical evaluations.

Method

A questionnaire describing 20 compressed-gas diving candidates who had a medical condition that can affect diving fitness was mailed, along with a reply-paid envelope, to two groups of doctors. The first was the cohort of DDDs currently registered with the then New Zealand Department of Labour (now WorkSafe NZ) for the conduct of occupational diving medical evaluations (*n* = 98). The second group comprised GPs selected alternately from the local (Auckland area) telephone book (*n* = 200), who were asked to complete the survey if they conducted diving medical fitness examinations for recreational divers as part of their normal practice, but only if they had not completed a course in diving medicine. The questionnaires were anonymous, but coded by administrative staff for later identification to enable feedback. Incentive to complete the questionnaire was offered in the form of Continuing Medical Education (CME) points (RNZCGP), and for the DDDs, the completion was a requirement to retain registration.

The cases were selected by one of us (CS) from the New Zealand occupational diver medical database and recreational diver candidate clinical records on the basis that there was a medical condition that could adversely impact risk in compressed-gas diving. The case set was then culled to a final set of 20 to obtain a mix of organ system issues, and to obtain a set where the 'certification outcome' would include a selection of positive, uncertain (where further investigations were needed to better define the level of individual risk), and negative responses (see Table Fourteen). The other two of us (DG and SM), both of whom are certified in diving medicine by the Australian and New Zealand College of Anaesthetists, comprised the 'expert review panel'.

Respondents were asked to categorise the medical fitness for compressed-gas diving (in general, not specifically recreational or occupational diving) for each of the 20 scenario candidates into one of three categories: medically fit to dive in accordance with the standards (see below) that apply in New Zealand; uncertain medical fitness for compressed-gas diving; or, as being medically unfit for compressed-gas diving. Respondents were also asked to write brief comments to justify their answers.

The DDDs were also asked to provide additional information in the form of an estimate of the number of dive medicals that they conducted per year, and the number of years that had elapsed since they completed a diving medicine course that would entitle them to DDD recognition.

Responses were compared with the opinion of the two of us who made up the expert panel and on the outcome that would arise from a consideration of the Australian and New Zealand Standards for recreational and occupational compressed-gas divers (Australian Standard, 2000; SPUMS, 2010; Australian and NZ Standard, 2007). Expert opinion differed in three cases (scenario numbers 10, 11 and 19), which were therefore excluded from further analysis. The expert opinion for the remaining 17 cases was also predictable from a consideration of the Standards and hence is used here as the ‘desired response’. Unless specifically stated, the scenarios were assumed to refer to recreational divers. For each respondent, the ‘concordance score’ was the percentage of scenarios where there was agreement with the ‘desired response’. For each scenario, the ‘concordance score’ was the percentage of respondents agreeing with the ‘desired response’. We have used the term ‘consensus’ to describe agreement within or between groups, whereas ‘concordance’ is used to describe agreement of an individual or group with a reference standard.

Statistical analysis was completed using SPSS software. Randolph’s free-marginal kappa values (κ) were derived to demonstrate consensus within each group of assessors and account for agreement by chance. To compare the DDDs with the GPs, both having been measured against the ‘desired response’, Student’s t-test of means (two-tailed) was used. To describe the correlation between concordance with the ‘desired response’ and time since completing a dive medicine course or number of dive medicals annually, Pearson’s correlation coefficient (r) was derived.

Results

The responses to the 20 scenarios are shown in Table Fourteen, as well as the ‘desired response’. Seventy-seven of 98 DDDs (79%) and 75 of 200 GPs (38%) responded to the questionnaire. The mean concordance score was 60% (range 24–88%) and 50% (range 12-82%) for DDDs and GPs respectively. By scenario, the mean concordance was 61% (range 26-94%) and 50% (range 19-89%) for DDDs and GPs respectively (Figure Nine). Consensus within each group was 52% (κ = 0.28) and 46% (κ = 0.18), for the DDDs and GPs respectively. Although both groups scored poorly, Student’s t-test of means showed DDDs were significantly more likely to express concordance with the ‘desired response’ than GPs (t = 3.88, 150 df, P = 0.0002). For those DDDs who provided the additional information (n = 51), there was a negative correlation (r = -0.3, P = 0.03) between their concordance score and the time elapsed since they completed a designated dive medicine course, and a positive correlation (r = 0.2, P = 0.03) with the number of dive medicals they did each year.

Table Fourteen **20 fitness-to-dive case scenarios and the gradings (as fit, unfit or unsure) awarded by a sample of 77 designated dive doctors (DDDs) and 75 GPs. (The desired response is written in italics)**

20 Fitness-to-dive case scenarios
Results from DDDs (*n* = 77) and GPs (*n* = 75)

Scenario			Fit	Unfit	Unsure
1	A 23yr old female with bipolar affective disorder and a history of psychotic symptoms, well-controlled on Lithium. *Unfit*	DDDs GPs	6 21	60 32	11 22
2	A 32yr old female who has a history of 2 spontaneous left-sided pneumothoraces, but who has had corrective surgery to the apex of her left lung. Spirometry is normal. *Unfit*	DDDs GPs	2 1	72 59	3 15
3	A 190cm 31yr old customs diver with a FVC of 7L but a FEV1/FVC of 0.69. He has a normal CXR, normal hypertonic saline challenge results and normal exercise tolerance. *Fit*	DDDs GPs	53 48	2 5	22 22
4	A fit 21yr old male who has Mobitz type 1 (Wenckebach) second degree heart block on resting ECG, but a normal exercise ECG. *Indeterminate*	DDDs GPs	39 29	11 15	27 31
5	A fit, asymptomatic 25yr old female with a soft systolic cardiac murmur heard best in the aortic region. *Indeterminate*	DDDs GPs	5 37	3 3	69 35
6	A 20yr old female with a history of 'wheezy bronchitis' in childhood. She used inhalers until she was 12yrs old but has not used any since then. Plain spirometry results are normal. *Indeterminate*	DDDs GPs	19 32	0 10	58 33
7	A 54 year old male hypertensive controlled with a diuretic. He has a normal exercise ECG and renal function. *Fit*	DDDs GPs	62 67	2 0	13 8
8	A 24yr old male with cerebral palsy who is able to walk with the use of sticks. *Unfit*	DDDs GPs	12 7	42 38	23 30

20 Fitness-to-dive case scenarios (cont)

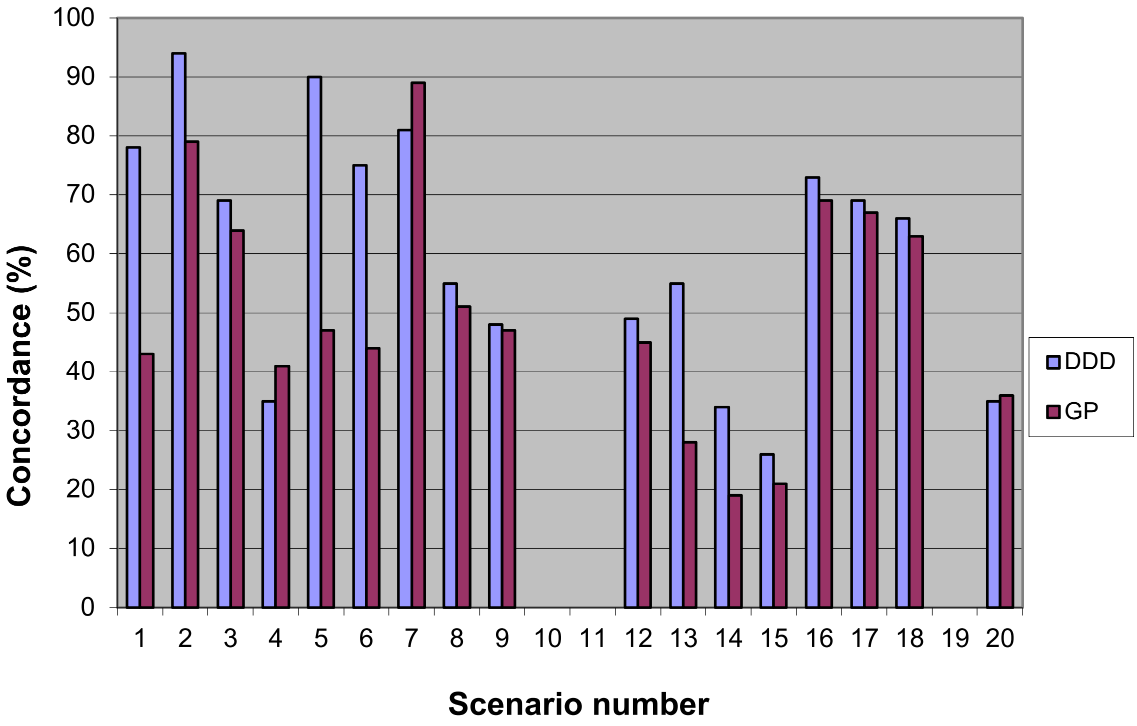
Results from DDDs (n = 77) and GPs (n = 75)

Scenario			Fit	Unfit	Unsure
9	An asymptomatic 45yr old male with atrial fibrillation diagnosed and fully investigated 10 years ago. He remains on warfarin and has normal exercise tolerance. *Unfit*	DDDs GPs	15 17	37 35	25 23
10	A 28yr old male with a BMI of 40. An exercise ECG to level 4 Bruce protocol showed no ischaemic changes. *Unfit*	DDDs GP	29 37	25 20	23 18
11	A 32yr old diver found on an epidemiological survey to have a patent foramen ovale (bubble contrast echo). He has been a Navy operational diver for 10 years without incident. *Unfit*	DDDs GPs	22 16	27 22	28 37
12	A 19yr old male with a history of convulsions as an infant, for which he was maintained for several years on phenobarbitone. The family GP has no record of any fits. *Indeterminate*	DDDs GPs	17 20	22 21	38 34
13	A 25yr old male who had a chest drain inserted after he suffered broken ribs and a haemo-pneumothorax three years ago in a car accident. He is back playing club rugby. His CXR and spirometry are normal. *Unfit*	DDDs GPs	16 36	42 21	19 18
14	A 45kg, 14year old female school swimming champion. *Indeterminate*	DDDs GPs	39 55	12 6	26 14
15	A 35yr old female with asthma since her teens. She is well-controlled on twice daily Fluticasone and last used her Salbutamol inhaler three months ago. She had a normal result on a recent hypertonic saline challenge test. *Indeterminate*	DDDs GPs	39 29	18 30	20 16

20 Fitness-to-dive case scenarios (cont)
Results from DDDs (n = 77) and GPs (n = 75)

Scenario			Fit	Unfit	Unsure
16	A 22yr old female with a history of severe head injury 5 years previously with small subdural haematoma but no surgical intervention. She fitted at the time. Was on Epilim for 2 years and has had no fits since discontinuing it. Recent MRI and EEG normal. She has had ongoing minor cognitive deficits and headaches. *Unfit*	DDDs GPs	9 4	56 52	12 19
17	A 29yr old female with a history of migraines. She has had no symptoms for the past year on prophylactic medication, but suffered severe bifrontal and occipital headaches during two familiarisation dives, the headaches onset at depth. *Unfit*	DDDs GPs	4 6	53 50	20 19
18	A 26yr old professional diver who was treated for neurological DCI 3 weeks ago. *Unfit*	DDDs GPs	1 2	51 47	25 26
19	A 49yr old male diabetic controlled by diet alone. He has mild diabetic retinopathy. *Unfit*	DDDs GPs	21 46	13 8	43 21
20	A 48yr old male with a past history of severe angina who has undergone successful coronary vessel grafting three years ago. No angina now and good exercise tolerance. *Unfit*	DDDs GPs	16 23	27 27	34 25

Figure Nine **Concordance of responses of doctors with basic training in diving medicine (DDD) and non-trained general practitioners (GP) with standard responses to fitness-to-dive scenarios**



The probability of assessing an ‘unfit’ diver as ‘fit’ was higher for GPs than DDDs (17.3% versus 11.7% respectively), and was also significantly higher for both GPs and DDDs than the converse probability of assessing a ‘fit’ diver as ‘unfit’ (3.3% and 2.6% respectively).

Concordance scores varied by greater than 15% (mean variance 27.7%) between DDDs and GPs (DDDs higher than GPs) in six of the scenarios (1, 2, 5, 6, 13 and 14). For the remaining 11 scenarios, the consensus between DDDs and GPs was high (mean variance 3.9%).

The concordance with the ‘desired response’ was <40% for both DDDs and GPs in 4 of the17 scenarios (three in common: scenarios 14, 15 and 20; DDDs in scenario 4, and GPs in scenario 13).

Discussion

The scenarios used in this survey were selected to include important respiratory, cardiovascular and neurological health issues for divers. Many of our ‘real-life’ cases were similar to those used in the Queensland study, some of which were fictitious and some real, emphasising that these are the kind of medical conditions that arise relatively commonly in assessing would-be divers (Simpson & Roomes, 1999). They were also selected to present a challenge to the assessing doctors as compared to more straightforward cases, which comprise the great majority of assessments. It follows that the current survey does not represent the outcome likely from a random selection of cases in which a much higher concordance would be expected.

The overall 38% response rate for surveyed GPs is likely to mask a much higher response rate for those GPs who fulfilled the inclusion criteria (those who conduct recreational diving medical fitness examinations but have not completed a diving medicine course) as many GPs do not undertake diving fitness assessments.

The published standards for fitness to dive are conservative, and if strictly applied they may result in divers being inappropriately denied medical clearance for diving (Australian Standard, 2000; SPUMS, 2010; Australian and NZ Standard, 2007). However, the finding that both DDDs and GPs were more likely to assess an unfit or indeterminate diver as fit, rather than the converse, suggests either disagreement with, or a lack of familiarity with the published standards, as the bias in the latter is in the opposite direction.

There was a wide range of opinions and a low mean concordance with the ‘desired response’ for both DDDs and GPs. This, together with the negative correlation between concordance score and time since completing a designated diving medicine course, suggests potential benefit could arise from periodic refresher courses and/or regular formative assessments of DDDs and GPs. It also suggests that the most reliable method of assessing someone's medical fitness for occupational diving involves an expert in diving medicine and/or a risk evaluation conducted by a specifically trained doctor who has ready access to expert advice. The problem with either of these 'solutions' is that there are very few diving medicine experts and hence access would be limited. The central audit facility for employed divers that exists in New Zealand is a workable solution to this problem and is clearly independent and less vulnerable to diver-advocacy bias. It is noteworthy that many divers who might otherwise have been disqualified, have been able to continue a career in diving, with specified constraints, due to the intervention of this facility.

For recreational divers, there is evidence both supporting and refuting the utility of a medical examination prior to training (Meehan & Bennett, 2010; Glen et al., 2000; Glen, 2004). In the face of this controversy, most countries have now adopted a self-declaration health questionnaire for recreational scuba diving candidates in line with the ISO standards (International Organization for Standardization, 2007). However, for occupational divers, there remains a widespread reliance on annual medical examinations conducted by doctors analogous to our DDDs. Our study suggested that in the absence of independent review, there is a strong possibility that candidates with significant medical conditions who undergo such an examination will receive a determination of fitness different to that which an expert would deliver or that expected by consideration of the relevant Standard. To the extent that we derived a 'desired response', this study suggests that independent review by such experts is a valuable adjunct to the process of occupational diver evaluation.

LIMITATIONS

The respondents, both DDDs and GPs, were asked only to assess the diving candidates' fitness to dive on the basis of the brief vignette. There was no specification regarding fitness for occupational versus recreational diving. Therefore, it is possible that some of the respondents, especially the GPs, may have applied a more liberal 'informed risk acceptor' approach in their decision making. It should be noted, however, that there are very few differences between the published standards for occupational and recreational diving.

Conclusions

This study supports the need for better, iterative and formative diving medical education for DDDs, and the desirability of diving medical education for any GP who wishes to conduct recreational dive medicals.

The overall low concordance of both DDDs and GPs with published recommendations and expert opinion is mitigated for DDDs performing occupational diving medicals in the New Zealand setting by the existence of a central, independent and expert audit authority (see Chapter Two).

CHAPTER SIX

Professional diver routine health surveillance and re-certification: an internet-based satisfaction survey of New Zealand divers

Prelude

Client (or stakeholder) cooperation is important for ensuring the effectiveness of a health surveillance or certification programme. Audits aimed at developing a robust programme necessarily involve canvassing the opinions of end-users to assess both the current situation and to establish an indication of essential or desirable modifications. The study described in this chapter has been published in peer-reviewed literature, and it determined the level of diver satisfaction and highlighted areas for improvement (Sames et al., 2020).

Introduction

Professional divers comprise a specialised group of workers whose occupation is regulated in most countries by government authorities responsible for workplace health and safety standards. For involved divers, this means mandatory compliance with a set of regulations regarding fitness for work and level of experience and/or training in order to achieve or maintain certification. Each jurisdiction is responsible for developing its own set of regulations and has authority to demand compliance from any diver entering its zone for work purposes. Many New Zealand divers seek employment in other countries to supplement their local work and, because there is no globally accepted set of regulations for this industry, there may be additional cost and duplication of certification processes such as medical examinations.

The New Zealand professional diver certification system has adopted changes over the past 15 years aimed at providing an efficient, cost-effective and evidence-based process. These changes have included firstly, and probably most notably, relaxation of the typical requirement for a full medical examination from annually to five-yearly. To clarify, the default position regarding the requirement for a full medical examination remains annually but, without a compelling health reason, divers are deemed exempt and to only require the examination five-yearly. Although this evolution was based on sound evidence, it placed the New Zealand system at odds with most other countries that have retained the traditional annual requirement with no exemptions (Greig et al., 2003). Admittedly, there is some global variability in the frequency of mandated medical examinations, dependent on type of diving and/or diver age.

Secondly, in addition to the full five-yearly medical examination, the New Zealand system requires completion of an on-line health questionnaire in each of the four intervening years. The questionnaire has been modified from the original Standard (AS/NZS 2299) version which was shown to be unfit for purpose, and it may be modified again pending the outcome of an ongoing study investigating the utility and wording of the component questions (Greig et al., 2003; Australian and NZ Standard, 1999). Responses to the questionnaire are audited by diving medicine experts.

Finally, routine chest and long bone X-rays were abandoned for lack of evidence of utility, and routine spirometry and audiometry may soon follow, based, in part, on the evidence of recent studies on the New Zealand professional diving population (Sames et al., 2009a, 2018, 2019a). However, the above changes were instigated in the context of a centrally audited system, so they may not be generalizable to systems that do not operate as such. Central audit involves review by a diving medicine expert of each diver's health questionnaire and medical examination before certification is issued. The advantage of central auditing is that it provides objective, consistent and expert advice on fitness to dive, but some divers have criticised administrative delay and cost, and also, such a system simply may not be feasible in some countries.

In New Zealand, in addition to the medical requirements, full certification for professional diving work requires successful application for a Certificate of Competence (CoC) on a five-yearly basis. This is assessed and awarded by the regulating authority, WorkSafe New Zealand, a department of the Ministry of Business Innovation and Employment, previously known as Occupational Safety and Health, a branch of the then Department of Labour. Application for the CoC involves submitting proof of training qualifications appropriate for a particular branch of diving and also evidence of a specified minimum level of recent diving activity.

The aim of this study was to canvass opinions of the end-users, New Zealand professional divers, regarding satisfaction with each of the above components of the current evaluation and certification system, to determine the prevailing sentiment and inform future modifications.

Method

The determination of the Health and Disability Ethics Committee was that review was not required for this survey. A brief multi-choice survey was added to the on-line, routine health questionnaire completed annually by all registered divers. The original intention of this addition was to conduct a regular 'user satisfaction' audit as a quality control measure. Apart from type and area of diving, no personal, demographic or health data were collected, and only anonymised, collated data were provided for this study.

The eight-question survey was designed to determine the level of satisfaction and areas of dissatisfaction with the current system of certification and health surveillance of New Zealand professional divers. Questions one and two sought information about principal category of diving and whether work was conducted exclusively in New Zealand, overseas or a mixture of both. The purpose of these questions was to determine any differences in level of satisfaction between the various groups of divers. Question three enquired about general satisfaction with the current certification system. A positive response meant that no further questions needed to be answered. However, it was anticipated that some divers who were satisfied with the system 'in general', but still felt a minor level of dissatisfaction, might respond to the remaining questions. Question four asked which aspect(s) of the certification system was/were thought to be unsatisfactory, with various options given. Questions five to seven expanded on aspects of the three main components of the system, namely; the five-yearly full medical examination, the annual on-line health questionnaire and the CoC requirement. Finally, question eight invited divers to proffer suggestions for any improvements they considered necessary or desirable.

Divers completed the survey on a diver-dedicated secure website, and a de-identified dataset comprising all of the data covering a 12-month period was collated.

STATISTICS

Statistical analysis was performed using SAS® v9.4 software (SAS Institute Inc., Cary, North Carolina, USA). Frequency and proportion (%) were used for describing the categorical variables of the questionnaire, such as type of diving, main place of work and satisfaction. 95% confidence intervals (95% CI) were estimated for the key categorical variables.

Results

The responses from 914 divers over the 12-month period to April 2019 represented a survey of all NZ professional divers completing their registration over that period.

A summary of the non-free-text response rates to questions one to four, and question eight, from the 914 divers, is presented in Table Fifteen. A small group of divers (20) responded to questions five, six and seven, despite having expressed that they were satisfied with the system. The response rates for questions five to seven, from only the 137 divers who claimed to be dissatisfied with the current system, are presented in Table Sixteen. The primary finding was that 85% (95%CI: 83−87%) of divers were satisfied with the current certification system. There was no significant difference in the level of dissatisfaction among those who worked in New Zealand or overseas or a combination of both (15.4%, 14.8%, 13.2% respectively). However, compared with other types of divers, a larger proportion of recreational diving instructors and divers who engaged in multiple diving roles comprised the 'dissatisfied' group (18.1%, 20.4% respectively).

Free-text comments were contributed by 24.9% of the total group. Of those who identified themselves as being dissatisfied (137) with the overall registration process, 75.2% contributed comments, compared with only 16.1% of satisfied (777) divers. Nevertheless, most comments (54.8%) were from satisfied divers. Of the comments from dissatisfied divers, 34% concerned the cost of the overall process, particularly the annual questionnaire. Some of those who counted themselves among the 'satisfied' also complained about the cost, although a predictably smaller proportion (12%). A reduction in overall cost was requested by 21.9% of all those who commented.

Table Fifteen **Responses of 914 New Zealand professional divers to Questions 1-4 and Question 8 of an on-line, eight-question survey to assess satisfaction with the current health surveillance and certification system**

Questions	Category / response	N	%
Q1. Type of diving?	Construction	210	23.0
	Recreation/Instructor	243	26.6
	Scientific/Photography	177	19.4
	Aquaculture	45	4.9
	Military/Police/Customs	103	11.3
	Other (Commercial)	43	4.7
	Multiple types	93	10.2
Q2. Main place of work?	In NZ	708	77.5
	Overseas	54	5.9
	Both	152	16.6
Q3. Satisfied with current diver certification system in NZ?	Yes	777	85.0
	No	137	15.0
Q4. Main problem if not satisfied?	The 5-yearly full medical	14	1.5
	The annual on-line questionnaire	39	4.3
	The 5-yearly CoC requirement	34	3.7
	More than one of the above	40	4.4
	Other (see Q8)	23	2.5
Q8. Comments	Comment made	228	24.9
	No comment made	686	75.1

Table Sixteen **Responses from 137 of 914 New Zealand professional divers to an eight-question on-line satisfaction survey**

Issue of concern	**Problem area**		
	5-yearly full medical *n* = 47*	Annual questionnaire *n* = 76**	5-yearly CoC *n* = 67***
Cost	25	35	8
Delay in processing	3	-	8
Not accepted by other jurisdictions	9	9	-
Can't see need for it	-	-	16
Easy to forget	-	6	-
More than one of above	7	17	22
Other (see Q8, Table Fifteen)	3	9	13

Responses to Questions 5, 6 and 7 of the eight-question on-line satisfaction survey from 137 of 914 New Zealand professional divers who reported dissatisfaction with the health surveillance and certification processes; these responses include: * 38; ** 40, and *** 39 divers from the 40 who answered Question 4 ("More than one of the above"; see Table Fifteen) positively

Positive comments such as: 'it works well', 'it's a good system', 'no changes are needed', etc. comprised 25%, while the remaining 75%, representing 18.7% of all respondents, provided comments that were constructively critical, and generally helpful suggestions for improvement (such as: 'send reminder texts or emails'). Recreational dive instructors accounted for 26.6% of respondents but they represented 69%, 43.9% and 61.5% of answers to questions 5, 6 and 7 relating to the costs of the full medical, the questionnaire and the CoC respectively.

Discussion

This 12-month survey of the currently registered New Zealand professional divers showed that a large majority was satisfied with the current certification system. The following discussion is in the context of a 15% dissatisfaction rate and focuses on the main themes raised by the survey, but comments may be applicable to the entire group and, possibly, to other occupational groups required to undertake routine re-certification, including medical fitness examination.

The most reported area of dissatisfaction was ‘cost’. Some comments on cost were simply that the overall compliance costs were too high for a group of workers described by some as ‘relatively poorly-paid’. Others questioned the ‘value for money’ aspect, particularly in regard to the annual on-line health questionnaire, which some suggested should cost nothing to complete. Such comments indicate a discrepancy between the perception of some divers, and the reality, regarding both the logistic challenges and the role of the central auditing process. The perception appears to be that, because the annual health questionnaire is completed on-line, analysis of diver responses and issuing of certificates must be an automated function. Automation would only be possible if the process were entirely prescriptive. In reality, each completed annual questionnaire, together with the additional documentation of a full dive medical on a five-yearly basis, is examined by a diving medicine expert and compared with previous responses or results before a determination of medical fitness is made.

If the perceived automation were possible and implemented, it would obviate the need for any involvement of an expert whose principal role is discretionary in determining fitness, based on knowledge of the diver’s medical record and of the tasks involved in the diving industry. Cost savings could result, but the process would not be robust. For example, purely prescriptive systems are at risk of reduced veracity because of manipulation (such as withholding of important health information) in order to achieve the desired outcome (certification). As well as putting divers at risk, such systems are likely to increase the exposure of other principal risk acceptors such as the employer or insurance company (or the Accident Compensation Corporation (ACC) in New Zealand). Because of the discretionary nature of the current system, divers are not unfairly denied certification if they admit to a health condition that is not incompatible with diving safely, possibly in a modified version of their particular diving role. In such cases, an accommodation can usually be reached with all involved risk acceptors at a face-to-face meeting, where, if limitations are deemed necessary, a modified job description can be negotiated. This approach, alluded to in Chapter Two, and involving facilitation of informed choice by all interested parties, is consistent with the principles of occupational health surveillance (Gorman, 2003; Alli, 2008). No additional cost is incurred by the diver for the conduct of such meetings.

Internationally comparative costs for diver certification are not easy to ascertain, as they are not published, and are likely to vary within any country. However, we believe current costs to New Zealand divers are reasonable, and likely to be lower than in many, if not most, jurisdictions, particularly in those countries where a full dive medical is required annually.

Some divers suggested that the central auditing component of the process should be abandoned in favour of devolving certification authority to ‘designated diving doctors’ (DDDs) who are usually general practitioners (GPs) with additional training in diving medicine. The perceived advantage for the diver is a reduction in both cost and delay to certification. This system prevails globally (apart from in New Zealand), and is consequently accepted as the ‘norm’, especially by those divers who live in New Zealand but work overseas. It is a popular system, not least because the diver can be issued with a fitness certificate ‘on the spot’. However, as mentioned in Chapter Two, weaknesses in such a ‘devolved’ system have been exposed by studies on certification processes for pilots and professional divers (Gorman & Scott, 2001, 2003; Simpson & Roomes 1999; Sames et al., 2012). The former demonstrated three main issues: firstly, the importance of the expertise of the designated examiner; secondly, potentially dangerous deterioration in the quality of unaudited pilot fitness certifications partly because of practice drift as a result of loss of physician objectivity (or possibly corrupt or ‘inappropriate advocacy behaviour’); and finally, the possible influence of ‘funder capture’. The latter two studies showed that even GPs with additional training in diving medicine were poor at discriminating between fit and unfit divers based on diver applicant scenarios (Simpson & Roomes 1999; Sames et al., 2012). Therefore, it appears that a central auditing system, where feasible, is likely to be safer for divers and associated risk acceptors. It also has the advantage of providing a repository of divers’ medical records from which useful material can be retrieved to inform policy on diver certification and health surveillance.

The two issues, certification and health surveillance, are essentially separate matters. The former is confirmation that the diver’s health/medical status has been determined to be compatible with safe conduct of his/her stated diving duties for a period of one year, provided there are no intervening changes in health, until the next routine review. The latter involves a broader assessment of the diver's health, including chronic conditions that may have little or no bearing on current 'fitness-to-dive', but may, if not addressed, have long-term adverse consequences (conditions such as hypertension, hyperlipidaemia, obesity, smoking, etc.). Collection of health data, including diving exposure and specific diving-related hazards, is integral to the surveillance process.

As previously stated, we believe that a health surveillance programme should not need to be conducted 'completely separately from annual fitness assessments' for fear of divers concealing health issues that could lead to denial of certification, as proposed by the Diving Medical Advisory Committee (DMAC) in their 2008 statement (Gorman et al., 2009; DMAC Statement, 2008). DDDs (and their international equivalents) are ideally placed to assist in collection of such data at the time of routine diving medical assessments, complemented by data contributed on-line by divers, and stored on an internet-based database. If privacy and other legal issues could be resolved, and there was sufficient international co-operation, as other authors have suggested, such a database (as currently exists in New Zealand) could be useful globally for this often quite mobile group of workers (Elliott & Millar, 2009).

Physical capacity and diving competence remain issues that are appropriately determined in the workplace setting, or a suitable surrogate, rather than by medical practitioners.

Finally, various aspects of the CoC process were common reasons for complaint, particularly from the largest group, the recreational dive instructors. A frequent theme of their comments questioned the role of a government department (WorkSafe New Zealand) in monitoring divers' levels of competence and training when this responsibility usually is, or should be, assumed by the employer. One of the key principles of the Health and Safety at Work Act 2015, and its equivalent in other jurisdictions, is employers' primary duty of care, to ensure the health and safety of employees (Ministry of Business, Innovation and Employment, 2015). Consequently, it is not surprising to find that employers may wish to verify the validity of claims of training and experience. However, WorkSafe has a governance role in ensuring compliance with health and safety regulations. Thus, even though some divers may see verification of their training and experience as an annoying duplication of what has already been audited by the employer, it should be a source of comfort.

To address the obvious discrepancies between diver perceptions and reality, and facilitate communication between the regulator and working divers in New Zealand, the Diving Industry Advisory Group (DIAG) was recently established. This group comprises diving medical experts as well as representatives of the regulating authority and of each of the various branches of occupational diving (e.g., scientific, construction, commercial, aquaculture, recreational instructors, etc.). Issues raised by the current survey, such as the perceived inappropriateness of requirements of the CoC for some branches of diving, are being investigated for possible modification. Because of the wide variety of tasks and expertise prevalent in this industry, a global standard of competence is inappropriate, but individual diver subgroup standards mean those divers working in multiple disciplines of professional diving will need to prove competence in each area.

The effect of any procedural changes to the certification system in response to the current survey will be measured by repeating a similar satisfaction survey after a suitable interval.

Conclusions

The current certification system is considered satisfactory by most New Zealand divers. Aspects of the process highlighted by the current survey, for modification, include refinement of the CoC requirements to be more task-appropriate, and improvement in communication with divers about costs and justification for various aspects of the process.

CHAPTER SEVEN

The professional diver annual health questionnaire: A qualitative review

Prelude

The study described in this chapter has not been submitted for publication at the time of submission of this thesis. As a logical follow-up to the study described in the previous chapter, and a further effort to optimise the diver certification process, it was important to determine the utility of the professional divers' mandatory annual health questionnaire in terms of both the value of the questions and the end-users' understanding of these. No previous study has formally canvassed expert opinion of the value of the questions, nor the professional divers' interpretations of them. This study provided evidence that, with minor modifications, we can have confidence in the value and utility of the questionnaire.

Introduction

Health screening questionnaires are widely used by both recreational and professional divers. Positive responses should trigger interaction with a medical practitioner with diving medicine qualification/experience. For recreational divers, when all responses were negative, data has variously demonstrated support for the use of a fitness-to-dive screening questionnaire alone, or alternatively, the questionnaire together with a face-to-face medical consultation (Glen et al., 2000; Glen, 2004; Meehan & Bennett, 2010). The latter has been proposed ostensibly to mitigate the possibility of incorrect or inconsistent responses resulting in the erroneous designation of an unfit candidate as medically fit for diving. Many different screening questionnaires are used in various settings for both groups of divers and these are of unknown quality. Although the present study focuses on professional divers, recreational divers comprise a more heterogeneous and therefore more vulnerable group. This has prompted, for example, expert consensus suggestions for mitigation of the risk for recreational divers by improvement in the utility of the widely used Recreational Scuba Training Council questionnaire specifically relating to the components screening for cardiac risk factors (Mitchell & Bove, 2011).

Routine health surveillance and certification of New Zealand (NZ) professional divers, including the origins and development of the annual health questionnaire, has been outlined in Chapter Two. To re-iterate, there is currently a requirement that divers complete a health questionnaire annually. This is submitted online, and if central audit detects a health issue, medical examination or further investigations may be required. If there are no issues of concern, a further year of medical certification is awarded without the need for an examination. However, a full medical examination is required five-yearly regardless of the questionnaire outcome.

The annual health questionnaire currently used by NZ professional divers has emerged as the crucial element in the health surveillance of this group of workers (Greig et al., 2003; Sames et al., 2009, 2016). As detailed in Chapter Two, the NZ version of the questionnaire has undergone modification over the past two decades, including reduction in the number of questions from 89 to 39 based on the poor understanding of most of the questions demonstrated by Royal New Zealand Navy (RNZN) divers and the finding that in its form at that time it was not an appropriate health survey tool (Greig et al., 2003). The published version of the questionnaire remains unchanged in the most recent iteration of the Australian and NZ Standard (2015). However, despite local modifications of the questionnaire format, we hypothesised that even the current 39 questions included some that were of low utility in determining fitness to dive, and/or that the wording of some questions was still such that divers might misinterpret the intended meaning. A qualitative review of the questionnaire's utility as a health surveillance screening tool was expected to provide information to guide further modification, if proven necessary. The aim of this review, then, was to discover evidence to support or refute a need for refinement of the questionnaire. If needed, such refinement would be based on both the expert opinion of the value of each question, and establishment of a high level of concordance of diver interpretations of the questions with their intended meaning.

Method

The opinion of the Health and Disability Ethics Committee was that this study did not require ethical committee review.
Three internationally recognised diving medicine experts (professors Des Gorman, Simon Mitchell and Richard Moon) graded each of the 39 questions comprising the NZ divers' annual health assessment questionnaire on the basis of both utility and perceived likelihood of misinterpretation as either low, medium or high. They were asked to consider 'utility' primarily to mean usefulness in the determination of fitness to dive, but secondarily, to mean of epidemiological significance. The experts were provided with a list of the 39 questions together with the results of an audit of the positive response rates from divers for each question over a 24-month period (Table 1). The individual expert gradings were given a numerical score (low = 1; medium = 2; high = 3) and then combined to attribute to the experts, as a group, a grade for each question in each of the categories 'utility' and 'likelihood for misinterpretation' (low = 3,4; medium = 5,6,7; high = 8,9). Questions considered to be of 'low' utility were identified for elimination from the questionnaire.

Table Seventeen NZ professional divers' annual health questionnaire with positive response rates (%) determined from 2884 responses over a 24-month period, and expert opinion of their value

Question	Positive response rate (%)	Value**
1. How many compressed gas underwater dives have you made in the last year?	N/A*	High
2. How many years have you engaged in compressed gas diving?	N/A	High
3. Have you had any problems that are related to underwater diving?	4.5	High
4. Have you had, or do you have any physical, psychological or mental health conditions?	0.4	High
5. Have you been hospitalised (including mental health facilities)?	35.7	High
6. In the past 12 months have you had CXR, LFTs, asthma challenge, audio?	N/A	Medium
7. Are you taking any medication on a regular or occasional basis?	11.2	High
8. Are you allergic to any agents, drugs or substances?	11.9	Low
9. What other occupations or sports do you take part in?	N/A	Medium
10. (Females) Are you, or may you be pregnant?	0.2	High
11. Do you, or have you had asthma?	3.2	High
12. Do you experience any breathlessness, chest pain or tightness, or wheeze or cough, during exercise or at night?	1.0	High
13. Have you had any problems with you vision?	10.3	Medium
14. Have you had any problems with ringing in your ears (tinnitus) or with a sense of spinning (either you spinning around, or the room spinning around you)?	8.0	High
15. Have you had any neck, back, bone or joint problems?	19.7	Medium
16. Do you, or have you experienced numbness and tingling and/or weakness or heaviness in your limbs after diving?	0.9	High
17. Do you, or have you experienced any form of recurrent headaches?	2.4	Medium
18. Do you, or have you experienced any form of fits, fainting, turns, epilepsy or convulsion?	1.1	High
19. Do you, or have you experienced any difficulty with your ears when diving or flying?	5.4	High
20. Do you, or have you experienced any form of chronic sinusitis?	2.1	Medium
21. Do you, or have you ever suffered any problems with hearing?	6.4	High
22. Do you, or have you experienced any state of confusion or impaired consciousness level?	1.5	High
23. Have you ever suffered from a head injury which caused you to lose consciousness?	10.7	High
24. Do you have diabetes mellitus?	0.0	High
25. Have you had any blood or urine tests for sugar?	15.3	Medium
26. Do you experience ankle swelling?	1.4	Low

Question	Positive response rate (%)	Value**
27. Have you experienced unusual beating sensations (palpitations) in your chest?	1.4	Medium
28. Have you suffered any heart disease or blood pressure problem?	1.7	High
29. Have you suffered any bone fractures or joint injuries/disease?	49.0	Low
30. Have you recently had any form of tooth pain related to diving?	0.3	Medium
31. Do you, or have you had an illness which affects your nervous system (brain and/or nerves)?	0.2	High
32. Do you have any conditions affecting your blood in any way (eg. anaemia, problems with clotting, or haemoglobin disorders)?	0.5	High
33. Do you currently smoke?	7.1	Medium
34. Do you, or have you suffered from any form of respiratory illness (eg. pleurisy, coughing up blood) or injury (eg. collapsed lung – pneumothorax) or infection (eg. pneumonia or TB)?	1.1	High
35. Have you undergone any surgery which involved your chest?	0.3	High
36. Do you suffer sea-sickness?	16.3	Low
37. Approximately how many standard-sized alcoholic drinks do you consume per week?	N/A	High
38. Do you currently use, or have you in the past 6-months used recreational drugs?	0.1	High
39. Are there any other ongoing medical conditions?	0.2	High

* Response rate is not applicable
**Combined expert opinion of the value of each question refers to the question's perceived epidemiological value and/or its utility in determination of fitness to dive as judged by a panel of three diving medicine experts.

To identify potential problems with interpretation, a non-probabilistic, purposive sampling method was adopted. That is, the interviewees were specifically chosen from a 'homogeneous' group with regard to their experience as NZ professional divers. Thus, consecutive consenting divers attending for an occupational diving medical examination were interviewed and recorded by one of us (CS) to canvass their understanding of the meaning of each question. Divers were specifically asked to primarily provide their own interpretation of each question rather than give an opinion on why the question was being asked or whether questions might be misinterpreted by others. As a secondary outcome however, they were also encouraged to suggest any changes they thought might aid clarification. The number of interviewees was determined by the nature of responses throughout the process, in accordance with accepted qualitative research methods (Mason, 2010; Crouch & McKenzie, 2006; Guest et al., 2006). The audio recording of each interview was transcribed for analysis. We anticipated using an iterative, modified Delphi approach, involving re-wording and re-presenting to divers any questions where there was deviation from the intended meaning, until there was a high degree of consensus for all questions. The Delphi method is a widely-used research tool for establishing reliable consensus of opinion among experts by presenting them with progressively modified questionnaires relating to the topic of interest. Each iteration of the questionnaire is modified by the researcher based on a distillation of previous responses and re-presented to the expert panel until consensus or near-consensus is achieved. For the 'interpretation' part of this study, professional divers were to serve as the experts, not to be mistaken for the diving medicine experts used in determining the value of the questions. Although usually used in quantitative research where statistical consensus is sought, various adaptations of the original Delphi method have been used for qualitative studies and are referred to as the Delphi "approach" rather than "method" (Mead & Moseley, 2001). However, the unanimous results from analysis of the initial interviews rendered such an approach unnecessary.

Results

Consensus opinion of the three diving medicine experts was that four of the 39 questions comprising the current questionnaire were of low value, both in terms of the determination of fitness to dive and epidemiological worth. These questions and their positive response rates were: Are you allergic to any agents, drugs or substances? (11.9%); Do you experience ankle swelling? (1.4%); Have you suffered any bone fractures or joint injuries/disease? (49%), and, Do you suffer sea-sickness? (16.3%). The experts agreed that none in the entire set of questions was 'highly likely' to be misinterpreted.

All twenty interviewed divers correctly interpreted all questions, obviating any need to employ a modified Delphi approach or significantly modify the questions. All divers indicated difficulty in articulating the meaning of the questions using alternative wording, suggesting that the questions were generally already well-constructed. Examples of the most common type of responses are: “I can’t think how else to say it” and “It’s obvious what it means”, so that the unanimous response from divers was ‘it means just what it says’ or words to that effect. Nevertheless, eight questions generated comments that some divers felt might further improve clarity. A summary of such comments/suggestions is as follows:

Q1. *How many compressed gas underwater dives have you made in the last year? (>30m, mixed gas, nitrox, heliox, trimix, other).* Divers commented that responses were unlikely to be accurate, and also that the category ‘air dives <30m’ should be included. If retained, it may be more appropriate to ask divers to estimate their annual number of dives into numerical categories.

Q4. *Have you had or do you have any physical, psychological (eg. fears of confined spaces or water) or mental health conditions?* Divers commented that psychological and mental health conditions are considered synonymous, so one term should be deleted.

Q7. *Are you taking any medication on a regular or occasional basis?* Divers thought this should specify whether it includes herbal and OTC medication and the oral contraceptive pill. All assumed it included everything.

Q13. *Have you had any problems with your vision (difficulty seeing clearly or distinguishing between colours)?* Divers commented that this should specify whether prescription glasses/lenses or laser surgery are included. All assumed that they are included.

Q17. *Do you or have you experienced any form of recurring headaches?* Divers commented that this should specify whether it includes occasional minor headaches. All assumed that it did not.

Q22. *Do you or have you experienced any state of confusion or impaired consciousness level?* Divers wondered whether this included mild concussion from a sporting injury. All assumed that it did.

Q24. *Do you have diabetes mellitus?* Divers thought the word ‘mellitus’ might cause confusion and should be deleted.

Q25. *Have you had any blood or urine tests for sugar?* Divers thought that this should specify ‘abnormal results’ because all who have had previous dive medical examinations answer ‘yes’ and then usually have to note that the results were normal.

Discussion

It was evident, after the initial 10 interviews yielded very similar responses, that these divers did not misinterpret the questions. No additional novel suggestions about wording changes were recorded after 15 interviews so we limited the interviewee number to 20, concluding that the point of ‘theoretical saturation’, the point where additional data adds no further useful information, had been achieved.

Questioning the value of either non-probabilistic, purposive sampling or the low sample numbers often associated with qualitative studies is understandable, particularly from those wedded to the notion that validity belongs exclusively to the ‘hard science’ of quantitative analysis. The consideration of low sample numbers has been addressed by several authors who have concluded that, for interview-based qualitative studies, such as this, the number of interviewees required to reach the point of theoretical saturation and yield applicable results is likely to be in the range 10-30 (Mason, 2010; Crouch & McKenzie, 2006; Guest et al., 2006). Non-probabilistic, purposive sampling provides neither results to which statistical significance can be attributed, nor even a quantifiably representative sample of the study group. The value of such a method lies in the discovery of a range of detailed, personal, but expert, opinions about the research topic, limited at the point of saturation. The present study was probably atypical in this regard because, at the outset, there was unanimous concordance of interviewees with the intended interpretation of the questions.

The issue of the applicability of the professional divers’ health screening questionnaire to the recreational diving cohort is outside the scope of this study. However, it is clear that because recreational diving is not subject to legal regulation as is professional diving, and because recreational divers are a more vulnerable group, measures to improve their safety should be specifically tailored. Such measures have been addressed by Mitchell and Bove (2011) and include on-going education of divers to voluntarily submit to regular health checks, especially if unwell or after a change in health, and the possibility of development of a specific, high-utility health screening questionnaire suitable for use by dive charter operators.

A limitation of this study was that it necessarily focussed on the version of the questionnaire currently used in New Zealand, so the conclusions are not generalizable to other jurisdictions unless they use the same questions. Furthermore, the possibility that any additional questions might improve its utility as a screening tool was outside the scope of this study. However, additional questions are unlikely to offer a significant improvement, as the current questionnaire has previously been reported to adequately detect the important health conditions that might preclude safe diving in professional divers who complete it annually (Sames et al., 2009, 2016). But, as noted above, Grieg et al. (2003) concluded that the value of the questionnaire as a screening tool correlated with audit by a diving medicine expert. Such audit should encompass review of the individual divers' historical records of previous questionnaire responses. In other words, and of relevance to divers' health surveillance universally, a health questionnaire is unlikely to achieve its intended function if audited by a computer programme or someone naïve to the health issues associated with diving. Regardless, no questionnaire can be considered useful unless the questions that comprise it are demonstrably correctly interpreted by those who use it.

Conclusions

New Zealand professional divers apparently have no difficulty interpreting the questions comprising the mandatory annual health questionnaire. Items identified for refinement of the questionnaire were minor. They included improved clarification in the wording of eight questions and deletion of four questions considered by diving medicine experts to be of low value.

CHAPTER EIGHT

The utility of regular medical examinations of occupational divers

Prelude

The two studies that comprise this chapter directly addressed the critical question considered in this thesis, namely, 'what is the utility of the system currently used in New Zealand for surveillance of diver health and determination of fitness for certification to work as a professional diver?' The first study was completed at the end of the first five-year cycle after the requirement for full medical examinations to be conducted annually was relaxed to five-yearly. The second study, using a different approach to address some of the limitations of the first study, was completed five years after the first. Both studies have been published in the peer-reviewed medical literature and are presented with minor modifications for cohesion (Sames et al., 2009b, 2016).

Introduction

Occupational health surveillance is undertaken for many different reasons and should be tailored to the specific occupational setting (Gorman, 2003). Thus, fitness for work assessments need to predict actual work fitness and identify health problems that might be exacerbated by the work situation, might be a safety concern at work, or might predispose the candidate to work-related injuries and illnesses. There are some occupations that are subject to relevant regulation, including public transport drivers, dangerous goods drivers, pilots and occupational divers.

In many jurisdictions, occupational divers are required to undergo an annual medical assessment that includes a history and comprehensive medical examination by an appropriately trained doctor. Required or recommended investigations may include lung function tests, audiology, various blood tests, resting and exercise electrocardiograms (ECG), chest radiographs (CXR), long bone radiographs, and even psychometric testing and magnetic resonance imaging (MRI) scans (Elliott, 1995). There is no evidence for this practice from occupational cohort studies or from evaluations of the routine medical examination of recreational divers (Glen et al., 2000; Glen, 2004).

In New Zealand and Australia, regulations have been based on the relevant Australian and New Zealand Standard, which prescribes a comprehensive medical examination and investigations both at entry to the industry and then annually (Australian and NZ Standard 2299.1, 1999). We have previously shown that this comprehensive approach is of doubtful validity at even the initial evaluation, let alone when repeated annually (Greig et al., 2003). As a consequence, the nature of the initial assessment for occupational diving in New Zealand was modified, and the need for ongoing assessment was relaxed, in the absence of health concerns, to a five-yearly comprehensive interview and examination by a doctor trained in diving medical fitness assessment. In the intervening years, the only regular requirement is for the diver to complete an annual health status questionnaire (see Chapter two). This is reviewed by expert diving physicians on behalf of the New Zealand Department of Labour. Where the questionnaire reveals any potentially significant health issues, defined in the relevant guidelines as "an accident, illness, a change of medication, or any medical circumstance which is likely to affect their medical fitness to dive", a new comprehensive interview and examination is required prior to recommencing work. In the past five years 12 (<1%) such additional assessments have been required.

This audit was undertaken to determine the validity of the revised process. The major concern is whether the reduced frequency of comprehensive assessment results in divers who have health problems working inappropriately. Consequently, we reviewed the records of those divers who had completed a full five year cycle leading to a second comprehensive evaluation to determine whether any important health problems had been 'missed' by the intervening questionnaire approach.

<u>Methods</u>

The revised system was introduced in 2003, and by 2008, 336 divers (23% of the total population of 1,475 registered occupational divers in New Zealand) had undergone a full five year cycle; in particular, they had been comprehensively assessed for the second time after completing four years of questionnaire-based assessment only. This was the same cohort of divers whose data was presented in Chapter Three related to the study of changes in lung function. *A-priori* consent was obtained from the divers at the time of each assessment and an anonymous clinical file audit was conducted on this sub-group of 336 divers. Regional Ethics Committee approval was sought but not required for this audit. We identified all subjects who had passed the first of the two comprehensive medical assessments, and in whom an impact on career was subsequently detected from either the questionnaire or the second comprehensive assessment and investigations approximately five years later. An impact on career was defined as the diver being issued with either a conditional certificate of fitness or being graded as temporarily or permanently unfit for diving. We then noted how the health issue precipitating the impact was first identified (questionnaire, oral history, examination, or investigation). Data were recorded into a purpose-designed database (Microsoft Access™).

Results

The demographic characteristics of the 336 diver cohort were presented in Table Four (see Chapter Three). The mean period between the comprehensive assessments for this group was 5.6 years. The self-assigned occupational sub-grouping of this cohort was 148 commercial divers, 122 scientific divers, 30 recreational dive instructors and 15 military divers. For 326 divers (97%), no important health problems were identified by questionnaire, interview, examination or investigation.

Over the five year period, only one diver was determined to be medically unfit for occupational diving on the basis of a spinal injury, which was declared by the diver on an annual questionnaire. Another four divers were considered temporarily unfit while further assessments were undertaken. Three of these situations arose because of questionnaire responses. One arose because of abnormal spirometric lung function testing, which was performed as part of the five-year assessment. Finally, a group of five divers had conditions imposed on their diving practice (see Table Eighteen). Again, all but one of these were identified on the basis of questionnaire responses. The exception similarly arose because of abnormal spirometric lung function testing at the five-yearly comprehensive assessment.

Table Eighteen **Details of ten New Zealand occupational divers whose employment was affected by the outcome of a regular medical examination or questionnaire**

Category	Sex/Age	Method of identification	Medical problem
Permanently unfit for diving	M/35	Questionnaire	Spinal injury
Temporarily unfit for diving	M/33	Spirometry	Impaired lung function
	M/55	Questionnaire	Heart surgery
	M/36	Questionnaire	Deafness and tinnitus
	M/36	Questionnaire	Deafness and head injury
Conditional certification for diving	F/45	Spirometry	Impaired lung function
	M/34	Questionnaire	Otic barotrauma
	M/49	Questionnaire	Heart surgery
	M/58	Questionnaire	Asthma
	M/53	Questionnaire	Atrial fibrillation

Discussion

Ten of 336 divers (3%) who completed a full five year cycle of the revised assessment system for medical fitness for occupational diving in New Zealand were found to have a health problem that impacted on their employment. Eight divers (including the only one who was unable to resume work as a diver) declared their problem on an annual questionnaire and two were identified by lung function testing at the five yearly medical. Although it can be argued that the two lung function abnormalities might have been detected earlier by annual comprehensive evaluations (including spirometry), it must be noted that neither diver was made permanently unfit to dive. Neither case challenged our belief that a diver with previously normal spirometry who developed a new lung problem serious enough to warrant disqualification from diving would be detected by a properly designed questionnaire.

Two conclusions are possible on the basis of this audit. First, despite the obvious reliance on honesty by responding divers, the questionnaire system does not seem to 'miss' any divers who have developed a critically important health problem that would subsequently be detected by a comprehensive assessment. Second, there needs to be some other justification for ongoing comprehensive assessments, even at 5-year intervals, as the detection rate for important health problems approaches zero.

We are not aware of any data that challenge the first of these conclusions. The authors of a study of 480 German Navy divers concluded that the annual routine medical examination, which included ECG, bicycle ergometry, CXR, spirometry or plethysmography, blood and urine testing, specialist eye, ENT and dental examinations, and a pressure test in the hyperbaric chamber (as well as a hyperbaric oxygen tolerance test for those divers who use nitrox or oxygen re-breather devices), contributed to minimising the risk of accidents in military diving operations (Weiss, 2003). However, no relevant supportive data were presented. By contrast, an earlier audit showed little utility for any element of the initial assessment process used in Australasia (Greig et al., 2003), and the present study suggested that comprehensive annual assessments of the type described by Weiss are an over-inclusive and unnecessarily expensive approach to ongoing health surveillance. Although not strictly relevant to occupational divers, routine medical examinations were also shown to be of little value in Scottish recreational divers (Glen et al., 2000), and a follow-up analysis undertaken three years after instituting a system of self-reporting questionnaires and clinical examination only in those recording a positive response, confirmed that the questionnaire was an effective screening tool (Glen, 2004).

It is relevant to our first conclusion that our system employs central arbitration by an expert who has access to the records of all divers' previous comprehensive examinations and questionnaires. This allows contextualising of questionnaire results and detection of inconsistencies over time; which almost certainly contributes to the sensitivity of the method in detecting significant problems. An added benefit is the prevention of inconsistent decision making between different practitioners at the initial and five yearly medical evaluations. This can be problematic, as demonstrated by an Australian postal survey, which showed that there was little consensus about what constitutes diving fitness among 52 Queensland doctors who perform diving medical examinations (Simpson & Roomes, 1999). This finding concurred with our later discovery (see Chapter Five) that only about half of all important health problems revealed on interview and/or examination of divers by 'trained' doctors are identified as such (Sames et al., 2012). The low rate of reporting by these doctors can be variously explained by a lack of knowledge at one extreme to 'client advocacy' at the other (Gorman, 2003).

The second conclusion relates to the broader principles of occupational health surveillance (Gorman, 2003). On the basis of this and the earlier audit (Greig et al., 2003) it is difficult to justify the present method of health surveillance in occupational divers with respect to work capacity assessment (Menard & Gorman, 2000), or for reducing the absolute risk of illness and injury (Gorman, 2003). However, work as a diver does involve the management of risk. The broader purpose of occupational diving health surveillance then, is to enable divers and their employers, and the wider community of interest, to make informed decisions in the context of risk understanding, acceptance and mitigation. This is important in an increasingly litigious society, and particularly if negative long-term effects of a career as a working diver become apparent (Macdiarmid et al., 2004).

On the basis of these conclusions, we did not recommend any further changes to the periodicity of the New Zealand system. There is likely to be value in a diver seeing an appropriately trained doctor at least every five years to discuss their health and work practices. In contrast, the content of the physical examination, investigations, and questionnaire will be changed on the basis of studies described above (see Chapters Three, Four and Seven) despite evidence that hearing, for example, deteriorates over time in occupational divers (Molvaer & Albrektsen, 1990). Our data from a subsequent study described in Chapter Four, showed that deterioration is sufficiently slow, and in fact no worse than the effect of ageing, that an impact on career might not be detected by this audit. However, these audit data do enable us to argue that annual comprehensive assessments are unnecessary. Finally, our reliance on a central expert panel to determine the medical fitness for occupational diving in New Zealand is reinforced by this audit, as is the value of a central register in executing such analyses.

AN EVIDENCE-BASED SYSTEM FOR HEALTH SURVEILLANCE OF OCCUPATIONAL DIVERS

Introduction

Most occupational divers world-wide are required to undergo an annual comprehensive medical examination. The widely accepted, but unproven rationale is that comprehensive health surveillance should reduce occupational morbidity and mortality. Industry standards and guidelines exist to assist examining medical practitioners in the determination of fitness for diving (Australian and NZ Standard, 2015; Diving at Work Regulations, 1997; MA1, 2015; OSHA Standards, 2011). These include examples of medical conditions that could render the diver unfit, or fit for diving, but with certain limitations.

One country where the requirement for annual comprehensive medical examination no longer applies is New Zealand, where a 2002 analysis of 300 occupational diving medical assessments cast doubt on the value of comprehensive medical evaluations and prompted institution of a system requiring such evaluations only 5-yearly with completion of a health screening questionnaire in the intervening years (Greig et al., 2003). An audit of the first 336 divers completing a 5-year cycle under this system demonstrated that the annual health questionnaire detected all significant health problems arising after the initial comprehensive medical, with the 5-yearly full medical examination adding little value (Sames et al., 2009b) (see above).

The aim of the current study was to revalidate or refute the latter finding in a larger and more contemporary cohort of occupational divers whose health status has been monitored under the New Zealand system.

Methods

This study was approved by the Waitemata District Health Board Human Ethics Committee (reference number RM13088). All divers whose records were accessed had consented to their anonymised occupational medical information being used for research purposes. The New Zealand occupational diver medical database was interrogated to identify all divers issued with a 'limited or conditional' medical clearance or considered 'unfit' for diving, over a 5-year period, from the beginning of 2010 to the end of 2014. When a diver was designated 'limited' or 'unfit', we recorded the reasons for this designation identified from the divers' individual records, and the source of the information leading to application of those designations, whether from the questionnaire alone or the examination component of the initial or 5-yearly comprehensive medicals or from the annual questionnaires. To be clear, we included any findings from discussions or system reviews in the definition of 'examination component' of the comprehensive medicals.

As the focus of this study was on the adequacy of the health surveillance of occupational divers, we limited our analysis to the experienced divers who had previously undergone an initial comprehensive dive medical examination followed by four annual health questionnaires. We therefore defined the 'gold standard' for the determination of diving fitness as the combination of the questionnaire plus the 'subsequent' medical examination and any investigations that were indicated. The primary outcome measure was a calculation of the sensitivity and specificity of the questionnaire alone in detecting problems leading to a designation of unfit or limited, in comparison with this gold standard.

Statistical analysis used a web-based Bayesian calculator for the exact 95% confidence limits of a proportion (or credible interval) to define the sensitivity, specificity and accuracy of the questionnaire compared with the gold standard. The accuracy of the questionnaire in determining 'unfitness' or 'limited fitness' to dive was calculated by dividing the sum of true positive and true negative outcomes by the total sample number. We defined a 'positive' finding as a finding of unfit, limited or lost to follow-up. The latter group was included as a conservative assumption for sensitivity calculations only because of the possibility of unfitness. As a secondary outcome we recorded the source of the critical information and the nature and incidence of various health conditions leading to the provisional 'limited' or 'unfit' designation.

Results

Within the entire programme (initial comprehensive medicals, annual questionnaires, 5-yearly repeat comprehensive medicals), 5178 certificates were issued over five years, representing 2187 active occupational divers, of which about 1000 apply or re-apply for registration each year. The age distribution of these divers is presented in Figure Ten. The mean age of all divers was 39 years (range: 18-68). The sources of key information leading to the designation of a diver as unfit or limited are summarised in Figure Eleven, and stratified by diagnosis in Table Nineteen. The bottom four lines of Figure Eleven represent the gold standard findings. The 158 unfit or limited certifications represented 130 divers (21 were represented more than once), of whom 29 were females, and whose mean age was 37 years (range: 18 – 65). Of the 28 of certifications (17.8%) where the critical information leading to a limited or unfit designation was revealed by medical examinations alone, 18 (64%) were at the initial compulsory medical examination. In contrast, in 130 of the 158 (82.2%) limited or unfit certifications, the critical information was revealed by the questionnaire.

Figure Ten **Age distribution of 2187 New Zealand occupational divers registered 2010-2014**

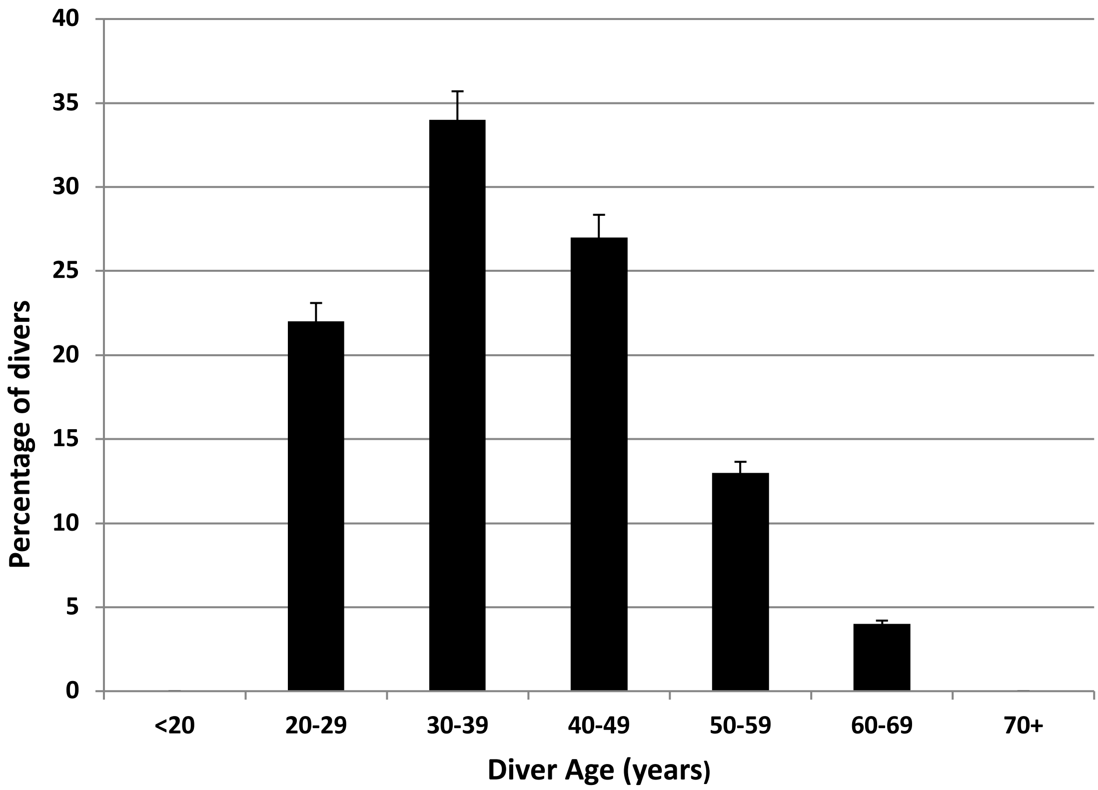
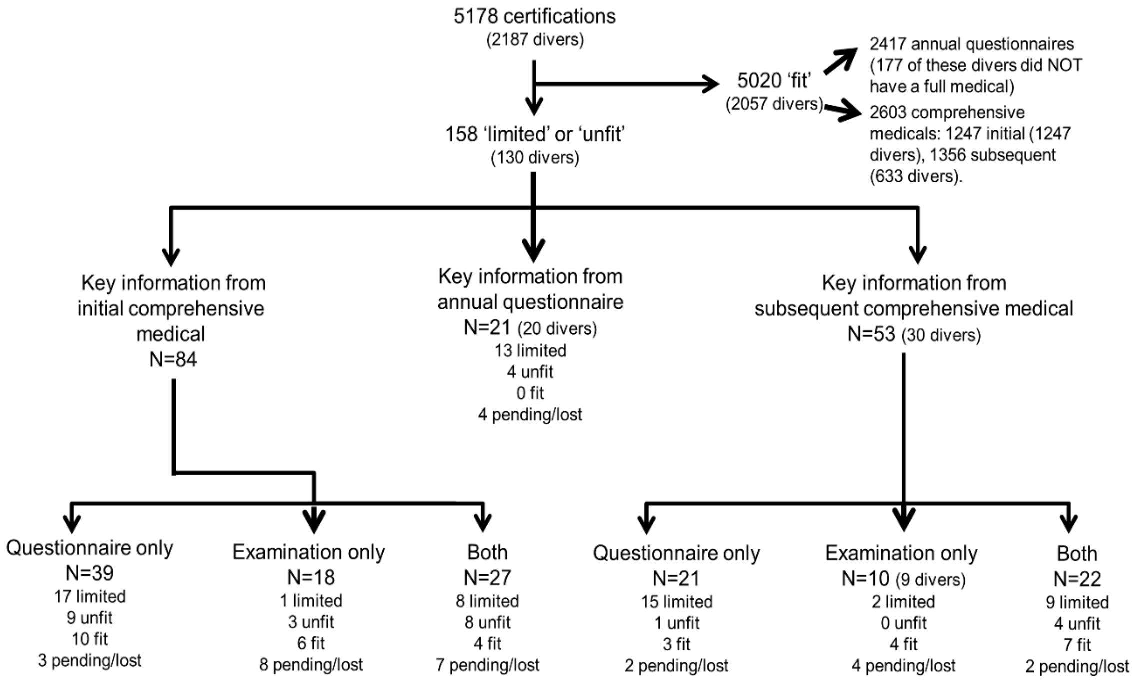


Figure Eleven **Sources of key information leading to various types of certification (limited/unfit/fit) of New Zealand occupational divers over a 5-year period (2010 – 2014)**



Key information on which the designation of 'fit', 'limited' or 'unfit' was based came from either the questionnaire component alone, the examination component alone, or from both the questionnaire and examination. In those comprehensive medical scenarios where key information is denoted as arising from 'both' the questionnaire and examination, it is implied that the initial identification of a potential problem was detected by the questionnaire

Table Nineteen **Incidence and source of diagnoses leading to provisional designation of 130 divers as limited certification or unfit over a 5 year period 2010-2014**

Diagnosis	Questionnaire (Q)	Medical examination (M)	Both Q+M	Total
Asthma	18	4	22	44
Abnormal LFTs	-	13	9	22
Obesity	-	11	8	19
Chamber attendant	14	-	-	14
Hearing deficit	5	1	8	14
Psych. Illness	13	-	1	14
Arrhythmia	5	-	3	8
Hypertension	2	3	2	7
Blood disorder	7	-	-	7
Hx pneumothorax	1	-	2	3
Colostomy	1	-	2	3
Bronchiectasis	2	-	-	2
Ankylosing Spondylitis	1	-	1	2
Hx DVT/PE	1	-	1	2
Recent hx DCS	2	-	-	2
Fibromyalgia	2	-	-	2
Psoriatic arthritis	2	-	-	2
Epilepsy	2	-	-	2
Tinnitus	-	-	1	1
Valvular defect	-	-	1	1
CAD	-	-	1	1
Hx chest pain	1	-	-	1
PFO	1	-	-	1
Recent IEBt	1	-	-	1
Migraine	1	-	-	1
Post conc. Synd	-	-	1	1
Recent retinal surgery	1	-	-	1
Thrombocytopaenia/SLE	1	-	-	1
Thyrotoxicosis	1	-	-	1
Recent head injury	1	-	-	1

CAD, coronary artery disease; DCS, decompression sickness; DVT, deep vein thrombosis; Hx, history; IEBt, inner ear barotrauma; LFT, lung function test; PE, pulmonary embolism; PFO, patent foramen ovale; SLE, systemic lupus erythematosus. Chamber attendant is included as a ‘diagnosis’ only for completeness because these workers are routinely given limited certification because they are trained as hyperbaric workers but not divers.

Nine of 663 divers (1.4%) who completed a 4-year cycle in which no important problems were detected by the annual questionnaire were provisionally designated as either limited or unfit based only on the examination component of the subsequent full medical examination. Of these, three were lost to follow up, four were designated 'fit' and two 'limited' (none 'unfit') after further investigations. The two 'limited' had had abnormal lung function tests, but then passed a hypertonic saline challenge test (HSCT) and so were designated 'limited' only because of a requirement for annual HSCTs. The three lost to follow-up represented four certifications because one of them presented for a full medical examination twice in consecutive years but was lost to follow up both times after failing to complete the recommended investigation. Two were obese and were asked to perform an exercise ECG, and the other had an abnormal lung function test and was asked to submit to a HSCT. Even counting these three divers as 'unfit', the unfitness detection rate for the examination component of the five-yearly comprehensive medical was 4/1409 (0.28%) certifications, or 3/663 (0.45%) individual divers.

In comparison with the gold standard, the sensitivity and specificity of the questionnaire to detect unfit divers was 84.6% (CL = 70.2%, 92.7%) and 99.3% (CL = 98.7%, 99.6%) respectively. Based on the five-year false negative value shown in Figure Twelve, this could mean one or two potentially unfit divers per year were missed by the questionnaire. The width of the confidence interval for the sensitivity suggests this study was underpowered, but the sensitivity estimate is conservative, based on the inclusion of two divers who were actually fit to dive but required annual respiratory review, and three whose fitness-to-dive is unknown. As mentioned above, none of these divers was definitively unfit. The accuracy of the questionnaire was 98.9% (CL = 98.16%, 99.30%).

The estimates of sensitivity and specificity were based on figures for true and false positives and negatives (TPs, FPs, TNs, FNs) derived from the data shown in Figure Eleven. The derivation of the values for TPs (33), TNs (1360), FPs (10) and FNs (6) is demonstrated in Figure Twelve. These numbers refer to the number of certifications, not divers. To clarify, using the 'gold standard' as defined above and the focus on the subsequent comprehensive medicals, the values in Figure Twelve were reached by following the right-hand branch of Figure Eleven. It is implicit that a finding of unfit by 'examination only' means that the questionnaire finding was 'fit'.

So, for example, to derive the figure for TPs, we added the gold standard findings where the questionnaire also found divers to be unfit (1+4), limited (15+9) or lost (2+2), giving a total of 33. For the TNs, we added the 1356 designated 'fit' at the first step (of the 5020 found to be 'fit' by both examination and questionnaire) to the four under the 'examination only' heading found fit by the gold standard because these were also found fit by the questionnaire, giving a total of 1360.

The most common positive responses to the questionnaire were to the questions on; current medication (38%), previous CXRs, audiograms, spirometry or HSCTs (33%), history of asthma (28%) and past hospitalisation (21%).

Figure Twelve   Derivation of true and false positives and negatives

		Gold Standard		
		Unfit/Limited/Lost (P)	Fit (N)	
Questionnaire	Unfit/Limited/Lost (P)	(15+9)+(1+4)+(2+2)=33 (TP)	3+7=10 (FP)	43
	Fit (N)	2+0+4=6 (FN)	1356+4=1360 (TN)	1366
		39	1370	1409

True and false positives (TP, FP) and true and false negatives (TN, FN) were derived from the data shown in the Figure Eleven flowchart following the right-hand branch that relates to subsequent comprehensive medicals. Numbers represent certifications, not individual divers. The 'gold standard' refers to the completion of a questionnaire and the 'subsequent comprehensive medical' plus further investigations as indicated.

Discussion

Our data demonstrated that important health information relating to fitness for occupational diving is much more likely to be revealed by a screening questionnaire than by examination or investigations conducted as part of a comprehensive medical evaluation. Moreover, the majority of any positive examination / investigation findings are made at the initial compulsory comprehensive medical evaluation rather than at subsequent or 5-yearly evaluations. Only 9 of 663 divers who completed an initial comprehensive medical and a 4-year intervening period of negative responses to a screening questionnaire had significant problems detected by a subsequent examination, and none of the six who completed further investigations was eventually found to be unfit. The assumption of a worst case ('unfit') designation for the remaining three divers who were lost to follow-up, resulted in an 'unfitness' detection rate of 0.45% (excluding those with 'limited' fitness) for the examination component of the 5-yearly comprehensive medical evaluation. This represented the contribution to unfitness detection from adding the examination and investigations to the questionnaire at the 5-yearly comprehensive medical stage.

This study corroborates the findings of our previous investigation which demonstrated that no important medical problems undetected by the annual questionnaire were subsequently detected by the examination component of the 5-yearly comprehensive medical in 336 divers who completed a 5-year cycle under that system (Sames et al., 2009b). The present study audited all certifications over a 5-year period, whereas the previous study (see above) followed a cohort of 336 occupational divers who completed two comprehensive medicals, and the intervening annual questionnaires, over the same timeframe. The advantage of auditing all certifications is that it captures the divers who 'fall at the first hurdle', and can deduce the health reasons, and method of detection.

These results provide an evidence base for challenging the "traditional" insistence on a comprehensive annual medical evaluation for all occupational divers. In particular, there appear strong grounds for claiming that after completion of a comprehensive medical evaluation on entry to the industry, ongoing health surveillance can be adequately achieved by annual completion of a well-designed screening questionnaire, with further comprehensive evaluations at greater than annual intervals (in our case every 5 years) if the questionnaire detects nothing of concern. In our setting, such a system has not resulted in important medical problems being overlooked, and considerable money has been saved by avoidance of expensive comprehensive consultations and repetitive investigations. The reasons for regulating authorities elsewhere adhering to the tradition of an annual comprehensive medical evaluation, in the face of evidence that there is no corresponding health benefit for divers, are unknown.

The value of routine, annual, comprehensive physical evaluations in the context of an asymptomatic general population has been questioned, apart from a small number of components (such as BP, weight, Pap smears) whose regular monitoring may result in improved health outcomes (Bloomfield & Wilt, 2011). However, such evaluations (the ‘yearly physical’) remain popular with both the general public and with physicians, who cite benefits such as reduction of patient anxiety, strengthening of the doctor-patient relationship and the sense of caring, and forestalling possible medico-legal complaints (Oboler et al., 2002; Prochazka et al., 2005; Boulware et al., 2007). In the context of routine occupational health assessments, it is likely that many employers take legal, rather than evidence-based medical advice regarding the frequency and comprehensiveness of physical examinations, but they may also be persuaded by these other putative benefits.

Divers, like many other occupational groups, face specific, job-related health risks, and although pre-existing health conditions can contribute, most of the risk derives from a combination of factors such as accidents, equipment failure, inexperience or adverse environmental conditions, rather than health status alone (Lippmann, 2008; Davis et al., 2002; McClelland, 2007). However, if risk mitigation is possible through periodic health assessments, regulating authorities and/or employers are obliged to ensure that the nature and frequency of such assessments is based on evidence.

Studies of questionnaire-based health assessments of recreational divers in Scotland have demonstrated virtually invariable detection of divers whose health required further investigation (Glen et al., 2000; Glen, 2004). A study of recreational diving in Australia challenged these findings in reporting 9 of 632 diver candidates answering in the negative to all questions on a screening questionnaire who subsequently failed a face-to-face medical (Meehan & Bennett, 2010). The reasons for some of these failures were open to debate (such as failure to meet arbitrary spirometry standards), and it can be argued that such problems are more likely in a more comorbid recreational population whose mean age is considerably higher than the occupation cohort reported here (Denoble et al., 2012). In the occupational setting, our previous audit of 336 New Zealand occupational divers over a 5-year period and the data presented here, support the Scottish findings (Sames et al., 2009b).

LIMITATIONS

This study has several limitations that must be acknowledged.
First, the questionnaire used for the annual health surveys is not the standard document designed for use in comprehensive occupational diver medicals in Australia and New Zealand. It is a modified questionnaire that focuses on enquiry about symptoms as much as diagnoses, and it went through a substantial development phase (see Chapters Two and Seven) in which we adjusted it to improve utility and comprehension during informal trials with divers. Its use would be generalisable, but the fact that it is not a standard questionnaire needs to be acknowledged.

Second, New Zealand has a system of central arbitration in which all returned questionnaires and completed comprehensive evaluations are viewed, and certifications are issued by a primary reviewer supported by a secondary expert panel. This may enhance the efficacy of questionnaires as tools for health surveillance because individual divers become known and can be tracked, although they may interact with different doctors in the community. This system also provides consistency in the evaluation of divers' fitness and mitigates the inconsistency found in the diving fitness decisions of doctors in both New Zealand and Australia (Simpson & Roomes, 1999; Sames et al., 2012). Although we believe a questionnaire system would still work if administered locally by individual doctors, the circumstances of the study do raise a possible limitation of the generalisability of our findings in those jurisdictions where it may not be practicable to develop a diver certification system that includes central evaluation.

Third, the low incidence of ‘unfitness’ in this cohort, likely to be a ‘healthy worker’ effect, resulted in the study appearing to be underpowered. We would expect a higher incidence of unfitness if we included divers attending their initial comprehensive medical, but we focused on the more experienced divers for this study, acknowledging that there is a pre-selection bias. To achieve the same sensitivity (85%) for the questionnaire to detect unfit divers, in comparison with the gold standard, with 95% confidence but narrower confidence limits of say 80% - 90%, would have required a sample size five times as large as our study cohort. In the New Zealand setting, this would require data collection over 25 years and is not currently feasible.

Finally, our results and conclusions could be challenged on the basis of value judgements about whether the cost and logistic savings from not requiring frequent comprehensive medical examinations outweigh the potential harm from a diver being incorrectly certified as healthy. Our response to such criticism would be twofold. First, not a single diver in our study was definitively found to be unfit based on information obtained solely from the examination component of the follow-up comprehensive medical. We have assumed the three divers who did not complete follow-up (see above) were unfit for the purposes of analysis, but this is a deliberately conservative assumption. Second, while we acknowledge that insistence on annual comprehensive medicals can only lower the risk of an adverse event, we believe that the principle of not pursuing costly interventions with very low yield just because there is a small chance of benefit is well established in medicine. A detailed cost-benefit analysis of our results is beyond the scope of this study, but is a probable topic for future consideration.

Conclusion

After the initial comprehensive medical evaluation, health issues leading to occupational divers being considered ‘unfit’ were discovered almost exclusively from an annual on-line health questionnaire. A routine 5-yearly comprehensive medical examination provided little or no extra critical information. Apart from their perceived ‘intangible’ benefits, costly annual comprehensive medical examinations are difficult to justify for occupational divers.

CHAPTER NINE

The impact of health on diver attrition rates

Prelude

The following study has been published in the peer-reviewed literature (Sames et al., 2019b). A search of relevant literature revealed no previous study investigating reasons for quitting a career as a professional diver, yet there is a plethora of studies regarding the possible health effects of diving. If it transpired that a significant proportion of divers left the industry for health reasons, failing to account for these divers would cast doubt on the validity of the many studies of the health effects of diving, and would also indicate that the current diver health surveillance/certification system was flawed.

Introduction

The impact of diving on health has been extensively investigated, but not the impact of health on diving. The registered professional diver workforce in New Zealand has remained relatively stable numerically, at approximately one thousand divers, for many years. However, a previous study of this group (see Chapter Nine) showed that over a 5-year period there was an attrition rate of 77%, suggesting considerable flux, with the number of newly registered divers roughly matching those either retiring or leaving the profession to pursue other employment (Sames et al., 2009b). There are many possible explanations for such a high rate of attrition, but of primary interest, and the focus of the present study, is whether health-related issues play a significant role in a diver's decision to depart from the profession. Diving is undeniably hazardous, with workers at risk of potentially catastrophic accidents, and also the possibility of long-term adverse health effects of diving. Anxiety about such outcomes may be one of the drivers of the reported high attrition rate. However, many studies have reported minimal long-term adverse health effects, even in relation to respiratory and auditory function, both commonly believed to be the most likely targets for damage (Sames et al., 2009a, 2018, 2019a; Hope et al., 1993; Pougnet et al., 2014; Tetzlaff & Thomas, 2017). One of the limitations of such studies is a possible sampling bias caused by the lack of data from divers who are no longer working, and who may have left the industry for health reasons, leading to erroneous conclusions due to a 'healthy worker effect' of unknown magnitude. However, in New Zealand, where occupational diver health is monitored by a comprehensive medical examination every five years and by a health questionnaire in intervening years, very few divers are found to have a health condition that disqualifies them from occupational diving (Sames et al., 2009b, 2016). One could conclude that almost all who leave the industry do so for reasons unknown because of a lack of relevant data. However, there remains the possibility that diver attrition may be due to health issues that the health surveillance system is failing to detect. The current study aimed to establish the significance of health issues as a determinant of departure from the professional diver workforce, and to verify that the current New Zealand diver health surveillance system is not failing to detect medical problems that cause divers to quit the industry.

Method

Ethical approval for this study was granted by the Health and Disability Ethics Committee (HDEC), approval number 18/CEN/180.

Professional divers were identified from a computerised database and categorised as either 'quitters' (with no derogatory implication intended) or 'stayers'. Quitters were arbitrarily defined as those who had remained registered for fewer than five years and had not re-registered in the last five years, while stayers were arbitrarily defined as current divers who have remained registered for 10 years or longer. Those divers who had been registered for 5-10 years formed an intermediate group, excluded from this study.

Quitters with a recorded email address were surveyed by asking them to complete a simple questionnaire designed to clarify whether or not they were still working as a diver (perhaps overseas), and if not, what type of diving they had been engaged in when they left, and, most importantly, whether they had quit diving for health reasons. Because of difficulties establishing communication with ex-divers, additional avenues of contact were attempted, namely by telephone and by the electronic social medium, Facebook®. To give an indication of a desirable sample size, a power analysis, based on a notional response distribution of 10% quitting for health reasons (agreed *a priori* based on clinician-author experience), demonstrated that a sample of 113 quitter-divers would be required to complete the survey, with a 5% margin of error, a 95% confidence limit and a total population of quitter-divers of 600. Any who reported that they were now employed as divers registered in another country were excluded from further analysis. The remaining group of respondents was compared with the group of non-respondent quitters to test for group homogeneity with the understanding that the non-respondents would also include an unknown number still working elsewhere as divers.

Any record of a health-related issue disclosed in initial or subsequent dive medical assessments was noted, and these results together with the category of occupational diving and other demographic data were compared between quitters and stayers.

Statistical analysis was performed using SAS® v9.4 software (SAS Institute Inc., Cary, North Carolina, USA). Frequency and proportion (%) were used for describing categorical variables, such as gender, smoking status and type of diving. Median with minimum and maximum were used for describing the continuous variables such as years registered and BMI, as they did not follow normal distribution. 95% confidence intervals were estimated for the reported proportions quitting for health reasons and for those with a recorded history of a health condition. Comparisons were made between the quitter group and the stayer group, and between responder and non-responder groups. Chi-squared test (and Fisher's exact test if suitable) and the non-parametric test (Wilcoxon rank sum test) were used for categorical and continuous variables respectively. A P-value of <0.05 was considered to be statistically significant.

Results

622 divers were identified as 'quitters', and 436 as 'stayers'. Quitters remained registered for a median of one year (range 1-5 years), compared with 14 years (range 10-25 years) for stayers. Record of either an email address or telephone

number was available for 364 quitters, but many were either incorrect or no longer active. There were 53 responses to email, a further 67 to telephone calls and 37 to Facebook® contact, giving a total of 157 responses (response rate 25.2%). Twenty one respondents (13.4%) were still active divers, but were registered and working in countries other than New Zealand. These divers were excluded from our analysis of health reasons for leaving the divers' register, and also from comparison of quitters with stayers, leaving a total of 601 quitters and 136 quitter-responders. Of the quitter-responders, four claimed that they had stopped diving because of a health issue (2.9% of responses, 95% CI = 0.8%-7.4%). Two were aquaculture workers, one was a construction worker and one was a recreational diving instructor. The specific health reason was described as a sinus problem in all four cases. The most common reason for quitting (97% of responses) was simply to provide a change in job/life direction, usually prompted by dissatisfaction with aspects of professional diving, such as poor remuneration and lack of consistency of employment. A similar proportion of quitters (11.1%, 95% CI = 8.7%-13.9%) and stayers (11.0%, 95% CI = 8.2%-14.3%) had a recorded medical condition (most commonly obesity or abnormal hearing or lung function requiring regular surveillance), but none of the four who quit for health reasons had any notable medical condition (including the sinus problems that resulted in quitting) recorded from their health questionnaire or initial medical examination.

For all divers, smoking was almost four times more common in 'quitters' than 'stayers' (18.6% vs 5.3%). The proportion of scientific divers who were current smokers was consistently low in both groups (1.6%), while the proportion of instructors and commercial divers who were current smokers was significantly higher in the 'quitter' than the 'stayer' group (17.7% vs 3.9%, and 31.2% vs 4.7% respectively). Quitters were almost twice as likely as stayers to be female (20.6% vs 11.2%) and also more than twice as likely to be an instructor (38.4% vs 17.4%), in fact 53.2% of females who quit and 26.5% who stayed, were instructors. Quitters were significantly less likely to be a scientific diver. These results are summarised in Tables Twenty and Twenty One.

Comparison of the responder and non-responder groups showed no significant differences apart from the proportions of the various diver sub-groups.

Table Twenty **Comparison of characteristics of New Zealand professional divers defined as either 'quitters' (who left diving within five years of registering) or 'stayers' (who remain registered after 10 or more years' diving)**

	All Quitters (*n*=601)	Quitter responders (*n*=136)	Stayers (*n*=436)
Male n(%)	477 (79)	108 (79)	387 (89)
Female n(%)	124 (21)	28 (21)	49 (11)
Age at last medical (yrs)*	29 (16-62)	28 (16-56)	43 (23-72)
Years registered (yrs)	1 (1-5)	1 (1-5)	14 (10-25)
Non-smoker n(%)	326 (54)	83 (61)	317 (73)
Ex-smoker n(%)	163 (27)	35 (26)	96 (22)
Current smoker n(%)	112 (19)	18 (13)	23 (5)
Height (cm)	177 (152-200)	178 (152-200)	178 (154-204)
Weight (kg)	81 (47-153)	83 (52-145)	85 (48-150)
BMI (kg/m^2)	26 (18-51)	26 (18-41)	27 (19-42)
Instructor n(%)	231 (39)	54 (40)	76 (17)
Commercial n(%)	138 (23)	15 (11)	86 (20)
Scientific n(%)	65 (11)	16 (12)	126 (29)
Aquaculture n(%)	49 (8)	16 (12)	24 (6)
Military/Police/Customs n(%)	53 (9)	26 (19)	56 (13)
Construction n(%)	41 (7)	3 (2)	55 (13)
HBU attendant n(%)	12 (2)	5 (4)	4 (1)
Film n(%)	12 (2)	1 (<1)	9 (2)
Medical issue on record n(%)	67 (11)	17 (12)	48 (11)
Reason for leaving:**			
Dissatisfaction n(%)	-	132 (97)	N/A
Health n(%)	-	4 (3)	N/A

*Values were taken from the most recent medical examination and are presented as median (and range) where not expressed as a percentage. Percentages are rounded to nearest whole number.
** 'Reason for leaving' values are not applicable (N/A) for 'stayers', and not available for 'all quitters'.

Table Twenty One **Prevalence of smoking amongst the principal categories of New Zealand professional divers who have either quit diving within five years of starting (quitters) or continued diving for >10 years (stayers)**

Diver Category	Quitters (*n*=601)	Stayers (*n*=436)
All n(%)	112 (18.6)	23 (5.3)
Scientific n(%)	1 (1.6) (N=65)	2 (1.6) (N=126)
Instructor n(%)	41 (17.7) (N=231)	3 (3.9) (N=76)
Commercial n(%)	43 (31.2) (N=138)	4 (4.7) (N=86)
Aquaculture n(%)	15 (30.6) (N=49)	3 (12.5) (N=24)
Military/Police/Customs n(%)	4 (7.5) (N=53)	5 (8.9) (N=56)
Construction n(%)	7 (17.1) (N=41)	6 (10.9) (N=55)

Discussion

The impact of health status on the attrition rate of professional divers was investigated by identifying and surveying a group of divers who left the industry within five years of joining. The reasons given for leaving were almost entirely related to the diving work environment, such as dissatisfaction with aspects of the job or just wanting a change in career, rather than anything to do with health. This finding will not surprise clinicians who have experience working with professional divers, but the purpose of the study was to quantify the impact of health on diver attrition, and we are not aware of any previous studies that address this issue. The finding that only 2.9% of responding professional divers leave the industry for health reasons undetected during formal health surveillance provides strong support for the integrity of the current system of health surveillance for this group of workers. This is particularly so since in every case the undetected medical problem responsible for the divers' decisions to leave the industry was highly unlikely to result in a life or limb-threatening event. In contrast, a high percentage quitting for undetected health reasons, particularly health problems with significant implications for diver safety, would have suggested an inadequate surveillance process and an unacceptably high false negative rate (if we define 'negative' as absence of health-related findings that would preclude safe diving).

These results are relevant to the many previous studies investigating the converse issue, the impact of diving on health, which could be criticised for sampling bias due to the omission of data from ex-divers. Our findings suggest that a 'healthy worker effect' is unlikely to have a significant impact on the validity of such studies of working divers, especially in relation to the possibility that serious diving-induced health problems might be significantly over-represented among divers who have left the industry. Although there might be potential for diving to have exacerbated the condition in the four divers we found who ceased diving because of sinus problems, it is more likely that diving unmasked a chronic predisposition to such problems.

The reasons for recreational diving instructors being more likely to quit than any other category of diver are speculative, but we suggest that instructors may, in general, be a more itinerant group, perhaps comprising those who consider instructing as a short-term, interim or secondary occupation. Work as an instructor may also be less consistent and more seasonal than some of the more 'stable' diving careers such as scientific, construction or military diving. We also noted a correlation between smoking and quitting diving, such that smokers were more likely to quit diving, and, as a corollary, non-smokers were far more common amongst stayers than quitters (72.7% vs 54.2% respectively). The proportion of instructors in the quitter group was more than twice that in the stayer group, and the proportion of instructors who smoked in the quitter group was more than four times that in the stayer group. This smoking association was even more pronounced for commercial divers, who represented a similar proportion in both quitter and stayer groups (23.0% vs 19.7%), but the proportion who smoked decreased six-fold in the stayer group (31.2% vs 4.7%). The median age of the stayer group was 15 years older than the quitter group, and although smoking prevalence rates in the general population decrease with age, the large difference we found between quitters and stayers emphasised a stayers' smoking prevalence rate significantly lower than the age-related New Zealand and international population norms (NZ Health Survey, 2017;

WHO global report on trends in prevalence of tobacco smoking, 2015). The quitters who responded to this survey were not asked their current smoking status, but further research could resolve the question of whether diving may act as a motivation to quit smoking, or conversely, that smoking possibly contributes to a departure from diving. If the former were true, however, we would have expected to find a higher proportion of ex-smokers in the stayers group.

LIMITATIONS

Limitations of this study include the following: Firstly, the study surveyed only those divers who quit early in their career, whereas there are likely to be some who leave for health reasons after a career spanning longer than five years. We agree that research including the more experienced group would be worthwhile, but note that a high rate of attrition has been reported in the first five years of the divers' careers. In addition, the results of many previous studies of the long-term health effects of diving suggest that clinically evident diving-related health reasons for quitting are very unlikely (Sames et al., 2009a, 2018, 2019a; Hope et al., 1993; Pougnet et al., 2014; Tetzlaff & Thomas, 2017). That said, we accept that current lack of a diving-related health reason for quitting diving does not necessarily exclude the possibility of delayed development of a diving-related clinical condition (eg. dysbaric osteonecrosis).

Secondly, our results are not necessarily generalisable to populations of professional divers in other countries. The characteristics, including health status, of professional divers throughout the world, may vary depending on local certification and health surveillance protocols. We therefore concede that early career attrition rates probably vary internationally.

Thirdly, we found that 13% of the group of quitter-responders were, in fact, working as divers, but registered in other countries. It is possible therefore, that a similar proportion of the quitter-non-responders were also still active divers. Our inability to determine this number reduces the accuracy of our comparison of quitter-responder and non-responder groups. Nevertheless, this had no effect on the primary outcome of the study, the influence of health status on the decision to quit diving.

Finally, as there was a relatively low quitter response rate, despite our employment of three methods to contact the ex-divers, we accept the possibility of a sampling (non-response) bias. It could be argued that there might be a higher rate of leaving for health reasons among the non-responders. On the other hand, our reported response rate of 25.2% should be considered conservative, as the majority of non-responders were unable to be contacted and so had no opportunity to respond. However, the fact that there was not a single report of a diver quitting because of a clearly diving-related health condition, suggests that health status is a minimal contributor to the professional diver attrition rate.

Conclusions

Diving-related health reasons are of minimal significance in accounting for attrition rates of professional divers. The low rate of health-related attrition from the professional diver workforce supports the integrity of the current diver health surveillance system. Conclusions drawn from studies of the health effects of diving on working divers are unlikely to be significantly affected by the absence of those who have left the industry.

CHAPTER TEN

Summary of findings

The studies comprising this thesis were conducted over a ten year period with the aim of discovering evidence that would either support or refute my working hypothesis that many components of the routine health surveillance programme for professional divers lack supporting evidence of utility and are therefore unable to be justified, and consequently, the process was in need of modification.

Review of the relevant literature (Chapter One) overwhelmingly supports the position that much of the screening of the asymptomatic general population has been, and to a large extent still is, without an evidence base. Screening can only be justified for a small number of health conditions, and only a small number of physical parameters are worth checking routinely. Several large studies have concluded that even some widely accepted screening programmes, such as prostate screening and mammography, result in nett harm. Similarly, screening of the workforce lacks consensus on what should be surveyed, how it should be surveyed, and how the efficacy of such survey should be assessed. It is evident that much occupational fitness-for-work screening is unjustly discriminatory, and is only justified for specific, high-risk, occupations. Its financially driven roots in the life insurance industry persist in today's booming health and safety compliance industry, where functionaries feel compelled to be seen to be doing something, rather than doing nothing, despite the cost to both employers and employees.

The composition and history of the development of the New Zealand professional diver certification and surveillance programme was described in Chapter Two, and was intended to help the reader gain understanding of that specific occupational group, used as an exemplar in this thesis, and the historical deficiencies in their certification and health surveillance programme. Chapter Two references modifications made as a consequence of the research comprising the subsequent chapters.

The two studies detailed in Chapter Three (Sames et al., 2009a, 2018) are audits of the long-term effects of diving on lung function. They were conducted almost ten years apart, and in the intervening years an improved and more extensive, global, lung function normative value database was published and was used in the second of these studies. Spirometry remains one of only two physical investigations mandatory for routine diver medical examinations, so the rationale for auditing the impact of diving on lung function over careers ranging from five to 25 years was to discover whether routine testing could be justified at all, and if so, at what frequency. There would be no justification for routine testing if there was no evidence of lung function deterioration due to diving. Prior to 2003, divers were required to submit to complete physical examinations, including spirometry, annually. As described in Chapter Two, an audit of the predictive power of the complete dive medical examination found that it had little influence on fitness-to-dive certification (Grieg et al., 2003), and the annual requirement was relaxed, on a case-by-case trial basis, to five-yearly. This action was validated partially by the results of both of the lung function audits, and further by the other studies described in this thesis.

Both of the lung function audits, involving 336 and 232 divers respectively, concluded that there was no evidence of significant long-term changes in lung function that could be attributed to diving. Minor statistically significant changes in some of the measured parameters were of doubtful clinical significance. The findings of both studies were in accord, and also consistent with most of the relevant published literature. The 2009 study also compared four normative data sets and found that the NHANES III set, which is most commonly used in New Zealand, is the most appropriate for use with New Zealand professional divers. The NHANES III data set has subsequently been absorbed into a new database devised by the Global Lung Initiative (Quanjer et al., 2012), used as the comparison data set for the 2018 audit. The consequence of the findings of these two audits was advice given to the regulating authority (WorkSafe), after conferring with the DIAG, that even routine five-yearly (let alone annual) spirometric testing of professional divers was not justified. The action advised was that the current requirement should be relaxed so that spirometry is required for the initial medical examination, and thereafter only as clinically indicated. This response is not only appropriate and defensible based on available evidence, but will result in no reduction in the health or safety of divers, and will save both time and money.

The audit of the long-term effect of diving on hearing, described in Chapter Four (Sames et al., 2019a), was conducted for the same reasons as outlined above regarding lung function. Data from New Zealand professional divers with careers spanning 10-25 years were compared with age-adjusted normative data derived from the most recently published ISO data. Divers' hearing, in general, was found to be worse than the age-matched comparison group, but deteriorated less than predicted with the passage of time, despite active diving careers. Multiple regression analysis found a statistically, but not clinically, significant correlation between hearing change and duration of diving at only one of the six tested frequencies in each ear, and with BMI, but failed to find any correlation between hearing change and either intensity of diving or smoking. Again, these findings were in agreement with most published literature, and suggested that hearing loss in divers is most likely to be due to either noise or barotrauma. In the absence of evidence for hearing loss due to diving *per se,* with divers' hearing actually faring marginally better than the age-matched population, routine audiometric testing cannot be justified. Consequently, the same advice was offered to WorkSafe as for lung function testing, that audiometry should be performed at the initial dive medical, and thereafter only if indicated.

The postal survey reported in Chapter Five (Sames et al., 2012) was conducted to provide evidence to either support or refute the value of the central audit function of the divers' health surveillance programme, specifically with reference to the determination of fitness to dive. The central audit facility, which is unique to New Zealand, is described in detail in Chapter Two, but its value has been questioned, and it has been criticised by some divers for causing delays in certification. This survey canvassed the opinions of doctors who conduct dive medical examinations on recreational and/or professional divers, regarding their determination of 'fitness-to-dive' for diving candidates presented to them in the form of case-based vignettes. The performance of two groups of doctors, those with additional training in diving medicine, and those without, were compared with 'gold standard' responses based on expert and published opinion. Both groups of doctors performed little better than random chance. Those with additional training responded correctly slightly more often than those without (in 60% and 50% of cases respectively). These results were almost as disappointing as those from a similar Australian study (Simpson & Roomes, 1999), but highlighted the value, in the New Zealand system, of having an independent, objective, central audit facility, to function as mitigation against 'practice drift', where either poor judgement or patient advocacy may influence a clinician's decision on certification. The study also found that doctors' accuracy was negatively correlated with time since completing an educational course in diving medicine, and positively correlated with the number of dive medicals completed each year. This study provided strong evidence of the value of the central auditing role in determination of fitness to dive, and also of targeted education for those doctors performing diver medicals.

As a quality assurance measure, to inform future modifications and to assess the acceptability of the current diver certification and health surveillance system, an internet-based survey was conducted of end-user (diver) satisfaction. This study, spanning a 12-month period, was reported in Chapter Six (Sames et al., 2020). A simple multi-choice questionnaire, with facility for free-text responses, was added to the divers' website so that divers could respond at the same time as they completed their mandatory annual health questionnaire as part of the re-certification process. The 914 respondents effectively represented all currently registered New Zealand professional divers. The majority (85%) expressed satisfaction with the current system. Of the remaining 15%, recreational dive instructors and divers who engaged in multiple roles were more likely than other groups to be dissatisfied, and 34% of this group identified high costs of the overall process as the main reason for dissatisfaction. Free-text comments indicated a lack of understanding about administrative costs, and comparisons with other countries, highlighting an opportunity for future improvement in communication between the regulating authority and divers. Similarly, some aspects of compliance for the CoC were criticised, and these will be examined for possible modification. This study formed the groundwork for comparison with future, similar, quality assurance surveys to be conducted at appropriate intervals.

The primary aim of the qualitative review of the divers' mandatory annual health questionnaire described in Chapter Seven was to discover whether there was a need for modification of the questionnaire because of misinterpretation of the questions by divers. Secondary aims were to identify questions of low epidemiological value or in determining fitness to dive and also whether minor wording changes might improve clarity. The intended modified Delphi approach proved unnecessary when analysis of initial interviews from 20 divers detected unanimous agreement regarding interpretation of the questions. Three diving medicine experts agreed that four of the 39 questions that comprise the current version of the questionnaire were of low value. Eight questions generated comments from divers regarding improvements that could be made for clarification. It is likely that, on the basis of this study, four questions will be deleted from the questionnaire and eight will undergo minor wording changes.

The two audits described in Chapter Eight (Sames et al., 2009b, 2016) were complementary, and validated the utility of the annual health questionnaire, and the lack of additional value provided by the medical examination, in determining fitness to dive. The audits were conducted about five years apart, and used different approaches in establishing the value of the various components of the diver health surveillance process.

The first of these audits was conducted five years after relaxation of the requirement for complete medical examinations from annually to five-yearly. After identifying all registered divers who had completed two of these complete medical assessments at least five years apart, their records were audited to determine which component, the questionnaire or the physical examination and investigations, provided the crucial information that affected their certification. Of the 336 qualifying divers, only ten were found to have health conditions leading to a change in their fitness certification. Eight were identified through the questionnaire, including the only one eventually deemed permanently unfit for diving. Two who had abnormal spirometry were eventually considered fit to dive, but with conditional certification. The conclusion was that the examination and investigations added a detection rate approaching zero to the value of the health questionnaire.

The second audit, conducted about five years after the first, analysed all certifications issued to professional divers over that period, focussing on divers who were denied certification or were issued with limited or restricted certificates. There were 5178 certificates issued to 2187 divers. Only nine of 663 divers who had completed an initial physical examination and four annual health questionnaires, were then found to have health problems detected at a subsequent examination. None of those, on further evaluation, were found to be unfit for diving. Because three of them were lost to follow-up, the most conservative estimate of the 'unfitness detection rate' for the examination component of the 5-yearly comprehensive medical was 0.45%. In contrast, the accuracy of the annual health questionnaire was found to be 98.9%. These results corroborated those of the previous audit and provided further support for the 5-yearly rather than the annual comprehensive health evaluation for divers. There does not appear to be any evidence of significant mitigation of divers' risk provided by routine mandatory comprehensive examinations.

Finally, a survey of 'retired' professional divers was conducted, and reported in Chapter Nine (Sames et al., 2019b), with the primary aim of determining whether divers leave the industry due to health conditions, particularly those that may be related to diving, or for other reasons. The implication, if there was a high health-related attrition rate, was that the current health surveillance system was inadequate. Ex-divers, who had left the industry within five years of joining, were contacted either by email, telephone or Facebook®, and asked their main reason for quitting. There was a very high attrition rate in the first few years after joining the industry, but the study found that only 3% of the 136 respondents quit for health reasons. Those few had minor health conditions such as sinusitis, and none was obviously diving-related. This finding supported the working hypothesis that the current health surveillance system adequately detects significant health conditions in divers. The almost universal reasons for quitting professional diving were industry-related, such as inadequate remuneration or job dissatisfaction. A secondary finding was that dive instructors and smokers were far more likely to quit diving than other classes of diver and non-smokers. Finally, the results of this study demonstrated that the 'healthy worker effect' is unlikely to be a significant factor in the many published studies on the impact of diving on health.

The above studies, their primary findings and consequent outcomes are summarised in Table Twenty Two.

Table Twenty Two Summary of primary findings and outcomes

Study	Primary finding	Outcome
The long-term effects of compressed gas diving on lung function in New Zealand occupational divers: a retrospective analysis. Diving Hyperb Med. 2009;39:133-7 Long-term changes in spirometry in occupational divers: a 10-25 year audit. Diving Hyperb Med. 2018;48:10-16.	Long-term diving has minimal effect on lung function	Relaxation of requirement for routine spirometry
The impact of diving on hearing: a 10-25 year audit of New Zealand professional divers. Diving Hyperb Med. 2019;49:2-8.	Long-term diving has minimal effect on hearing	Relaxation of requirement for routine audiometry
Postal survey of fitness-to-dive opinions of diving doctors and general practitioners. Diving Hyperb Med. 2012;42:24-9.	Dive doctors perform poorly in determination of fitness to dive	Ratification of crucial central audit facility. Institution of DDD re-certification process.
The impact of health on professional diver attrition. Diving Hyperb Med. 2019;49:107-111.	Professional divers do not quit diving for health reasons. Current system detects all significant health issues.	Ratification of value of health questionnaire
Professional diver certification: an internet-based satisfaction survey of New Zealand divers. Diving Hyperb Med. 2020;50:28-33.	Most divers are satisfied with the diver certification and health surveillance system	Areas for further improvement identified
The professional diver annual health questionnaire: A qualitative review. (unpublished)	Divers did not have problems interpreting questions. Experts found four questions of low value. Minor wording changes could help clarity.	Modification of the annual health questionnaire
Utility of regular examinations of occupational divers. Intern Med J. 2009;39:763-70. An evidence-based system for health surveillance of occupational divers. Intern Med J. 2016;46:1146-52.	The examination component of routine health assessments contributes little to what is discovered by questionnaire	Ratification of the transition from annual to 5-yearly requirement for full medical examination, and the value of the health questionnaire.

CHAPTER ELEVEN

Conclusions, suggestions for further study, and implications for the wider working community

The work comprising this thesis represents a longitudinal, systematic analysis of the process of certification and health surveillance of NZ professional divers. Professional divers are an example of a particular group of workers for whom mandatory routine health screening, involving physical examination, has been historically and universally embedded and accepted, without reference to supporting evidence of efficacy, as an appropriate mechanism of occupational health and safety management. Such screening programmes have existed, relatively unchanged, for many decades, possibly since the early years of professional diving.

This work demonstrates that significant components of the screening process, such as tests of lung function and hearing, and the physical examination itself, do not contribute significantly to the determination of fitness to dive, apart from at the initial examination. Conversely, the health questionnaire, despite need for further modification, is not only far more expedient, but has been shown to detect the important health issues that might preclude safe diving. Changes to the NZ system have been instigated as a consequence of the findings of the research reported in this thesis (see Table Twenty Two, Chapter Ten). However, wider acceptance of the need for change is uncertain in view of the research presented in Chapter One, suggesting that routine screening programmes can become entrenched rituals, and there is resistance to abandoning such practice even when there is a lack of supporting evidence (Martin et al., 1982; Sox et al., 1981; Keating et al., 2002; Doust & Del Mar, 2004). Inappropriate testing remains pervasive, despite guidelines from the International Labour and International Maritime Organisations recommending against it (International Labour Office, 2013). Many reasons are likely to contribute to the maintenance of a system that is demonstrably unjustifiable with respect to employee health and safety, including financial gain for those with a vested interest. This has been a conspicuous motive since the earliest days of screening programmes, applied to both the general population and asymptomatic workers, and, as previously mentioned, extends into the modern, booming, health and safety compliance industry.

There are many other groups of workers who, like divers, undergo similar, mandatory, over-inclusive routine medical/fitness examinations (eg. offshore workers, military personnel, police, pilots, etc.) and for whom there is also a lack of evidence of benefit. In fact, for divers in countries other than NZ and for some of these other groups, despite evidence of lack of benefit, costly, exhaustive, screening programmes persist. For example, in the case of offshore workers, a review of 19 pre-employment medical examination protocols revealed that many of these programmes included tests that are more appropriate for diagnostic purposes when there is suspicion of disease, rather than for screening an asymptomatic group of workers to detect unidentified diseases or disease risk factors (Horneland & Stannard, 2017). The same is true of previous iterations of the NZ divers' routine medical examinations, and the system currently used in Australia.

Two main themes emerge from these studies: Firstly, it has been possible to modify the health surveillance process for professional divers by studying each component of the existing programme to find evidence that either supports or refutes its value. It is unlikely that there are any elements of this model that could not be applied to comparable programmes prescribed for workers in other safety-critical industries such as construction, aviation, nuclear power, etc. Currently, huge costs are expended by employers, and contracted employees, in pursuit of a 'clean bill of health' that can be provided to the relevant regulating authority. Other than acting as a badge of compliance with often evidence-free health and safety regulations, such pursuit is almost meaningless. It could be argued, with support from Human Rights and Privacy legislation and complying with the spirit of Health and Safety at Work legislation, the absence of reliable evidence of its utility should preclude mandatory testing. Almost any test has the potential to cause physical and/or psychological harm, including unjust denial of employment. The impact of that harm is amplified if the test was, in fact, completely unnecessary.

Secondly, the importance of discretionary rather than prescriptive outcomes of the health assessments has been emphasised. The core element of the modifications to the professional divers' health surveillance programme has been the deliberate shift of the locus of responsibility for worker health and safety, as much as possible, toward the worker/employer/regulator triumvirate, and away from the occupational physician. That is to say, for the vast majority of workers, this responsibility can be de-medicalised. Of course there are some aspects that should remain prescriptive, such as when there is evidence of a physical or mental condition that precludes working safely in a specific job, but as we have seen with divers, those cases are few in number, and most can be adequately screened for by way of a questionnaire. Since the predominantly prescriptive approach to diver certification and health surveillance has transitioned to one that is predominantly discretionary, no increase has been noted in recorded health and safety parameters, such as incidence of DCS or other diving injuries. This belies the common argument that making a self-disclosing health questionnaire pivotal in the process would lead to problems with veracity and the presumed adverse health outcomes.

Professional divers are important to the New Zealand economy, and the studies comprising this thesis were facilitated by the relatively small size of the NZ population, and more importantly, the early establishment of a centrally audited certification and health surveillance system. The primary objective of this collection of studies was to provide an evidential basis for modifications to the existing system of diver health surveillance, so that all of its components are justified, and those found unnecessary, eliminated, without increasing risk to divers. The secondary objective was to provide groundwork for possible extrapolation of the methods used in this work, to the broader working community, particularly the safety-critical industries. The conclusions drawn from these studies, and the processes involved in conducting them, highlight the importance of both the objectivity provided by the central auditing process, and the facility to conduct regular audits of divers' health and the certification and surveillance process itself, because of computerisation of the professional divers' database.

The sentiment expressed in the quote (from American systems scientist, Peter Senge) at the beginning of this thesis, that "people don't resist change, [but] they do resist being changed", is apt. Consequently, a demonstration of unequivocal evidence of the need to change should at least facilitate the change process. But accepting the proposition that change means improvement is only the first step. Those responsible for instituting it, as well as those to whom it applies, must overcome a natural affinity for the status quo and the discomfort, uncertainty and additional work that usually accompanies change. Whether there will be either the interest or capacity to develop similar systems, applicable in jurisdictions larger and more complex than New Zealand's, remains unknown. However, even if such a thing proves unfeasible, the conclusions of these studies, used to justify modifications to the NZ professional divers' health surveillance system, are applicable globally. I am hopeful that, where possible, other jurisdictions may consider modifying their current mandatory requirements accordingly.

APPENDICES

Appendix One	Spirometry prediction equations used in the lung function studies described in Chapter Three.
Appendix Two	Brief description of the derivation of the NHANES III and GLI (2012) spirometry prediction equations.

Appendix One: Spirometry prediction equations used in the lung function studies described in Chapter Three

The following lung function prediction equations are adapted from Knudson et al., (1976) and Knudsen et al., (1983).

(A = Age in years, H = Height in centimetres)

FVC (L)

Males: 0.0844H – 0.0298A – 8.782

Females: 0.0444H – 0.0169A – 3.195

FEV_1 (L)

Males: 0.0665H – 0.0292A – 6.515

Females: 0.0309H – 0.0201A – 1.405

FEF 25-75% (L/sec)

Males: 0.0579H – 0.0363A – 4.5175

Females: 0.0209H – 0.0344A + 1.1277

PEFR (L/sec) (1976)

Males: 0.094H – 0.035A – 5.993

Females: 0.049H – 0.025A – 0.735

FEF 25%(L/sec) (1976)

Males: 0.088H – 0.035A – 5.618

Females: 0.043H – 0.025A – 0.132

FEF 50%(L/sec) (1976)

Males: $0.069H - 0.015A - 5.4$

Females: $0.035H - 0.013A - 0.444$

FEF 75%(L/sec) (1976)

Males: $0.044H - 0.012A - 4.143$

Females: $- 0.014A + 3.042$

The following lung function prediction equations are adapted from Gore et al., (1995). (A = Age in years, H = Height in metres)

FVC (L)

Males: $12.675 - 0.0002764 A^2 - 10.736 H^2 + 4.79 H^3$

Females: $-3.598 - 0.0002525 A^2 + 4.68 H$

FEV_1 (L)

Males: $2.081 + 0.5846 H^3 - 0.01599 AH$

Females: $1.597 + 0.5552 H^3 - 0.01574 AH$

PEFR (L/sec)

Males: $-6.099 - 0.0003425 A^2 + 9.708 H$

Females: $3.364 - 0.02654 A + 1.036 H^3$

FEV_1/FVC %

Males: $92.963 + 0.002487 A^2 - 0.2260 AH$

Females: $-4068.039 + 0.7137 A + 0.002234 A^2 + 7675.039 H - 4719.018 H^2 + 967.776 H^3 - 0.6946 AH$

FEF 25-75% (L/sec)

Males: $(\log_{10}FEF_{25\text{-}75}) = 0.5707 - 0.00005695 A^2 + 0.025818 H^3$

Females: $-556.706 + 1036.012 H - 637.715 H^2 + 131.013 H^3 - 0.02708 AH$

The following lung function prediction equations are adapted from Hankinsen et al., (1999). (A = Age in years, H = Height in metres).

FEV_1

Male: $0.5536 – 0.01303A – 0.000172A^2 + 0.00014098H^2$

Female: $0.4333 – 0.00361A – 0.000194A^2 + 0.00011496H^2$

FVC

Male: $- 0.1933 + 0.00064A – 0.000269A^2 + 0.00018642H^2$

Female: $- 0.3560 + 0.01870A – 0.000382A^2 + 0.00014815H^2$

PEF

Male: $1.0523 + 0.08272A – 0.001301A^2 + 0.00024962H^2$

Female: $0.9267 + 0.06929A – 0.001031A^2 + 0.00018623H^2$

FEF 25-75%

Male: $2.7006 – 0.04995A + 0.00010345H^2$

Female: $2.3670 – 0.01904A – 0.000200A^2 + 0.00006982H^2$

The following lung function prediction equations are adapted from Marsh et al., (2006). (A = Age in years, H = Height in metres).

FEV_1

Male: $-2.73 + 0.57 – 0.031A + 4.47H$

Female: $-2.73 – 0.031A + 4.47H$

FVC

Male: $-5.87 + 0.65 – 0.03A + 6.73H$

Female: $-5.87 – 0.03A + 6.73H$

Log PEF

Male: 5.43 + 0.30 – 0.0053A + 0.56H

Female: 5.43 – 0.0053A + 0.56H

FEF 25-75%

Male: 342.2 + 52.8 – 3.5A

Female: 342.2 – 3.5A

FEF 25%

Male: 530.4 + 124.9 – 3.17A

Female: 530.4 – 3.17A

FEF 50%

Male: 376.2 + 56.8 – 3.4A

Female: 376.2 – 3.4A

FEF 75%

Male: 46.9 + 12 – 1.82A + 68.2H

Female: 46.9 – 1.82A + 68.2H

FEV_1/FVC

Male: 108.1 – 0.24A – 10.6H

Female: 108.1 – 0.24A – 10.6H

Appendix Two: Brief description of the derivation of the NHANES III and GLI (2012) spirometry prediction equations

Third National Health and Nutrition Examination Survey (NHANES III)

The NHANES III prediction equations are based on data collected from a random sample of the population across the USA between 1988 and 1994. The initial total of 20,627 subjects from three ethnic groups (Caucasian, Afro-American and Mexican-American) was reduced to 7,429 after exclusions to comply with the criteria that all subjects were asymptomatic, life-long non-smokers and could provide at least two acceptable spirometric manoeuvres. Subjects were between 8 and 80 years old. In 1999 the analysis and resulting prediction equations were published by Hankinson et al. (1999). The equations are race/ethnic group and gender specific, with age and height as independent variables. The equations are polynomials of the form: Lung function parameter = $b_0 + b_1 x Age + b_2 x Age^2 + b_3 x Height^2$, where b_0 is the intercept and b_1, b_2 and b_3 are coefficients that vary for each lung function parameter with race/ethnic group and gender. There are also different sets of coefficient values for males under 20 and females under 18 years old.
This set of equations gained considerable global popularity, and has recently been the reference dataset most commonly used throughout New Zealand (Marsh et al., 2007).

Global Lung Function Initiative

A new set of lung function reference value prediction equations was developed and published in 2012 by the Global Lung Function Initiative (Quanjer et al., 2012).
This large collaborative study resolved many of the inherent problems with the existing collection of published prediction equations for spirometric reference values. Specifically, problems with existing datasets included small population/ethnic group sample numbers, out-moded methodologies and discontinuity between age groups. Through collaboration with researchers from 70 centres in 26 countries across 5 continents, and including data from earlier significant studies, such as NHANES III, Quanjer et al. (2012) derived continuous equations suitable for ages from 3 to 95 years based on data from 74,187 healthy non-smokers. The equation is in the form

of a linear regression expression using age and height as independent variables, with coefficients dependent on lung function parameter, gender and ethnic group. The four ethnic groupings specified are Caucasian (providing most of the data), Afro-American and North and South East Asian. Another set of equations, based on an average of the others, can be used for ‘other’ ethnic groupings. The authors consider the development of this dataset complete for the Caucasian group, but ongoing for possible future modification when further data has been collected from the other ethnic groups.

Calculations for individuals or large groups have been facilitated by the GLI-2012 group’s provision of the required software on their website (Quanjer et al., 2012). This dataset has been endorsed by the major respiratory and thoracic societies from Europe, America, Asia, Australia and New Zealand.

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