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Analysis of some individual risk factors for decompression sickness in Hong Kong

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Lam TH, Yau KP. Analysis of some individual risk factors for decompression sickness in Hong Kong. Undersea Biomed Res 1989; 16(4):283–292.—Individual risk factors for decompression sickness (DCS) were studied in 932 men who had worked for 12 shifts or more at maximum working pressure (MWP) of 1 bar or above in a compressed air tunneling project in Hong Kong. Two dependent variables were used: presence or absence of bends and number of bends experienced by a man. Three hundred and fifty-six men (38.2%) had one or more bends. Univariate analysis showed that many variables were associated with presence or absence of bends. Logistic regression showed that the best equation included five independent variables: MWP, number of exposures, past number of bends, job (being a miner), and Quetelet Index (or Body Mass Index). The number of bends was also associated with many variables. Stepwise multiple regression revealed five important independent variables: ethnicity, MWP, Quetelet Index, number of exposures, and past number of bends. Obesity and past number of bends were therefore important risk factors for DCS after taking into account MWP and number of exposures. The age effect observed in univariate analysis could be due to obesity. Miners and Japanese had higher risks of DCS, probably due to their strenuous labor.

decompression sickness
individual risk factors
compressed air tunneling
compressed air workers
obesity
past experience

Many factors are associated with the occurrence and incidence of decompression sickness (DCS) (1–4), and in compressed air work these factors may be classified under the following broad categories:

Environmental and work factors. These are factors within the compressed air environment and the nature of the work practice such as level of air pressure, duration of exposure, temperature, humidity, gas content, length of shift, single or split shift, single or multiple exposures within a shift, nature of the work or degree of heavy labor required, labor turnover, acclimatization, etc.

Decompression practices or procedures. These include the types of decompression tables used, whether the tables are followed strictly or modified, decanting, use of hyperbaric oxygen, etc.

Individual risk factors. These are susceptibility factors of an individual such as age, nature of the job, obesity, physical or mental characteristics (somatotypes, pain threshold, anxiety, illness behavior such as self-medication or symptom-reporting), past and present medical history, past experience in compressed air or bends, fatigue, excessive exercise or use of limbs, malingering, etc.

Medical factors. These are factors concerning the medical practice and supervision of compressed air workers by the physician in charge such as the criteria used in preemployment medical examination for medical fitness as well as those used for medical surveillance after workers have started compressed air work, selection and disqualification procedures, practice of diagnosis of decompression sickness and its treatment, etc.

To study the risk factors associated with DCS, the most important dependent variable is the bends rate. It should be noted that the denominator of this index is man-decompressions and not the number of men exposed. While it is a useful index for the study of the effect of pressure and duration, it cannot be used for the study of individual risk factors.

Lam and Yau (5) reported that on a compressed air tunneling project in Hong Kong the bends rate increased with maximum working pressure (MWP) and duration of exposure. In their study of the manifestations of DCS (6), the effect of acclimatization (bends rate in new starters v. non-new starters) was confirmed and several minor variables were found to be unimportant, such as multiple exposures within a work shift, decanting or decompressions that did not follow prescribed tables, histories of upper respiratory infection, injury of affected parts, or excessive use of limbs. Their experience and results of preemployment medical examinations have also been described (7), and it was suggested that the strict criteria adopted in the selection of workers could have contributed to the low incidence of DCS. In this paper, the various individual risk factors will be analyzed. The objective was to study the various individual risk factors in relation to the occurrence of bends in individuals, such as age, obesity, and past compressed air experience, while taking into account the individuals' exposures to compressed air.

MATERIALS AND METHODS

Details of the compressed air tunneling project have been described previously (6). Briefly, this was the largest project for the construction of the Island Line of the Hong Kong Mass Transit Railway. Compressed air work started in October 1982 and ended in May 1984. The total number of man-shifts was 141,361. The MWP was 3.30 bar (4.26 ATA, 47.9 psig) and the Blackpool Decompression Tables were used (8). A total of 793 cases of DCS (792 cases of type I and 1 case of type II) were observed after 139,721 man-decompressions after exposure to 1 bar or above, resulting in an overall bends rate of 0.57%.

Two dependent variables for occurrence of bends were used in this study as follows:

Presence or absence of bends. Workers were classified into 2 groups according to whether they had no attacks of bends or they had one or more attacks of bends during their employment in the present contract. This was a dichotomous variable.

The number of bends. Each worker might experience no attacks or one or more attacks of bends in the present contract. The number of bends that each man had was taken as the dependent variable, which was a continuous variable.

Data on occurrence and frequency of attacks of bends for each man were derived from the decompression sickness case sheets.

The independent variables were, first, age, job, ethnicity, height, weight, Quetelet Index (QI = weight in kg/height in m^2, also called Body Mass Index), skinfold measurements (for workers who started in the project later due to delayed availability of the equipment), past compressed air experience, and past history of bends (before the present contract). These data were derived from the compressed air worker's medical cards with information from preemployment examinations. After they had started working the workers were weighed during periodic examinations but no major variation was found. Only preemployment data were used in this study. Because complete data were available for weight and height but not for skinfolds, QI was used in the present study as the best available index of obesity (9). The value of 25 in QI was adopted as a cut-off point, and subjects with QI over 25 were classified as obese (10). Second, data on exposure to compressed air were derived from the Individual Air Records to yield the independent variables relating to exposure: MWP, number of shifts worked, number of hours compressed air work, and number of exposures to compressed air (same as the number of decompressions). The medical data were collected by the compressed air physician with the assistance of medical lock keepers, whereas the exposure data were collected by the male lock-keepers. Data from the three types of forms were merged into a data file by the mainframe computer using a medical number that was unique for each worker.

Two exclusion criteria were used as follows: a) Men included must have been exposed to MWP of 1 bar or more. All those who had only been exposed to MWP below 1 bar were excluded because there was no bends after exposure to these low pressures in the present contract. b) Men who had worked less than 12 shifts (a period of 2 wk since the workers worked six shifts per week) were excluded. This was necessary because of the increased risk in new starters. Many new starters who had bends within the initial shifts were disqualified from further compressed air work (6), thus eliminating the effect of lack of acclimatization in new starters.

The number of men included after applying the above criteria was 932. Before exclusion, the total number of men in the merged file was 1549. About 40% of the men in the latter file had worked for less than 12 shifts or in MWP of less than 1 bar.

Analysis using the first dependent variable of presence or absence of bends was done first. Univariate analysis was done by comparing the means of the 2 groups for continuous variables. For categorical variables, cross-tabulations were done and odds ratio (OR) calculated to check whether there was any statistical association (11). Multivariate analysis was then done by logistic regression analysis using the program LOGRESS developed by McGee (12). This program is easy to use and has gained increasing popularity among epidemiologists. For the second dependent variable of number of bends, simple linear regression and correlation coefficient were done to study the relationship between number of bends and each of the independent continuous variables. Stepwise multiple regression analysis was then performed to ascertain the best predictors from a list of independent variables using the Statistical Packages for the Social Sciences (SPSS).

RESULTS

Of the 932 men included, 853 were Chinese (91.5%), 72 were Japanese (7.8%), 5 were Europeans (0.5%), and 2 were Indians or Pakistanis (0.2%). Most of the men were miners (65.2%), and the others had a great variety of occupations. There were 356 men (38.2%) with bends (one or more attacks) and 576 (61.8%) with no bends. Of the 356 men with bends, 225 (63.2%) had one bends only, 73 (20.5%) had two, 29 (8.1%) had three, 13 (3.7%) had four, 5 (1.4%) had five, 5 (1.4%) had six, 3 (0.8%) had seven, 2 (0.6%) had eight, and 1 (0.3%) had nine.

Table 1 compares men with bends to men without bends. Statistically significant differences were found for all the variables except height. Of the three variables on amount of exposures in the present compressed air project, the number of exposures was most relevant relative to the number of shifts and number of hours and showed the highest statistical significance. Although the differences observed were small, the variables with significant differences should be included in the following multivariate analysis of risk factors of DCS.

Table 2 shows that the Japanese workers had a higher risk (OR = 2.0) of bends than the Chinese workers. However, there was also a great difference in their job distributions. Of the Japanese, 90.3% were engineers and surveyors, whereas among the Chinese, 71.0% were miners and only a few were engineers and surveyors. Analysis of engineers and surveyors showed that the difference between Japanese and Chinese was statistically significant with an OR of 5.3.

Based on the QI using the cut-off point of 25, the proportion of obese men in those with bends was 56.9%, as compared with 37.2% in those without bends. The OR for obesity was 2.2 (95% confidence intervals = 1.3–3.9, $P < 0.01$).

No significant association between bends in the present contract and previous compressed air experience was found: 41.9% of the men with bends had past compressed air experience, as compared with 36.4% of the men without bends. Table 3

TABLE 1

COMPARISON BETWEEN 356 MEN WITH BENDS AND 576 MEN WITHOUT BENDS

	Bends		
	No	Yes	*P*, *t* Test
Age, yr	27.5	28.4	< 0.05
Height, cm	168.1	168.3	NS
Weight, kg	59.1	60.4	< 0.05
Quetelet Index	20.9	21.3	< 0.05
Log skinfold			
Triceps[a]	164.0	169.4	< 0.01
Subscapular[a]	198.4	203.8	< 0.01
Past no. of bends[b]	0.38	0.58	< 0.05
Present CA work			
No. of exposures	132.3	162.5	< 0.001
No. of shifts worked	121.3	143.9	< 0.001
No. of hours worked	726.9	819.7	< 0.05
MWP, bar	2.42	2.59	< 0.001

[a]*n* for men with no bends = 344, *n* for men with bends = 182.

[b]For those with past compressed air (CA) experience only, *n* for men with no bends = 173, *n* for men with bends = 125. NS = not significant.

TABLE 2
RELATIONSHIP BETWEEN BENDS AND ETHNICITY, CHINESE VS. JAPANESE

Ethnicity	Bends: No	Bends: Yes	Row, %	OR[a]	95% CI	*P*
All jobs						
Chinese	538	315	36.9	1	–	–
Japanese	33	39	54.2	2.0	1.2–3.3	< 0.01
Total	571	354	38.3			
Engineers and surveyors only						
Chinese	34	8	19.0	1	–	–
Japanese	29	36	55.4	5.3	2.1–13.1	< 0.001
Total	63	44	41.1			

[a]e.g., 538 × 39/(33 × 315) = 2.0.

TABLE 3
RELATIONSHIP BETWEEN BENDS AND PAST COMPRESSED AIR EXPERIENCE AND PAST BENDS[a]

Past Compressed Air Experience or Bends	Bends, Present: No	Bends, Present: Yes	Row, %	OR	95% CI	*P*
No past CA experience	403	231	36.4	1	–	–
With past CA experience but no past bends	127	76	37.4	1.04	0.8–1.5	NS
With past CA experience and past bends	46	49	51.6	1.86	1.2–2.9	< 0.01
Total	576	356	38.2			

[a]χ^2 (2 df) = 8.1, $P < 0.05$. Test for trend: $\chi^2 = 5.8$, $P < 0.05$. NS = not significant.

shows that there was no difference between those without past compressed air experience and those with past compressed air experience but without past bends. However, those with past bends had an increased risk.

Because statistically significant associations were found in many variables with presence or absence of bends, logistic regression analysis was performed to study all these independent variables together. The eight variables studied were MWP, number of exposures, past compressed air experience (1 = yes, 0 = no), past number of bends (those without past compressed air experience were included as having had zero past bends), job (1 = miner, 0 = others), QI, ethnicity (1 = Japanese, 0 = others), and age. Skinfold measurements were tested but they were less useful than QI because too many data were missing. The number of shifts and number of hours worked in the present contract were strongly associated with the number of exposures. Because the former two variables had weaker associations with the dependent variable than the latter, only the latter was included in subsequent analysis.

Table 4 shows the results of the best logistic equation, which included five significant independent variables, each of which had some effect independent of the other variables. These were MWP, number of exposures, past number of bends, job (being a miner), and QI. Inclusion of another variable or an interaction term between MWP and number of exposures did not significantly increase the likelihood ratio statistic. It should be noted that ethnicity and age were not included in the equation because of lack of statistical significance. If the probability of a man to have one or more attacks of bends is P, the best logistic equation can be expressed as follows:

$$\log P/1 - P = -5.8585 + 1.2034\,(\text{MWP}) + 0.0019\,(\text{no. of exposures}) + 0.3161\,(\text{past no. of bends}) + 0.4163\,(\text{job}) + 0.0837\,(\text{QI})$$

and the value of P can be found by $P = e^{\alpha} + \beta_i \times i/1 + e^{\alpha} + \beta_i\, i \times 1$

where α is the constant (intercept) and β_i is the coefficient for the independent variable x_i. The OR for MWP of 3.33 means that there was an increased risk of 3.33 times for every unit (i.e., 1 bar) increase of MWP after adjusting for the effects of the other four variables. The OR for job means that miners had an increased risk of 1.52 times that of non-miners, again, after adjusting for the effects of the other four variables.

Using the number of bends as the dependent variable, linear regression and correlation analysis were carried out separately in relation to each of the continuous independent variables of age, QI, and skinfold thickness. Because the independent variables themselves might be related, their interrelationships were also studied. Table 5 shows a correlation matrix. Significant associations with number of bends were found for QI and the two skinfold measurements. The correlation coefficient r for QI (0.19) was slightly higher than those for skinfolds, although all r's were small. Age is related to QI and subscapular skinfold but not to number of bends.

Table 6 shows the results of stepwise multiple regression using number of bends as dependent variable and the eight independent variables used in logistic regression analysis, namely, MWP, number of exposures, past compressed air experience, past number of bends, job, QI, ethnicity, and age. Again, skinfold measurements were not used because too many data were missing. The five significant variables included in the equation were ethnicity, MWP, QI, number of exposures, and past number of

TABLE 4

RESULTS OF THE BEST LOGISTIC EQUATION RELATING BENDS TO EIGHT INDEPENDENT VARIABLES BUT WITH FIVE INCLUDED IN THE EQUATION[a]

Variables in Equation	Coefficient	SE	OR	95% CI	P
MWP, bar	1.2034	0.20	3.33	2.26–4.91	< 0.001
No. of exposures	0.0019	0.0006	1.0019	1.0007–1.0032	< 0.01
Past no. of bends	0.3161	0.14	1.37	1.05–1.80	< 0.05
Job, 1 = miner, 0 = others	0.4163	0.16	1.52	1.12–2.06	< 0.01
Quetelet Index	0.0837	0.03	1.09	1.02–1.16	< 0.01
Constant	−5.8585	0.90			

[a]Likelihood ratio statistic, 5df = 69.0, $P < 0.001$.

TABLE 5
CORRELATION MATRIX[a] OF NUMBER OF BENDS, AGE, LOG SKINFOLDS, AND QUETELET INDEX[b]

	No. of Bends	Age	QI	Log Skinfold Triceps	Log Skinfold Subscapular
No. of bends	–	0.07	0.19	0.17	0.13
Age	0.07 NS	–	0.23	0.0007	0.17
QI	0.19 $P < 0.001$	0.23 $P < 0.001$	–	0.63	0.70
Log skinfold triceps	0.17 $P < 0.001$	0.007 NS	0.63 $P < 0.001$	–	0.76
Log skinfold subscapular	0.13 $P < 0.01$	0.17 $P < 0.001$	0.70 $P < 0.001$	0.76 $P < 0.001$	–

[a]The correlation coefficients (Product Moment Correlation Coefficient or Pearson's Correlation Coefficient) r with P values are shown in the left lower half of the matrix whereas only the r's are shown in the upper right half.

[b]$n = 526$. Many men did not have skinfold measurements because of the late availability of the equipment.

NS = not significant.

TABLE 6
SUMMARY RESULTS OF STEPWISE MULTIPLE REGRESSION ANALYSIS OF NUMBER OF BENDS (DEPENDENT VARIABLE) WITH EIGHT INDEPENDENT VARIABLES BUT WITH FIVE INCLUDED IN THE EQUATION[a]

Step	Variables	Multiple R	R^2	R^2 Change
1.	Ethnicity, 1 = Japanese, 2 = others	0.2979	0.0888	0.0888
2.	MWP, bar	0.3432	0.1178	0.0290
3.	Quetelet Index	0.3589	0.1288	0.0111
4.	No. of exposures	0.3680	0.1354	0.0066
5.	Past no. of bends	0.3744	0.1401	0.0047

[a]Overall $F = 30.05$, $P < 0.001$.

bends. Compared with the results of logistic regression in Table 4, ethnicity was included here instead of job. The other four variables were similar. The multiple regression coefficient R of 0.3744 was not very high and the amount of variation explained by these five variables was low ($R^2 = 14.01\%$).

DISCUSSION

The risk factors for DCS are so numerous that it is not possible to study them equally. One major difficulty is the lack of complete and reliable data for some variables. Moreover, within one construction project, some variables are held constant and their effects cannot be studied within the project itself. Comparison between different contracts is needed to examine these variables, although the differences in different contracts are often so great that comparison is of doubtful value if not totally useless.

The bends rate is frequently used in the study of decompression procedures in different contracts using different decompression tables, despite the reservations expressed by McCallum (1). The bends rate can also be used for the study of the two most important variables, MWP and duration of exposure. Because data on man-decompressions are routinely collected in any contract, the bends rate can be easily studied. However, the study of individual risk factors is more difficult because a) data must be collected systematically for all the workers and this is usually difficult and incomplete; b) data are usually recorded in different forms and stored in different places so that record linkage is a prerequisite before any analysis can be done; c) differences in an individual's job, work, and exposure pattern, and particularly in mobility within or outside the project were great; and d) individual differences in pain threshold and in symptom-reporting behavior cannot be assessed reliably.

In the present study, serious attempts to overcome the above difficulties were not completely successful. Skinfold thickness was measured only in workers who joined the contract later, because skinfold calipers were not available earlier. Some men only worked for a short period and their exposure and medical data tended to be less complete or more difficult to trace than those who worked for a longer period. The record-keeping system was not without defect and some records could not be traced.

Nevertheless, there were reasonably good and complete data in the present contract for the analysis of some important risk factors. Simple univariate analysis showed that a number of variables were associated with bends when the two dependent variables (with or without bends and number of bends) were used. The two obvious variables were MWP and number of exposures. It was therefore essential in any study of individual risk factors that these two variables be taken into account. Multivariate analysis showed that obesity was also a risk factor after adjusting for the effects of other variables. These results were consistent with the findings in the Tyne Road Tunnel by the U.K. Decompression Sickness Panel (13).

Skinfold thickness measurements were not required in Hong Kong and were only done in the present contract for the purpose of this study. Although it was difficult to evaluate its usefulness because not all workers were measured, this study did suggest that the QI was a useful measure of obesity. The QI was related slightly more to the number of bends than to skinfold thickness. It can be calculated from routine measurements of body weight and height. There is also a convenient cut-off point of 25 for the assessment of whether a man is obese or not (10). Skinfold measurements however require special equipment and some training in the method. Although obesity is a risk factor for bends, it is difficult to disqualify a man if he is only slightly overweight. From the results of the present study, 56.9% of the obese men (with QI > 25) had one or more attacks of bends. If a man with QI over 25 is employed, it would be necessary to warn him of the risk and to advise him to reduce his weight for the sake of prevention.

This study also showed that men with past bends tended to have more bends. This might be due to increased susceptibility of an unknown nature or to their greater readiness to report their symptoms and seek treatment. From the preventive point of view, it would be advisable to consider screening out those who had frequent attacks of bends for employment because they are more susceptible to attacks.

The miners were unskilled, heavy manual laborers and their increased risk of bends could be due to their heavy exercise. It should be noted that among the miners who had bends, very few reported that they used their limbs excessively, probably reflecting the common acceptance of the heavy labor involved in tunneling work. Another explanation could be the heavy fluid loss as a result of excessive sweating due to the heavy work and the high temperature and humidity inside the tunnels.

The finding that Japanese had an increased risk was difficult to explain. Our observation was that Japanese workers were very hard working and they took little rest. Although all men were encouraged to drink more water during compressed air work, the Japanese were found to drink much less water than their Chinese counterparts. The depletion of body fluid might have increased the serum surface tension and rendered them more susceptible to bends (2).

Age is commonly considered a risk factor for bends (3). Lo and O'Kelly (14) reported an increased risk with increasing age, but no multivariate technique was used to test whether the risk continued after taking into account other variables. In the present study, an association between age and bends was found for presence or absence of bends but not for the number of bends in univariate analysis. This association became statistically insignificant in multivariate analysis. Because age was associated with obesity, the effect of age on bends might be due to obesity.

Results of multivariate analysis in the present study also showed that several risk factors at the same time increased the chances of bends much more than did one risk factor. The logistic equation could give an estimate of the predicted risk of developing bends but extrapolation beyond the range of the original data from which the equation was computed would not be justified. Taking a relatively common situation in the present contract as an example, for a miner (job = 1) with QI of 23 and one past bends incident, working in MWP of 2.5 bar for 72 exposures (about 3 mo.), the predicted probability of having bends was 48.6%. Taking a relatively extreme example, for a miner with QI of 26 and three past bends, working in MWP of 3.3 bar for 72 exposures, the probability would be as high as 85.7%.

For practical purposes, the computation required is too complicated without a computer, but the potential of a logistic equation is great with the widespread use of microcomputers. If the data are entered into the computer during preemployment medical examination, the probability of a man having bends can be made available immediately to the compressed air physician for his consideration of whether a man should be employed or not. Without such help, the physician has to deal with many variables at the same time in a haphazard way. It is hoped that such software for systematic data collection and analysis can be developed and can be put into use in the near future by compressed air physicians. It should be noted that any model used may generate better predictive values for environmental conditions similar to those from which the equation is calculated but not necessarily for environmental conditions that are very different.

Although several variables had been found to be risk factors, the small multiple R in multiple regression analysis showed that the number of bends that a man had was explained only to a minor extent by these variables. A better explanation probably lies in the elucidation of the pathogenesis of the disease so that other new variables can be identified. These variables can then be measured and tested in an epidemiologic study, after taking into account variables already known as risk factors.

Finally, from our day-to-day experience, we observed several factors that might increase the susceptibility of an individual to bends, such as taking a cold bath, running after compressed air work, or injury to the limbs. We also had the impression that after working in compressed air a worker who goes for a radiologic examination of the joints tends to have a higher chance of having bends. Because of lack of systematically collected quantifiable data, we were not able to study these factors further. They are mentioned here as some personal experience which could be investigated in the future. Furthermore, the data presented here cannot shed light on type II DCS because only 1 case was encountered in this project.

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