Risk of decompression sickness with patent foramen ovale

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Bove AA. Risk of decompression sickness with patent foramen ovale. Undersea Hyper Med 1998; 25(3):175–178.—Several reports have described populations of divers with decompression sickness (DCS) who have a patent foramen ovale (PFO). The presence of a PFO is known to occur in about 30% of the normal population, hence 30% of divers are likely to have a PFO. Although observations have been made on the presence of a PFO in divers with and without DCS, the risk of developing DCS when a diver has a PFO has not been determined. In this study, Logistic Regression and Bayes' theorem were used to calculate the risk of DCS from data of three studies that reported on echocardiographic analysis of PFO in a diving population, some of whom developed DCS. Overall incidence of DCS was obtained from the sport diving population, from the U.S. Navy diving population, and from a commercial population. The analysis indicates that the presence of a PFO produces a 2.5 time increase in the odds ratio for developing serious (type II) DCS in all three types of divers. Since the incidence of type II DCS in these three populations averages 2.28/10,000 dives, the risk of developing DCS in the presence of a PFO remains small, and does not warrant routine screening by echocardiography of sport, military, or commercial divers.

patent foramen ovale, diving, undersea medicine, decompression sickness, metaanalysis

Since the study by Hagen et al (1) of postmortem hearts, the prevalence of patent foramen ovale (PFO) has been considered to be about 30% of the normal asymptomatic population. Later studies by Lynch et al. (2), using echocardiography, confirmed the high prevalence of this finding in normal subjects, and echocardiographic studies of adults with strokes (3–5) indicated that a PFO may contribute to the etiology of stroke in otherwise healthy individuals. Whether PFO could contribute to the etiology of decompression sickness (DCS) is presently unclear.

Three echocardiographic studies have been done on large populations of divers, some of whom had evidence of DCS, and in these studies a population of divers without evidence of DCS was also studied. The data from the combined studies, which include divers with PFO and no DCS, divers with PFO and DCS, and divers with no PFO with and without DCS, constitute the necessary populations to perform a metaanalysis using Bayes' theorem (6) to calculate the probability of DCS with and without a PFO, and Logistic Regression (7) to determine the odds ratio for developing DCS in the presence of a PFO. This analysis indicates that a PFO does increase the risk of DCS, but the absolute incidence remains small and does not support routine screening for a PFO in a diving population.

METHODS

Data from three published studies (8–10) were analyzed to establish four groups of divers. The divers were classified as PFO present, DCS present (PFO+/DCS+), PFO present, DCS absent (PFO+/DCS-), PFO absent, DCS present (PFO-/DCS+) and PFO absent, DCS absent (PFO-/DCS-). Probabilities were calculated from the total data of the three studies for analysis of risk for any form of DCS, and in two studies for type II DCS. Calculation of posttest probabilities was performed using Bayes' theorem, with the incidence of DCS estimated from air diving data from the sport diving population (11,12), from the incidence of DCS in the U.S. Navy (13), and from commercial diving experience (14). The population of sport divers with potential for reporting diving accidents to the Divers Alert Network was estimated to perform 2.5 million dives annually, and other reports provided actual number of dives performed and number of cases of DCS (Table 1). The combined population incidence was used in the Bayes' Theorem calculation. To determine the odds ratio for DCS risk with and without PFO, we used logistic regression analysis for a single exposure variable (7). In the case of a single exposure variable, logistic regression analysis can be performed using algebra and does not require curve fitting

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Table 1: Frequency of DCS in Sport, Military, and Commercial Air Diving Populations

Source Reference	Military (13)	Sport (11,12)	Commercial (14)	All
Total dives[a]	648,488	2,577,680	43,063	3,269,231
Total DCS[a]	172	878	152	1,202
Type II DCS[a]	86	649	9	744
Incidents DCS[b]	2.65	3.41	35.3	3.68
Incidents DCS II	1.33	2.52	2.09	2.28

[a]Values are number of events; [b]incidents per 10,000 dives, DCS II - DCS type II.

techniques. Calculations were done using Microsoft Excel running in a Macintosh computer.

RESULTS

Analysis of the overall DCS incidence in sport, military, and commercial diving populations showed similar results among the sport and military divers and a higher incidence in the commercial population (Table 1). Of interest is the observation that commercial divers have a higher incidence of type I DCS compared to both sport and military divers, whereas the incidence of type II DCS is similar among the three groups (Table 1). Wilmshurst and associates (8) found that the prevalence of a PFO was similar to the normal population in divers with type I DCS, but divers with type II had a higher than normal prevalence of a PFO.

Tables 2 and 3 show the distribution of PFO and DCS in the three studies. Table 3 does not contain the Cross data (10) because they reported no type II DCS in their population. Table 4 shows the posttest probability determined from Bayes' theorem.

The odds ratio for comparing risk with and without PFO and the 95% confidence interval of the ratio were calculated using logistic regression. Figure 1 shows the odds ratio and 95% confidence interval for risk of any form of DCS and for type II DCS alone in the presence of a PFO. Since the confidence interval does not include 1.0, the odds ratios are significantly different from 1 ($P < 0.001$) and indicate that presence of a PFO increases the risk for any form of DCS by 1.93, and for type II DCS by 2.52.

DISCUSSION

This metaanalysis of three studies of divers with PFO indicates that there is an increase in risk for DCS in the presence of a PFO. Interest in risk of DCS caused by the presence of a PFO was first raised by Moon et al (15) in 1989 when they found that divers with severe DCS, which seemed to be out of proportion to the diving exposure, had a high prevalence of PFO. Subsequent studies by Wilmshurst and colleagues (8) showed that PFO prevalence was higher than normal in divers with early onset DCS (<30 min after surfacing) and similar to the normal population in divers with onset of DCS later than 30 min after surfacing. Moon et al. published further details of their observations in 1991 (9) from a larger population of divers, and concluded that PFO was found more frequently in divers with type II DCS. Cross and colleagues (10), however, by studying divers with PFO who had extensive exposure to diving and no case of DCS in their diving careers, suggested that divers with PFO were not at increased risk. To understand the contribution of a PFO to DCS, a statistical analysis calculating the posttest probability and the odds ratio for DCS in the presence of a PFO must be done. The data of the three studies noted above provide the basis for performing a metaanalysis using the three populations. The analysis indicates that risk for type II DCS is increased 2.5 times in divers who have a PFO, compared to divers without a PFO, but the absolute

Table 2: Data From Echocardiographic Studies by Wilmshurst et al. (8), Moon et al (9), and Cross et al. (10) on Divers With All Forms of DCS[a]

All DCS	Moon-91	Wilms-89	Cross-91	Totals
PFO+/DCS-	20	22	26	68
PFO+/DCS+	40	25		65
PFO-/DCS-	81	41	52	174
PFO-/DCS+	50	36		86

[a]Values in table are number of divers; total divers – 393.

Table 3: Data From Echocardiographic Studies by Wilmshurst et al. (8) and Moon et al. (9) on Divers With Type II DCS[a]

Type II DCS	Moon-91	Wilmshurst-89	Totals
PFO+/DCS-	20	22	42
PFO+/DCS+	29	23	52
PFO-/DCS-	81	41	122
PFO-/DCS+	30	30	60

Table 4: Calculated Probabilities of DCS With PFO Using Bayes' Theorem[a]

	All DCS	Type II DCS
P (DCS+/PFO+)	0.00053	0.00047
P (DCS+/PFO−)	0.00028	0.00019
Odds ratio	1.93	2.52
P value	<0.001	<0.001

[a]Odds ratio and P values are derived from logistic regression calculations.

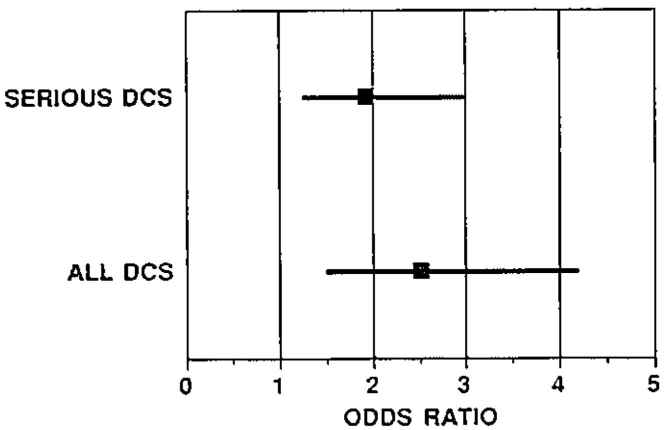

FIG. 1—Plot of odds ratios and 95% confidence intervals for risk of DCS comparing presence of PFO to absence of PFO. Ratio for all forms of DCS and for type II DCS are both significantly greater than one at $P < 0.001$.

increase is small (from 2.3 to 5.7 cases per 10,000 dives) and does not justify routine echocardiographic screening in divers to find a PFO. If the assumed incidence of a PFO in the average population is 30%, then compared to the average population (a mix of people with and without a PFO), which is the basis for current experience with DCS, a PFO will increase DCS risk about 1.8 times over the average population risk, and absence of a PFO will reduce risk of DCS to 0.67 times the average population risk. Although the incidence of DCS varies when comparing sport, commercial, and military divers, these differences do not produce changes in the risk ratio among these populations. Thus, risk of type II DCS is more than doubled in any type of diver with a PFO when compared to divers without a PFO. The proportion of type II DCS relative to all DCS cases varies from less than 10% in the commercial air diving population to 74% in the sport diving population (Table 1).

Recent interest has developed in the relation of stroke to a PFO. Hanna et al. (4) found that a PFO could be related to recurrent cerebral infarction, and Labovitz et al. (5) suggested that transesophageal echocardiography increases sensitivity in detecting a PFO in patients with unexplained cerebral ischemia. These studies indicate that a PFO allows passage to the arterial circulation of thrombus originating in the venous circulation.

The location of free gas in divers with DCS remains controversial. Gas has not been localized in the case of type I DCS involving the joints. The mechanism of spinal cord injury in DCS is thought to involve venous occlusion compromising blood drainage from the spinal cord (16), elution of gas from the cord tissue (17), or embolization by arterial bubbles (18). In cases of pulmonary barotrauma with arterial gas embolism (AGE), the presence of intra-arterial gas has been shown to compromise cerebral and spinal cord function due to arterial occlusion (19). Thus, venous bubbles crossing to the arterial circulation via a PFO would create a syndrome with features of both DCS and AGE. Arterial bubbles would contribute to the increased risk of DCS by their direct embolic effects and by acting as nuclei for bubble growth in tissues supersaturated with inert gas (20).

In conclusion, a metaanalysis of three studies of DCS in divers with a PFO shows that the risk for type II DCS is increased about 2.6 times by the presence of a PFO. However, the absolute risk is small and does not warrant screening of divers by echocardiography to detect the presence of a PFO. In addition, this small increase in risk does not provide a basis for recommending against diving in candidates who are known to have a PFO. These conclusions are valid for sport, commercial, and military divers.

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