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Research Article

Real World Thoracic Echocardiography for the Assessment of Right-To-Left Shunt: Experience from Scuba Divers

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Abstract

Introduction and Method: The presence of a Right-to-Left Shunt (RLS), most commonly produced by a patent foramen ovale, has been correlated to Decompression Illness (DI) in scuba divers and is suspected to increase the risk of suffering diving accidents. It is therefore mandatory to ensure a proper detection of RLS in divers who have suffered a DI and hopefully also in asymptomatic subjects who are being assessed for the fitness to diving. Transthoracic Ecocardiography (TTE) is commonly used to assess RLS, but its sensitivity is probably less tan optimal. Therefore we compared the performance of TTE for identifying RLS in consecutive 141 divers studied at the Hyperbaric centre of Ravenna where the protocol for assessing the fitness to diving includes a standardized contrast enhanced transcranial Doppel (TCD).

Results: Overall, RLS was identified by TCD in 117 subjects, whereas TTE was positive for RLS in 70. In the 117 subject with RLS detected by TCD the shunt was large in 104 and small in 13. TTE missed 52 out of 117 shunts (5/13 small and 47/104 large), whereas TCD missed 5 of the 70 cases deemed positive by TTE.

Conclusion: Compared with standardized contrast enhanced TCD, the performance of real world TTE in insufficient to guarantee a reliably accurate identification of RLS in scuba divers. This will have to be taken into account when assessing the risk of diving in asymptomatic subjects as well as in survivors of DI.

Keywords: Echocardiography; Scuba Divers; Right-to-Left Shunt

Introduction and Aim of The Study

The presence of a Right-to-Left Shunt (RLS), most commonly produced by a patent foramen ovale (PFO), has been correlated to Decompression Illness (DI) in scuba divers and is suspected to increase the risk of suffering diving accidents [1-5]. It is therefore mandatory to ensure a proper detection of RLS in divers who have suffered a DI and hopefully also in asymptomatic subjects who are being assessed for the fitness to diving.

Two main methods for investigating RLS are commonly available, Transcranial Doppler Sonography (TCD) and Transthoracic Echocardiography (TTE), the relative merits and limits of which have been extensively discussed [6]. Despite its relatively low sensitivity TTE is still largely used as the only tool, with the implicit risk of underestimating the frequency of RLS, a major drawback in a setting in which missing a PFO might bear serious consequences for the subject [4].

Since 2011 The Hyperbaric Centre in Ravenna, Italy, has implemented a protocol for the assessment of fitness to diving which includes the systematic search for a RLS by means of contrast enhanced TCD, which is performed by a certified physician (P.Li.) following the guidelines of the Consensus Conference of Venice [7].

This has afforded the opportunity to compare the performance of TCD with that of TTE in subjects who had already performed the latter at the time of the visit at the Hyperbaric Centre.

The results of this investigation are the object of the present paper.

Material and Methods

Between May 2011 and march 2019, a consecutive series of 414 divers (279 men and 135 women, mean age 45 + 11, range 13 – 79 years) attending the Hyperbaric Centre (Centro Iperbarico) in Ravenna, Italy, for the assessment of fitness to diving, underwent TCD sonography with the aim of detecting the presence of an RLS.

Among these, 141 divers (m/f = 101/40, mean age 45 + 11 range 23-79) had already performed a TTE, most of the times prescribed by the GP, prior to undertaking the visit at the Hyperbaric Centre. From the TTE report we only extracted the information on RLS dichotomized as yes or no, to compare with TCD results. TCD examination was done in all cases by the same physician, with a DWL Multidop P or, more recently, with a Doppler Box machine. Bilateral monitoring was performed with probes specifically designed to fit in with the LAM-Rack standard probe support (DWL). The first segment of both Middle Cerebral Arteries (MCAs) was recorded at the depth of 50 - 55 mm. A specifically DWL software for emboli detection and count was activated at the start of the examination. The Doppler spectrum and emboli count (microbubbles) were recorded and stored on a hard disk. Patients received a 10 - ml bolus of agitated saline solution (enriched with drops of autologous blood) via an antecubital vein. TCD ultrasonography was considered as positive (indicating the presence of a RLS) when at least one typical High-Intensity Transient Signal (HIT) was recorded on the Doppler spectrum, 5 - 51 seconds after the injection. After the injection at rest, the test was repeated with provocative maneuver (Valsalva maneuver). The efficacy of Valsalva maneuver was documented by the decrease of blood velocity in the MCAs during strain. The hemodynamic relevance of the RLS was graded following the classification proposed by the 1999 International Consensus Meeting of Venice: 0 = no HITS, 1 = less than 10 HITS, 2 = 10 to 20 HITS, 3 = > 20 HITS shower appearance, 4 = > 20 HITS curtain appearance [7]. The final grading of the RLS was defined after the provocative maneuver when grade 1 or 2 was recorded on normal breathing, whereas in grade 3 or 4 detected during normal breathing Valsalva maneuver was deemed unnecessary. For statistical purpose, we classified "small shunts" those ranked as grade 1 or 2, and "large shunts" those ranked as grade 3 or 4. Data was analyzed with SPSS statistical package. Three 2 x 2 contingency tables were built for three comparisons between TCD and TEE: any shunt vs. no shunt, small shunts (as defined by TCD) vs. no shunt, large shunts (as defined by TCD) vs. no shunt. For each table the percentage of agreement and K statistics (8) were calculated.

Results

Overall, RLS was identified by TCD in 117 subjects, whereas TTE was positive for RLS in 70.

In the 117 subject with RLS detected by TCD the shunt was large in 104 and small in 13.

Contingency tables comparing any shunt vs. no shunt, large shunt vs. no shunt and small shunt vs. no shunt showed that TTE missed 52 out of 117 shunts (5/13 small and 47/104 large), whereas TCD missed 5 of the 70 cases deemed positive by TTE (Tables 1, 2, 3).

	TCD pos	TCD neg	Total
TTE pos	65	5	70
TTE neg	52	19	71
Total	117	24	141

Table 1: Comparison between TCD and TEE for any shunt.

Agreement= 60%

K coefficient= 0,20

	TCD pos	TCD neg	Total
TTE pos	8	5	13
TTE neg	5	19	24
total	13	24	37

Table 2: Comparison between TCD and TEE for small shunt.

Agreement= 73%

K coefficient= 0.41

	TCD pos	TCD neg	Total
TTE pos	57	5	62
TTE neg	47	19	66
total	104	24	128

Table 3: Comparison between TCD and TEE for large shunt.

Agreement= 59%

K coefficient= 0.20

The overall percentage of agreement was 60%, which became 73% for small and 59% for large shunt respectively. As a consequence, Cohen' s k coefficients were 0.20 for any shunt, 0.41 for small shunts and 0.20 for large shunts. According to Landis and Koch's guidelines [8] the agreement between TCD and TTE was moderate for small shunts but no more than fair for large shunts and for any shunt.

Discussion and Conclusion

Decompression illness is a feared consequence of scuba diving which may result in serious permanent disability or even death [4] and is caused by the formation of gas bubbles, related to the failure to remove inert gases (nitrogen), in supersaturated blood or tissues during the diver's ascent. Most divers with venous emboli remain asymptomatic, because these bubbles are filtered by pulmonary circulation. Symptoms may occur with high bubble load (i.e. pulmonary gas embolism in case of violation of decompression regimen) or from paradoxical embolism (permanent or transient RLS), as RLS can facilitate the passing of the bubbles in the arteries [4].

The connection between DI and PFO was first described in 1980s [9]. Since then a number of studies have addressed the relationship between PFO and diving suggesting that RLS can not only double the chance of DI, but also enhance the occurrence of clinically silent brain lesions [10].

Although not required as a prerequisite for getting the diving license , the search of RLS is mandatory after a DI has occurred [10]. TTE is still the most widespread initial screening tool, although it has a much lower sensitivity compared with contrast TCD [11]. On the other hand, the sensitivity and specificity of TCD for RLS detection have been found to vary in different studies [12-17]. In Komar series TCD had an 89% negative predictive value, 98% positive predictive value, 95% sensitivity and 92% specificity [16]. In this study only 4.8% of TEE positive cases did not show the passage of contrast on TCD [16]. A recent meta-analysis reported that TCD had a mean sensitivity and specificity of 97% and 93% with TEE as the reference standard [17]. Similar results have been reported by Katsanos., *et al.* [6]. In the above mentioned studies TEE was taken as the gold standard, assuming it had 100% sensitivity in detecting PFO, whereas recent findings have shown that this assumption is flawed. As far as in 1995 Anzola., *et al.* had shown that unequivocal RLS detected by TCD may be missed by TEE [18]. More recently, Van., *et al,* by simultaneously performing intracardiac echocardiography and TCD in patients undergoing PFO closure, found that TEE underestimated the shunt by 34% compared with TCD [15]. Likewise, Caputi and colleagues reported that permanent shunts were better identified by TCD than by TEE [19]. For these reasons the Hyperbaric Centre in Ravenna has adopted a protocol with TCD as the only instrument to assess RLS in divers with prior DI and in asymptomatic subjects.

Yet, it happens that RLS be assessed with only TTE in a significant proportion of cases.

The subjects included in the study had already performed TTE on an individual basis, i.e without a specific protocol devised to investigate PFO or more in general RLS, in contrast with the dedicated protocol which is followed in all subjects in Ravenna.

The results of the comparison, although somewhat predictable, exceeded the expectations.

In terms of sensitivity for RLS detection, TTE performed almost at chance level as it missed about half of the positive cases identified by TCD not only among small shunts, but also in large shunts, which is somehow intriguing as large shunts are expected to be more easily detectable.

On the other hand, TTE identified 5 shunts that TCD had not recognized. Reasons for false positive results include mistaking a large persistent Eustachian valve for the atrial septum during contrast study, pseudocontrast caused by Valsalva effect and streaming effect by which shunted bubbles do not reach the brain and are dispersed in peripheral vessels. On the other hand false negative results may result from the inability of the subject to perform an adequate Valsalva maneuver or the presence of a pulmonary arteriovenous malformation instead of a PFO that delays the opacification of the left atrial chamber [20].

Whatever the mechanism, it is clear from our findings that using TTE as a screening tool to investigate PFO involves a dangerous risk of missing a significant proportion of positive cases. It is possible that in our cohort a number of subjects had undertaken TTE without contrast injection, thus further reducing the yield of the examination [6], but in any case, he bad performance of TTE as compared with TCD reflects the spectrum of outcomes in daily practice.

The prevalence of RLS in our cohort of patients was 117 out of 141 studied subjects (83%), which clearly outnumbers the expected prevalence of 25% of the general population [3]. The reasons for this discrepancy are likely multiple but we would mainly attribute the finding to selection bias as almost all subject were divers who had experienced a DI and RLS is overrepresented in this class [21,22]. However, this is irrelevant for the scope of the study which was to assess the relative performances o TCD and TTE.

It is unclear why for small shunts the percentage of agreement and the ensuing K coefficient were sensibly higher than for large shunts, contrary to what would have been expected. Because of the very small number of subjects constituting the cohort of small shunts it may well be that this finding may have resulted from the play of chance. However, for large shunts the agreement between TCD and TTE was no better than fair, mainly because of the inability of TTE to pick up almost half the cases that TCD had discovered. This result is even more intriguing inasmuch as only large as compared with small shunts are associated with DI [22,23].

In conclusion, our results clearly indicate that, compared with standardized contrast enhanced TCD, the performance of real world TTE is insufficient to guarantee a reliably accurate identification of RLS in scuba divers. This will have to be taken into account when assessing the risk of diving in asymptomatic subjects as well as in survivors of DI also for possible therapeutical options [24].

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