The Fractal approach as a tool to understand asymptomatic Brain hyperintense MRI Signals in Divers

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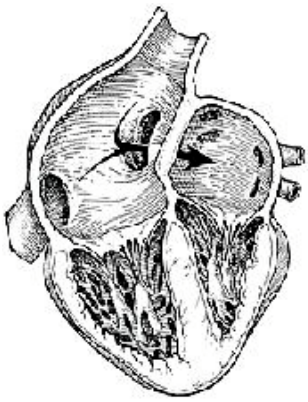
1. Introduction

Since 1989 the first publication that spoke about the possible correlation between the presence of a Patent Foramen Ovale and the occurrence of decompression sickness (Moon *et al.*, 1989) there has been no respite in the quest about the possibility of such a relationship. Since 1996 the research department of DAN Europe set out to investigate and respond to a serious concern at the time as a result of this alarming article: is there really an increased risk of DCS for a diver who has PFO? (Wilmshurst *et al.*, 1986; Wilmshurst *et al.*, 1995; Knauth *et al.*, 1997).

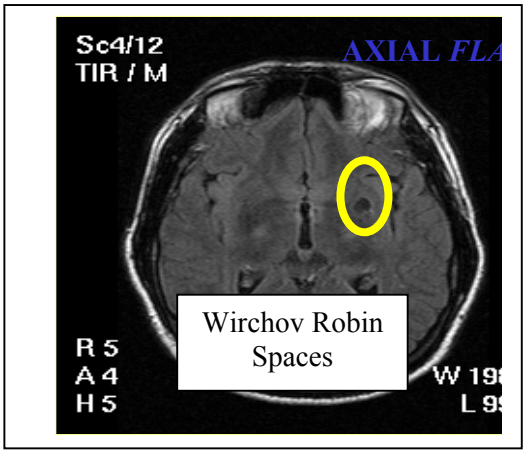
The decompression bubbles are found primarily in the veins; in the heart they are mainly found in the superior and inferior vena cava. Frequently, divers regard PFO as a hole that allows the continual passage between the right atrium and the left - the arterial part of the heart where we don't want to see bubbles (see the illustration). The flow coming from superior vena cava has to pass over a fold, providently given by Nature before touching the PFO (or the Fossa Ovalis).



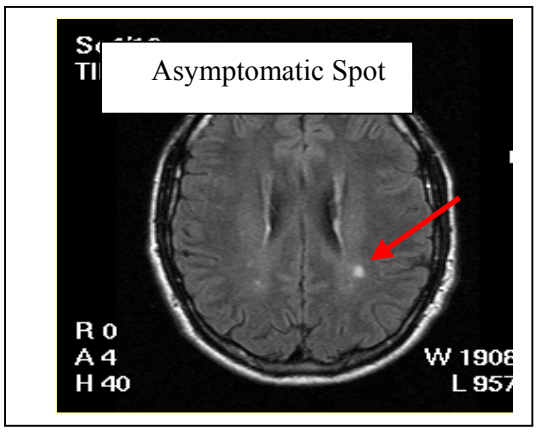
This causes a sudden increase in the rate of the flow, which meets the flow coming from the inferior vena cava and thus turbulence is caused which causes the bubbles to be TAKEN AWAY from the interatrial septum. Therefore if we understand correctly, the bubbles would not cross the Foramen Ovale in natural conditions. But then why the injections of bubbles that are made during the transesophageal echocardiogram to measure the PFO, since they pass in the left atrium?

The reason is that respiratory movements are made to reverse the intracardiac flow caused by variations in the intrathoracic pressure.

2. Spots on the brain and PFO



A number of years ago some studies declared the relationship between PFO and cerebral "LESIONS" (Reul *et al.*, 1995) (Knauth *et al.*, 1997). Since then others have found that there was not a direct relationship(Gerriets *et al.*, 2000; Saary & Gray, 2001). In all of these studies, however, we encounter the same population bias. DAN therefore asked two groups of people to sit a test of nuclear magnetic cerebral resonance imaging; 50 were divers and 50 were non-divers. All of the participants had to be under 41 years old because according to studies spontaneous lesions cerebral can occur after 45 years. The distinguishing feature was that this population was randomised; we asked 400 volunteers: 200 divers and 20 non-divers. We asked the divers to declare that they had never suffered from DCS. However, often certain accidents and cerebral incidences in particular were not declared because of benign or brief symptoms.



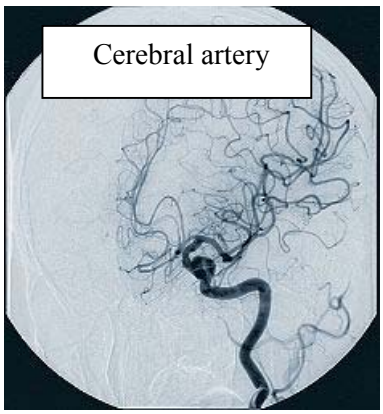
How many divers had have felt a little dazed after a dive ...which goes away after a few minutes ... a case of badly equalised ears or a transient cerebral bubble?

To avoid this situation of poor choice of population we took the case of 1 diver in 4.

Then we made a comparison between the numbers and the size of the "spots" found among the divers and those found among the divers and non-divers.

A little more spots were detected among the divers but there was not significantly more. This is contrary to what some authors say with populations that are not randomised and without a control group. Also, to ensure accuracy in the results a particular imaging filter, which allows a reliable diagnosis of the FLAIR sequence to be made, was used. Another pitfall that was present was the possibility of finding naturally lacunar zones known as the Wirchow-Robin spaces and diagnosing them as "LESIONS".

The use of fractal analysis is a known technique in clinical science and particularly in pathology (Rossitti, 1995; Sisodiya *et al.*, 1995; Cross, 1997a; Caldwell *et al.*, 1998; Handels *et al.*, 1998; Luzi *et al.*, 1999) , the interesting predictive opportunity of fractal analysis in breast cancer (Byng *et al.*, 1996a; Byng *et al.*, 1996b; Velanovich, 1998; Heymans *et al.*, 1999; Zheng & Chan, 2001) or osteoporosis (Feltrin *et al.*, 2001; Dougherty & Henebry, 2002; Lespessailles *et al.*, 2002; Libouban *et al.*, 2002) is related in pattern differentiation on the medical diagnostic images.

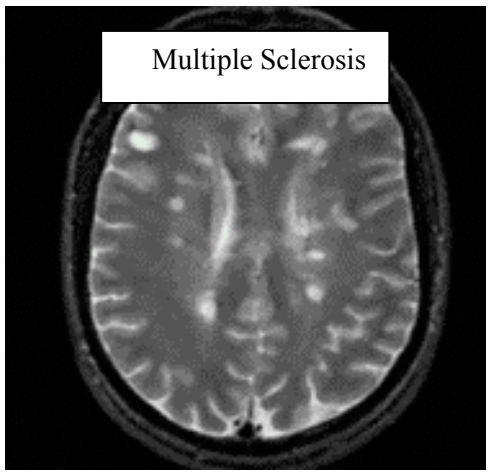


The important possibility of diagnosis before the rise of real objective or clinical symptom is a paramount of interest in the medical field. The precise use of fractal analysis in neuroimaging is a moving field with a very promising future. The study of with matter hyperintense signal has been analyzed with the fractal approach in geriatric patients to see if some links can be considered with the white matter hyperintense "spots" and the epileptic seizures (Takahashi *et al.*, 2001) .

In the young patient, to our knowledge, nothing has been done yet in order to investigate some relations between the significant difference of the fractal dimension of some hyperintense white matter spots in the brain and their spatial distribution.

We tried to use the self-similarity concept of the fractals as this has already been used to mark differences between architectural (Cross, 1997b; Chen & Chen, 1998; Behar, 2001) or even cancerous structures (Peiss *et al.*, 1996).

Our aim was to verify if the fractal dimension of some cerebral vascularization images was compatible with the Fractal Dimension of the a symptomatic brain Spots in divers who never experienced a decompression disease nor PFO related headache (Anzola *et al.*, 1999; Wahl *et al.*, 2001; Sztajzel *et al.*, 2002). All these criteria were included in the population selection criteria.



To calculate the fractal dimension of the images we used the Harfa 4.0 program applying the box counting method after appropriated filtering and thresholding and accepting the final result as the fractal dimension the better occurrence of the slope described in the slope analysis option.

3. Methods

Our population was a group of 50 healthy divers (scuba divers) not older then 40 yr. This population has been randomized from a larger population of 200 voluntary divers, which has been drastically selected by very strict criteria: less than 41 yr old; at least 200 dives; no history of cardiovascular or decompression disease and other conditions such as multiple sclerosis or headache brain lesions.

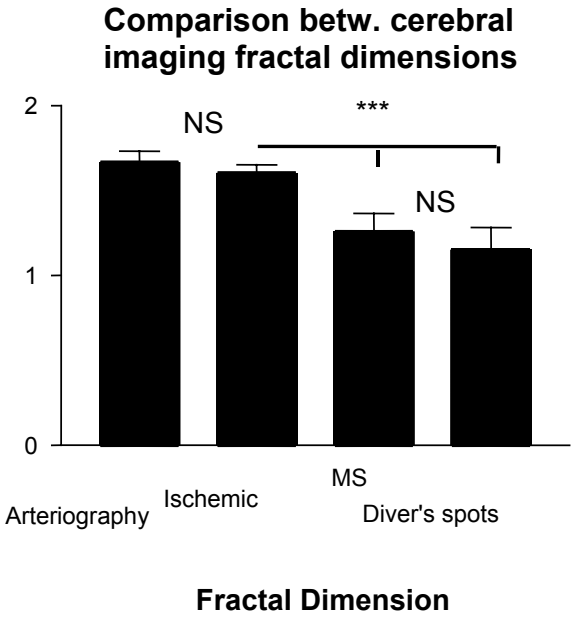
The randomization has been performed to exclude some population bias that can occur in such a voluntary based selection process.

We tried to compare the fractal dimension of some clearly non-vascular spots in the white cerebral matter and the dimension of some other spots from other origin.

The purpose was to determine weather the "lesion like" spots could be associated with the circulating arterial bubbles coming up to the brain from the patent cardiac Foramen Ovale or just another unexplained or non diving dependent mechanism.

Furthermore to investigate the potential difference of the spatial distribution between the fractal dimension ischemic lesions of the cerebral vascular accident and the haemorragic ones we separated them and controlled exclusively the clearly ischemic ones.

If the "lesions like asymptomatic spots" were from vascular origin, their spatial distribution should be compatible either with the cerebral vascular images or the ischaemic lesions fractal dimension.



4. Results

We could find in our population of 50 asymptomatic divers (randomized out of 200; 1 excluded for MS) 4 lesion like white matter hyperintense spots. Then we compare the fractal dimensions of 18 brain angiographies; 9 images of Multiple Sclerosis; 5 Ischemic vascular brain lesions images. (see graph.)

The Anova statistical test was performed after testing the normality of the population and the posttest performed was the Neuman-Keuls discriminate test.

The differences between all the vascular depending images fractal dimension and the "diver's sports" were highly significant ($p<0.001$), conversely the differences between the vascular bed spatial distribution and the ischemic lesions images was not statistically different. This allows us to be sure that the fractal dimension is a good tool to be used in our experimental paradigm.

The non-vascular brain lesion fractal dimension was not statistically different of the "diver's spots" one, thus our assumption was to postulate that those spots are not clearly to be defined likes vascular related ischemic lesions as generally admitted.

5. Conclusions

The fractal analysis of cerebral images is good tools to determine weather the spatial distribution is compatible with the vascular bed and allow us to postulate another non vascular mechanism. Moreover the link between the patency of the Foramen Ovale of the heart and the diver's "brain spots" seem not to be as clear as it has been postulated. (Knauth *et al.*, 1997; Schwerzmann & Seiler, 2001)

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