# Crochetage Pattern: An Electrocardiographic Warning Sign for Scuba Divers

## Crochetage Pattern

Crochetage pattern is defined as a 'M'-shaped or bifid notch near the apex of the R wave in one or more inferior limb leads II, III, and aVF. It is associated with atrial shunts including ostium secundum atrial septal defect (ASD) and patent foramen ovale (PFO) and is so named for the notch resembling a crochet needle.

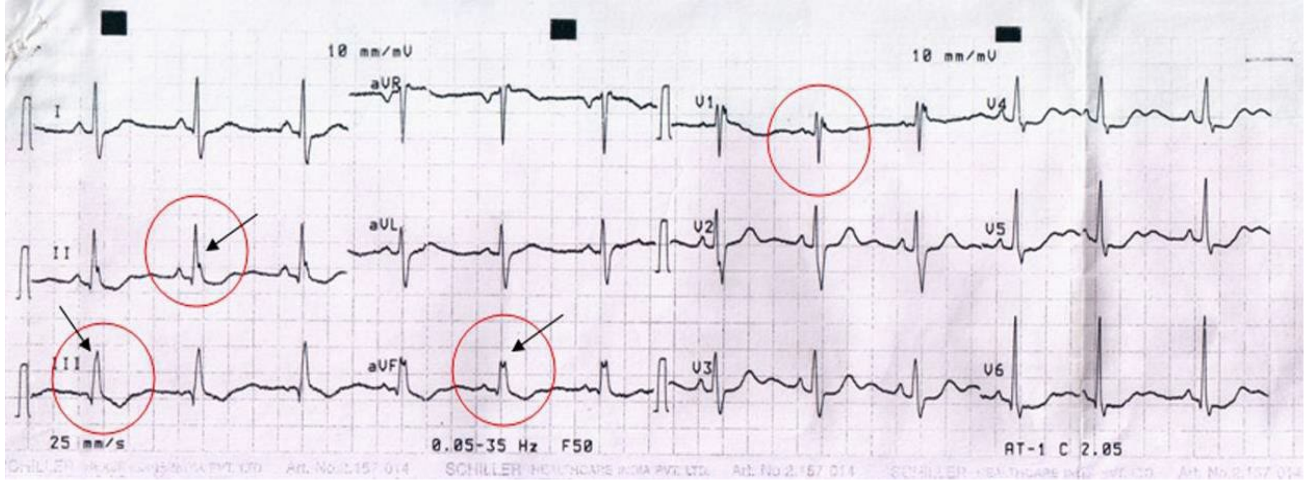



**Figure 1**. Crochetage present in all 3 inferior leads (II, III, aVF). There is also a right bundle branch block (RBBB) pattern in V1, that is commonly associated with ASDs (Bhattacharyya 2016).

## Background

Crochetage pattern was first described in 1958 by Toscano *et al*. Further research in 1996 by Heller *et al.* described the pattern in relation to atrial shunt severity; it was found that the incidence of crochetage increased with larger shunt sizes and greater shunting. In 1998, the pattern emerged to help identify PFOs in cryptogenic stroke patients and served as an EKG marker for PFO associated with embolic stroke. Per Ay *et al.*, the sensitivity and specificity of crochetage for the diagnosis of PFO in cryptogenic stroke patients were found to be 36% and 91%. The positive predictive value (PPV) was 77%, and the NPV (negative predictive value) was 62%. The difference in crochetage prevalence in PFO patients remained significant with $P<0.05$. To date, the electrophysiological mechanism for crochetage remains unknown.

## Crochetage and Scuba Divers

To assess why crochetage may be an EKG warning sign in scuba divers, one must first understand decompression illness (DCI). DCI can in part be understood with Boyle's Law. Per Boyle's law, at constant temperature, the pressure of any given quantity of gas varies inversely with its volume. As pressure increases, the gas volume is reduced; as the pressure is reduced, the gas volume increases. This is why dissolved gases come out of solution during ascent and expand to form bubbles.

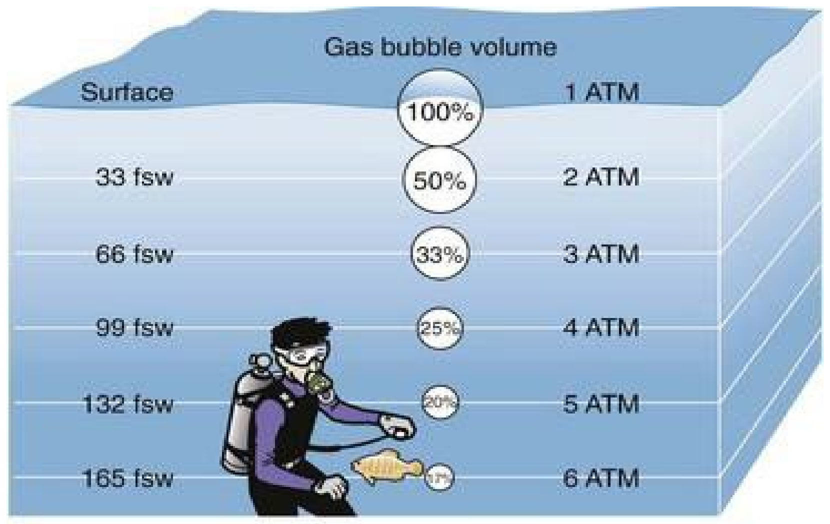



**Figure 2**. Depiction of Boyle's Law (Byyny and Shockley 2015).

## Decompression Illness

DCI encompasses both decompression sickness (DCS) and arterial gas emboli (AGE). It occurs when breathing compressed air at depth, which causes nitrogen (or other inert gas, such as helium in technical diving) dissolved in the tissues to come out of solution and form bubbles during ascent. While venous gas emboli (VGE) are estimated to occur in 80-91% of scuba divers, divers usually remain asymptomatic as the bubbles are transported from the tissues to the alveoli for exhalation. If, however, the bubble load is too large to overcome, these excess bubbles will not be filtered by the pulmonary circulation, and DCI can manifest. When a diver ascends too quickly, these bubbles enter the tissues, expand, and induce local tissue damage or embolize throughout venous blood. The bubbles can block blood flow, cause clotting activation, and tissue inflammation resulting in mechanical and biochemical problems. With DCS, bubbles can come out of solution almost anywhere in the body, and therefore symptoms tend to be variable and range in severity.

## PFO in Divers

While DCS risk in recreational divers has been reported at 3.6 cases per 10,000 dives, divers with PFO have 2.5 times greater overall risk of DCS than divers without a PFO. They also have 4 times greater risk of neurological DCS. As PFO prevalence in the general population has been estimated to be 27.3%, this raises a legitimate concern for divers. PFOs can serve as conduits for venous thromboemboli to arterialize into the systemic circulation causing cerebrovascular events (cryptogenic stroke, transient ischemic attack) and DCI.

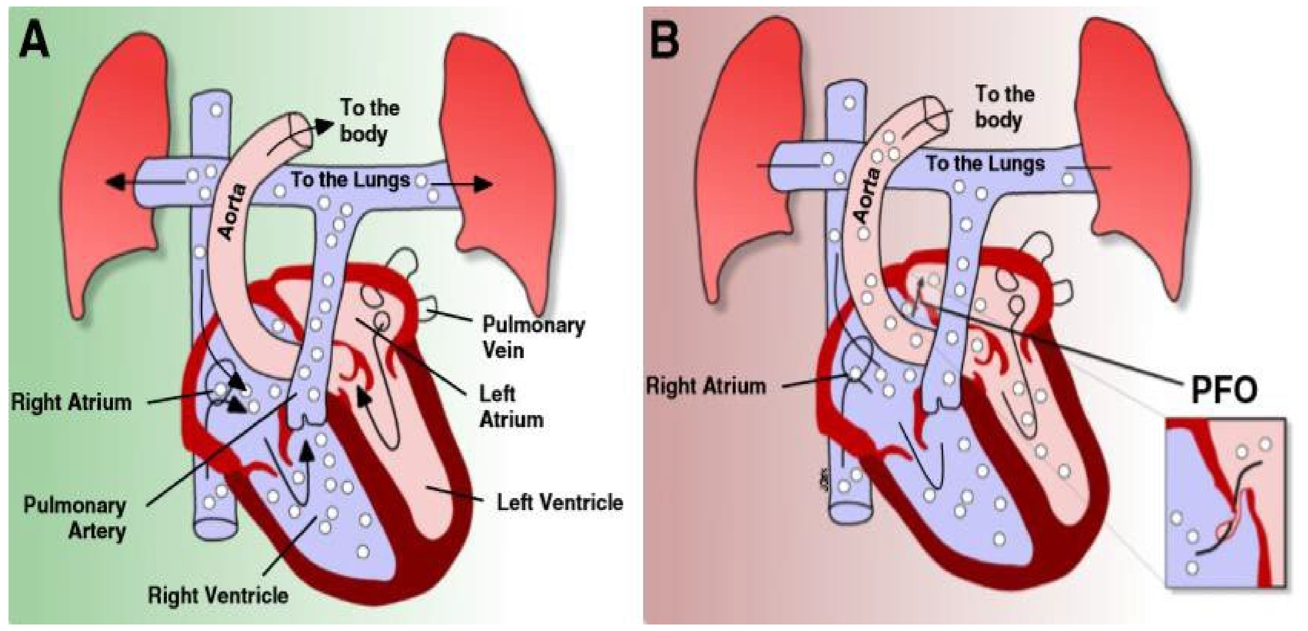



**Figure 3**. (A) Schematic depicting the physiological mechanism for venous gas bubble elimination in scuba divers. (B) PFO serves as a conduit for paradoxical emboli (Sykes and Clark 2013).

Divers with PFO are at increased risk because when submersed at depth and during equalization of the middle ear via the Valsalva maneuver, blood redistributes from the periphery to the thorax. This increases right atrial pressure, enhancing flow across the right-to-left interatrial shunt. It has been found that the greatest risk of DCI is in those with larger PFOs, particularly those over 1 centimeter. Studies have also found right-to-left shunts or large PFOs to be associated with 44% of neurological DCI cases. When it comes to inner ear DCS, 74% of cases have been said to result from a large spontaneously shunting PFO.

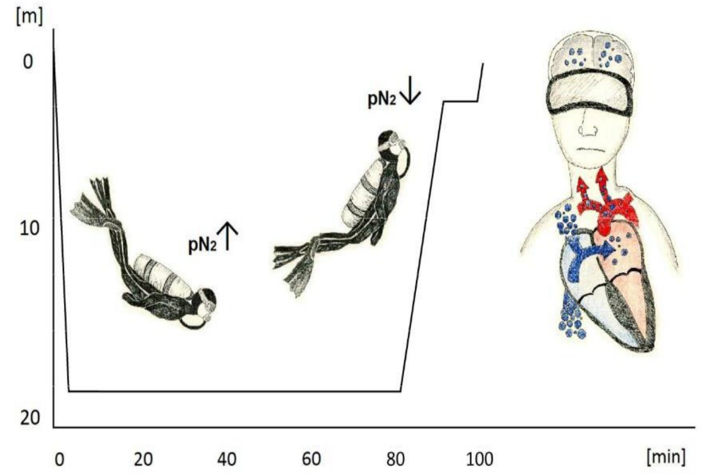



**Figure 4**. Pathophysiology of bubble formation and subsequent paradoxical embolization through a PFO (Honěk *et al.* 2015). *$pN_2$ = partial pressure of nitrogen

## Methods

All research to date examining the presence of crochetage pattern on EKGs was utilized to gather information and data for this project. Papers date back to 1958, when the sign was first discovered. As there has been minimal research studying crochetage prevalence in atrial septal defects, all works including case reports were included.

## Results

Regarding PFO, Ay *et al.* determined a trend between infarct size and crochetage - there were larger infarct sizes in PFO patients with crochetage compared to PFO patients without crochetage. In their study, 75% of patients who were referred for PFO closure due to recurrent embolic events exhibited crochetage. Interestingly, unlike the reports from ASD studies, the crochetage pattern remained unchanged after PFO closure. There was also a statistically significant increase in the prevalence of crochetage in inferior EKG leads in patients with PFO and cryptogenic stroke compared to control patients with cryptogenic stroke and no PFO. There was crochetage in at least 1 inferior lead in 36% of PFO patients as opposed to 9% of control patients.

Overall, it has been found that patients with PFO and crochetage are more likely to suffer from cerebral infarction than PFO patients without crochetage. Crochetage has a specificity of 91% and a PPV of 77% in recognizing PFO patients prone to paradoxical embolism. As such, crochetage sign may be a useful tool in recognizing PFO and predicting stroke risk.

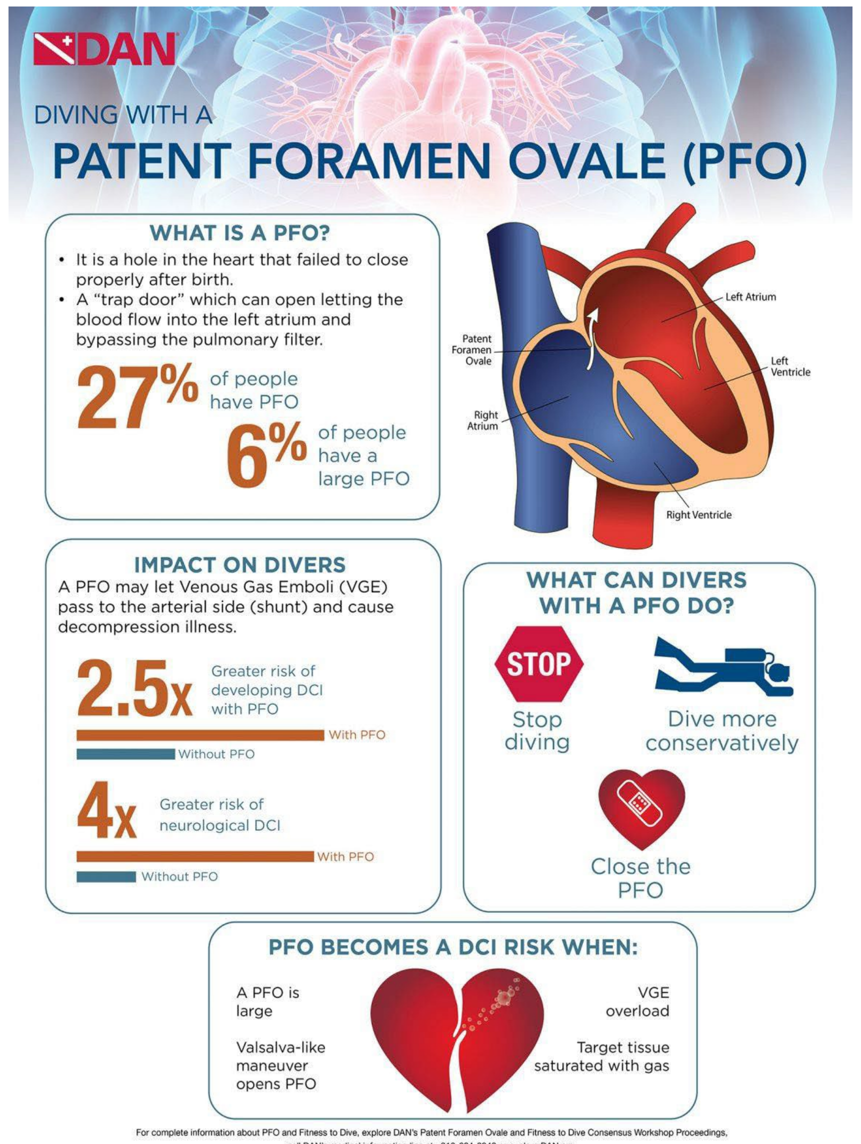
## Discussion

Given widespread availability and cost-effectiveness of EKGs, crochetage pattern may serve as a tool to accelerate the search for PFOs in scuba divers suffering from recurrent DCI. The EKG pattern may help stratify patients for further screening with an echocardiogram as there was a high specificity (91%) and moderately high PPV (77%) for crochetage in detecting paradoxical emboli secondary to PFO. Limitations to current research include small sample sizes and lack of generalizability. Future studies need to determine whether crochetage correlates with DCI risk in divers with PFO. PFO size and degree of right-to-left shunting should also be investigated in relation to crochetage. Overall, EKGs may be useful in streamlining the diagnostic workup of paradoxical emboli and may accelerate the speed at which an echocardiogram is ordered in divers with recurrent DCI.

## PFO Closure in Divers

Many diving physicians advocate for PFO closure (PFOC) in divers who suffer recurrent DCI and wish to continue diving. Although there are no randomized controlled trials to support closure, observational studies suggest efficacy in prevention of DCI. That, along with the safety profile of closure, PFOC is suggested to be a feasible option for scuba divers.

While routine PFO screening is not indicated on the initial Diving Medical Participant Questionnaire, if divers experience more than one episode of DCS with cerebral, spinal, vestibulocochlear, or cutaneous involvement, one should consider PFO testing via bubble contrast echocardiogram and the use of provocative maneuvers to promote right-to-left shunting including Valsalva. If a diver does undergo PFOC and wishes to return to diving, a repeat bubble contrast echo must be conducted a minimum of three months post closure. Adequate shunt closure must be demonstrated.




## Conclusion

Crochetage may serve as a readily available EKG marker to motivate the search for PFO in divers with recurrent DCI. This is important for providers performing medical evaluation of divers.

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