Dysbaric osteonecrosis in recreational divers: A study using magnetic resonance imaging

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ABSTRACT

Objective – We set out to identify whether magnetic resonance imaging (MRI) would identify evidence of dysbaric osteonecrosis (DON) in a group of experienced recreational scuba divers.

Design – Local British Sub Aqua Club divers of at least Trainee Dive Leader grade were offered MRI scans (T1 and TIRM sequences) of hips, femora and shoulders. Anonymous images were interpreted separately by two radiologists, and cases not considered unequivocally normal were discussed for consensus opinion.

Results – Of 26 divers imaged, five merited discussion. Four of these were considered to show unrelated normal variants or incidental findings. Only one case (abnormalities in the right humerus and left femur) could have possibly represented osteonecrotic lesions. After obtaining plain radiographs and more detailed clinical and dive history, these lesions were considered “indeterminate” but probably not DON by both reviewers and after taking further specialist musculoskeletal MRI opinion.

Conclusion – This study found no evidence that DON is a significant risk in recreational scuba diving and as such concurs with prevailing current opinion.

INTRODUCTION

Dysbaric osteonecrosis (DON) is well known as a complication of prolonged and/or repetitive exposure to the hyperbaric environment, even though the exact mechanisms leading to bone death are still debated. While a few case reports exist of DON in recreational divers, they are not considered to be at significant risk. However, as the injury may be asymptomatic, uncertainty remains. As magnetic resonance imaging (MRI) is currently recognized as the gold standard for detecting osteonecrosis [1], we undertook a pilot study of recreational divers using MRI to document any evidence of DON.

MATERIALS AND METHODS

Formal ethical approval was obtained. Divers from six British Sub Aqua Clubs (BSAC) local to the lead author’s MRI unit were approached through their email circulation lists. Entry criteria were solely that the diver held the qualification level of at least BSAC Trainee Dive Leader, PADI Rescue Diver or equivalent. A questionnaire was completed providing details of age, sex, dive qualification, approximate number of dives (20-49, 50-99, 100-249, 250-499, 500+), years of diving, and whether they had frequently/occasionally/rarely/never dived below depths of 20/35/50/70 meters. Conditions of the ethical approval precluded collection of personal medical information, but we did ask whether divers had ever experienced what was, or might have been, symptoms of decompression illness (DCI).

MRI scans of shoulders, hips and femora were performed on Siemens Magnetom Symphony Maestro Class 1.5T magnets with the parameters shown in Table 1 (see Page 282).

Results were analyzed using the statistical software package SPSS (SPSS Software, Chicago, Ill.). Scans
were interpreted independently by two experienced consultant radiologists using the definitive diagnostic criteria for DON of a geographical band pattern on T1 images. Any other pattern would be evaluated on a case-by-case basis and resolved by discussion.

RESULTS

MRI scans were performed on 26 divers whose characteristics are listed in Table 2 (on facing page). The mean and standard deviation (SD) diving experience was 13.2 years (SD=9.0 years). The mean and SD age was 49.3 years (SD=11.1 years).

While a number of normal variants and minor or unrelated abnormalities were detected, there were no cases the authors considered to represent DON. Unrelated abnormalities included a possible rotator cuff tear and benign prostatic hypertrophy, each in one diver. Small signal voids on both T1 and TIRM were common, seen in many sites, and considered bone islands of no significance (Figure 1, Page 284).

There were several examples of atypical variants of patchy marrow distribution, the most obvious (Figure 2, Page 284) occurred in a 36-year-old female Trainee Dive Leader with nine years’ experience and between 100 and 250 dives to her credit, of which a few had been below 35 meters. She had experienced two episodes of lymphatic bends. The marrow changes were approximately symmetrical in hips and shoulders and considered not to represent DON. Several cases of superficial pits or cysts were seen related to the rotator cuff insertion, only one of which merited discussion between independent reviewers (Figure 3, Page 285) before being discounted.

The only abnormalities causing any real concern occurred in a 45-year-old male Trainee Dive Leader (Figure 4, Page 286) – the second case listed in Table 2. He had the least exposure to hyperbaric stress of the divers in this cohort, with only two years’ experience, between 50 and 100 dives, only rarely going below 35m, and no history of decompression illness or untoward events. The MRI of left femur showed a well-defined oval bony lesion with a high-signal T1 and TIRM center and no surrounding signal change.

This was slightly too deep to be considered truly cortical in position, being rather deep cortex or subcortical. The right humerus showed a clearly defined flame-shaped low-signal (T1 and TIRM) lesion in a similar subcortical position in proximal shaft.

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**Table 1 – MRI Scan Parameters**

<table>
<thead>
<tr>
<th><strong>Hips and Upper Thighs</strong> – CP side Arrays, CP Body Array + CP Body Array Ext</th>
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| **T1 Coronal** – FOV425, FOV Phase 100  
16 slices 5mm, Base resolution 384, Phase Resolution 90%, TR450, TE13, Flip 150, IPAT=Yes, averages=2 |
| **TIRM Coronal** – FOV425, FOV Phase 100  
16 slices 5mm, Base resolution 320, Phase Resolution 100%, TR1990, TE39, TI150, Flip 150, IPAT=Yes, averages=1 |
| **Knees & Lower Thighs** |
| **T1 Coronal** – FOV200, FOV Phase 100  
16 slices 5mm, Base resolution 384, Phase Resolution 90%, TR450, TE13, Flip 150, IPAT=Yes, averages=2 |
| **TIRM Coronal** – FOV200, FOV Phase 100  
19 slices 3mm, Base resolution 320, Phase Resolution 85%, TR549, TE12, Flip 150, averages=2 |
| **Shoulders** – each scanned in turn, Shoulder Array |
| **T1 Coronal** – FOV200, FOV Phase 100  
19 slices 3mm, Base resolution 384, Phase Resolution 85%, TR549, TE12, Flip 150, averages=2 |
| **TIRM Coronal** – FOV200, FOV Phase 100  
19 slices 3mm, Base resolution 256, Phase Resolution 77%, TR4330, TE29, TI130, Flip 150, averages=2 |
### TABLE 2 – Divers’ Details

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### KEY

**Diver Grade:**
- DL = BSAC Dive Leader
- PADI = Professional Association of Diving Instructors
- AI = Assistant Instructor

**Dive Depths:**
- The ‘<’ indicates diving below stated depth – e.g. <20m = dives deeper 20 meters
- f = frequently
- o = occasionally
- r = rarely
- n = never

**DCI events:**
- n = no, y = yes
- superscript 1 = 2 events: Lymphatic bends over left and right arm. Treated.
- superscript 2 = Scintillating scotoma 20 minutes after dive. No Rx.
- superscript 3 = Minor joint bend and possible neurological bend (tingling in fingers).
- superscript 4 = 2 skin bends. Treated, PFO.
- superscript 5 = Minor joint bends.
- superscript 6 = Possible joint bend (elbow) – never checked by medic.
- superscript 7 = Details not supplied.
- superscript 8 = Possible joint pains after a series of dives.
Plain films were arranged, which showed the right humeral lesion as a well-defined sclerotic area and the left femoral lesion as an equally well-defined sclerotic area with a lucent center. The diver was asymptomatic. These lesions were considered indeterminate, but unlikely to represent DON.

Eight divers reported symptoms which were or might have been decompression illness. There was no statistically significant relationship between the reported DCI events and age ($p=0.144$), sex ($p=0.339$), number of dives (more, or less than 250 dives, $p=1.000$), or mean years of diving experience ($p=0.33$). Information on frequency of diving depth proved problematic to analyze and was abandoned in favor of the simpler, if less accurate, proxy of diver grade. Table 2 shows that divers with fewer than 100 dives had
rarely dived below 35 meters and never below 50 meters, while only divers with at least 250 dives to their credit had dived below 50 meters. There was a suggestion that DCI was more common in advanced divers compared to those of less than that grade (chi square \( p = 0.049 \)). However, when Yates’ correction for small samples is applied, the statistical significance is less (\( p = 0.123 \)).

Age when beginning diving was created by subtracting years of diving experience from the diver’s age. In the 18 divers not reporting DCI, the mean when starting diving was 39.4 (SD=11.8) years. In the eight reporting DCI, the mean was 28.6 (SD=11.2) years, a highly significant difference (unpaired Student’s T-test \( p = 0.039 \)) of some interest and uncertain significance.

**DISCUSSION**

Accepted wisdom is that dysbaric osteonecrosis is found in divers with prolonged deep and/or repetitive diving such as might be found in commercial or military worlds, or in compressed-air workers. It has not been regarded as a significant risk in recreational diving. That said, there have been a small number of reports of DON in recreational divers.

Laden [2] reported a case of juxta-articular necrosis of the humeral head with MRI correlation in a sport diver using mixed gas for deep diving. Wilmshurst [3] reported a similar case with a less aggressive diving history, while Gorman’s case [4] was confounded by the coexistence of trauma and diabetes. Williams’ series [5], showing lesions in three of 19 sport divers was based on plain X-ray findings.

Indeed, much of the accumulated knowledge of DON is based on plain radiographic occupational surveys such as that published by the United Kingdom decompression sickness central registry in 1981 [6] and those on Royal Navy [7] and U.S. Navy [8] divers. These three studies found definite bone lesions in 4.2%, 4.7% and 1.7% respectively.

Very recently a Turkish study of experienced divemasters and instructors using plain films followed by MRI where indicated, found DON in 25% (14 of 56) divers [9]. These were occupational divers and had deeper and more frequent hyperbaric exposure than would be found in sport divers.

Since MRI is more sensitive in identifying the changes of bone necrosis than plain radiographs [10-12] and since necrotic lesions are usually asymptomatic unless juxta-articular and causing collapse [13] or accompanied by marrow edema [14,15], is it theoretically possible that recreational divers could be harboring asymptomatic X-ray-invisible lesions?
To our knowledge we have undertaken the first MRI study of a group of recreational UK club divers. While PADI divers face a depth limit of 30 meters (the separate PADI deep diver qualification allows 40 meters), other agencies allow deeper diving. In the British Sub Aqua Club, Sport Divers are rated to 35 meters, while Dive Leaders and above are rated to 50 meters. Our entry criteria were chosen to exclude inexperienced divers and those unlikely to have dived to at least 30 meters.

Our choice of MRI sequences was influenced by the need to scan the most important areas (shoulders, hip and femora) within a time frame which would not impact overly on the clinical workload of a busy MRI department. While critical assessment of suspected dysbaric lesions might involve multiple sequences and scan planes, we felt coronal T1 and TIRM would allow rapid confirmation of normality, good resolution and reasonable assessment of any infarct.

A major problem in this and other studies is the absence of a matched control group, which renders DON liable to a false positive diagnosis. Radiographic studies of DON have demonstrated that some lesions which might have been considered due to bone infarction (bone islands, cystic areas, and some sclerotic patterns) were in fact common findings in normal patients [16].

Similarly, interpreting skeletal MRIs in “normal volunteers” such as in this study is not without difficulties. The diagnosis of bone necrosis can be made with confidence when a clearly defined geographical lesion with a hypointense marginal band is seen in a typical site [17].
The lesion’s other characteristics are variable, and infarcts may have other patterns including areas of cystic or increased bone density change [10-12, 17, 18]. These other patterns allow room for misdiagnosis of what is usually an asymptomatic lesion, as nicely tabulated in Bolte’s article of MRI in Navy divers [12]. Specifically, red marrow is present in patchy, linear, curvilinear, subchondral, and combination patterns in many normal adult humeral and femoral epiphyses and can be mistaken for poorly marginated osteonecrosis on T1 MRI images [19,20]. Even once confidently diagnosed, an aseptic infarct in a diver is not necessarily due to hyperbaric exposure, and a lesion in a well asymptomatic control is not necessarily “normal” or innocent. There are thus considerable difficulties facing a small scoping study such as ours. Despite these difficulties, we are confident that there were no cases of juxta-articular infarcts in our group. We have shown other lesions which we believe were innocent, unrelated or normal variants. The single case of doubt is also, we believe, not due to dysbaric osteonecrosis, but accept that this cannot be proven either way. If we were to accept that this single doubtful case is indeed DON, the prevalence of DON in our study is 0.0385 (3.9%) with Wald 95% confidence interval of <0.0001 to 0.2045 (<0.01% to 20.5%).

In summary, we have not been able to prove the existence of dysbaric osteonecrosis in a small group of BSAC club divers. We believe this provides qualified reassurance to the recreational diving community.

ACKNOWLEDGEMENTS

We would like to acknowledge the considerable help of Dr. David Crook, Ph.D., for statistical advice, Mr. Kevin Harding, senior MRI Radiographer for performing the scans. Mr. Tim Venables, both a Research Manager at Imperial College and an officer of Sussex Diving Club provided invaluable assistance with design of the study and recruitment of divers. Musculoskeletal radiologists Drs. John Bush and Geoff Price provided advice and additional opinion. The work was supported by a grant from the BSAC Jubilee Fund.
REFERENCES


