


# The ‘wave sign’ in hip arthroscopy: a systematic review of epidemiological factors, current diagnostic methods and treatment options

Jason Derry Onggo<sup>1</sup>, James Randolph Onggo <sup>2,3\*</sup>, Mithun Nambiar<sup>3,4</sup>,  
Andrew Duong<sup>5</sup>, Olufemi R. Ayeni<sup>5</sup>,  
John O’Donnell<sup>6,7</sup> and Parminder J. Singh<sup>4,7</sup>

<sup>1</sup>Department of Orthopaedic Surgery, Tan Tock Seng Hospital, Singapore,

<sup>2</sup>Department of Orthopaedic Surgery, Box Hill Hospital, Box Hill, Victoria, Australia,

<sup>3</sup>Faculty of Medicine, Nursing and Health Sciences, Monash University, Clayton, Victoria, Australia,

<sup>4</sup>Department of Orthopaedic Surgery, Maroondah Hospital, Ringwood, Victoria, Australia,

<sup>5</sup>Department of Surgery, Division of Orthopaedic Surgery, McMaster University Medical Centre, McMaster University, Ontario, Canada,

<sup>6</sup>Department of Surgery, Swinburne University of Technology, Hawthorn, Victoria, Australia and

<sup>7</sup>Hip Arthroscopy Australia, Richmond, Victoria, Australia.

\*Correspondence to: J. R. Onggo. E-mail: jamesonggo1993@gmail.com

Submitted 7 July 2020; Revised 28 October 2020; revised version accepted 17 November 2020

## ABSTRACT

This study aims to present a systematic review and synthesized evidence on the epidemiological factors, diagnostic methods and treatment options available for this phenomenon. A multi-database search (OVID Medline, EMBASE and PubMed) was performed according to PRISMA guidelines on 18 June 2019. All studies of any study design discussing on the epidemiological factors, diagnostic methods, classification systems and treatment options of the wave sign were included. The Newcastle–Ottawa quality assessment tool was used to appraise articles. No quantitative analysis could be performed due to heterogeneous data reported; 11 studies with a total of 501 patients with the wave sign were included. Three studies examined risk factors for wave sign and concluded that cam lesions were most common. Other risk factors include alpha angle  $>65^\circ$  (OR=4.00, 95% CI: 1.26–12.71,  $P=0.02$ ), male gender (OR 2.24, 95% CI: 1.09–4.62,  $P=0.03$ ) and older age (OR=1.04, 95% CI: 1.01–1.07,  $P=0.03$ ). Increased acetabular coverage in setting of concurrent cam lesions may be a protective factor. Wave signs most commonly occur at the anterior, superior and anterosuperior acetabulum. In terms of staging accuracy, the Haddad classification had the highest coefficients in intraclass correlation ( $k=0.81$ , 95% CI: 0.23–0.95,  $P=0.011$ ), inter-observer reliability ( $k=0.88$ , 95% CI: 0.72–0.97,  $P<0.001$ ) and internal validity ( $k=0.89$ ). One study investigated the utility of quantitative magnetic imaging for wave sign, concluding that significant heterogeneity in  $T1\rho$  and  $T2$  values ( $P<0.05$ ) of acetabular cartilage is indicative of acetabular debonding. Four studies reported treatment techniques, including bridging suture repair, reverse microfracture with bubble decompression and microfracture with fibrin adhesive glue, with the latter reporting statistically significant improvements in modified Harris hip scores at 6-months (MD=19.2,  $P<0.05$ ), 12-months (MD=22.0,  $P<0.05$ ) and 28-months (MD=17.5,  $P<0.001$ ). No clinical studies were available for other treatment options. There is a scarcity of literature on the wave sign. Identifying at risk symptomatic patients is important to provide prompt diagnosis and treatment. Diagnostic techniques and operative options are still in early developmental stages. More research is needed to understand the natural history of wave sign lesions after arthroscopic surgery and whether intervention can improve long-term outcomes. Level IV, Systematic review of non-homogeneous studies.

## INTRODUCTION

Hip arthroscopy is an established surgical approach for diagnosing and treatment of chondral and labral injuries of the hip joint. While labral injuries can be more readily visualized on preoperative imaging, certain chondral injuries may only be demonstrable intraoperatively [1]. In particular, acetabular debonding may be diagnosed intraoperatively by observing the ‘wave sign’ (also known as the ‘carpet phenomenon’ or ‘bubble sign’) [2].

Some reports have associated the wave sign with chondral tears due to the wavy appearance of intra-articular cartilage fibrils of the chondral flaps in hip arthroscopy [3]. This description is inaccurate. Rather, the wave sign is an intraoperative diagnostic sign that is elicited by pushing the lateral border of the acetabular chondral surface, resulting in a rippling of the chondral surface that resembles a wave [4]. Hence, the injury may not be readily perceptible on conventional preoperative magnetic resonance imaging (MRI) because the delaminated cartilage would sit flushed on the underlying bone when the lateral border is not probed [4].

There is a paucity of literature on the wave sign to guide decision making. Given its high association with cam lesions, there is a propensity to progress into full thickness defects, exposure of subchondral bone and eventual degenerative arthritis [4–6]. Hence, there is value to provide early synthesized evidence to raise the awareness of diagnostic and operative techniques to treat the wave sign. Hence, the aim of this systematic review is to present evidence on the epidemiological factors, clinical presentations, classification systems, diagnostic methods, intraoperative findings and outcome of treatment options associated with this phenomenon.

## MATERIALS AND METHODS

### Definition

The wave sign, also known as bubble sign or carpet phenomenon is an intraoperative finding associated with acetabular cartilage debonding [2]. Similar to Jannelli *et al.* [4], for the purpose of this review, we defined acetabular debonding as an area of degenerated cartilaginous surface at the chondrolabral junction. This results in a partial detachment of the articular cartilage from the subchondral bone without exposing it and without interruption of the articular surface. Debonding is considered to be an early to intermediate grade of chondral damage, usually not associated with the presence of osteoarthritis [4, 7].

### Literature search strategy

This study was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) criteria [8]. A comprehensive search was conducted using multiple electronic data-bases (PubMed, Ovid MEDLINE and Embase) from the date of inception until 18 June 2019. The Medical Subject Headings and Boolean operator terms used for the search were ‘(hip joint OR hip arthroscopy OR Acetabulum) AND (bubble OR wave OR delamination OR impingement)’. The identified articles and their corresponding references were reviewed according to the selection criteria for consideration of inclusion in the study.

### Selection criteria

All articles that described the epidemiological factors, diagnostic methods, classification systems or treatment options of the wave sign were included in the study. Non-English language studies, non-peer reviewed studies, unpublished manuscripts, conferences and abstracts were excluded. Two independent authors (J.D.O. and J.R.O.) reviewed the records that were retrieved in the initial search and excluded those that were duplicates or published in non-English language. The titles and abstracts of the remaining articles were then screened against the inclusion criteria. Only articles meeting the inclusion criteria were accepted and critically reviewed according to a predefined data extraction form. At the end of the selection process, any differences in opinions regarding the inclusion of articles was resolved by discussion among authors.

### Data extraction

Extracted data parameters included details on study design, publication year, patient numbers, basic demographics, study characteristics, clinical presentation, classification systems, radiographic results, treatment outcomes and complications.

### Methodology assessment

The Newcastle–Ottawa Quality Assessment Tool [9] was used to critically appraise the standards of cohort and case-controlled studies included in our review. The Newcastle–Ottawa appraises three main categories, namely selection, comparability and outcome, which consist of four, one and three items, respectively. Each study can be awarded a maximum of one point for each item within the selection and outcome categories, while a maximum of two points can be awarded for comparability. The number of points awarded is compared against the threshold standards outlined by the Agency for Healthcare Research and Quality (AHRQ).

### Statistical analysis

No statistical analysis was performed due to a lack of consistent reporting of data. Data presented in this study are a synthesis of the limited evidence currently available.

## RESULTS

### Literature search and study details

Article selection was performed according to PRISMA guidelines as illustrated in Fig. 1 [8]. A total of 5520 studies were identified from the initial search, of which 2324 duplicates and 160 non-English studies were removed. Titles and abstracts of remaining 2819 studies were screened with 332 full text articles scrutinized. A total of 11 articles were included in the review.

### Methodology assessment

The individual points awarded to each item within different categories of the remaining studies are illustrated in Table I. Overall, there are six good quality and three poor

quality studies as outlined by the AHRQ standards. The existing literature currently provides some evidence for the epidemiology, risk factors, site of lesion and reliability of classification systems. However, evidence on diagnostic techniques and treatment options are still sparse, with no clinical comparisons made with other plausible options. Two studies were technical reports and excluded from methodology assessment.

### Demographics

A total of 11 studies consisting of 1327 patients and 1340 hips were included. Of six studies reporting mean age, the aggregated mean age of 501 patients with confirmed acetabular debonding was 35.8 years. Only 2 studies reported follow-up periods with a mean period of 25.2 months. Three studies [4–6] discussed on the epidemiology, incidence and risk factors of wave sign; one study [10] discussed diagnostic imaging of cartilage debonding; three studies [11–13] discussed on the reliability of classification

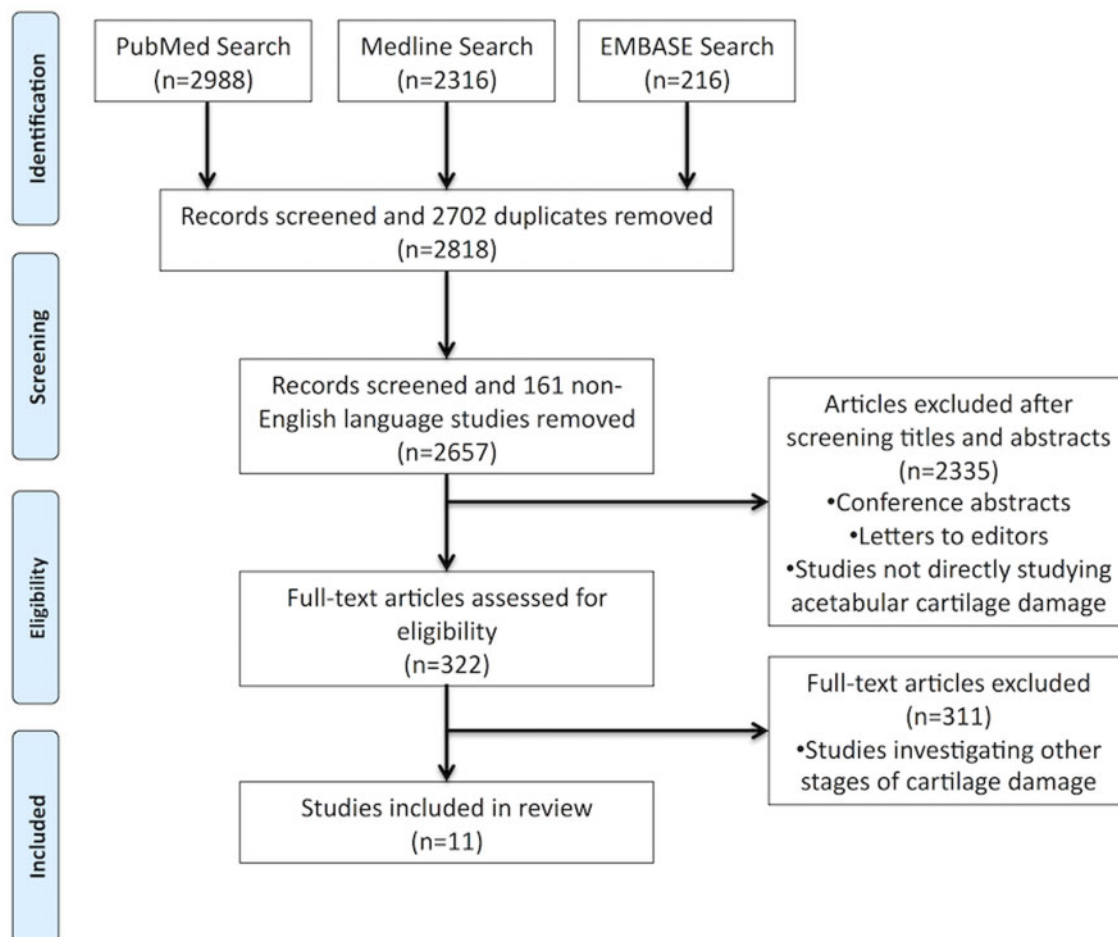


Fig. 1. PRISMA search flowchart.

Table I. Newcastle–Ottawa quality assessment tool

Cohort studies									
Articles	Selection (max. 1 point)			Comparability (max. 2 points)		Outcome (max. 1 points)			AHRQ
	Representativeness of the exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design or analysis	Assessment of outcome	Was follow-up long enough for outcomes to occur	Adequacy of follow up of cohorts	
Amenabar (2015)	1	0	1	1	0	0	0	0	Poor
Beaule (2012)	1	0	1	1	2	1	1	0	Good
Fontana (2016)	1	1	1	1	2	1	1	0	Good
Jannelli (2019)	1	1	1	1	2	1	1	0	Good
Nepple (2012)	1	0	1	1	0	0	0	0	Poor
Konan (2011)	1	0	1	1	0	0	0	0	Poor
Stafford (2011)	1	0	1	1	1	1	1	1	Good
Tzaveas (2010)	1	0	1	1	1	1	1	1	Good
Case-control									
Articles	Selection (max. 1 point)			Comparability (max. 2 points)		Outcome (max. 1 points)			AHRQ
	Is the case definition adequate?	Representativeness of the cases	Selection of controls	Definition of controls	Comparability of cases and controls on the basis of the design or analysis	Ascertainment of exposure	Same method of ascertainment for cases and controls	Non-response rate	
Samaan (2018)	1	1	1	1	1	1	1	0	Good

**Table II. Basic demographics**

Author	Publication year	Country	Study design	Number of patients	Number of males	Number of females	Number of hips	Number of acetabular debonding (intraoperatively)	Mean age/years (18–55)	Mean follow-up /months	Methods/objectives	Risk factors	Histology examination/lesion	Classification systems assessed	Imaging studies assessed	Treatment	Clinical outcome
Amenabar	2015	Australia	Prospective	40	17	23	40	—	30.3 (18–55)	—	Comparing the reliability of acetabular chondral damage classification systems via video analysis	—	No	Beck, Haddad, Outerbridge	—	—	—
Beaule	2012	Canada	Retrospective	167	129	38	180	64 (35.6%)	38.4 (17–60)	—	Strength of correlation between alpha angle and severity of FAI/chondral debonding	Cam-type FAI, Alpha angle > 65°, male, older age	No	Anterior, superior	—	—	—
De Lazari	2018	Brazil	Technical report	—	—	—	—	—	—	—	Explaining the technique of reverse microfracture for the repair of acetabular debonding	—	No	—	—	Reverse microfracture with bubble	—
Fontana	2016	Italy	Retrospective	359	203	156	359	113 (31.5%)	37.6 (19–53)	—	Estimate the frequency, location and extension of acetabular debonding in FAI patients	Cam-type FAI, male, older age	No	Superior	—	—	—
Jannelli	2019	Italy	Retrospective	613	—	—	613	226 (37%)	39.3	—	To describe the epidemiology, histology of	Cam-type FAI, pin-cer-type	Yes	Superior	—	—	—

(continued)

**Table II. (continued)**

Author	Publication year	Country	Study design	Number of patients	Number of males	Number of females	Number of hips	Number of acetabular debonding (intraoperatively)	Mean age/years	Mean follow-up /months	Methods/objectives	Risk factors	Histology examination/lesion	Classification systems assessed	Imaging studies assessed	Treatment	Clinical outcome
Kaya	2015	Japan	Technical report	—	—	—	—	—	—	—	acetabular debonding in patients with FAI	FAI, labral lesions, ligamentum teres lesions, femoral head chondral lesions	—	—	—	Bridging suture repair	—
Konan	2011	UK	Retrospective	10	—	—	10	1 (10%)	—	—	Explaining the technique of bridging suture repair of acetabular debonding	—	No	—	—	—	—
											Assessment of the internal consistency and reproducibility of the Haddad classification system compared to other classification system used	—	No	Beck, Haddad, Outerbridge	—	—	—
Nepple	2012	USA	Retrospective	40	—	—	40	—	—	—	Assessing reliability of Beck classification	—	No	—	—	—	—
Samaan	2018	USA	Case-control	36	19	17	36	36 (100%)	35.7	—	Assess the utility of voxel-based relaxometry in	—	No	Anterosuperior	—	Voxel-based relaxometry MRI	—

(continued)

**Table II. (continued)**

Author	Publication year	Country	Study design	Number of patients	Number of males	Number of females	Number of hips	Number of acetabular debonding (intraoperatively)	Mean age/years	Mean follow-up /months	Methods/objectives	Risk factors	Histology examination/lesion	Site of systems assessed	Classification systems assessed	Imaging studies assessed	Treatment	Clinical outcome
Stafford	2011	UK	Retrospective	43	25	18	43	43 (100%)	34.2 (18-53)	28 (16-42)	T1 $\rho$ and T2 mapping to detect hip joint acetabular debonding and lesions	—	No	—	—	—	with T1 $\rho$ and T2 mapping	Modified Harris hip score
Tzaveas	2010	UK	Retrospective	19	5	14	19	19 (100%)	36 (18-57)	19 (2-78 months)	Investigating effectiveness of fibrin adhesive to repair acetabular debonding	—	No	Anterior,	—	—	Microfracture and fibrin adhesive glue	Modified Harris hip score

FAL=femoracetabular impingement

**Table III. Comparison of different classification system**

Grade	Beck	Chondral/Haddad	MAHORN	Modified Outerbridge
0	Normal; macroscopically sound cartilage	Normal; macroscopically sound cartilage	Normal; macroscopically sound cartilage	Normal; macroscopically sound cartilage
1 or A	Malacia; roughening of surface, fibrillation	Loss fixation to the subchondral bone resulting in a wave sign	Focal or extensive softening	Cartilage with softening and swelling
2 or B	Debonding, loss of fixation to the subchondral bone, macroscopically sound cartilage, carpet phenomenon	Cleavage tear, separation at the chondrolabral junction, but no evidence of delamination	Detached cartilage from bone with intact periphery	A partial-thickness defect with fissures on the surface that do not reach subchondral bone or exceed 1.5 cm in diameter
2a	—	—	—	Fibrous degeneration of cartilage, debonded by subchondral bone, without any interruption of fibrous layer
3 or C	Cleavage, loss of fixation to the subchondral one; frayed edges, thinning of the cartilage, flap	Macroscopic delamination of the articular cartilage	Pocket; detached cartilage from bone with one free edge	Fissuring to the level of subchondral bone in an area with a diameter more than 1.5 cm
4 or D	Full-thickness defect	Exposed subchondral bone	Flap; detached cartilage from bone with more than one free edge	Exposed subchondral bone
5 or E	—	—	Exposed with no coverage over bone	—
Additional	—	Zones: 1 (anteroinferior), 2 (anterosuperior), 3 (middle superior), 4 (posterosuperior), 5 (posteroinferior), 6 (middle inferior)  Distance of lesion from acetabular rim to cotyloid fossa: A (<1/3 of distance), B (1/3–2/3 of distance), C (>2/3 of distance)	—	—

Red boxes correspond to the classification grade of wave sign in different classification system

systems of to diagnose wave sign and four studies [14–17] on the treatment and outcomes of cartilage debonding (Table II).

### Incidence and epidemiology

Three retrospective studies reported on the incidence of wave sign in patients undergoing hip arthroscopy [4–6]. Across these three studies, a total of 1139 patients and 1152 hips underwent hip arthroscopy, indicated by hip pain for a minimum of 3 months with no previous interventions or known injuries [4–6]. About 48.6% (472/972) of hips were diagnosed with femoroacetabular impingement (FAI) as the main cause of hip pain, of which 58.1%

(274/472) had cam-type FAI. The wave sign was noted intraoperatively in 35% (402/1152) of hips [4–6]. The mean age of patients from the three studies was 38.6 years [4–6] (Table II).

### Risk factors and comorbid injuries

Three studies reported that cam-type FAI was the most common risk factor found to have a positive correlation with wave sign noted in hip arthroscopy [4–6]. They reported that an alpha angle greater than 65° (OR=4.00, 95% CI: 1.26–12.71,  $P=0.02$ ), the male gender (OR 2.24, 95% CI: 1.09–4.62,  $P=0.03$ ) and older age (OR=1.04, 95% CI: 1.01–1.07,  $P=0.03$ ) were also found to be



independently associated with having a positive wave sign as well as more severe chondral damage [4–6]. On the other hand, Beaulé *et al.* [6] reported that acetabular coverage (OR=0.94, 95% CI: 0.89–0.99,  $P=0.01$ ) was a protective factor, especially when centre-edge angle is above 40° in the presence of concurrent cam-type FAI. Jannelli *et al.* [4] also reported that the wave sign was positively correlated with the presence of isolated cam-type (OR=5.87,  $P<0.01$ ) and pincer-type (OR=1.79,  $P<0.03$ ) FAI. Amongst various associated intra-articular lesions, labral lesions (94.25%,  $P<0.01$ ), ligamentum teres lesions (28.32%,  $P<0.05$ ) and femoral head chondral lesion (19.9%,  $P<0.01$ ) were most frequently associated with the wave sign.

### Histology

Only one study described the histological findings of the delaminated cartilage [4]. Histological examination showed hypocellularity (about 30% of normal) associated with fragmentation and fissuring within the matrix, extending deep to the subchondral bone, but not superficially to the articular surface. Hence, the chondral coat remains continuous. The matrix was also found to contain architectural disorder with diffuse eosinophils and myxoid degeneration foci [4].

### Site of lesion

Five studies described the most common location of articular debonding [4–6, 10, 15]. Two studies [6, 15] reported that articular debonding occurred more commonly in the anterior region of the acetabulum, while three studies [4–6] superior region. Two studies reported that the anterosuperior acetabular region was most common [10, 15]. Jannelli [4] and Fontana *et al.* [5] reported 93.8% and 87% of patients had acetabular debonding lesions detected on the superior acetabular region. While Fontana *et al.* [5] reported the presence of superoposterior acetabular involvement in 77% of patients with acetabular debonding lesions, Jannelli *et al.* [4] reported only 5.3% at the same site. Beaulé *et al.* [6] reported the incidence of Beck grade 3 and 4 lesion to be 18.8% at the anterior region only, 18.8% at the superolateral region only and 31.2% at both the anterior and superolateral regions.

### Classification

Four different classification systems commonly utilized in hip arthroscopy were found, namely Beck [7], Haddad [11], Multicenter Arthroscopy of the Hip Outcomes Research Network (MAHORN) [18] and Modified Outerbridge [5, 19] classification systems (Table III). Wave sign is classified as a grade 1 lesion in Haddad

classification, grade 2 lesion in the Beck and MAHORN classification and grade 2A lesion in the modified Outerbridge classification.

Konan *et al.* [11] reported a high intraobserver reliability of the Haddad classification with an intraclass correlation coefficient (ICC) of 0.81 (95% CI: 0.23–0.95,  $P=0.011$ ), high inter-observer reliability ICC of 0.88 (95% CI: 0.72–0.97,  $P<0.001$ ) and high internal validity with Conbach's alpha of 0.89. Amenabar *et al.* [12] compared three classification systems and reported inter-observer reliability average weighted Cohen *K*-value for the Outerbridge, Beck and Haddad classifications to be 0.28 (95% CI: 0.16–0.39), 0.33 (95% CI: 0.24–0.41) and 0.47 (95% CI: 0.42–0.51), respectively. In terms of intraobserver reliability, the average weighted Cohen *K*-values were 0.62 (range: 0.39–0.74), 0.63 (range: 0.32–0.85) and 0.68 (range: 0.53–0.85), respectively. However, Nepple *et al.* [13] reported a much higher average weighted Cohen *K*-value for the Beck classification system, with inter-observer kappa value of 0.65 and intraobserver kappa value of 0.80, but no comparison was made with other classification systems [13]. Haddad classification system appears to be the most reliable classification to diagnose chondrolabral injuries [11, 12].

### Diagnostic imaging

Samaan *et al.* [10] used quantitative magnetic imaging technique to diagnose acetabular cartilage debonding by evaluating  $T1\rho$  and  $T2$  relaxation time heterogeneity, reflecting a change in glycosaminoglycan content within debonded cartilage in FAI patients. Samaan *et al.* [10] found that FAI patients, when compared to non-FAI patients, exhibited higher  $T1\rho$  than  $T2$  values in global ( $T1\rho$ : 34.5 ms versus 32.8 ms,  $P=0.04$ ,  $T2$ : 28.8 ms versus 26.5 ms,  $P=0.01$ ), posterior ( $T1\rho$ : 35.3 ms versus 31.9 ms,  $P<0.001$ ,  $T2$ : 29.6 ms versus 24.9 ms,  $P<0.001$ ), anterior ( $T1\rho$ : 9.81 ms versus 8.39 ms,  $P=0.001$ ,  $T2$ : 10.1 ms versus 7.91 ms,  $P<0.001$ ) and anterosuperior ( $T1\rho$ : 11.2 ms versus 7.12 ms,  $P<0.001$ ,  $T2$ : 10.6 ms versus 6.7 ms,  $P<0.001$ ) acetabular cartilage. Of note, the most significant heterogeneity was found in the anterior superior acetabular cartilage, corresponding to an area where debonding is typically observed. This demonstrates a strong ability to detect acetabular debonding lesions ( $T1\rho$  AUC: 0.96,  $P<0.001$ ,  $T2$  AUC: 0.93,  $P<0.001$ ).

### Treatment

Four studies reported a treatment options for wave sign [14–17]. Two studies [14, 15] described microfracture with fibrin adhesive glue, one study [16] described

bridging suture repair, and another [17] reported on reverse microfracture with bubble decompression.

Two studies [14, 15] investigating fibrin glue reported clinical outcomes of 62 patients. Stafford *et al.* [14] ( $n=43$ ) reported significant improvement in combined modified Harris hip score (MHHS) post-operatively (79.4 versus 61.9,  $P<0.001$ ), pain (35.8 versus 21.8,  $P<0.001$ ) and function (43.6 versus 40.0,  $P<0.001$ ) levels at a mean of 28 months when compared to preoperative values. Tzaveas [15] ( $n=19$ ) concluded that fibrin glue is a safe and efficient material. Tzaveas [15] reported significant improvement in the post-operative MHHS for pain and function, at 6 months (MHHS: 77.5 versus 58.3, pain: 28.3 versus 15.7, function: 42.2 versus 37.2,  $P<0.05$ ) and 1 year (MHHS: 80.3 versus 58.3, pain: 28.9 versus 15.7, function: 44.1 versus 37.2,  $P<0.05$ ) when compared to preoperative scores. However, no further significant improvements were illustrated when MHHS was compared at 1 and 3 years post-operatively ( $P=0.44$ ). Kaya *et al.* [16] and De Lazari *et al.* [17] solely reported on the surgical technique of bridging suture repair and reverse microfracture with bubble decompression, respectively and did not include any patient data.

## DISCUSSION

The wave sign is an early intraoperative finding associated with acetabular cartilage debonding, most frequently associated with FAI in the superior, anterior or superoanterior aspect of the acetabulum. Early preoperative diagnosis can be achieved with quantitative MRI comparing between  $T1\rho$  and  $T2$  relaxation time. A significant heterogeneity of values would indicate altered glycosaminoglycan content of the cartilage, suggesting chondral debonding. Fibrin adhesive glue and microfracture is a possible treatment options, though it is too early to conclude its efficacy and safety from the small number of patients involved. More research is needed to determine an optimal treatment.

Cam-type FAI is strongly associated with articular debonding [20, 21]. Jorge *et al.* [22] theorized that the cam-lesion results in an aspherical contour of the femoral head and increases its radius on the anterior side, with an extension of bone and articular cartilage located at the femoral head-neck junction. This leads to increased friction on the acetabular cartilage and labral structures during hip flexion and internal rotation [23]. Shearing forces concentrated at the chondrolabral junction causes acetabular detachment from the subchondral bone, leading to acetabular debonding [22–24]. Fontana *et al.* [5] also complemented this theory by highlighting physiological consequences of the spherical joint, where concave surface of the acetabulum is exposed to larger shear forces during weight bearing

as compared to convex surface of the femoral head. Furthermore, acetabular cartilage layers are thinner than the femoral head [5], contributing to major physiological weakness of the acetabular cartilage. This is physiologically consistent with the predilected anterior, superior and anterosuperior sites of acetabular debonding observed from the literature [4–6, 10, 15, 25]. In addition, McCarthy explained that the relatively poorer vascular supply of the anterior labral region compared to others also increases its vulnerability to wear and progressive acetabular cartilage damage without the ability to repair itself [26].

Beaule *et al.* [6] also explained that a greater alpha angle is associated with greater shearing frictional stresses exerted on the acetabular cartilage, even with small flexion or internal rotation movements of the hip [23, 27]. Although males were found to have higher risks of acetabular debonding, this was not due to body mass index differences [6]. A possible explanation is that males tend to engage in higher intensity physical activities, exposing the hip to greater shearing forces and stresses [28].

However, we noted some inconsistencies with the results presented by Beaule *et al.* [6] who reported increased acetabular coverage being a protective factor in their study of 167 patients, while Jenelli *et al.* [4] reported the opposite in 613 patients with pincer-type FAI being a risk factor. This could be due to a more heterogeneous and advanced chondral damage patient group in the study by Beaule *et al.* [6] compared to Janelli *et al.* [4]. A major difficulty in making a fair comparison and recommending conclusive evidence was likely due to the lack of a consensus definition and classification of the wave sign, leading to vary patient selection and clinical outcome criteria being utilized and the subsequent introduction of selection and reporting bias.

Another interesting area to explore is the association of wave sign in the setting of hip dysplasia with decreased acetabular coverage. These patients were specifically excluded in the study by Beaule and hence no information was available. While labral tears and chondral lesions is a known common finding in hip dysplasia [29], it seems that the incidence and relevance of wave sign in this group of patients have yet to be evaluated and published in a homogeneous patient population.

Classification systems with high intra- and inter-observer reliability are important in clinical decision making and have strong prognostic implications. Despite the lack of statistical comparisons between different classification systems, the limited evidence available suggests that Haddad classification may be most reliable with the highest validity and reliability coefficients, likely due to its specific development for the hip [12]. In comparison, commonly

used Outerbridge classification was developed primarily for knee arthroscopy. It is argued that Outerbridge grades 2 and 3 do not add value for the hip since the main difference between them resides in their size rather than lesion severity. Moreover, common findings, such as chondral debonding or articular cleavage, flaps and delamination are absent from Outerbridge classification [12]. Amenabar *et al.* [12] believes that lower reliability of Outerbridge in describing hip joint pathology, as opposed to previous reports in the knee, is attributed to the unique anatomy of the chondrolabral junction and specific damage patterns caused by FAI. Similarly, Beck classification was not developed specifically for hip arthroscopy initially. Despite using specific knowledge of FAI and its damage patterns in its development, it was still criticized for not correlating with chondral damage progression [11], with disagreements between grade 1 and 2 lesions among observers [30].

The lack of a consensus classification system has inevitably led to heterogeneous and ambiguous comparisons of patients between studies. The lack of explicit use of the terminology 'wave sign' in these classifications may also lead to ambiguity in interpretation. For example, the Haddad *et al.* [11] classification classifies both chondromalacia and wave sign together as grade 1, while the Beck *et al.* [7], MAHORN [18] and modified Outerbridge [5, 19] classifications identified chondromalacia separately as grade 1 and debonding as grade 2, 2, and 2a, respectively. As such, this could explain why Haddad *et al.* [11] classification had higher reliability, since two pathologies have been classified together.

Janelli was the only study reporting chondrocyte viability in the wave sign and reported poor results at 40%. It is surprising that other studies have reported more promising evidence on cellular viability of chondrocytes in more advanced chondral abnormalities, such as chondral flaps. In fact, Meulenkamp *et al.* [31] and Wright *et al.* [32] examined a total of 22 chondral flaps and found nearly 90% of viable chondrocytes on average. While the sample size in these studies were small and hardly conclusive, it suggests that the relative importance of the distinction between softening, wave sign and chondral flaps in terms of natural history, progression and prognosis.

Diagnostic imaging to identify acetabular debonding has poor results overall. Articular delamination, flaps or cleavage tears are readily diagnosed if fluid is present between subchondral bone and delaminated cartilage [23]. However, articular surface in cartilage debonding is undisrupted and injury patterns are difficult to discern on MRI. Furthermore, the hip being a contained ball and socket joint, the femoral head may push debonded acetabular cartilage flushed against subchondral bone, making diagnosis

difficult [23]. The debonded region is usually more prominent when elicited by a shearing force. *In vivo*, this is achieved by hip flexion and internal rotation [23]. However, the relatively confined space of MRI machines makes this infeasible. Although hip MRI done under traction for wave sign has not been formally looked into, this is a plausible alternative in the diagnosis of delamination lesions. The concept is to stretch the hip joint capsule and create a negative pressure to lift the delaminated cartilage off subchondral bone into the hip joint. This may lead to easier detection of the delaminated cartilage area.

Current possible diagnostics include qualitative and quantitative MR arthrogram imaging techniques. Qualitative technique employs intermediate-weighted fat-saturated and T1-weighted images to detect hypointense signal in debonded cartilage. Pfirrmann *et al.* [23] proposed that this could be related to fibrous metaplasia of hyaline cartilage with associated ground substance proteoglycan depletion from the extracellular matrix. Recently, quantitative techniques using voxel-based relaxometry are increasingly utilized to accurately assess joint cartilage composition while maintaining consistency with traditional region of interest-based methods, and to achieve greater sensitivity in detecting local changes. Quantitative MRI allows for more sensitive detection of localized differences by attaining comparable numerical values. However, this niche technique is not widely available and requires further evaluation.

There is no study available in the current literature that investigates the natural history and progression of wave sign with or without treatment. This is likely due to the lack of diagnostic modalities to accurately identify the occurrence or healing of such lesions. Furthermore, there is a greater inclination in hip preservation surgery to perform concomitant procedures to remove the cause of chondral damage and treat acetabular debonding simultaneously in a single surgery. This not only thwarts the progress of chondral damage but also reduces the risk of iatrogenic chondral damage from instruments.

Three surgical techniques were described as treatments for wave sign in addition to associated cam-lesion corrections. Due to paucity of studies describing outcomes, there is insufficient data to effectively compare treatment modalities. Furthermore, patients had other concomitant procedures performed to address other pathologies, which makes outcome comparison for each modality more difficult. While there may be options to treat acetabular debonding, there is no current evidence to support them in isolation. Nevertheless, two clinical studies reported the outcomes of microfracture and fibrin glue technique in 62 patients [14, 15]. Microfracture aims to increase marrow-

stimulation by exposing debonded chondral regions to underlying mesenchymal stem cells from the marrow cavity [14, 33]. They also create keyholes for fibrin glue to adhere to and enhance healing by acting as a biological scaffold for ingrowth of native cells [14, 34]. Tzaveas [15] advocated for this technique over excision of debonded flaps as flaps may contain large numbers of viable chondrocytes that may still stand a chance of recovery. Unfortunately, long-term efficacy of this technique is unknown due to short follow-up periods and no mention of debonding recurrence post-operatively [14, 15].

The quality and conclusiveness of evidence presented here is limited by the sparse literature available. This is not surprising since the wave sign is a niche specialty topic. This article would be a significant launchpad for further research to build on and extend the current knowledge. The authors postulate that future directions in wave sign may be a push towards surgical techniques focussing on refixation of the delaminated chondral areas, especially with recent studies showing significant viability of chondrocytes in the affected areas.

#### LIMITATIONS

Limitations include heterogeneity of patient populations, lack of standardization of definitions and descriptions of wave sign and low numbers of studies directly investigating wave sign. Hence, selection and recall bias cannot be excluded. A meta-analysis could not be performed due to variability of outcome measure. Standardization of outcome measures is important for clinical data consolidation in future studies.

#### CONCLUSION

There is a scarcity of literature on the wave sign. Identifying at risk symptomatic patients is important to provide prompt diagnosis and treatment. Diagnostic techniques and operative options are still in early developmental stages. More research is needed to understand the natural history of wave sign lesions after arthroscopic surgery and whether intervention can improve long-term outcomes.

#### ACKNOWLEDGEMENT

There is no further acknowledgement to be made.

#### FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

#### CONFLICT OF INTEREST STATEMENT

None declared.

#### Data availability

The nature of this article involves the use data previously published. Hence, no new patient data is involved in our study.

#### REFERENCES

1. Kassarian A, Belzile E. Femoroacetabular impingement: presentation, diagnosis, and management. *Semin Musculoskelet Radiol* 2008; **12**: 136–45.
2. El-Radi MA, Marin-Pena OR, Said HG *et al*. Basics in hip chondrolabral lesions and state of the art. *Sicot J* 2017; **3**: 73.
3. Zaragoza E, Lattanzio PJ, Beaulé PE. Magnetic resonance imaging with gadolinium arthrography to assess acetabular cartilage delamination. *Hip Int* 2009; **19**: 18–23.
4. Jannelli E, Parafioriti A, Acerbi A *et al*. Acetabular delamination: epidemiology, histological features, and treatment. *Cartilage* 2019; **10**: 314–20.
5. Fontana A, Mancini D, Gironi A *et al*. Hip osteochondral lesions: arthroscopic evaluation. *Hip Int* 2016; **26**: 17–22.
6. Beaulé PE, Hynes K, Parker G *et al*. Can the alpha angle assessment of cam impingement predict acetabular cartilage delamination? *Clin Orthop Relat Res* 2012; **470**: 3361–7.
7. Beck M, Leunig M, Parvizi J *et al*. Anterior femoroacetabular impingement: part II. Midterm results of surgical treatment. *Clin Orthop Relat Res* 2004; **418**: 67–73.
8. Moher D, Liberati A, Tetzlaff J *et al*; The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009; **6**: e1000097.
9. Wells G, Shea B, O'Connell D *et al*. *The Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Nonrandomised Studies in Meta-analyse*. 2013. Available at: [http://www.ohri.ca/programs/clinical\\_epidemiology/oxford.aspoth](http://www.ohri.ca/programs/clinical_epidemiology/oxford.aspoth), accessed on 1st March 2020
10. Samaan MA, Padoia V, Zhang AL *et al*. A novel mr-based method for detection of cartilage delamination in femoroacetabular impingement patients. *J Orthop Res* 2018; **36**: 971–8.
11. Konan S, Rayan F, Meermans G *et al*. Validation of the classification system for acetabular chondral lesions identified at arthroscopy in patients with femoroacetabular impingement. *J Bone Joint Surg Br* 2011; **93-B**: 332–6.
12. Amenabar T, Piriz J, Mella C *et al*. Reliability of 3 different arthroscopic classifications for chondral damage of the acetabulum. *Arthroscopy* 2015; **31**: 1492–6.
13. Nepple JJ, Larson CM, Smith MV *et al*. The reliability of arthroscopic classification of acetabular rim labrochondral disease. *Am J Sports Med* 2012; **40**: 2224–9.
14. Stafford GH, Bunn JR, Villar RN. Arthroscopic repair of delaminated acetabular articular cartilage using fibrin adhesive. Results at one to three years. *Hip Int* 2011; **21**: 744–50.
15. Tzaveas AP, Villar RN. Arthroscopic repair of acetabular chondral delamination with fibrin adhesive. *Hip Int* 2010; **20**: 115–9.
16. Kaya M, Hirose T, Yamashita T. Bridging suture repair for acetabular chondral carpet delamination. *Arthrosc Tech* 2015; **4**: e345–8.

17. De Lazari LC, Laguna CB, Picado CHF *et al.* Reverse microfracture of the hip acetabulum: a technique for the wave lesion. *Arthrosc Tech* 2018; **7**:e607–10.
18. Safran MR, Hariri S. Hip arthroscopy assessment tools and outcomes. *Oper Tech Orthop* 2010; **20**: 264–77.
19. Outerbridge RE. The etiology of chondromalacia patellae. *J Bone Joint Surg Br* 1961; **43-B**: 752–7.
20. Agricola R, Waarsing JH, Arden NK *et al.* Cam impingement of the hip: a risk factor for hip osteoarthritis. *Nat Rev Rheumatol* 2013; **9**: 630–4.
21. Pascual-Garrido C, Li DJ, Grammatopoulos G *et al.* The pattern of acetabular cartilage wear is hip morphology-dependent and patient-demographic-dependent. *Clin Orthop Relat Res* 2019; **477**: 1021–33.
22. Jorge JP, Simoes FM, Pires EB *et al.* Finite element simulations of a hip joint with femoroacetabular impingement. *Comput Methods Biomech Biomed Engin* 2014; **17**: 1275–84.
23. Pfirrmann CW, Duc SR, Zanetti M *et al.* MR arthrography of acetabular cartilage delamination in femoroacetabular cam impingement. *Radiology* 2008; **249**: 236–41.
24. Johnston TL, Schenker ML, Briggs KK *et al.* Relationship between offset angle alpha and hip chondral injury in femoroacetabular impingement. *Arthroscopy* 2008; **24**: 669–75.
25. Arriaza CR, Sampson TG, Olivos Meza A *et al.* Findings on repaired full-thickness acetabular articular cartilage defects during revision hip arthroscopy allowing a second look. *J Hip Preserv Surg* 2020; **7**: 122–9.
26. McCarthy JC, Noble PC, Schuck MR *et al.* The Otto E. Aufranc Award: the role of labral lesions to development of early degenerative hip disease. *Clin Orthop Relat Res* 2001; **393**: 25–37.
27. Ng KC, Mantovani G, Lamontagne M *et al.* Increased hip stresses resulting from a cam deformity and decreased femoral neck-shaft angle during level walking. *Clin Orthop Relat Res* 2017; **475**: 998–1008.
28. Azevedo MR, Araujo CL, Reichert FF *et al.* Gender differences in leisure-time physical activity. *Int J Public Health* 2007; **52**: 8–15.
29. Wyatt MC, Beck M. The management of the painful borderline dysplastic hip. *J Hip Preserv Surg* 2018; **5**: 105–12.
30. Beck M, Kalhor M, Leunig M *et al.* Hip morphology influences the pattern of damage to the acetabular cartilage: femoroacetabular impingement as a cause of early osteoarthritis of the hip. *J Bone Joint Surg Br* 2005; **87-B**: 1012–8.
31. Meulenkamp B, Gravel D, Beaulé PE. Viability assessment of the chondral flap in patients with cam-type femoroacetabular impingement: a preliminary report. *Can J Surg* 2014; **57**: 44–8.
32. Wright VJ, McCrum CL, Li H *et al.* Significant chondrocyte viability is present in acetabular chondral flaps associated with femoroacetabular impingement. *Am J Sports Med* 2018; **46**: 149–52.
33. Steadman JR, Rodkey WG, Singleton SB *et al.* Microfracture technique for full-thickness chondral defects: technique and clinical results. *Oper Tech Orthop* 1997; **7**: 300–4.
34. Ahmed TA, Dare EV, Hincke M. Fibrin: a versatile scaffold for tissue engineering applications. *Tissue Eng. Part B Rev* 2008; **14**: 199–215.