A review of imaging modalities for the hip

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Abstract Hip arthroscopy is one of the fastest growing surgical procedures performed by orthopaedic surgeons, with the number of hip arthroscopies expected to double in 2013. The increase in surgical prevalence is at least in part due to an increased awareness of prearthritic hip pathology. The diagnoses of prearthritic hip conditions are made through a comprehensive history, physical examination, and selection of appropriate diagnostic imaging modalities. The purpose of this review article is to provide the practicing orthopaedic surgeon with an overview of the imaging modalities available for the diagnosis of prearthritic hip pathology, with a focus on literature supporting advancements in imaging techniques and new applications of existing modalities.

Keywords Arthroscopy · Hip · Femoroacetabular impingement (FAI) · Imaging · Radiology · Ultrasound · Computed tomography (CT) · Magnetic resonance imaging (MRI) · Injections

Introduction

The capacity to assess and treat injuries about the hip has increased tremendously in the last decade and, as a result, the

number of hip arthroscopies is expected to double in the United States in 2013 [1]. This is in large part due to a greater understanding of the causes of hip pain and an ability to visualize the pathology with improved imaging techniques. The differential diagnosis of the painful prearthritic hip is vast (Table 1) and beyond the scope of this review; however, the approach to this patient population should be systematic and reproducible. The evaluation of the painful prearthritic hip should begin with a thorough clinical examination. Once the differential diagnosis has been narrowed, the appropriate imaging modalities should be implemented to confirm a diagnosis and identify and recognize concomitant intraarticular and extraarticular pathologies that may affect and guide the management plan. In general, diagnostic imaging of the hip may be achieved with a number of modalities, including radiography, ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and CT or MRI following intraarticular contrast injection [2]. Intraarticular or extraarticular diagnostic injections under ultrasound or fluoroscopic guidance are also available to assist in the diagnosis of hip pain [3–5]. The purpose of this review is to discuss the strengths and weaknesses of the available imaging techniques, present new techniques and applications of existing modalities, and provide the reader with an imaging algorithm for the painful prearthritic hip.

Radiography

Following a thorough history and physical examination, the first imaging technique indicated is radiography. The global objective of radiography is to refine the preliminary differential diagnosis ascertained during the history and physical examination. The standard radiographic assessment of hip or groin pain should begin with a true anteroposterior (AP) radiograph of the pelvis and at least one lateral view of the affected hip. Care should be taken to ensure correct film-

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Table 1 Overview of the broad differential diagnosis of hip pathology in the young adult with hip pain

Differential diagnosis of hip pain in the prearthritic patient

Traumatic injury:

Fracture or stress fracture

Hip dislocation

Soft tissue contusion

Soft tissue hematoma

Cartilage injury:

Lateral impaction

Loose body

Chondral shear

Osteoarthritis

Osteonecrosis

Labral injury:

Trauma

Femoroacetabular impingement

Hip joint hypermobility

Dysplasia

Capsule pathology:

Capsular laxity

Adhesive capsulitis

Capsular inflammation/synovitis

Synovial proliferative disorders:

Pigmented villonodular synovitis

Synovial chondromatosis

Chondrocalcinosis

Inflammatory conditions:

Rheumatoid arthritis

Reiter syndrome

Psoriatic arthritis

Infection:

Septic arthritis

Osteomyelitis

Tumor:

Benign soft tissue neoplasm

Benign osseous neoplasm

Malignant soft tissue neoplasm

Malignant osseous neoplasm

Metastatic disease

Metabolic disorders:

Paget's disease

Primary hyperparathyroidism

Extraarticular musculoskeletal disorders:

Coxa saltans

Trochanteric bursitis

Athletic pubalgia

Abductor impingement

Psoas impingement

Ischial bursitis

Osteitis pubis

Table 1 (continued)

Differential diagnosis of hip pain in the prearthritic patient

Tendonitis (flexors, abductors, or adductors)

Sacroiliac pathology

Nonmusculoskeletal disorders:

Inguinal hernia

Spine pathology

Iliopsoas muscle abscess

Intraabdominal pathology (endometriosis, ovarian cyst)

Peripheral vascular disease

Unknown etiology:

Transient osteoporosis of the hip

Bone marrow edema syndrome

focus distance and proper centering of the x-ray beam to prevent a false impression of altered joint morphology [6]. This is especially true for the AP pelvis radiograph, in which the obturator foramina should appear symmetric and the coccyx should be centered 1.5–2.0 cm above the pubic symphysis to avoid a false interpretation of acetabular under- or overcoverage [7, 8]. Additional imaging of the affected hip should include an AP and lateral radiographic view to quantify offset and asphericity of the femoral head–neck junction [9, 10]. Options are available for the lateral view, including a 45° or 90° Dunn lateral radiograph performed with the hip at 45° or 90° of flexion, respectively, and 20° of abduction in neutral rotation. This radiographic view has been validated by Meyer et al. [10] and Barton et al. [11] as a radiographic tool for defining femoral head–neck morphology. In contrast, the frog-leg lateral radiograph is performed with the hip flexed 30°–40° and abducted 45° so that the heel rests against the contralateral hip. The cross-table lateral radiograph is performed with the leg internally rotated approximately 15° and the beam oriented at a 45° angle relative to the leg but is often limited in its ability to characterize the morphology of the head–neck junction secondary to overlap of the greater trochanter. Lastly, a false-profile radiograph of the affected hip, as recently reviewed by Lequesne and Bellaïche [12], may be useful to obtain a general assessment of anterior femoral head coverage and the status of the anterior joint space.

Once the appropriate radiographs are obtained, the clinician must perform a systematic review to ensure a detailed evaluation of all osseous hip structures. This review should begin with the AP pelvis, and a fundamental review should begin with an identification of the proper acetabular lines and landmarks, including the ilioischial (Kohler's) line, the iliopectineal line, the anterior acetabular wall, the posterior acetabular wall, the tear drop, and the sourcil (acetabular roof). Acetabular version is assessed by evaluation of the relationship between radiographic lines that represent the

anterior and posterior acetabular walls. In a normal individual with physiologic anterior acetabular version, the posterior rim is seen lateral to the anterior rim. If the two rim lines cross and form a “figure of 8” or “crossover sign,” this indicates focal or cranial retroversion as seen in pincer-type femoroacetabular impingement (FAI). Care must be taken, however, not to mistake a prominent or down-sloping anterior inferior iliac spine (AIIS) with a crossover sign to avoid the risk of errant rim recession in the absence of focal retroversion. Recent work by Zaltz et al. [13•] suggests that even in a standardized, well-positioned AP pelvis, the inferior extension of the AIIS may overlap the anterior superior acetabular rim and be partially or completely responsible for the appearance of a crossover sign even in the setting of an anteverted acetabulum. These authors advocate for careful inspection of the AIIS on radiographs and further quantitative assessment of acetabular version with advanced cross-sectional imaging if there is concern for relative acetabular retroversion [13•]. Global acetabular overcoverage is assessed by the relationship between the ilioischial line and the acetabular fossa. In the normal hip variant, the acetabular fossa line is lateral to the ilioischial line, while in coxa profunda and protrusio, the floor of the acetabular fossa and the femoral head may be medial to the ilioischial line, respectively. The lateral center–edge angle of Wiberg quantifies lateral acetabular coverage. Center–edge angles less than 20° indicate lateral acetabular dysplasia (undercoverage), and values greater than 40° indicate overcoverage and profunda deformity [6]. In a normal hip, the acetabular index (Tönnis angle) is 0°–10°; an increased angle may indicate acetabular dysplasia and risk of progressive lateralization of the femur. A negative Tönnis angle is also representative of overcoverage and pathologic pincer-type FAI. In addition to the AP pelvis, the false profile view is valuable for determining the amount of anterior acetabular coverage of the femoral head and evaluating contrecoup joint-space narrowing at the posteroinferior acetabular margin (Fig. 1a–c) [6, 14, 15].

Assessment of the proximal femur is also performed on the AP hip and elongated neck lateral views. The parameters that should be measured for each patient include the alpha angle, beta angle, femoral head–neck offset, and femoral neck–shaft angle. Cam impingement is suggested by alpha angles larger than 50°, as originally described by Notzli and colleagues [16]. The alpha angle is calculated as the angle between a line drawn from the center of the femoral head through the central axis of the femoral neck and a second line drawn from the center of the femoral head to the point anteriorly where the radius of the femoral head first exceeds the radius of the more centrally located portion of the femoral head (Fig. 1d). In addition, the amount of anterior offset can be measured as the distance from a line that is tangential to the convexity of the femoral head to another line that is

parallel to the femoral neck. Less than 9–11 mm of offset may indicate cam-type deformity that is significant but distinct from femoral head asphericity [17, 18]. The femoral neck–shaft angle determines the amount of relative coxa valga or coxa vara, with values greater than 135° and less than 120° suggestive of the former and latter, respectively.

Radiographs are also paramount for evaluating conditions in which arthroscopic intervention would be contraindicated. For example, fractures of the acetabulum or femur may appear on radiographs. In addition, radiographs are useful for diagnosing osteoarthritis, characterized by osteophyte formation, asymmetric joint-space narrowing, sclerosis, and subchondral cyst formation [19]. Appearance of these findings on radiographs would lead to a poor outcome if arthroscopic intervention was pursued. Philippon et al. [20] have reported less than 2 mm of preserved joint space as a negative prognostic factor for hip preservation surgery, and Clohisy et al. [21] have reported a rate of conversion to hip arthroplasty as high as 25 % after hip arthroscopy in the setting of osteoarthritis.

Ultrasound

Ultrasound serves an important role in the evaluation of the periarticular soft tissues in the patient with a painful prearthritic hip. This becomes increasingly useful in the athletic patient with dynamic snapping or catching with specific provocative maneuvers of athletic activity. Dynamic ultrasound and ultrasound-guided injections are often implemented to make the diagnosis of coxa saltans interna or externa [3, 22]. With the transducer centered over the iliopsoas at the level of the inguinal ligament, the patient is prompted to flex and externally rotate the hip into a frog-leg position and then slowly return the leg to a straight position. In patients with symptomatic snapping iliopsoas tendon, the medial fibers of the iliacus become temporarily interposed between the psoas major tendon and the ilium, and during the return to a straight-leg position, the muscle tendon unit can be visualized abruptly snapping back into place, with the iliopsoas tendon making contact with the ilium. The ultrasound evidence may be correlated with a palpable snap felt in the transducer hand of the examiner and exacerbated symptoms felt by the patient [3, 22]. Additional locales for snapping hip syndrome include a snapping iliotibial band or gluteus maximus relative to the greater trochanter and intraarticular loose bodies, the former of which may be identified more readily via ultrasound [3, 23]. Greater trochanteric pain syndrome, commonly due to gluteus minimus or medius tears or tendinopathy, can be appropriately assessed by sonography [24, 25].

Although less reliable than alternative imaging modalities, ultrasound may be used to evaluate for intraarticular hip

abnormalities. A hip joint effusion is diagnosed with the presence of anechoic or hypoechoic distention of the anterior recess of the hip capsule over the femoral neck [26]. Labral pathology may also be rudimentarily identified as a hypoechoic cleft or detachment in an otherwise hyperechoic, smooth, triangular-shaped labrum. The disadvantages of using ultrasound to evaluate the labrum are the limited evaluation of the posterior labrum and the low sensitivity (44 %), as compared with MR arthrography [27]. Paralabral cyst, often associated with a torn labrum, appears as hypoechoic multilocular collections abutting the labrum [28]. With improving resolution and technology, ultrasound may be used to evaluate the extent and topography of the cam deformity [29].

Computed tomography

CT is invaluable for defining the dynamic and static abnormalities in a young patient with hip pain. Acetabular version cannot be defined on radiographs alone and is not a single “global” value but, rather, is defined by the relative relationship of the anterior and posterior walls and is variable at different clock face locations along the rim. This relationship cannot be defined on radiographs and is highly vulnerable to error from subtle changes in radiographic technique and tilt or obliquity of the beam and pelvis. Correspondingly, femoral torsion cannot be reliably measured on radiographs, since the epicondylar axis of the distal femur must be defined. In addition, focal anterior overcoverage, or “cephalad retroversion,” can be difficult to distinguish from true acetabular retroversion on radiographs. Distinguishing these lesions is critical, since the treatment plans and approaches for these two pathomorphologies are different. Cranial acetabular overcoverage can be effectively corrected with rim osteoplasty, while a globally retroverted acetabulum may require correction with an anteverting periacetabular osteotomy. Errant, aggressive anterior rim resection in this setting due to a failure to recognize the morphologic abnormality could result in iatrogenic dysplasia. In this regard, CT scans with three-dimensional (3-D) reconstruction have proven invaluable not only for defining the location of focal pincer morphology, but also for accurately defining coverage and version of the acetabulum at each location along the rim [30]. The CT scan should include the entire pelvis to make accurate measurements [31] and, in this regard, can allow for accurate and reproducible measurement of alpha angle, beta angle, acetabular version from cranial to caudal aspect of the acetabulum, sagittal and coronal center–edge angle, and femoral version.

While cam morphology may be evident on the Dunn lateral radiographs, the topography and extension of deformity medially or posterolaterally along the head–neck

junction may not be appreciated without CT imaging (Fig. 1e). This information with respect to both the size and extent of the cam morphology is critical, since an effective osteoplasty must restore sphericity and offset in all planes and may affect the selection of an open versus arthroscopic approach. Recognition of cam-type impingement that extends superiorly or even posteriorly behind the lateral retinacular vessels on CT scan is an important finding and may be difficult or potentially unsafe to approach arthroscopically. The beta angle described by Brunner et al. [32] provides more of a dynamic assessment of the interaction between the femoral-sided cam lesion and acetabular rim overcoverage. The beta angle is formed by the line connecting the center of the head to the point at which sphericity is lost (same line as that used for the alpha angle) and the line connecting the center of the head to the edge of the acetabulum. Although no standard value has been documented, hips with impingement trend toward negative beta angles where the edge of the acetabulum overlies the cam deformity, while hips without impingement lesions have values ranging between 20° and 40°.

As was mentioned previously, CT scan can also be helpful in characterizing extraarticular anatomy and the morphology of the AIIS in cases that may be concerning for symptomatic subspine impingement. Even with a properly positioned and aligned AP pelvis radiograph, the AIIS may contribute to the appearance of a crossover sign (Fig. 1f) [13•, 33]. Zaltz et al. [13•] demonstrated that only 19 of 38 patients with a crossover sign on AP radiographs had focal or global acetabular retroversion when confirmed on 3-D CT. In all 19 patients with anteverted acetabula and a false positive crossover sign on radiograph, the AIIS was partially or completely responsible for the appearance of the crossover sign (Fig. 1g). The authors concluded that acetabular retroversion cannot be definitively diagnosed on the basis of radiographs alone and that the presence of a crossover sign may be an indication to pursue advanced imaging prior to rim recession [13•].

An area of increasing interest has been the application of novel 3-D CT-based imaging software not only to quantify the location and magnitude of femoral and acetabular deformity, but also to perform a dynamic analysis to determine the location of mechanical conflict with specific athletic activities that reproduce symptoms. Milone et al. [34•] demonstrated that an automated 3-D CT-based imaging software was more accurate than conventional CT or Dunn lateral radiograph in identifying the location and magnitude of cam lesions. Bedi and colleagues [35] applied similar 3-D CT-based imaging software technology to quantify the location and topography of the cam lesion and demonstrate predictable improvements in range of motion with surgical treatment of the deformity. The authors suggested that CT-based modeling of the impingement pattern and subsequent dynamic virtual resection modeling may provide the most accurate preoperative plan for successful treatment based on

◀ **Fig. 1** Representative imaging modalities for the evaluation of the hip. **a** Anteroposterior (AP) pelvis radiograph calculating the Tonnis angle of the right hip. **b** AP pelvis radiograph calculating the center–edge angle of Wiberg for the right hip. **c** AP pelvis demonstrating a positive “crossover” sign. **d** Lateral view of the left hip demonstrating the calculation for alpha angle, with arrow denoting the asphericity associated with the cam lesion. **e** Three-dimensional reconstruction of the left hemipelvis, with red circle denoting the asphericity associated with the cam lesion. **f** AP pelvis demonstrating an appropriate, well-aligned radiograph with arrow denoting “crossover” sign attributed to AIIS. **g** Three-dimensional reconstruction of the right hemipelvis denoting caudal extension of AIIS below the anterior superior acetabular rim. **h** Magnetic resonance image of the right hemipelvis, with arrow denoting the paralabral cyst. (Reprinted with permission from SLACK Incorporated: Kelly B, Bedi A, Larson C. *Sports Hip Injuries: Diagnosis and Management*. Thorofare, NJ: SLACK Incorporated; due 2014, and from Zaltz I, Kelly BT, Hetsroni I, Bedi A. The crossover sign overestimates acetabular retroversion. *Clin Orthop Relat Res*. Epub 9 Nov 2012; doi: 10.1007/s11999-012-2689-5, with permission)

individual athletic needs and expectations. In the future, this technology may be combined with intraoperative computer-assisted navigation tools to ensure a complete resection during arthroscopy [35].

Magnetic resonance imaging

MRI and magnetic resonance arthrography (MRA) are imaging modalities frequently employed to evaluate the acetabular labrum, articular cartilage, joint capsule, and periarticular soft tissues such as bursae, tendons, and muscles (Fig. 1h) [36–38]. Generally, the benefits of MRI include the use of nonionizing radiation and its noninvasive nature. Images may be reformatted into the coronal, axial, sagittal, and oblique planes and can be obtained in thin slices (2 mm). Coronal images provide the optimal orientation for evaluation of the superior labrum and articular cartilage of the suprafoveal femoral head and lateral acetabular dome. The coronal plane is also advantageous for evaluating the hip abductors, short external rotators, ischiofemoral space, and the iliopsoas muscle–tendon units. The anterior labrum is best evaluated in the sagittal plane, and the articular cartilage of the femoral head and acetabular dome may also be evaluated in this orientation. The axial images allow for excellent visualization of the anterior and posterior acetabular chondrolabral complex, the iliopsoas tendon, and the sciatic, femoral, and obturator nerves. The bare area and ligamentum teres are evaluated on the axial images for the presence of loose bodies or tears, respectively. Axial images distally at the level of the femoral condyles are used to determine the femoral version [39]. Lastly, fat-suppressed images in all orientations should be examined for the presence of edema, fluid collections, or masses.

MRI is the gold standard imaging for evaluation of the articular cartilage and the chondrolabral complex in the

prearthritic painful hip. These images are particularly critical in decision making for cases with mild to moderate degenerative changes in the setting of dysplasia or FAI and may help to define those cases with significant articular cartilage injury that may not be evident on radiographs. Axial oblique images oriented along the axis of the femoral neck should be obtained to quantify the lack of femoral offset in cases of femoral-sided FAI. Chondrolabral tears, delamination, and degeneration can be identified on traditional T1-weighted 3-D fat-suppressed gradient echo sequences at the anterosuperior margin of the acetabular dome, the corresponding location of bony impingement [40]. Adjacent intraosseous ganglion cysts and iliofemoral ligament thickening are often concomitant findings. In isolated pincer-type FAI, the MRI may demonstrate intralabral ossification, a deep acetabulum, and posteroinferior chondral lesions [6, 41].

Advances are being made in quantitative imaging techniques to noninvasively assess articular cartilage quality and quantity with greater accuracy. A number of experimental techniques, not routinely used in clinical practice, are being investigated, including T2 mapping, charged gadolinium contrast, T1ρ, sodium MRI, and various other mapping techniques [42]. Within the past year, Apprigh et al. [43•] demonstrated the feasibility of using MRI T2 mapping to assess for early signs of chondral degeneration in the hip joints of 22 patients with symptomatic FAI. T2 mapping is a technique that can provide quantitative information about the collagen orientation and water content of the articular cartilage on the basis of the slope of the transverse relaxation time constant, T2. As the articular cartilage nears the subchondral bone, the relaxation times are shorter due to the high order of the collagen in the radial zone. In the transitional zone, near the articular surface, the relaxation times are prolonged. These differences in relaxation times allow for recognition of areas of early arthrosis even in the presence of cartilage that appears morphologically normal [44, 45]. Delayed gadolinium-enhanced MR imaging of cartilage (dGEMRIC) is an imaging modality that relies on the variable penetrance of the negatively charged diethylenetriaminepentaacetic acid gadolinium(III) dihydrogen salt (Gd-DTPA) into the articular cartilage. The negatively charged salt, Gd-DTPA, is repelled by the negatively charged glycosaminoglycans (GAGs) present in high concentration in healthy cartilage. The preferential uptake of the salt is seen in regions of low GAG concentration and, thus, can be used as a measure of articular damage. Patients must be cautioned that this technique requires an injection of a relatively large concentration of gadolinium and that the injection is followed by a period of exercise to distribute the gadolinium systemically [44, 46]. For those patients who are uncomfortable with the gadolinium injection or wish to pursue entirely noninvasive options, spin lattice relaxation in the rotating frame, known as T1ρ, is a cartilage-mapping technique that relies on regional differences in proteoglycan concentration of

cartilage and does not require contrast media. Elevated T1 ρ values are indicative of areas in which proteoglycan has been depleted, and thus the degeneration of cartilage has begun, even if the volume of cartilage appears normal on standard imaging [45, 47, 48].

Although the introduction of contrast makes a previously noninvasive procedure potentially more harmful, the increased risk is slight, and many surgeons often utilize MR arthrography to fully evaluate the painful hip. A recent meta-analysis [49•] concluded that, overall, the diagnostic accuracy of MRA was superior to that of MRI, and several studies have demonstrated the superiority of MRA in evaluating the acetabular chondrolabral complex [50–53]. Byrd and Jones [4] compared the diagnostic accuracy of traditional MRI with that of MRA for cartilage and labral pathology. They found MRI to be 25 % sensitive and 65 % specific for labral tears, while MRA was 66 % sensitive and 75 % specific. Similarly, in the evaluation of chondral lesions, MRI was 18 % sensitive and 100 % specific, while MRA was 41 % sensitive and 100 % specific [4]. The ability to administer local anesthetic and antiinflammatory medications at the time of contrast injection may provide some additional diagnostic information and therapeutic relief for the symptomatic or in-season athlete.

Diagnostic injections

Injections have proven to be an extremely valuable adjunct diagnostic and therapeutic tool in the approach to the painful prearthritic hip. While the duration and extent of relief is variable, fluoroscopically or ultrasonographically guided intraarticular injections of corticosteroid and local anesthetic medication should typically alleviate symptoms attributable to intraarticular pathology, such as labral tears, synovitis, mechanical impingement, and osteoarthritic changes. A failed response to a well-placed injection should prompt evaluation for extraarticular sources of pain and raise concern regarding the potential benefit of hip surgery without further evaluation. Symptom relief with an intraarticular injection has been shown to be 90 % reliable as an indicator of intraarticular hip pathology [4]. Peritrochanteric or lumbar pain may improve after an intraarticular injection, providing some evidence that these symptoms are likely secondary sequelae and compensatory injuries related to mechanical impingement of the hip that leads to abnormal kinematics and strain of the periarticular soft tissue envelope. Recognition of all potential pain generators is critical to thoroughly addressing all offending pathology at the time of surgery. Therefore, ultrasound-guided injections into the adductor cleft, pubic symphysis, sacroiliac joint, subspine space, psoas tendon, trochanteric bursa, or hamstring tendon origins

may be of diagnostic and therapeutic use if clinical symptoms warrant their application.

Conclusion

Following a thorough history and comprehensive physical examination, imaging of the hip should be performed to confirm a diagnosis and create a treatment plan. The implementation of these modalities should follow a standardized approach and work from least to most invasive. Radiography should be used as a screening modality but can offer significant information on the pathomorphology of the acetabulum and proximal femur in cases of prearthritic hip pain. CT and associated 3-D reconstruction images may be best for definition of the location and topography of deformity and can be utilized in conjunction with dynamic analysis software to understand the specific locations of mechanical conflict and impact of a surgical correction with a joint-preserving procedure. MRI and MRA are most useful in the evaluation of the articular cartilage surfaces and the chondrolabral complex, as well as extraarticular soft tissue pathology. Diagnostic injections are beneficial when it is difficult to discern intraarticular versus extraarticular pathology and to prognosticate the potential relief with a surgical procedure. Quantitative assessment of articular cartilage based on evolving MR sequences are areas of ongoing research that show great promise in advancing our understanding and treatment of the painful prearthritic hip.

Compliance with Ethics Guidelines

Conflict of Interest Asheesh Bedi is a paid educational consultant for Smith & Nephew. Alexander E. Weber and Jon A. Jacobson declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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