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Ultrasound guidance to perform intra-articular injection of gadolinium-based contrast material for magnetic resonance arthrography as an alternative to fluoroscopy: the time is now

Carmelo Messina [1] · **Giuseppe Banfi** [2,3] · **Alberto Aliprandi** [4] · **Giovanni Mauri** [4,6] · **Francesco Secchi** [4,5] · **Francesco Sardanelli** [4,5] · **Luca Maria Sconfienza** [4,5]

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Abstract Magnetic resonance (MR) imaging has been definitively established as the reference standard in the evaluation of joints in the body. Similarly, magnetic resonance arthrography has emerged as a technique that has been proven to increase significantly the diagnostic performance if compared with conventional MR imaging, especially when dealing with fibrocartilage and articular cartilage abnormalities. Diluted gadolinium can be injected in the joint space using different approaches: under palpation using anatomic landmarks or using an imaging guidance, such as fluoroscopy, computed tomography, or ultrasound. Fluoroscopy has been traditionally used, but the involvement of ionizing radiation should represent a remarkable limitation of this modality. Conversely, ultrasound has emerged as a feasible, cheap, quick, and radiation-free modality that can be used to inject joints, with comparable accuracy of fluoroscopy. In the present paper, we discuss the advantages and disadvantages of using fluoroscopy or ultrasound in injecting gadolinium-based contrast agents in joints to perform magnetic resonance arthrography, also in view of the new EuroSAFE Imaging initiative promoted by the European Society of Radiology and the recent updates to the European Atomic Energy Community 2013/59 directive on the medical use of ionizing radiation.

Key Points
- *Intra-articular contrast agent injection can be performed using different imaging modalities*
- *Fluoroscopy is widely used, but uses ionizing radiation*
- *Ultrasound is an accurate, quick, and radiation-free modality for joint injection*
- *X-rays should be avoided when other radiation-free modalities can be used*

Keywords Magnetic resonance arthrography · Ultrasound · Fluoroscopy · Ionizing radiation · Radiation protection

✉ Luca Maria Sconfienza
io@lucasconfienza.it

1 Scuola di Specializzazione in Radiodiagnostica, Università degli Studi di Milano, Via Mangiagalli 31, 20100 Milano, Italy

2 IRCCS Istituto Ortopedico Galeazzi, Via R. Galeazzi 4, 20161 Milano, Italy

3 Università Vita-Salute San Raffaele, Via Olgettina 58, 20132 Milano, Italy

4 Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Via Mangiagalli 31, 20100 Milano, Italy

5 Servizio di Radiologia, IRCCS Policlinico San Donato, Piazza Malan 1, 20097 San Donato, Milanese, Italy

6 Unità di Radiologia Interventistica, Istituto Europeo di Oncologia, Via Giuseppe Ripamonti 435, 20141 Milano, Italy

Abbreviations

MR	Magnetic resonance
MRA	Magnetic resonance arthrography
GBCM	Gadolinium-based contrast material
US	Ultrasound
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
CT	Computed tomography
EURATOM	European Atomic Energy Community

Magnetic resonance (MR) imaging has been definitively established as the reference standard in the evaluation of joints around the body, being capable of assessing thoroughly all articular components, such as tendons, ligaments, fibrocartilage, hyaline cartilage, and subchondral bone [1]. Similarly, MR arthrography (MRA) has emerged as a technique that has been proven to increase significantly the diagnostic performance if compared with conventional MR imaging, especially when dealing with fibrocartilage and articular cartilage abnormalities [2, 3]. Even with the advent of higher field equipment, the diagnostic accuracy of MRA proved to be still superior compared to conventional MR imaging, as shown by Magee [4]. MRA is commonly used for imaging of the shoulder, but it is also used for imaging of other joints, including the hip, the wrist, the elbow, the ankle, and the knee [5–7].

MRA can be performed with a direct or indirect approach. While the indirect approach implies the intravenous administration of 0.2 mmol/kg of a gadolinium-based contrast material (GBCM) [2], direct MRA is obtained with the injection of a solution of diluted GBCM into the joint space. This allows for safely distending joint space, thus highlighting even minimal abnormalities that may be missed at conventional MRI [2, 3, 8].

When ruling out certain diagnostic problems, direct MRA especially achieves almost the same sensitivity and specificity as the surgical reference standard [8–10]. For these reasons, in recent years, orthopaedic surgeons are increasingly prescribing this examination [11]. There are no official data regarding the number of MRA performed per year worldwide. In 2013 at our institution, a medium-sized university general hospital in Milan, Italy, out of 4,239 musculoskeletal MR examinations (excluding spine MRI), we performed 394 MRAs (9.3 %). This number is certainly expected to be higher in orthopaedic hospitals.

Diluted GBCM can be injected into the joint space using different approaches: under palpation using anatomic landmarks or using an imaging guidance, such as fluoroscopy, computed tomography (CT), MR imaging, or ultrasound (US) [2, 12]. In particular, fluoroscopy is still used in most institutions, being a low-cost, efficient, and easy technique [13, 14]. Nevertheless, fluoroscopic guidance has relevant disadvantages. First, it exposes both patients and operators to ionizing radiation. According to a report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) issued in 2010, which offers a wide assessment of the magnitude of medical radiation exposure around the globe between 1997 and 2007, the average effective dose of an X-ray arthrogram is 0.17 mSv [15]. This value is almost ten times higher than the effective dose of a postero-anterior chest X-ray, whose average effective dose is 0.02 mSv [16]. On the other hand, original data from Binkert et al. [17] showed an effective dose of 0.0015 mSv for fluoroscopy-guided injection of the glenohumeral joint, a dose that may even decrease using full-digital X-ray image detector. At any rate, even though it may seem a very small radiation dose compared to other diagnostic and interventional procedures using ionizing radiations, the cumulative dose on general population will result in an unjustified radiation exposure. This is of even greater importance, as MRA is usually performed on young adult patients. Moreover, it should be noted that the shoulder and hip are the most commonly imaged joints, and they are very close to highly radiosensitive organs, namely the thyroid and gonads, respectively, which are, therefore, inevitably irradiated. In the literature, we were not able to find any traces of the use of thyroid and pelvic lead shields used in patients being injected to perform MRA contrast injection under fluoroscopic guidance, thus confirming the lack of awareness on this topic. Second, additional time for planning and performing the procedure may be needed, particularly if the fluoroscopic suite is distant from the MR room. Of note, for MRA, the degree of visualization of intra-articular structures depends on the time elapsed between contrast injection and MRI. MRA of the shoulder and hip should be performed within 90 min, and MR arthrography of the wrist should be performed within 45 min after intra-articular injection to minimise absorption of the contrast agent and the loss of capsular distension [18].

Fluoroscopic guidance has some other drawbacks. During fluoroscopy, intra-articular needle placement should be confirmed with an injection of a small amount of iodinated contrast agents or adding iodinated contrast to the diluted

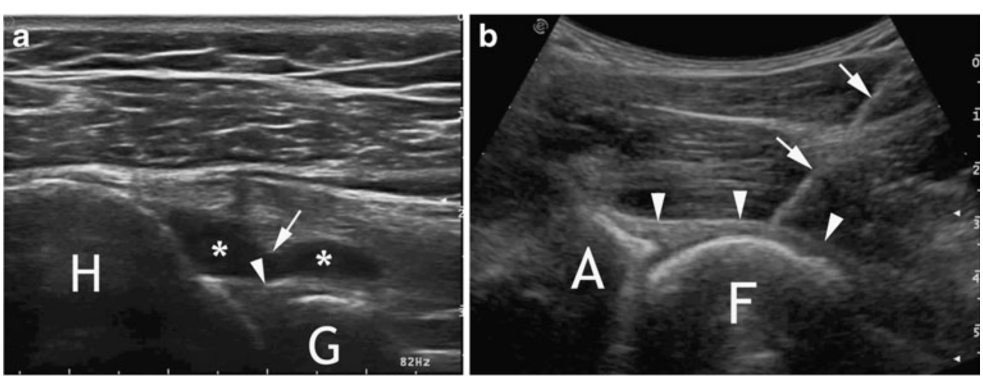

Fig. 1 Examples of ultrasound-guided intra-articular injections. (***a***) Posterior gleno-humeral injection with out-of-plane approach. Only the needle tip is visible (*arrow*). The posterior joint recess is distended by gadolinium-based solution (*asterisks*). *H* = humerus, *G* = glenoid, *arrowhead* = glenoid labrum. (***b***) Hip injection with in-plane approach. The needle shaft (*arrows*) is totally visible. *F* = femoral head, *A* = acetabulum, *arrowheads* = joint capsule

gadolinium. Nonetheless, iodinated contrast has been shown to influence the T1 and T2 relaxation times in a dose-dependent manner, producing altered contrast-to-noise ratios [19–21]. Finally, although feasible and easy to perform, fluoroscopy still rests on two-dimensional images.

Conversely, US guidance of musculoskeletal interventional procedures has been extensively reported to be safe and feasible [22–24], and it is also known to have multiple advantages. First, no ionizing radiation is delivered, thus preserving the integrity of both patients and operators. Second, the needle tip can be seen more effectively with US compared to fluoroscopy, as the whole length of the needle can be followed on its major axis. Also, the needle tip can be clearly seen entering the joint space, thus implying that no iodinated contrast is needed to confirm correct needle positioning. Third, small portable US systems can be located directly in a medication room adjacent to the MR suite. This implies that a dedicated room is not needed for this procedure and the time between injection and MRA examination is reduced to minimum (Fig. 1).

Arthrography is generally considered a safe procedure with few serious complications [25]. Of these, septic arthritis is the most feared by physicians, although its incidence is reported to be as low as 0.003 % [26]. Of note, a recent paper of Vollman et al. reports three cases of MRA-related infections followed by fluoroscopic injection of gadolinium. Authors propose that contamination source was related to barium swallow studies which preceded the arthrogram injections in the same room [27]. However, since the injection procedure itself is very similar when using both fluoroscopic or US guidance, complication rate is expected to be comparable. However, no papers are available comparing directly these two injection modalities.

Several papers evaluated the feasibility and accuracy of US-guided GBCM injection for MRA in different districts, also comparing US to other arthrographic techniques such fluoroscopy and CT [14, 28, 29]. They conclude that US is an effective alternate guidance modality for the injection of gadolinium into shoulder, hip, knee, and wrist joints for MRA. For the glenohumeral joint, Ng et al. concludes that US injection is comparable with fluoroscopic-guided injection in terms of patient comfort, time, and efficiency [14]. The success of shoulder injection seems to be comparable both using anterior and posterior approaches [30]. Similar results are shown for US guidance when used for MRA of the hip [29]. A recent review by Berkoff et al. investigated the effect of US guidance on different variables (needle placement, cost-effectiveness, clinical outcomes) in comparison with anatomical landmark-guided intra-articular injections [31]. Comparing 13 studies, they reported that US guidance of knee injections resulted in better needle placement accuracy compared to anatomical guidance (95.8 % versus 77.8 %, respectively). Also, the authors refer to a randomized controlled trial by Sibbit et al. in which they compared the clinical outcome of US-guided versus anatomical guided arthrocentesis and intra-articular corticosteroid injection, concluding that US guidance determined 48 % less procedural pain and 46 % less pain at 2 weeks [32]. US represents a feasible technique also for wrist and ankle intra-articular injections with a 100 % success rate, as shown by Choudur et al. in 2011 [33]. US-guided intra-articular elbow joint injections resulted in better intra-articular delivery than palpation-guided, as confirmed by Kim et al [34]. Clearly, the main advantage is that ionizing radiation is not involved.

One may argue that the use of fluoroscopy to inject patients is an approach of the past. To clarify this aspect, we empirically performed a quick search on the PubMed using "MR arthrography" as a keyword, including papers published in 2013. Out of 130 retrieved records, we selected 29 papers in which the guidance technique is clearly illustrated. Excluding one paper in which injection was performed using palpation guidance, the use of US is reported in six papers only (21 %), while the majority of authors (22 papers, 76 %) still prefer to use fluoroscopy to inject patients (unpublished data). Nevertheless, we included in this search all the anatomic districts. In certain regions, such as the wrist, the use of fluoroscopy may have a supplementary diagnostic value, even though it can be considered a different and separate examination from injection guidance itself. In other words, if fluoroscopy (i.e., conventional arthrography) is needed for whatever diagnostic purpose, it should be performed (and possibly reimbursed) as a separate examination, but the use of fluoroscopy with the mere purpose of joint injection is questionable. One reason for such a widespread use of fluoroscopic guidance may be because the use of US in the musculoskeletal system has only recently increased, especially in countries such as the United States, so that the preferred method to inject is traditionally fluoroscopy [35]. For the same reason, it is possible that radiologists feel more confident with fluoroscopy compared to US.

In the European Union, the exposure of patients to ionizing radiation for medical purposes has been traditionally ruled by the European Atomic Energy Community (EURATOM) with its 97/43/EURATOM directive dated 1997, adopted in the following years by all European countries. This directive was recently reviewed and updated, and the new text is contained in the directive 2013/59/EURATOM, which should be adopted by European countries during the coming years [36]. This directive makes the European Union unique, because no other country has something similar. In the United States, each single state has different regulatory mechanisms for the medical use of X-rays [36]. In chapter VII of 2013/59/EURATOM, entitled "Justification to medical radiation exposure" it is clearly stated that exposure should "take into account the efficacy, benefits, and risks of available alternative techniques having the same objective but involving no or less exposure to ionizing radiation" [36]. In other words, if an imaging modality without ionizing radiation can be reasonably used to achieve the same result, it should be invariably used. To be realistic, there is no real reason why US should not replace fluoroscopy to inject joints, except the mere preference and inclination of the individual radiologist. To pursue this goal, the medical and scientific community should be more focused on the promotion of special educational courses to spread the practical use of US in performing these procedures.

To embrace this necessity for coordinating radiation safety actions in medical imaging, the European Society of Radiology launched the EuroSAFE Imaging campaign during the 2014 European Congress of Radiology, in order to support and strengthen medical radiation protection across Europe, interacting with the regulatory bodies of the European Union and trying to increase awareness of both patients and radiologist on radiation protection in clinical practice. Still, a lot of work has to be done [37].

In conclusion, US has emerged as an easy, cheap, effective, and radiation-free imaging modality to perform interventional procedures in the musculoskeletal system, particularly to perform joint injections for MRA. The use of fluoroscopy in this field should be restricted to very specific cases, namely when US is not available or cannot be used for certain reasons. Last, our community should promote education of musculoskeletal radiologists, both on the use of US in performing musculoskeletal procedures and on the potential damages and legal issues deriving from unjustified radiations exposure. "Progress is impossible without change, and those who cannot change their minds cannot change anything" (George Bernard Shaw).

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