Use of ultrasound–magnetic resonance image fusion to guide sacroiliac joint injections: a preliminary assessment

M. Zacchino · J. Almolla · E. Canepari ·
V. Merico · F. Calliada

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Abstract

Background The sacroiliac joint is one of the sources of chronic lower back pain. Intra-articular injections of anesthetic drugs and/or steroids are currently used in these cases for diagnostic and therapeutic purposes. However, given the anatomic and functional complexity of the joint, imaging guidance is mandatory during such procedures. In this context, the technique of fusing images obtained with two different modalities can often overcome the limitations and enhance the advantages of single-modality guidance. **Aim** The aim of this study was to evaluate the technique of ultrasound (US)–magnetic resonance (MR) image fusion to guide intra-articular injections of drugs into the sacroiliac joint.

Materials and methods We evaluated seven sacroiliac joints in six patients with sacroiliac pain syndrome (four females, two males; mean age 59 years; range 46–76 years). Five were candidates for radiofrequency thermolysis, and a therapeutic nerve block was performed in the sixth. Using the volume navigation system, we fused three-dimensional MR images with simultaneously acquired real-time ultrasound images and used them to guide the intra-articular injections.

Results In all patients, spatial accuracy was considered excellent, with definition of registration errors of less than 3 mm. The diagnostic blocks produced positive results in all patients with 80 % reductions in pain (measured with a Numerical Rating Scale, NRS) relative to baseline. The patient who underwent the therapeutic nerve block

experienced complete resolution of symptoms that has been maintained over time. There were no complications. **Conclusions** US–MR imaging fusion guidance of sacroiliac joint injections is feasible and effective, in accordance with the data in the literature. The use of the MR for three-dimensional imaging eliminates the risk of radiation exposure.

Keywords Image fusion technique · Sacroiliac joints · Ultrasound

Riassunto

Background il dolore sacro-iliaco è una delle cause di dolore lombare cronico. L'infiltrazione intra-articolare di farmaci anestetici e/o steroidi, costituisce uno strumento correntemente utilizzato a scopo diagnostico e terapeutico. Tuttavia, la complessità anatomico-funzionale dell'articolazione impone l'utilizzo della guida imaging all'infiltrazione. La fusion imaging si pone in questo contesto come strumento che risolve i limiti delle singole metodiche e ne amplifica i vantaggi.

Scopo l'obiettivo del nostro lavoro è valutare la fusion imaging come strumento per la guida della somministrazione farmacologica intra-articolare dell'articolazione sacro-iliaca, utilizzando la co-registrazione di immagini ecografiche e di risonanza magnetica.

Materiali e Metodi sono state valutate 7 articolazioni sacro-iliache in 6 pazienti (4 femmine, 2 maschi; età media 59 anni; range 46–76 anni) con sindrome dolorosa sacro-iliaca; 5 candidati al trattamento di termolesione, 1 sottoposto a blocco terapeutico. L'iniezione intra-articolare è stata condotta con la guida della fusion imaging ottenuta con i dati tridimensionali RM visualizzati in maniera simultanea alle immagini real-time ecografiche mediante l'utilizzo di un "volume navigation system".

M. Zacchino (✉) · J. Almolla · E. Canepari · V. Merico · F. Calliada
IRCCS Foundation, San Matteo Medical Center,
Institute of Radiology, University of Pavia, Pavia, Italy
e-mail: michelazacchino@gmail.com

Risultati l'accuratezza spaziale è stata considerata ottimale in tutti i pazienti, con definizione di valori di errore di registrazione inferiori ai 3 mm. Il blocco diagnostico è risultato positivo in tutti i pazienti con riduzione del dolore (misurato con scala Numerical Rating Scale, NRS) dell'80 % rispetto al basale. Il paziente sottoposto a trattamento terapeutico ha mostrato una completa risoluzione della sintomatologia, mantenuta nel tempo. Non si è verificata nessuna complicanza.

Conclusioni la guida fusion nell'infiltrazione delle articolazioni sacro-iliache si è confermata attuabile ed efficace in linea con i dati presenti in letteratura. L'utilizzo della RM come imaging tridimensionale ha il vantaggio di annullare il rischio di esposizione radiante.

Introduction

Ten percent of the cases of chronic lower back pain are related to disorders of the sacroiliac joint [1]. The most accredited method for diagnosing these cases is based on a positive response to intra-articular injection of anesthetics [2]. Sacroiliac pain can be caused by a variety of factors that alter rotational and axial loading, producing damage to several anatomical/functional components of the joint. From an operative point of view, intra-articular and extra-articular causes can be distinguished, and the former category includes both inflammatory and infectious factors.

The aim of therapy is to eliminate the cause of the pain or, when this is not possible, to eliminate the symptoms. Available treatment methods include conservative approaches (medication or physical therapy) and more invasive interventions involving intra-articular injections of anesthetics and/or corticosteroids or radiofrequency joint denervation procedures. If the response to conservative therapy is unsatisfactory, intra-articular drug injections are indicated. Therapeutic nerve block should be done if the diagnostic nerve block produces a reduction in symptom severity of 80 % [1].

The sacroiliac joint is a complex anatomical-functional unit consisting of a fibrous posterosuperior portion and an anteroinferior synovial component. Because of its structural complexity, injections into the sacroiliac joint are particularly difficult to perform, and without radiological guidance, successful results are rare. Rosemberg et al. [3] reported a success rate of 22 % for injections performed without radiological guidance.

There is a large body of scientific data on the various imaging modalities that can be used to ensure proper intra-articular injection of drugs and the advantages and disadvantages of each option. They include fluoroscopy, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound.

Thanks to the development of ultrasound machines equipped with navigation and dynamic positioning systems, it is now possible to combine real-time ultrasound images with previously acquired CT or MR data. The advantages of various imaging techniques can, thus, be combined in the context of an ultrasound examination, and this is the central aim of the technique known as image fusion. Thus far, image fusion has been used to guide a variety of diagnostic and interventional applications. In the field of pain management, the group headed by Galiano was the first to use image fusion as an aid for teaching the technique of periradicular and facet joint injections into the lumbar and cervical spine. The approach they used involved simultaneous visualization of anatomic landmarks on ultrasound and CT images [4].

The first studies published on the use of fusion imaging in in vivo locoregional anesthesia were conducted by Zacchino et al. and Klauser and colleagues [5, 6]. The former group evaluated the feasibility of performing pudendal nerve blocks using US-3DCT image fusion as a guide. The innovative aspect of this approach is that it facilitates placement of the needle in Alcock's channel, which is generally difficult with CT or US guidance alone. Image fusion also furnishes additional anatomic details that are useful for executing the nerve block. For example, the pudendal vascular bundle and the sacrotuberous and sacrospinous ligaments can be visualized with the same modality, independent of the depth of the nerve. At the end of the procedure, there was an immediate resolution of the pain [5].

The aim of the present study was to evaluate image fusion for guiding drug injections in the sacroiliac joint. In contrast to previous studies of this type reported in the literature, we used MR instead of CT for volumetric imaging, which further reduced the risk of radiation exposure.

Materials and methods

Patients

We evaluated seven sacroiliac joints in six patients with suspected sacroiliitis (four females, two males; mean age 59 years; range 46–76 years). Five were candidates for radiofrequency thermolysis performed with the SIMPLICITY catheter, and the sixth was treated with a therapeutic nerve block. Each patient gave informed consent to the intra-articular joint injection procedure and to the MR examination. All patients were evaluated for lumbar pain in the Pain Management Outpatient Clinic of our hospital. Two patients had failed back surgery syndrome (FBSS), and one had been diagnosed with rheumatoid arthritis.

Patients were enrolled using the following inclusion criteria:

- Clinical findings consistent with pain related to the sacroiliac joint (characteristics of reported pain and pain radiation patterns)
- Positive findings on physical examination
- Exclusion of other possible causes of pain
- Failure of conservative therapy

When sacroiliitis was suspected, patients were treated with a cycle of ultrasound-guided sacroiliac joint injections of local anesthetic and steroids (therapeutic nerve block). When this approach produced relief of the patient's pain that lasted less than 6 months, a diagnostic double-block procedure was performed under image fusion guidance. In fact, when therapeutic nerve block fails to provide satisfactory relief but the pain is still believed to originate from the sacroiliac joint, the evidence-based treatment protocol used in our Pain Management Clinic provides for radio-frequency denervation. The latter procedure, however, must be preceded by the double-block test, which involves two intra-articular injections of local anesthetics, one with a short-acting drug and the second (performed 1 week after the first) with a longer-acting product. The test is considered positive when patients report pain reductions on the NRS scale of at least 80 %, compared with baseline scores, with a duration compatible with that of the specific local anesthetic used.

In one patient, image fusion was also used in the preliminary stage to guide the therapeutic intra-articular injection.

Exclusion criteria were:

- Contraindications to the administration of local anesthetics or steroids
- Uncontrolled coagulopathy
- Pregnancy
- Contraindications to MRI.

The presence of a cardiac pacemaker is an absolute contraindication to the use of MRI, but it is also a specific contraindication to the use of any type of image fusion (US–MR or US–CT) since it can also interfere with the electromagnetic navigation system.

Technique

The ultrasound examination was performed with a 6–14 MHz linear-array transducer (LOGIQ E9; GE Healthcare, Milwaukee, WI, USA) with patients lying prone and their arms crossed under their heads.

In a previous session, each patient had undergone MRI (Siemens Magnetom Symphony 1.5T; Siemens, Erlangen, Germany) for three-dimensional (3D) data acquisition with a 3D constructive interference in steady state (CISS) sequence. The patient was placed in the same position described above. The field of view extended from the lower border of the body of L4 to the ischial tuberosities. The purpose of the MRI was to provide 3D data for fusion with the US images, and also to define the anatomic and pathologic features of each case, which were important for planning the intervention.

Image fusion was achieved with volume navigation technology, which associates US and volumetric data with the aid of a magnetic sensor that localizes the position of the ultrasound transducer. The first step is to link the different elements to the US system's positioning system, which includes a transmitter placed near the region being examined and a dual-sensor receiver attached to the ultrasound transducer. The sensors record changes in the position, rotation, and orientation of the probe within the magnetic field created by the transmitter. Subsequently, the previously acquired MRI data, stored in DICOM format on a CD-ROM support, are imported into the ultrasound scanner using the volume navigation system. They appear

Fig. 1 Visualization of the sacroiliac joint

Fig. 2 Sonographic visualization of the advancement of the needle

on the monitor in split view with the ultrasound images acquired in real time.

A co-registration algorithm is used to integrate the data from the two sources. When the data have been associated, the navigation system allows the operator to move over the MR images simply by changing the orientation and position of the probe. The crucial step of the procedure is when the two image formats are combined they move synchronously. Fusion of the US and RM data in the same coordinate system is achieved with the aid of anatomical landmarks that can be readily identified with both imaging modalities. The first landmark used was a plane passing through the body of L5 (plane registration). To ensure correct overlap of the ultrasound and MR images and RM, we defined four other appropriate anatomical landmarks with both methods (point registration). These landmarks, which were used in all patients, consisted of the apex of the spinous process of L5; the right and left sacral horns at the level of the sacral hiatus; the apex of the intergluteal line in the skin plane. The US and MR images are displayed on the monitor in parallel, and the ultrasound scan area is outlined on the MR image with a green box (Fig. 1). When the point registration has been completed, the software automatically calculates the registration error, which represents the discrepancy between spatial coordinates on the MR volume and those on the ultrasound image.

The procedures described above were carried out after a sterile field had been established and a sterile cover placed over the ultrasound transducer. The fused images were then used as a guide during intra-articular placement of a spinal needle with a Quincke-type tip (22 G; 3.50 × 0.7 mm) (Fig. 2). During the diagnostic procedures, two injections were made, 1 week apart, and the operator was blinded as to the local anesthetic used (lidocaine 2 %, 1 ml, or 0.1 % ropivacaine, 1 ml). In the therapeutic procedures, ropivacaine 0.1 % (4 ml) was used for the first injection and methylprednisolone acetate (40 mg) for the second, which was performed 1 week later. Each patient

was asked to rate the severity of his/her pain before and after each session using the numeric rating scale (NRS). The patients were reassessed 1 week after treatment in the Pain Management Outpatient Clinic.

Results

Clinical and radiological outcomes were assessed in all patients. The latter involved assessment of the feasibility of the procedure on the basis of the registration error calculated by the software itself. In all patients, the error was kept below the predetermined cut-off of 3 mm considered acceptable for the purposes of the procedure. If the error exceeded the cut-off, registration was repeated and greater precision was applied in defining the anatomical landmarks. Registration errors tended to decrease over time (although this trend was not statistically defined) as the operator's experience and skills increased.

Clinical outcomes were positive in all cases: the double-block test with local anesthetics reduced the patients' pain (self-reported via NSR) by more than 80 % (compared with pretreatment baseline scores) and the duration of the effect was compatible with that of the drug used. Of the five patients who underwent diagnostic double-block testing, three have already sacroiliac joint denervation, one is scheduled to undergo this treatment, and the fifth has been lost to follow-up. The patient who underwent therapeutic nerve block experienced complete and immediate pain relief that persisted over time (NSR at the 6-month follow-up: 0). There were no procedure- or drug-related complications.

Discussion

The enrolled patients were evaluated in our hospital's Pain Management Outpatient Clinic with a protocol that allowed

us to make a diagnosis of sacroiliac joint-related pain that was eligible for treatment with radiofrequency thermolysis performed with a SIMPLICITY catheter. Imaging studies were carried out in a nonsystematic manner, i.e., depending on the features of each case, with the aim of excluding other organic causes (local or systemic) of the pain. The patients were then treated with intra-articular injections of local anesthetics and steroids. Radiofrequency thermolysis was considered to be indicated when the local therapeutic intervention had failed and the results of the image fusion-guided double-block test confirmed that the pain was indeed related to the sacroiliac joint.

As noted above, the sacroiliac joint has a complex anatomical structure that makes imaging guidance mandatory during intra-articular injections. In our cases, precise location of the anesthetic injection was fundamental for confirming the sacroiliac origin of the pain and for subsequent treatment. This is why imaging guidance is so important during interventional procedures.

There is a large body of literature on this topic, which provides an estimate of the currently used methods with pros and cons for each.

Dussault et al. proposed fluoroscopic guidance as fast, safe, reproducible method. Real-time verification of the intra-articular position of the needle can be achieved by injecting a few milliliters of iodinated contrast medium. The drug injections were effective in 64 % of the joints they treated, with pain reduction amounting to 50 % or more 10 min after treatment [7].

Magnetic resonance has also proved to be an effective guide for intra-articular injections administered to treat sacroiliac pain. In a well-designed study reported in 2008, Fritz et al. demonstrated the effectiveness of MR guidance during diagnostic and therapeutic injections. They used a high-field magnet that was wide enough to allow easy access to the sacroiliac region and MR-fluoroscopy, a method resembling real-time imaging characterized by the high-speed acquisition of two-dimensional sequences. Intra-articular injections (documented thanks to the addition of a few milliliters of paramagnetic contrast medium to the drug) were achieved in 95.4 % of the 108 procedures that were performed successfully. The mean duration of the injection phase was about 22.5 min [8].

Computed tomographic guidance is still the most frequently used method, in part because of its efficacy, but also because it reduces procedure times. Although the latter varies from study to study, around 15 min are usually required for treatment of a single joint and 25–30 min for bilateral injections [9]. CT guidance, however, is associated with radiation exposure ranging from 10 to 30 mGy/min, and this can be an important drawback when the patient is young or when treatment has to be repeated. Although both CT and MRI offer high contrast and spatial

resolution, they are also expensive, time-consuming, and require sophisticated technical equipment.

The first reported experience with ultrasound guidance dates back to 2003, when Pekkaali et al. evaluated its feasibility and efficacy during intra-articular injections to treat sacroiliac pain. The reported rate of intra-articular injections was 76.7 %, with a mean procedure time of 9 min [10]. One of the advantages of sonographic guidance is that it reduces radiation exposure for patients and operators, which means that it can be used on patients of reproductive age and those who require repeated treatment. The technique provides effective real-time visualization of the needle as it advances and of the diffusion of the drug within the joint space. Moreover, compared with MR and CT, ultrasound is more widely available, easier to learn, and less costly in terms of the use of equipment, staff, and facilities.

To promote standardization, Migliore et al. [11] provided a clear explanation and definition of the sonographic technique and introduced the use of color-Doppler imaging for visualizing the diffusion of the injected drug. The most important contribution in optimization of the technique has been made by Klauser et al. who demonstrated the fundamental importance of precisely defined anatomical landmarks in facilitating intra-articular injections and reducing the incidence of incorrectly placed (i.e., extra-articular) drug delivery. They reported a success rate of 100 % with a mean procedure time of approximately 3 min [12].

However, the success of an ultrasound-guided intra-articular injection depends not only on the experience of the operator, but also on the characteristics of the patient and the stage of the disease. Indeed, image resolution is known to be influenced by the patient's body mass index (BMI) as well as by the presence of osteophytes, joint space reduction, and/or ankylosis related to the disease itself. Pekkaali et al. [10] reported a failure rate of 23.3 %. Klauser and colleagues [6] identified two possible levels of injection in the sacroiliac joint and reported successful intra-articular injections in all the ten patients they treated: the needle was successfully placed in the lower portion of the joint in 8/10 patients and in the upper portion in the remaining two (20 %).

In our Pain Management Clinic, ultrasound guidance is currently used for both therapeutic and diagnostic intra-articular injection procedures. However, the increasing need for more accurate techniques capable of circumventing the limits discussed above has stimulated interest in complementary techniques. Image fusion is one of the options available for improving guidance performance.

Image fusion

The fusion system allows simultaneous display of images from an ultrasound study and those previously acquired

with either CT or MRI. The MR/CT study generates a set of three-dimensional data representing the patient's anatomy, which can be easily stored in the DICOM format. Ultrasound is a widely used image technique, and with the aid of volume navigation technology, previously acquired, static data on the patient that has been acquired with CT or MR can be virtually projected onto the space being investigated in real time with ultrasound. During the study, the ultrasound system simultaneously displays the images being acquired sonographically in real time and the corresponding MR or CT image of the same anatomic area.

The images can be viewed in different layouts. They can be displayed side by side with the ultrasound image on one side of the monitor and the corresponding MR/CT on the other side (split screen image). In this case, the magnification of the MR/CT and US images can be adjusted synchronously. The operator can thus see structures within the limited field of view of the US and, thanks to the MR/CT image, the area outside this field as well, but in the same plane. Image fusion, thus, combines the advantages of the wide field of view offered by CT and MR with the restricted view offered by ultrasound.

Other software packages allow a display of the superimposed MR/CT and US images.

Image fusion allows registration of three-dimensional data with real-time ultrasound data. This is done with an electromagnetic transmitter placed near the patient and two sensors associated with the transducer. All these components are connected to a GPS system that tracks the position of the transducer and correlates it with the three-dimensional MR or CT data.

With the fusion technique, each imaging modality compensates for the limitations of the other. In particular:

- Ultrasound provides a restricted field of view. MRI/CT allows one to expand the field of view without sacrificing contrast resolution.
- Ultrasound provides real-time imaging that can be useful during a variety of interventional procedures.
- With image fusion, images acquired with color-Doppler or CEUS can also be superimposed on the CT/MR images.
- Reduction of the number of exposures to ionizing radiation, costs, and time.

The crucial phase of the procedure is the intermodal registration, which involves careful identification of anatomic landmarks in both sets of images. Spatial accuracy and its assessment during an intervention are critical issues, especially when image fusion is used to guide diagnostic or therapeutic interventions involving hepatic lesions or other anatomical structures. In the system used by our group, concordance between the two sets of images (i.e., the spatial accuracy of the co-registration), was judged to be optimal when the registration error was less than 3 mm. If

larger errors were observed, the system was reset and the entire procedure repeated, using the same set of landmarks, until the error had been reduced to an acceptable level. The registration error represents the discrepancy between a distance measured on the three-dimensional volume and that measured on the real volume. It must be kept low to ensure that the correct coordinates are delivered to the system, and this is especially important if the data are being used in an interventional procedure.

Klauser evaluated the use of CT and US image fusion to guide sacroiliac joint injections in ten cadavers and ten joints in seven patients. The basic concepts are similar to those of intra-articular injections at other sites: anatomical landmarks were thus chosen to allow fusion of the CT and US images, i.e., the spinous process of the fifth lumbar vertebra (L5), the posterosuperior and posteroinferior iliac spines, the first and second posterior sacral foramina, and the sacroiliac joint itself. In addition, anatomic features such as osteophytes were also used as landmarks when they were visualized with both methods. The technique proved to be feasible in all cases, with recording errors ranging from 0.2 to 0.4 mm in patients and even lower errors in the cadaver studies. The overall success rate was high, also in terms of the clinical outcome (pain relief based on pre- and post-procedure scores). The mean overall procedure time was approximately 20 min with a mean image registration time of around 15 min [12].

To ensure reproducibility in our study, we used the same anatomical landmarks in all cases (i.e., additional findings such as osteophytes were not considered). A reference plane at the level of L5 was used for the purposes of preliminary orientation. This was subsequently refined with the use of surface landmarks, such as the cranial extremity of the intergluteal cleft (assessed without applying undue pressure with the transducer), and three deeper bony landmarks at the level of the spinous process of L5 and the right and left sacral horns at the sacrococcygeal transition.

In choosing the osseous landmarks, the objective was to use cortical contours with reduced anteroposterior and transverse dimensions, limited depth, and relatively little overlying muscle and subcutaneous tissue. Our initial experience had revealed reduced spatial concordance and high registration errors when we used extended cortical contours with a large radius of curvature as landmarks (e.g., the edge of the iliac bone or the ala of the sacrum). The intergluteal cleft also satisfied this criterion, with the added advantage that it could be directly visualized by the operator. In addition, the apex of the spinous process of L5 is widely used as a landmark in the treatment of pain, because it can also be objectively evaluated.

Our case series comprised six patients (for a total of seven joints). Six of the joints were injected for diagnostic

purposes and the seventh with therapeutic intent. None of the procedures was associated with complications.

For interventions involving the sacroiliac joint, limitations related to respiratory movements or patient position are for the most part clinically irrelevant. In line with previous studies (20), our MR images were acquired with the patients lying prone and their arms beneath their heads, the same position assumed during the intra-articular injections. This position, which is relatively comfortable for most patients, is mandatory during registration of the MR and US data sets and during the interventional procedure itself.

Once the tip of the needle has been advanced into the hypoechoic joint space, it can no longer be visualized directly on the real-time ultrasound images. To avoid unnecessary radiation exposure, we did not verify correct placement of the needle with fluoroscopy or CT. However, the efficacy of the technique was verified clinically with the double-block test, which was positive in all cases. The single patient who underwent therapeutic nerve block experienced long-lasting relief of symptoms and, therefore, did not require further assessment.

Our experience confirms previous reports on the efficacy of image fusion as a guide for sacroiliac joint injections [12] and provides the first data on the feasibility of US–MR image fusion for this purpose. Aside from the advantages of three-dimensional imaging, the use of MRI also eliminates the problem of radiation exposure, and in some cases the images can also be useful for assessing joint inflammation.

The limits of our study lie mainly in the small number of cases examined, which is, however, fairly similar to that of other studies reported in the literature [12]. In addition, the efficacy of the technique was documented radiologically on the basis of the registration errors, but correct intra-articular placement of the needle tip was not verified with another imaging modality.

Conclusions

The ideal technique used for imaging guidance in interventional procedures provides clear anatomical definition of the target and adjacent structures, together with real-time, multiplanar visualization.

Image fusion has proved to be useful in guiding sacroiliac injections. The spatial and contrast resolution of volumetric modalities such as CT or MR combined with the extended field of view and real-time capabilities of ultrasound are essential for carrying out interventional procedures safely (without inadvertent penetration of blood vessels, hematoma formation, etc.).

Our experience confirms previous reports on the feasibility and efficacy of this type of guidance during infiltration of the sacroiliac joint.

When planning the procedure, the following essential points must be kept in mind:

- The patient must be placed in the same position for the MRI and US examinations;
- Anatomical landmarks must be chosen that can be recognized easily and reproducibly with both imaging modalities;
- Spatial accuracy should be as high as possible and must be documented.

Conflict of interest M. Zacchino, J. Almolla, E. Canepari, V. Merico and F. Calliada declare that they have no conflict of interest.

Informed consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 (5). All patients provided (written) informed consent to enrolment in the study and to the inclusion in this article of information that could potentially lead to their identification.

Human and animal studies The study described in this articles did not include any procedures involving humans or animal.

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