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INTERVENTIONAL MSK PROCEDURES SPECIAL FEATURE: REVIEW ARTICLE

Paediatric musculoskeletal interventional radiology

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ABSTRACT

Interventional radiology technique is now well established and widely used in the adult population. Through minimally invasive procedures, it increasingly replaces surgical interventions that involve higher percentages of invasiveness and, consequently, of morbidity and mortality. For these advantageous reasons, interventional radiology in recent years has spread to the paediatric age as well. The aim of this study was to review the literature on the development, use and perspectives of these procedures in the paediatric musculoskeletal field. Several topics are covered: osteomuscle neoplastic malignant and benign pathologies treated with invasive diagnostic and/or therapeutic procedures such as radiofrequency ablation in the osteoid osteoma; invasive and non-invasive procedures in vascular malformations; treatment of aneurysmal bone cysts; and role of interventional radiology in paediatric inflammatory and rheumatic inflammations. The positive results that have been generated with interventional radiology procedures in the paediatric field highly encourage both the development of new *ad hoc* materials, obviously adapted to young patients, as well as the improvement of such techniques, in consideration of the fact that children's pathologies do not always correspond to those of adults. In conclusion, as these interventional procedures have proven to be less invasive, with lower morbidity and mortality rates as well, they are becoming a viable and valid alternative to surgery in the paediatric population.

MUSCULOSKELETAL MALIGNANT TUMOURS

Osteosarcoma, Ewing sarcoma and rhabdomyosarcoma are the most common musculoskeletal tumours of childhood and adolescence.¹ Osteosarcoma is the most common malignant bone tumour with an incidence of 4.4 cases per million.^{1,2} Ewing sarcoma is the second most common malignant bone tumour with an incidence of 2.9 cases per million and can also involve soft tissues.^{1,3} Rhabdomyosarcomas account for more than half of the soft-tissue sarcomas in children, with an incidence of 4.5 cases per million children and adolescents per year.^{1,4} Although modern radiological imaging techniques have a good predictive value in differential diagnosis, percutaneous core needle biopsy (PCNB) of musculoskeletal tumours is usually necessary to obtain a definitive diagnosis and provide optimal management and treatment of the neoplasm.^{5,6} The treatment of choice in musculoskeletal paediatric malignant tumours is primary or neoadjuvant chemotherapy. Smaller tumours are directly surgically removed.⁶ While at some institutions open surgical biopsy is still considered the gold standard to obtain adequate tissue samples, imaging-guided PCNB is emerging as an

important diagnostic tool for sampling a variety of lesions thanks to its relative ease, safety and cost-to-benefit ratio.⁶⁻⁸ PCNB allows an earlier administration of chemotherapy or radiation therapy, while a delay even up to 3 weeks is required after surgical biopsy because of wound healing time to avoid infection and bleeding.^{6,9} The overall diagnostic success rate of musculoskeletal PCNB reported in literature^{6,7,9-13} is significantly high (80–90%). In particular, Mitton et al⁹ refer a success rate of 93% for the malignant lesions. According to imaging findings, suspected diagnosis and treatment options, planning of PCNB should be co-ordinated between the interventional radiologist and the surgeon. The biopsy needle tract should be incorporated into the final surgical excision if surgery is the ultimate procedure of local tumour control.^{1,6,11} Ultrasound guidance is preferred to PCNB of superficial soft tissue masses or superficial bone lesions with cortical interruption and involvement of adjacent soft tissues.^{6,8,9} The advantages of ultrasound technique are the ready availability, low cost, true real-time imaging and lack of ionizing radiation. However, the lack of high-resolution tissue penetration and acoustic shadowing from bone and gas

does not allow its use in the deep lesions.⁸ CT and fluoroscopic guidance are the first choice for PCNB of deep bone tumours, extremity skeletal lesions and complex skeletal regions.^{8,11} CT-guided needle biopsy helps to avoid neurovascular bundles and vital organs, providing safe biopsy route.^{9,12} However, ionizing radiation is a disadvantage of CT PCNB in the paediatric population. During the CT-guided PCNB, the tube current–exposure time has to be markedly reduced to the lowest level that permits adequate visualization of the lesion.^{8,10} Patel et al¹⁴ demonstrated the feasibility of performing CT-guided biopsies with acceptable image quality and diagnostic accuracy using the lowest possible scanner settings for tube current and voltage. MRI is a further imaging guidance tool for musculoskeletal PCNB. The high MRI contrast resolution allows detailed visualization of both the lesion and the oedema within the tissues, even without the use of the contrast media. As MRI does not require the use of ionizing radiation, this is highly advantageous in the paediatric population. MRI-guided PCNB could be particularly challenging owing to its high costs, complexity of instruments and devices in the room and safety issues. Moreover, some devices used for MRI-guided PCNB are not always ideal for penetrating through the cortical bone. Even if there is lacking evidence on large patient samples on the evaluation of the diagnostic value of MRI in musculoskeletal biopsies, Kerimaa et al⁸ reported that MRI-guided PCNB is safe and feasible. All musculoskeletal PCNBs are performed under general and local anaesthesia and in sterile conditions.^{6,12} Coaxial biopsy system is usually preferred for the soft-tissue lesions. The coaxial introducer allows multiple sampling from a single percutaneous puncture and minimizes seeding risks and damage to the surrounding tissues. Samplings of 13–23 mm are obtained through either full-automatic or semi-automatic 16- to 18-G needle. Moreover, coaxial system allows the placement of particles of absorbable haemostatic sponges in case of venous bleeding from the lesions.^{1,5,6} Bone lesions with or without intact cortex are usually carried out with Trap System (HS Hospital Service Spa, Rome, Italy). This device drills the cortex and allows sampling of both bony and soft tissue parts of the tumour.^{5,10} Fine needle aspiration (FNA) of the bone marrow for the cytology can also be performed through the introducer sheath of the Trap System after the biopsy.^{8,13} Multiple biopsy specimen samples—usually 4 to 6—are promptly collected by an experienced musculoskeletal pathologist during the procedure for primary histology, immunochemistry and fluorescence *in situ* hybridization.^{6,9,13} PCNB complications are represented by bleeding, infection, fracture or neoplastic seeding of the needle tract. However, the low complication rate reported in literature demonstrates the safety of imaging-guided PCNB.^{6,9,12} Future prospects for image-guided PCNB can be represented by the use of contrast-enhanced ultrasound, cone beam CT with image fusion and the positron emission tomography/CT-guided biopsies. These new techniques could be useful in lesions not reliably highlighted by conventional imaging.^{8,9,15–17} Surgical treatment of bone tumours can often be complex owing to large tumour size, hypervascularization and anatomical localization of the lesion. Moreover, massive blood loss during surgery could be a severe life-threatening complication. Tumour location in the pelvis or spine often requires pre-surgical selective embolization as a useful adjuvant treatment to minimize intraoperative blood

loss and improve the tumour resectability.^{18–22} Pre-operative angiography must identify tumour-feeding vessels. Particular attention should be paid to the visualization of spinal arteries—artery of Adamkiewicz—in case of the spine neoplasms.^{18,21} Commonly used embolic agents are the absorbable gelatin sponge (AGS) and polyvinyl alcohol (PVA) particles, coils and glue. AGS and PVA are usually preferred for distal embolization. Particularly, AGS allows a temporary occlusion and is degraded by enzymes between 7 and 10 days. PVA are insoluble non-absorbable inert particles that occlude tumour vessels proximal to or at capillary bed. Coils are useful for proximal and permanent arterial occlusion. Surgery should be performed 24 h after the radiological interventional procedure to prevent recanalization.²² Pre-operative embolization of hypervascular musculoskeletal tumours is a safe and effective technique able to reduce intraoperative blood loss.^{18–22}

MUSCULOSKELETAL BENIGN TUMOURS

Image-guided bone biopsies play an important role in the diagnosis of benign bone lesions using FNA and core cytology bone biopsy (CCBB). CT is generally the imaging technique chosen to guide the biopsy procedure as it offers great precision in terms of the access route and in relation to the intralesional sampling. Although the “gold standard” in terms of accuracy is the surgical biopsy, percutaneous technique associated to CCBB and FNA has very similar accuracy in terms of cost-to-benefit ratio.^{23,24} However, despite the reduced invasiveness of the percutaneous biopsy, the presence of the following contraindications should be taken into account: bleeding diathesis, thrombocytopenia, systemic or local infections on the bioptic path, non-co-operation of patients and highly vascularized lesions. Overall, the percentage of complications reported in literature²³ (especially bleeding, infections, nerve damage) is about 0.2–2%, significantly lower than the percentage for surgical biopsy (2–20%).

Osteoid osteoma

Osteoid osteoma (OO) is a benign osteoblastic tumour which represents 10–12% of all benign bone tumours and 2–3% of all primary benign tumours.^{25,26} Although age of onset varies from a few months to 70 years, the majority of patients are adolescents and young adults: in 85% of cases, age at onset is between 5 and 24 years.²⁷ There is a strong male predominance with a ratio between males and females ranging between 1.6:1 and 4:1.²⁵ Up until a few years ago, surgical resection or curettage was the only therapeutic alternative to medical treatment. Surgical resections have reported a success rate ranging from 88% to 97%.²⁶ However, they lead to resection margins larger than the actual size of the lesion, prolonged hospitalization, need for rehabilitation and exposure to a greater likelihood of pathological fractures, even after a long time following surgery.^{28,29} For these reasons, the goal of researchers focuses on minimally invasive procedures that can allow treatment of OO; among these, the gold standard is CT-guided radiofrequency ablation (RFA). According to Rosenthal et al,³⁰ a comparison between the success rate of surgery and RFA has not shown a significant difference (91% vs 89%). In addition, RFA proves to be a better tool in treating symptomatic recurrences after surgical resections (100% vs 90%).³⁰ Several authors have published articles^{29–38}

reporting a significant therapeutic success, confirming the effectiveness of RFA also in the long-term and on large series, showing that RFA is a safe method for treating OO with a low number of complications. Flanagan and Lindskog,³⁹ in their study, referred an efficacy of this technique equals 92.8%, in agreement with the previous data reported in literature. Over the last few years, this procedure has proved to be a safe and effective alternative to surgical resection even in the paediatric population.^{40,41} Generally, the ablation procedures on paediatric patients are performed in general sedation as OO puncture and ablation are usually very painful for patients. CT images obtained with low-dose technique are used to guide the electrode positioning.⁴⁰ The right choice of the electrodes to be used during the procedure is essential. Most of the studies^{29,30,32,37,40} report the use of a single standard electrode, without internal cooling devices, with an active exposed tip of 5–10 mm. Taking into consideration that the tissue damage caused by RFA extends a few millimetres beyond the tip of the probe, a sufficient distance from the vital structures should be ensured; the standard safety distance is at least 1 cm. The majority of operators use a device for temperature control, integrated into the needle electrode, that allows temperatures to reach 90 °C and maintain that temperature more easily for 4 or 6 min, up to the achievement of the complete and radical ablation (Figures 1 and 2). The total and homogeneous necrosis of the nidus is favoured by the little heat dissipation, owing to the so-called “oven effect”, which is generated by the shell of the thickened bone. A 24-h hospitalization is generally required for OO treatment with a RFA procedure. Patients after treatment can immediately load weight on the treated area and physical activity should be limited only in particular cases. Usually, OO nocturnal pain symptoms recede immediately after treatment with RFA, leading to a healing rate of about 97% of cases, after the first session.⁴² The main studies^{29,32,33} on RFA indicate a procedural complication rate of only 3%, the most common of which seems to be skin burning in the treated site, followed by local infection, necrosis of the adjacent structures and post-intervention fractures. Minor complications are loss of sensitivity in the treated site that generally improves spontaneously in about 2 weeks. RFA procedure may be complicated when there is not a safe pathway to reach the lesion to be treated. It is not uncommon to have to resort to complex approaches that foresee a double inclination of the needle, to perform OO targeting. A contraindication is represented by the presence of neurovascular structures in the immediate proximity of the area that is subject to thermoablation; in particular, it might be difficult to treat some spine injuries.²⁹

The procedure failures are rare and usually related to misdiagnosis, poor visualization of the lesion and a wrong electrode placement. However, symptoms recurrence after a period of comfort is not uncommon (7% at 2 years).⁴³ Lesions of larger dimensions appear to be linked to a higher risk of recurrence, especially if previously treated with surgery. Moreover, recurrences are more frequent in the youngest patients.⁴³ Relapses usually occur within 3–6 months after treatment, while in the following months, the risk tends to decrease. Cases of recurrence after 24 months of treatment with RFA are very rare. Some authors, in order to reduce the risk of recurrence, proposed the combined treatment of OO with radiofrequency in association

with procedures of alcoholization, during the same session. The injection of a small amount of pure ethyl alcohol in a variable amount, depending on the size of the nidus (<1 ml), is carried out immediately after the end of the ablation with RFA. The rationale is based on the capability of ethanol to induce the coagulative necrosis of the tissues with which it gets into contact, through a dehydrating effect on the cells, the denaturation of the protein structures and their ischaemic necrosis secondary to endothelial and vascular thrombosis. MR-guided focused ultrasound (MRgFUS) is a new imaging-guided surgical technique that allows a minimally invasive ablation that has the large advantage of not using ionizing radiations and does not require access incisions, therefore eliminating the risk of infections. Claustrophobia and, especially, interposition of anatomical structures of ligament and tendon type limit their use. In 2014, Geiger et al⁴⁴ carried out a prospective multicentre study on 30 patients with non-spinal OO, in order to evaluate the effectiveness of the method. At 1-year follow-up, MRgFUS has proven to be effective in the resolution of the painful symptoms in 90% of patients, in the absence of complications, thus demonstrating it to be an effective alternative in the treatment of non-spinal OO.⁴⁴ Further studies on the efficacy, safety and the comparison with other methods are necessary, also for the evaluation of costs. MR is used to guide other minimally invasive ablation procedures: MR-guided laser ablation seems to offer interesting perspectives compared with RFA, also in terms of costs.^{45,46} The advantages of such technique are those typical of MR: a better identification of the soft tissues, which results in a more accurate identification of some structures, such as nerves and blood vessels. Furthermore, MR allows detection of temperature variations in real time, which can therefore be monitored during the procedure. Some authors recommend the use of CT-guided ablations with microwaves for the treatment of epiphyseal OO, since these lead to cell death through a coagulative necrosis caused by the high intratumoral temperature, produced in turn by agitation of the water molecules subjected to an electromagnetic field. This is why microwaves have a higher percentage of success in the ablation of larger lesions, even when the needle electrode is not positioned in the centre of the nidus. This technique seems to be efficacious on pain symptoms, although it should be confirmed by further and larger studies.⁴⁷

Aneurysmal bone cysts

Aneurysmal bone cyst (ABC) is a tumour-like lesion of the bone, first described as a distinct clinicopathological entity by Jaffe and Lichtenstein,⁴⁸ and represents from 3% to 6% of all primary bone tumours; about 80% patients are under 20 years of age. It is composed of blood-filled spaces separated by connective tissue septa containing fibroblasts, osteoclast-type giant cells and reactive woven bone.⁴⁹ The most common locations are the long tubular bones, axial skeleton, feet, hands, pelvis and craniofacial bone. ABC may present as a primary osteolytic lesion (65%), including the solid variant,⁵⁰ or as secondary changes in another lesion (35%).^{51,52} No case of malignant transformation of a primary ABC has ever been reported.⁵² Management includes surgical curettage with or without bone grafting, cementing of the cavity, reconstructive surgery, embolization and, more recently, sclerotherapy.⁵³ It has been reported that occasionally these lesions heal spontaneously or after a pathological fracture

Figure 1. A 2-year-old girl with left tibial pain and lameness. (a-c) Typical findings of osteoid osteoma of left tibia on radiographic, scintigraphic and CT images. (d, e) CT-guided biopsy and radiofrequency ablation of the lesion. (f) Needle tract within the lesion on post-procedure CT scan.

or biopsy alone.⁵⁴ The recurrence rate of ABCs, particularly associated with juxtaphyseal locations in skeletally immature patients,⁵⁵ and the potential of disturbance of growth when the

lesion is near a physeal plate after traditional surgical treatments is high and ranges from 30.8% to 50% according to Marcove et al,⁵⁶ Cole⁵⁷ and Schreuder et al.⁵⁸ This suggests mini invasive

Figure 2. A 7-year-old boy with lumbar pain. (a-c) Lumbar spine osteoid osteoma with soft tissues inflammatory oedema on MR, CT and scintigraphic images. (d) CT-guided radiofrequency ablation of the lesion.

Figure 3. An 8-year-old girl with left supraclavicular swelling. (a) Large osteolytic aneurysmal bone cyst of the left clavicle. (b) Fluoroscopic-guided sclerotherapy of the lesion. (c, d) Progressive ossification of the bone in 2-year follow-up.

management of ABCs such as embolization or sclerotherapy. Embolization of the feeding vessels was initially a pre-operative procedure performed to reduce intraoperative bleeding.

Thereafter, embolization has shown to be effective after surgical failure or as a single therapy with good results reported by Amendola et al.⁵⁹ However, ABC often lacks large feeding

Figure 4. A 6-year-old boy with pathological fracture of the left humerus. (a, b) Metadiaphyseal humerus aneurysmal bone cyst on radiographic and MR images. (c) Sclerotherapy of the lesion performed with the “double-needle” technique. (d) Remodelled bone at 2-year follow-up.

Table 1. Hamburg classification of vascular malformations

Vascular malformations	
Predominantly arterial malformations	Truncular (aplasia, obstruction, dilatation)
	Extratruncular (infiltrating, localized)
Predominantly venous malformations	Truncular (aplasia, obstruction, dilatation)
	Extratruncular (infiltrating, localized)
Predominantly lymphatic malformations	Truncular (aplasia, obstruction, dilatation)
	Extratruncular (infiltrating, localized)
Predominantly arteriovenous malformations	Truncular (deep, superficial)
	Extratruncular (infiltrating, localized)
Combined or mixed malformations	Arterial and venous without fistula
	Haemolymphatic

Data taken from Lee *et al*.⁷⁸

arteries to be embolized, and repeated procedures are frequently required when arterial embolization is selected as the single therapy.⁶⁰ When ABC is cranial or spinal, the vicinity of arteries supplying the brain or the spinal cord makes the procedure hazardous.^{61–65} Sclerotherapy^{66,67} is a newer treatment procedure introduced in the 90s and is based primarily on the premises that ABC is a vascular malformation pre-disposed on a haemodynamic disturbance and would heal if the vascular lesion is controlled (Figures 3 and 4). Sclerosants act by causing damage to the endothelium of vessels and by starting a coagulation cascade that results in thrombosis. Falappa *et al*⁶⁸ reported that direct percutaneous Ethibloc injection (Ethicon, Norderstedt, Germany)—an alcoholic solution of zein

(unavailable now)—was effective in the treatment of ABC and can be recommended as the first-choice treatment. Ethibloc was a very viscose substance that progressively hardens in a wet milieu until it becomes solid, satisfying the criteria of a sclerosing substance, and its injection is in line with the tendency to reduce invasiveness, producing similar results to surgical treatments. Ethibloc is then absorbed by macrophages until its total disappearance. Very recently, Lambot-Juhan *et al*⁶⁰ hypothesized that the efficacy of Ethibloc was the existence of alcohol in the solution. Absolute alcohol is known as a highly effective sclerotherapy agent for venous and lymphatic soft-tissue malformations.⁶⁹ In the case series reported by Lambot-Juhan *et al*,⁶⁰ absolute alcohol (ethanol 96%) was injected in all cases using

Table 2. 2014 International Society for the Study of Vascular Anomalies (ISSVA) classification of vascular anomalies

Vascular anomalies	
Vascular tumours	Benign
	Locally aggressive or borderline
	Malignant
Simple vascular malformations	Capillary malformations
	Lymphatic malformations
	Venous malformations
	Arteriovenous malformations
	Arteriovenous fistula
Combined vascular malformations	Capillary venous malformations
	Lymphatic capillary malformations
	Lymphatic venous malformations
	Capillary arteriovenous malformations
	Capillary lymphatic arteriovenous malformations
	Other combinations
Malformation of the major vessels	
Associated vascular malformations and other congenital anomalies	

Data taken from Dasgupta and Fishman.⁷⁹

Figure 5. A 9-year-old girl with venous malformation of the left distal medial vastus muscle extended to the soft tissues of the suprapatellar region. MR images (a–c) and ultrasound Doppler (d, e) of the venous malformation with ectatic venous vessels and phleboliths. (f) Phlebography shows deep femoral vein drainage. Sclerotherapy was performed after tourniquet positioning.

double-needle technique (employed also by us and still in use in our experience). This technique is based on the assumption that most of the alcohol used to induce ABC sclerosis is drained through the second needle positioned close to the first, permitting larger volumes treatment. In summary, the cysts were “washed out” with absolute alcohol. Progression of sclerosis was checked by looking at the appearance of the exiting fluid becoming viscose second by second. The venous blood, in fact, progressively turned black (cooked blood) due to coagulation induced by alcohol. In cases of clear fluid cysts, the fluid turned white (milky) due to coagulation of proteins. The limit of 1 ml kg^{-1} weight of injected alcohol was carefully observed, as most of the alcohol was re-aspired thanks to the multiple-needle technique. If massive venous drainage of injected contrast medium is apparent, a tourniquet was applied before alcohol injection and left in place for 10 min to allow complete thrombosis of the cyst content and avoid migration of alcohol into the systemic circulation. Repeated procedures may be needed when the architecture of ABC is complex and in the presence of multiple cavities. In the series reported,⁶⁰ the treatment response was considered good in 59%, partial in 31% and poor in 10% of the cases.

Rastogi et al⁷⁰ reported a case series of 72 patients treated with percutaneous intralesional injections of polidocanol with a cure rate of 97%. Similarly, Varshney et al⁷¹ reported in a prospective study that sclerotherapy was as effective as intralesional excision, but with less morbidity. Anyway, the complications of sclerotherapy have included pulmonary embolism, skin necrosis, pain, swelling and fever.^{66,70} In a preliminary report, Shiels and Mayerson⁵⁴ discussed the use of percutaneous doxycycline

treatment in ABCs. Doxycycline is an antibiotic with a direct cytotoxic effect on the mesenchymal ABC cells. Beyond simple cytotoxicity, doxycycline is antiangiogenic, a potent inhibitor of matrix metallo proteinase (MMP), an inhibitor of osteoclastic activity, induces apoptosis in osteoclasts and promotes osteoblastic activity.^{54,72–75} The authors reported a lesion volume reduction in all patients treated with one minor complication (skin necrosis) and 5% recurrence. Percutaneous sclerotherapy is well-described and is now the primary treatment of ABC in many centres; since surgical treatment may be difficult at certain sites, has higher risk of complications and a 10–44% local recurrence rate.^{76,77}

VASCULAR MALFORMATIONS

Vascular malformations are a group of congenital anomalies, that are extremely heterogeneous, and therefore require a careful and precise disease classification. Hamburg classification⁷⁸ (Table 1) subdivides all vascular malformations into truncular forms that develop along the course of the vascular axes, and the most common extratruncular forms which instead include all the focal malformations, characterized by a disorder of migration and development. International Society for the Study of Vascular Anomalies (ISSVA) 2014 Classification⁷⁹ (Table 2) differentiates malformations from the other vascular abnormalities and lists them according to their anatomical–pathological features. Vascular malformations increase proportional to the child tissues’ development, and their natural history varies according to type, site and anatomical–functional changes. Therapeutic treatment is established mainly on the basis of symptoms onset, development disorders between the malformation and the surrounding tissues or in

Figure 6. A 14-year-old boy with troncular arteriovenous malformation of the right arm. CT (a) and digital subtraction angiographic images (b–d) show multiple aneurysms of the humeral artery and arteriovenous fistula within the lesion. Selective catheterism (d, e) and the embolization with glue (f) of a fistula.

the event of alterations that might involve complications. The musculoskeletal apparatus can be directly affected by deep vascular malformations or be subjected to minor alterations, such as hypertrophies, hypotrophies or oedema caused by hypoperfusion (Still syndrome), hypervascularization or congestion due to venous hypertension. Lymphangioma is the most common lymphatic malformation; subdivided into macrocystic and microcystic forms, it presents cyclical volumetric variations, owing to bleeding or, more rarely, endocystic infections in the presence of infectious episodes. This clinical setting is typical of childhood; following puberty lymphangioma tends to regress, maintaining a morphovolumetric stability. Muscles are often involved in the extensive and deep forms, while bones are rarely affected. Sclerotherapy has been elected as the first-line therapy for macrocystic lymphangioma treatment, while surgery is still recommended for the microcystic forms.^{80,81} Sclerotherapy is usually performed through ultrasound-guided puncture and fluoroscopic contrastographic control of the cyst, followed by endocytic injection of sclerosing agents. Literature⁸² reports experiences of CT-guided and CT-controlled sclerotherapy. The choice of the sclerosing agent has been a main topic of research and testing in terms of the risk-to-benefit ratio. Ethanol at a dosage of 0.75 ml kg^{-1} is the most effective sclerosing agent, with a positive outcome in 87.5% of patients in terms of resolution, but it is poorly tolerated and carries a high rate of tissue necrosis and cardiorespiratory complications. Cahill *et al*⁸³ reported an efficacy of 76% in the various types of lymphangioma, and a resolution of 51% only in the macrocystic forms by using doxycycline, while injections of bleomycin at a dosage of 8–16 mg shows an

efficacy up to 74% and a resolution ranging from 20% to 35.7%.⁸⁴ Since the first studies carried out by Ogita *et al*,⁸⁵ OK-432 (Picibanil; Chugai Pharmaceutical Co. Ltd, Tokyo, Japan) has proven to be the most suitable drug. The numerous works published,^{85,86} also analysed OK-432 in comparison with other sclerosing agents, confirm that OK-432 is the less invasive drug, with a higher average response, and characterized by an effectiveness ranging from 85% to 98%. Experience with sclerosing therapy of the microcystic lymphangioma using OK-432 has led to disappointing results, with an efficacy of 33%.

Venous malformations represent the most commonly found category in the paediatric population and include numerous truncal and extratruncal forms (Table 1). Malformation identification and classification is essential to foresee its development and choose the most appropriate therapeutic approach. A haematological screening is suggested in order to identify possible coagulopathies; the onset of thrombosis and calcifications is a common event and is often a cause of pain.⁸⁷ In the complex or syndromic forms, a multidisciplinary clinical approach is strongly recommended. The initial therapy is based on the prevention with a conservative treatment; the elastic compression is mainly being used in the truncular forms, and therapy with heparin at low molecular weight is suggested in all the cases characterized by flow stagnation or thrombosis. Scleroembolization is the preferential treatment for the venous malformations; it consists of the injection of sclerosing agents directly into the affected intravascular compartment, which results in immediate thrombosis and endothelial sclerosis. After direct percutaneous ultrasound-guided access to the venous malformation

Figure 7. A 13-year-old girl with back pain, without fever and normal laboratory tests. (a, b) MR and scintigraphic images of the spine show multiple vertebral deformities. (c, d) CT scans show focal osteolysis of the superior plate in L1 (first lumbar vertebra). (e, f) CT-guided biopsy was performed in the suspect of histiocytosis. The final diagnosis was chronic recurrent multifocal osteomyelitis.

and identification of the venous drainage pathways through contrast medium injection, the sclerosing agent is infused under fluoroscopic control (Figure 5). Ethanol is the most widely used sclerosing agent for its high effectiveness with a dosage not higher than 2.1 ml kg^{-1} for each procedure. Possible splitting of the therapy and anticoagulant prophylaxis are recommended. Only recently gel-ethanol, with an addition of ethyl cellulose, which maintains the sclerosing effect for a longer time reducing the side effects and the relative morbidity, is being used.⁸⁸ Polidocanol (3%) has a sclerosing effectiveness lower than ethanol but entails fewer risks; it is used in the superficial venous malformations and has proved to be scarcely efficacious in the deep forms. Sclerotherapy effectiveness often fails to meet its high expectations: an immediate and evident reduction in volume is in fact associated with progressive relapses and sometimes a late change in the malformation morphology and dynamics. On the other hand, as sclerotherapy has been shown to have a successful analgesic effect in the symptomatic forms characterized by pain, surgery is still the therapy of choice. The ultrasound-guided interstitial laser therapy is a viable alternative to sclerotherapy in the muscle forms. Endovascular laser for treatment of truncal venous malformations is a valuable alternative to traditional surgery and sclerosing agents.⁸⁹

Arteriovenous malformations (AVMs) are characterized by an abnormal connection between arteries and veins, with or without interposition of a dysplastic nidus and divided into high or low flow, according to the extent of shunts and their flow rate.

Table 1 shows separately extratruncal and truncular forms. The later can present with ectasia, aneurysm or stenosis of the

dysplastic arteries, with or without arteriovenous shunts. The soft tissues closed to the malformation can suffer from the steal phenomenon and develop a collateral dysplastic vasculature. This circulation improves the vascularization of the healthy tissue, but it is potentially recruitable from the malformation.⁹⁰ Some forms have severe prognosis, particularly the complex limb forms, such as the Parkes Weber syndrome, where an evident limb hypertrophy is associated with a hypoxic-metabolic involvement affecting all the tissues. Embolization is the first choice of treatment for AVMs; its primary objective is to selectively occlude the nidus or the origin of the fistula, preserving the collateral circulation. The result is considered optimal if the embolization agent permanently closes the shunts and avoids the reperfusion from these collateral vessels. The most used compound for the AVMs embolization is the glue (*N*-butyl-cyanoacrylate) suitably mixed with Lipiodol® (Guerbet, Aulnay-sous-Bois, France). Onyx® (Coviden, Paris, France) is a valid alternative to glue; it is mainly used in brain AVMs, but also widely employed for the peripheral AVMs, as it allows an optimum intranidal cast of elastic texture, well suited to the malformations placed at joints and limbs^{91,92} (Figure 6). Coils or plugs are usually preferred for high-flow arteriovenous fistula treatment. Moreover, in order to perform surgery preoperative embolization should provide a temporary devascularization of the malformation.

INFECTIOUS AND RHEUMATOLOGIC DISORDERS

Inflammatory lesions of the osteoarticular system are the most frequent and severe pathologies in paediatric age and can lead to significant morbidity and mortality. The most common germs are *Staphylococcus aureus*, *Streptococcus* and *Kingella kingae*.

Figure 8. A 2-year-old boy with left coxal pain and claudication. (a, b) Plain film and CT scan show lytic lesion of the left femoral neck. (c) T_1 weighted fat-sat post-gadolinium MR image shows enhancement within the lesion. (d) Fluoroscopic-guided biopsy allowed the diagnosis of chronic recurrent multifocal osteomyelitis.

The most frequent locations are hip (37%), knee (25%) and ankle (23%); however, any bone segment can be affected. In diagnosing the inflammatory diseases of the musculoskeletal apparatus, interventional radiology, through its minimally invasive procedures, plays a key role, as it can allow an early diagnosis as well as an indication for the proper therapy to adopt. Before deciding whether a biopsy is necessary, a multidisciplinary team should evaluate laboratory tests, medical history and physical examination.^{93,94} Biopsy is required to characterize unifocal bone lesions not detectable through typical imaging techniques (bone scan and MRI). Conversely, radiological findings of multifocal bone lesions, in particular the ones with metaphyseal involvement in the long bones, are strongly suggestive for chronic recurrent multifocal osteomyelitis and do not require any histological examination.⁹⁵ Together with biopsies, percutaneous withdrawals for microbiological studies can be performed.⁹⁶ Relative contraindications are severe coagulopathy and proximity to vital structures.^{94,96} CT, fluoroscopy and ultrasound are the first-line techniques for biopsy procedures, FNA of synovial or abscess fluids, as well as for drug infiltration. The choice between these procedures depends on the lesion location, depth, size and morphology (Figures 7 and 8). In the lesions involving the bones, CT-guided needle biopsy is the method of choice. Conversely, ultrasound guidance that allows a “real-time” visualization of puncture and withdrawal, possibly assisted by Doppler to control the vascular structures, is the technique preferred for the lesions affecting soft tissues.^{96–98} In suspected infections, such as osteomyelitis, biopsies should be performed very carefully as there is a high risk of obtaining inadequate samples. Therefore, it is essential to choose the suitable needle gauge, the number of samples

to be taken, and the area to target (necrotic or calcified portions must be avoided).⁹⁹ For the bone lesions a “core biopsy” method (Trap System 8/11/13G) is preferable; in muscle or soft tissue lesions “cutting needles” (from 14, 16, 18 G) are mostly used. The coaxial system allows multiple withdrawals using a single access.^{100–108} Arthrocentesis is defined as a joint puncture with subsequent aspiration of joint fluid. The most common indications for arthrocentesis are diagnosis of septic arthritis or crystal-induced arthropathies, via synovial fluid analysis, diagnosis of bone or ligamentous injury confirmed by blood presence in synovial fluid, pain relief via decompression of acute effusion or haemarthrosis and determination of whether or not a laceration or fistula communicates with a joint.¹⁰⁹ Arthritis is one of the most common rheumatic diseases in Western Europe. Juvenile arthritis is part of a group of inflammatory disorders affecting children under the age of 16 years, with common clinical characteristics (e.g. limited range of motion and stiffness, impaired walking and running).¹¹⁰ Ultrasounds are performed using a high-frequency linear-array transducer, adjusting the frequency to achieve the needed penetration depth. The site for arthrocentesis is marked with ink marker before the procedure. Prior to the needle insertion, it is fundamental to measure the depth from the skin to the bony entrance of the joint. According to these measurements, the needle length and gauge are selected. Thin and shorter needles (27 G and 40 mm) are preferred; if the penetration depth exceeds 3 cm, longer and thicker needles (23 G and 60 mm) are used.¹¹⁰ Advantages of ultrasound-guided joint injection are widespread availability and cost effectiveness. Ultrasound-guided joint injection is a safe and feasible technique for the treatment of arthritis in children.¹¹⁰

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