The Journal of Rheumatology 2022;49:346–57
doi:10.3899/jrheum.210368
First Release February 15 2022

The Journal of Rheumatology

Review

Overview of Imaging in Adult- and Childhood-onset Takayasu Arteritis

Florence A. Aeschlimann[1], Francesca Raimondi[2], Tim Leiner[3], Giovanni Donato Aquaro[4], David Saadoun[5], and Heynric B. Grotenhuis[6]

ABSTRACT. Takayasu arteritis is an idiopathic large-vessel vasculitis that affects young adults and children and can lead to ischemia and end-organ damage. Vascular imaging is crucial for diagnosis, assessment of disease extent, and management of the disease. Here we critically review evidence for the clinical use of the different imaging modalities: conventional angiography, magnetic resonance imaging, computed tomography, Doppler ultrasound, and ^{18}fluorodeoxyglucose positron emission tomography. We thereby focus on their clinical applicability, challenges, and specific use in children.

Key Indexing Terms: angiography, imaging, large vessel vasculitis, Takayasu arteritis

Takayasu arteritis (TA) is an idiopathic granulomatous vasculitis of the aorta, its major branches, and the pulmonary arteries. TA predominantly affects young women under the age of 40 years. Disease onset in children is far less frequent but observed in up to 20–30% of patients.[1,2,3] Clinical presentation is highly variable and results from systemic and local vascular inflammation as well as organ dysfunction secondary to ischemia. Most patients have a relapsing remitting disease course, and eventually achieve remission after a variable disease duration. TA disease burden is high and mortality substantial.[4,5]

The precise etiology of TA remains poorly understood. Current knowledge is extrapolated from mouse models, surgery specimens from patients with TA, and genome-wide association studies.[6] Evidence suggests that both the innate and adaptive immune systems are involved in the pathogenesis of TA.[7] Genetic studies reveal an association with classes I and II HLA loci, in particular the HLA-B52 allele, as well as genes involved in immune-regulatory and inflammatory pathways.[7,8] Inflammatory infiltrates, consisting of macrophages and lymphoid cells, expand through the vasa vasorum to the adventitia and media, possibly affecting all 3 tunics.[9] This leads to vessel wall edema and degeneration of smooth muscle and elastic components with laminar necrosis and elastic fiber fragmentation, and ultimately to fibrosis and arterial remodeling.[10] Macroscopically, these processes are reflected by wall thickening and may result in arterial stenosis, dilatation, or aneurysm formation, all of which are again directly reflected by the clinical features with strong effect on prognosis.

The diagnosis of TA is based on clinical criteria and abnormalities on vascular imaging and is supported by laboratory findings. Characteristic vascular abnormalities include circumferential wall thickening, multiple arterial lesions, and/or luminal abnormalities such as stenosis or aneurysms. Occlusion and occasionally arterial dissection may be seen. Lesions are typically found close to the origin of the aortic branches and are often segmental with a patchy distribution.[11] Given the important role of imaging in TA, efforts were undertaken to describe angiographic patterns.[12,13,14,15] Various angiographic patterns with distinct clinical presentation have been identified in different ethnicities.[11,12,13,15] However, these angiography-based classifications of TA still require validation regarding outcome prediction.

Therapeutic management consists of medical and vascular interventions. Corticosteroids remain the mainstay of immunosuppressive medication.[16] As relapses are frequent, the use of corticoid-sparing agents, including conventional disease-modifying antirheumatic drugs, such as methotrexate, azathioprine, mycophenolate mofetil, and cyclophosphamide,

[1]*F.A. Aeschlimann, MD, MPH, Pediatric Immunology, Hematology and Rheumatology Unit, Hôpital Necker – Enfants Malades, Paris, France and Division of Pediatrics, Kantonsspital Winterthur, Winterthur, Switzerland;* [2]*F. Raimondi, MD, Unité Médicochirurgicale de Cardiologie Congénitale et Pédiatrique, Centre de Référence des Maladies Cardiaques Congénitales Complexes (M3C), Hôpital Universitaire Necker – Enfants Malades, Paris, France;* [3]*T. Leiner, MD, PhD, Department of Radiology, University Medical Center Utrecht, Utrecht, the Netherlands;* [4]*G.D. Aquaro, MD, 4 Fondazione Toscana Gabriele Monasterio, Pisa, Italy;* [5]*D. Saadoun, MD, PhD, Sorbonne Université, AP-HP, Groupe Hospitalier Pitié-Salpêtrière, Département de Médecine Interne et Immunologie Clinique, and Centre National de Références Maladies Autoimmunes Systémiques Rares, Centre National de Références Maladies Autoinflammatoires et Amylose Inflammatoire, Inflammation-Immunopathology-Biotherapy Department (DMU 3iD), INSERM 959, Groupe Hospitalier Pitié-Salpêtrière, AP-HP, Paris, France;* [6]*H.B. Grotenhuis, MD, PhD, Division of Pediatric Cardiology, Department of Pediatrics, Wilhelmina Children's Hospital, University of Utrecht, the Netherlands.*

The authors declare no conflicts of interest relevant to this article.

Address correspondence to Dr. F.A. Aeschlimann, Pediatric Immunology, Hematology and Rheumatology Unit, 149, Rue de Sèvres, F-75743 Paris, France. Email: florence.aeschlimann@aphp.fr.

Accepted for publication November 23, 2021.

for severe disease has been recommended upfront.[17,18] Recent advances in the understanding of underlying disease pathophysiology led to the increasing use of pathway targeting agents such as tumor necrosis factor, interleukin (IL)-6, or Janus kinase inhibitors with improved TA disease control, particularly in treatment-refractory patients.[17,19,20] Revascularization may be indicated to treat symptomatic organ ischemia or life-threatening vascular lesions.[10]

Imaging is required for diagnosis, assessment of disease extent, and management of TA. Distinguishing between acute active and chronic inactive disease is crucial to guide clinical care and allow for personalized treatment with appropriate tapering of immunosuppressive therapy. A delicate balance should be pursued between prevention of irreversible damage resulting from uncontrolled inflammation and the exposure to the potentially life-threatening side effects from unnecessary immunosuppressive therapy. However, correct assessment of TA disease activity remains challenging. Symptoms may be nonspecific (ie, headaches) and can also result from prior vascular damage rather than active inflammation. Biomarkers that accurately assess TA disease activity are lacking. Acute-phase reactants (APRs) such as C-reactive protein and erythrocyte sedimentation rate are routinely used in clinical practice; however, they are nonspecific and may not allow for differentiation between clinically active and inactive disease.[21] In addition, APRs rapidly normalize after treatment with IL-6 inhibitors, further complicating assessment of TA disease activity in tocilizumab-treated patients.[22]

Recent advances in radiological imaging have the potential to improve the management of TA by adequate and correct visualization of all arterial sequalae and by detection of early vascular inflammatory changes. TA disease state changes should be detected to facilitate prompter diagnosis and recognition of disease flares. However, the value of subtle imaging anomalies remains unclear and may result in overtreatment. More accurate monitoring of disease activity would allow for appropriate tailoring of immunosuppressive therapy. Given the lifelong and serial follow-up required, especially in children, the optimal imaging modality for the diagnosis and management of TA should be noninvasive and nonirradiating, easily accessible, and inexpensive, allowing for repeat exams and comparisons. It should quantify disease extent and accurately assess disease activity as well as treatment response.

The aim of this review is to provide an update on the available imaging methods in adult- and childhood-onset TA including conventional angiography (CA), magnetic resonance imaging (MRI), computed tomography (CT), Doppler ultrasound (US), and ^{18}fluorodeoxyglucose positron emission tomography (^{18}F-FDG PET), and to discuss their advantages and challenges (Table 1). The terms *MRI* and *CT* also encompass the specific angiography techniques MR angiography and CT angiography.

Methods

Literature search was conducted using PubMed combining the following search terms: "Takayasu arteritis," "large vessel vasculitis," "childhood," "pediatric," "imaging," "angiography," "MRI," "CT," "US," and "^{18}F-FDG PET." All types of articles (full papers, review articles, recommendations, case reports, abstracts) were looked at and screened for relevance. An article was considered relevant if it included data on clinical presentation, imaging modality, and interpretation. Additional articles were identified through the reference lists from the initial search and authors' knowledge of the literature. Supplementary Table 1 (available with the online version of this article) provides information about the quality of the cited studies.

Conventional angiography

CA (intraarterial digital subtraction angiography) provides images of the arterial lumen (Figure 1). Its strengths include an excellent spatial resolution and the possibility of visualization of any collateral vascularization.[23,24] CA may also be useful to accurately measure central artery pressure in the presence of arterial stenosis in all extremities. Data on CA in children are scarce and limited to descriptions of imaging modalities within case series or case reports of childhood-onset TA.[25–33]

Historically, CA is still considered the gold standard for evaluation of the arterial vasculature, but as the arterial wall is not visualized, early inflammatory disease changes may therefore be missed and diagnosis delayed.[34] The lack of information about the vascular wall also increases the difficulty to distinguish TA from other diseases causing vascular narrowing, such as chronic wall fibrosis, leaving only pattern recognition of affected arterial segments as being supportive of TA diagnosis.[35] Finally, CA is invasive, with high exposure to radiation and risk of potential procedural complications. As a result of these disadvantages and the wide availability of MRI and CT, CA is not recommended in clinical routine and is usually restricted to angiographic imaging prior to revascularization procedures, especially in children.[18,23,25,29,36] Overall, quality of evidence regarding CA in TA is low, as most data in both adults and children originate from retrospective cohorts or case series/reports.

Magnetic resonance imaging

MRI provides valuable information on disease extent in all vascular territories by visualization of luminal abnormalities (stenosis, occlusion, aneurysm; Figure 2 and Figure 3). MRI allows also for depiction of arterial wall lesions (thickening, edema). Principally used sequences in TA are T1- and T2-weighted fast spin echo (black blood imaging) and delayed contrast-enhanced sequences (Figure 2). In black blood imaging using inversion recovery technique, the inversion pulse nulls the blood so there is enough difference between the T1 or T2 signal of myocardium and blood for an optimal visualization of the myocardium and vascular walls.

T2-weighted imaging is sensitive to water content and depicts mural edema that may appear as a bright T2 signal[37,38] in higher contrast with the black aspect of blood. T1-weighted imaging also allows visualization of the thickened intima and media, permitting evaluation of TA disease extent and quantification of vessel stenosis and dilation (Figure 4). Delayed contrast enhancement reflects increased vascularity and/or excessive leakage of contrast out of the vasa vasorum, suggestive of more acute disease and allowing for identification of inflammation and/

Table 1. Advantages and disadvantages of the different imaging modalities.

Imaging Modality	Advantage	Disadvantage	Recommendation for Use in Clinical Practice
CA	Excellent spatial resolution Good visualization of collateral vascularization Possibility of interventional procedures	No visualization of vessel wall Invasive, risk of procedure-related complications High exposure to ionizing radiation Contrast media	Not recommended routinely, but if needed for interventional procedures
MRI	Excellent spatial resolution Visualization of disease extent, luminal and mural vessel abnormalities Multiple planes and 3-D views No radiation exposure Noninvasive	Poor visualization of small vessels and calcifications Potential overestimation of arterial narrowing Contrast media Expensive, long scan time, limited availability Contraindication with electronic devices, intraluminal stent implantation, claustrophobia	Recommended as first imaging modality for suspected TA in adults and children Recommended for long-term monitoring and suspected disease flares in adults and children
CT	Excellent spatial resolution Visualization of disease extent, luminal and mural vessel abnormalities Multiple planes and 3-D views Visualization of calcifications Noninvasive	Exposure to ionizing radiation Contrast media	May be used as alternative imaging modality in adults with suspected TA May be used for long-term monitoring and suspected disease flares in adults
Doppler US	Good visualization of luminal and mural vessel abnormalities Lack of exposure to ionizing radiation Noninvasive	Poor acoustic window due to obesity, artifacts from overlying structures, and bowel gas Limited field of view, particularly origin of neck, abdominal, and pulmonary vessels	May be used as alternative imaging modality in adults and children with suspected TA, alone or in combination with MRI or CT May be used for long-term monitoring and suspected disease flares in adults and children, alone or in combination with MRI or CT
PET	Functional evaluation Noninvasive	Low spatial resolution No visualization of luminal abnormalities Exposure to ionizing radiation Expensive, long scan time, limited availability Complex patient preparation Lack of standardization	May be used as 2nd intention imaging modality in adults and children with suspected TA, in addition to MRI or CT

CA: conventional angiography; CT: computed tomography; MRI: magnetic resonance imaging; PET: positron emission tomography; TA: Takayasu arteritis; US: ultrasound.

or fibrosis in the arterial wall. Owing to its capability to detect signs of vascular inflammation such as arterial wall thickening and edema, MRI permits recognizing TA in the early prestenotic phase.

However, its utility for monitoring disease activity during follow-up is less clear. Although disease activity on contrast-enhanced MRI has been shown to correlate with clinical disease status and APRs in some small prospective and retrospective case series,[37,39,40,41] it remains difficult to differentiate active from inactive disease on MRI as specificity of the presence of edema or postcontrast arterial enhancement for active disease is still debated.[42,43] Tso et al prospectively evaluated 77 MRI studies with standardized T2-weighted sequences from 24 patients with TA and found a high frequency of vessel wall edema not only in patients considered clinically active (MR images consistent with edema in 94% of patients) but also in > 50% of patients considered clinically inactive or having an uncertain clinical disease activity status.[43] Some concerns were raised about results because the study protocol did not require a contrast agent. However, similar findings were presented in a more recent prospective, observational cohort directly comparing standardized MRI and ^{18}F-FDG PET imaging with blinded clinical disease activity assessment in 65 patients with large-vessel vasculitis (LVV), of whom 30 were with TA.[44] Notably, in 51% of studies, both MRI and PET were interpreted as active imaging while patients were considered in clinical remission. This raises the question of whether the imaging abnormalities observed in clinically inactive patients represent subclinical vascular inflammation or nonspecific vascular remodeling.[44] A further challenge regarding interpretation is the ongoing difficulty to adequately assess disease activity in TA because reliable outcome measures of ongoing vessel inflammation are lacking.

Clinical disease activity scores and biological biomarkers have their limitations; thus, lack of correlation between imaging and clinico-biological disease activity assessment may also point to the limitations related to these latter ones. In addition, the appearance of vascular lesions on imaging is usually delayed compared to biological inflammation. To make it even more

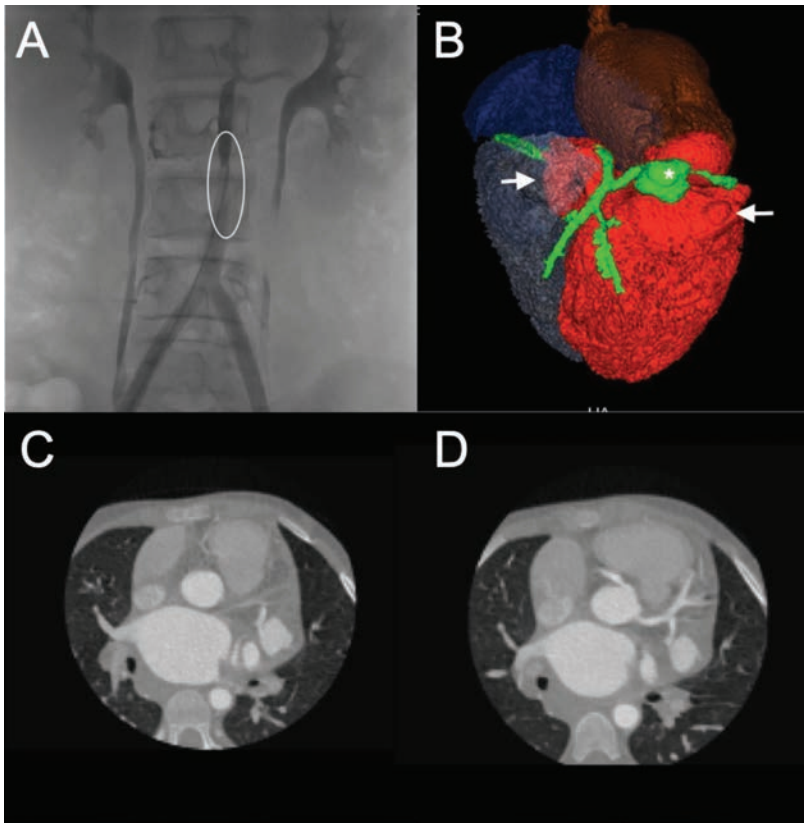

Figure 1. A 13-year-old girl presenting with fatigue, dyspnea, and anemia. Conventional angiography revealed vascular stenoses of the (A) abdominal aorta (ellipse), splanchnic vessels, subclavian arteries, and coronary artery abnormalities. (B) 3-D reconstruction of cardiac computed tomography scan shows an aneurysm of the circumflex artery (asterisk) associated with aneurysms of the left ventricular wall and interventricular septum (arrows). (C) Axial and (D) oblique (multiplanar reconstruction) view of the aneurysm of the circumflex artery.

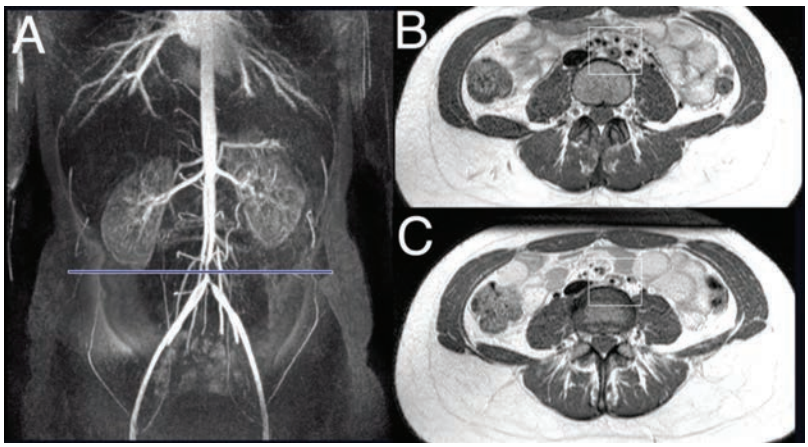

Figure 2. Takayasu arteritis in a 25-year-old female who presented with intermittent claudication. (A) The magnetic resonance angiogram shows a focal stenosis in the distal abdominal aorta with typical smooth "hour-glass"–like narrowing (blue line). (B,C) The corresponding pre- and postcontrast T1-weighted turbo spin echo images show concentric luminal narrowing (box) due to aortic wall thickening that intensely enhances after administration of contrast.

complicated, there have been reports of patients who were considered in clinical remission and inactive on imaging but were found to have histologic evidence of ongoing active vasculitis (from vascular surgery or autopsy).[22,45] Thus, correlation with histopathology would help to address these issues, but these findings are rarely available.[22,43]

The value of delayed contrast enhancement (DCE) in identifying patients with active or stable TA was previously reported in

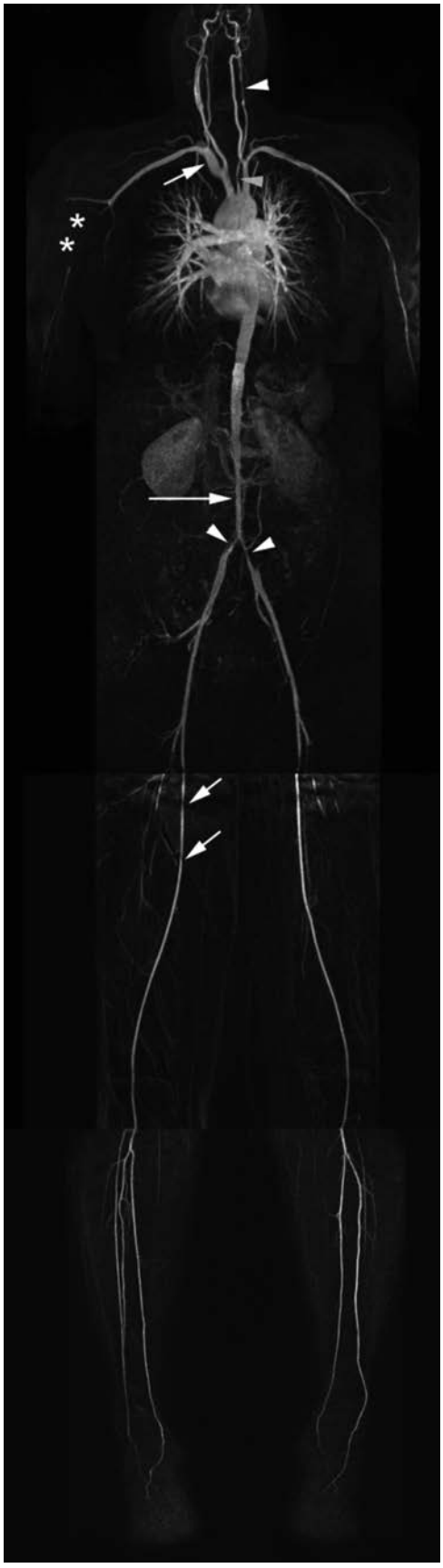

Figure 3. A 29-year-old female with long-standing complaints of lower and upper extremity intermittent claudication due to Takayasu arteritis. Total body contrast-enhanced magnetic resonance angiogram shows multiple smooth, short segmental stenoses (arrowheads), as well as aneurysmal dilatation of the proximal right subclavian artery (short, upper arrow) and somewhat longer segmented stenoses in the distal abdominal aorta (long arrow) and common iliac arteries (short, lower arrows). These findings are characteristic of circumferential vessel wall thickening due to inflammation. The left brachial artery is nearly occluded (asterisks).

an observational cohort study using standardized imaging protocols.[46] While DCE of the arterial wall (aortic vessel or pulmonary artery) could be observed in patients with active TA, it was not observed in patients with TA with stable disease. Moreover, stenotic lesions were comparable in active and stable patients with TA, but DCE was more present in patients with active than those with stable disease, demonstrating the potential of DCE to detect arterial vessel compromise before anatomical changes occur. These results are inspiring for future studies about the value of dynamic contrast-enhanced techniques in early identification of active phases of the illness and for subsequent monitoring of treatment effects.[46]

In children, data on MRI are limited to retrospective cohorts and case reports describing the use of MRI for diagnosis and follow-up monitoring of pediatric TA.[47–52] Aluquin et al published a study on 3 children with both clinically and radiologically active TA at diagnosis. Follow-up MRI after 7 and 12 months showed reduced wall thickness and DCE in the 2 patients with clinical amelioration, while the third patient, who presented ongoing fatigue and limp claudication, did not demonstrate any improvement on MRI.[53] The authors concluded that MRI findings correlated with clinical and serological disease activity, even though they noted that imaging improvement lagged 1 year behind clinical response to treatment in 1 child.[53] This likely reflects the difficulty of disease activity assessment during follow-up MRI, similar to that in the adult population.

MRI may be used during pregnancy; however, gadolinium has been shown to cross the placenta and its long-term effects on the fetus are currently unknown.[54]

Disadvantages of MRI include reduced visualization of smaller vessels and short focal lesions, and potential overestimation of the severity of arterial narrowing, all of which are related to limitations of MRI spatial resolution.[55] Arterial wall calcifications can also be missed.[55] CT may then be advantageous given its improved spatial resolution and ability to depict calcifications. Pseudostenosis, an MRI artifact mimicking arterial stenosis, may be identified in the distal subclavian artery.[56] Practical limitations are the high costs, duration of the procedure, and the requirement of contrast media and sedation in young children, all of which restrict availability, especially in low-income countries.[57] Despite these limitations, the lack of invasiveness and of radiation delivery makes MRI highly appealing for serial assessments of TA.[58] Hence, it is currently widely used in TA (especially in children) and has been proposed as the first imaging modality of choice for suspected TA by the recent European Alliance of Associations for Rheumatology recommendations on imaging

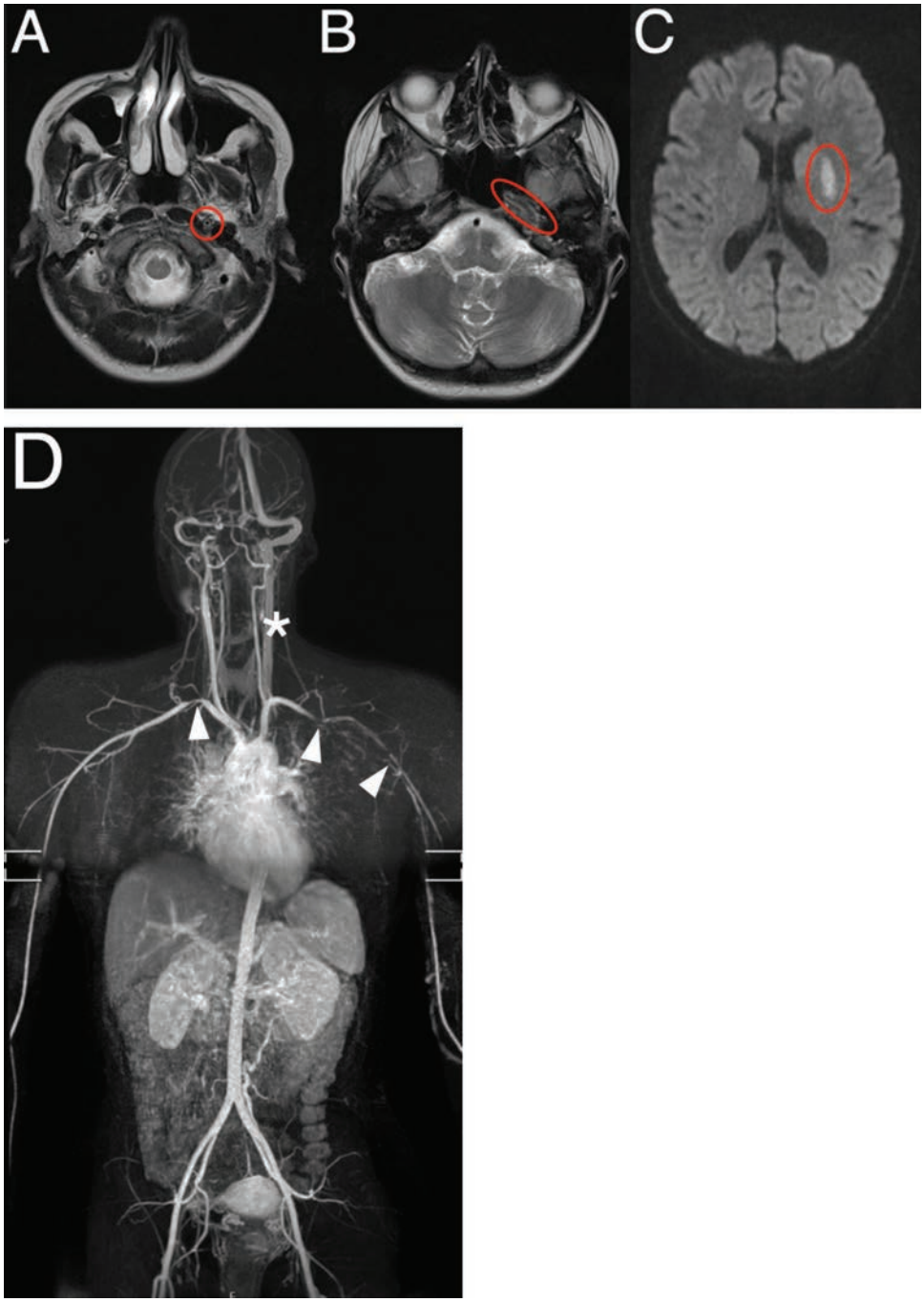

Figure 4. A 17-year-old female presenting with cerebral ischemia due to inflammatory narrowing of the left internal carotid artery and subsequent thrombus formation in the left middle cerebral artery. (A) Axial MRI (T2 spin echo) showed mild concentric narrowing of the left internal carotid artery (circle) and (B) severe narrowing in the petrous part of the carotid artery (ellipse) compared to the normal, barely perceptible vessel wall of the right internal carotid artery. (C) There is restricted diffusion in the left cerebral hemisphere indicative of cerebral ischemia (ellipse; MRI diffusion b1000). (D) Subsequent magnetic resonance angiogram showed near complete occlusion of the entire left common and internal carotid arteries (asterisk), focal smooth luminal narrowing of the right subclavian artery (left arrowhead) and near-occlusion of the left subclavian artery over a longer trajectory (between right 2 arrowheads). The findings are consistent with an inflammatory arteriopathy. MRI: magnetic resonance imaging.

of LVV[36] and the European consensus-based recommendations for the diagnosis and treatment of rare pediatric vasculitides.[18]

Computed tomography

Similar to MRI, CT evaluates anatomical changes of the arterial lumen and wall and localizes the extent of the vascular lesions with good spatial resolution[24,59] (Figure 1). Precontrast CT may demonstrate concentric arterial thickening, which appears attenuated compared with the lumen, and mural calcifications.[60] While transmural aortic calcifications are characteristic

of chronic TA, calcifications limited to the inner aspect of the aortic lumen are suggestive of atherosclerosis.[60] The arterial phase CT may reveal mural thickening with inhomogeneous enhancement, which possibly reflects the vascularization of the tunica media.[24] Postenhanced CT (delayed, venous phase) typically demonstrates a "double ring" appearance, with an inner ring with low enhancement (likely representing the thickened intima) and an outer ring with high enhancement (representing the florid active inflammation and vascularization in the media and adventitia).[24,60] This double ring enhancement pattern has been suggested to be useful to evaluate treatment efficacy.[60,61,62]

Various reconstructed images including maximum intensity projection (MIP), curved planar reformation, and volume-rendered images allow more detailed evaluation of luminal changes[24,63]; MIP and volume-rendered images are also useful to visualize small vessel changes.[63] Advanced CT technology with new-generation machines permits faster and higher-resolution scanning[64,65] and accurate assessment of the severity of aorto-ostial lesions, particularly of coronary arteries and distal lesions,[64,65,66] with low-dose radiation exposure.[67,68,69,70] However, radiation exposure remains the main concern in children, especially considering that the lifetime risk of radiation exposure is cumulative.[71] Epidemiologic studies provide clear evidence that the organ doses from a common CT scan (2 or 3 scans, resulting in a dose between 30 and 90 mSv) increase the risk of cancer, especially in children, who are more radiosensitive compared to adults.[72,73] Hence, CT is rarely used, and whenever possible, MRI should be preferred to avoid repeated radiation exposure.[18] Pediatric data are therefore scarce and restricted to case reports and small series.[26,29,33,48,74–78] As previously mentioned, the main disadvantages are the radiation delivery and the need for contrast media. Similar to MRI, the contrast bolus has to be timed perfectly in order to overcome high concentration venous contrast that interferes with the evaluation of the subclavian and brachiocephalic vessels.

The quality of the cited studies evaluating CT in TA ranges from high-level evidence for prospective studies using standardized imaging protocols[60,61,64] to low-level evidence for retrospective cohort studies and case series/reports.

Doppler ultrasound

Doppler US is inexpensive and noninvasive, and does not involve radiation exposure. It is useful for the visualization of the arterial wall, measurement of intima-media thickness, and anatomic study of vascular stenosis or aneurysms. The "macaroni sign," a long, homogeneous, midechoic, concentric arterial wall thickening, is considered characteristic of TA.[79,80] In contrast, atherosclerotic plaques are inhomogeneous, irregular, and often calcified.[55]

B-mode US shows wall morphology (ie, increased thickness). Doppler US provides valuable information regarding altered blood flow characteristics, thereby helping to detect TA in a prestenotic phase.[81] In addition, it can also indirectly measure arterial stiffness, which is often increased in adults and children with TA.[81,82] Contrast-enhanced US improves the visualization of the vascular lumen, the parietal vasa vasorum, and arterial vessel wall perfusion.[80,83,84,85] Using standardized contrast-enhanced US in a prospective cohort of patients with TA, Ma et al found significantly higher carotid artery wall thickness and more severe neovascularization in patients with active vs inactive TA.[86] Consequently, carotid artery wall thickness and severe vascularization have been suggested as a potential marker of disease activity in adult patients with TA[86] and the grade of vascular inflammation to correlate with disease activity observed on ^{18}F-FDG PET.[87] Contrast-enhanced US can also detect reduction of vessel wall thickness as a response to therapy[81,86]; thus, it may be a useful tool for diagnosis and monitoring of treatment response in TA patients with supra-aortic vessel involvement.

In children with TA, Doppler US is increasingly used, as it is noninvasive and nonirradiant. Doppler US has been shown to be an efficient imaging tool for diagnosis and follow-up management of some pediatric TA cases. It may be routinely used in the presence of an experienced pediatric radiologist, as well as in determining vessel involvement for those vessels that can be accessed by Doppler US.[18,29,49,88] Challenges include the lack of pediatric radiologists with expertise in US imaging of vasculitis. Moreover, supra-aortic vessel involvement, which is well covered by Doppler US, is less common in children with TA compared to adults.[1] Pitfalls of US include the investigator-dependent quality of the exam and the limited accessibility to study vessel anatomy according to acoustic technical limits; an example is the descending thoracic aorta, particularly in children.[89] Disadvantages of contrast-enhanced US include its limitation to 1 vessel due to short examination time during contrast infusion, higher costs, and longer examination times compared to conventional US.

Given the lack of radiation, Doppler US may be safely used for diagnosis and follow-up monitoring of TA in pregnant women.

^{18}Fluorodeoxyglucose positron emission tomography

^{18}F-FDG PET detects vascular areas with increased metabolic activity (^{18}F-FDG uptake by metabolically active, inflammatory cells of the vascular wall). Lesions are considered active when the tracer uptake within the vascular wall is higher than the tracer uptake of the liver. In early disease, activation of inflammatory cells precedes the morphologic changes.[90,91] ^{18}F-FDG PET is therefore widely used for diagnosis of suspected TA, where it has been shown to have a good sensitivity[92] (Figure 5).

However, its value for follow-up evaluation is uncertain. While a partial or complete reduction of tracer uptake during treatment has been reported in some studies,[93,94,95,96] the correlation between tracer uptake and disease activity markers was poor in others.[44] In all these studies, definition of disease activity was based on the presence of clinical features attributable to vasculitis, and in all but one additionally on the presence of elevated APRs.[93,94,95,96] Grayson et al investigated the utility of ^{18}F-FDG PET (standardized imaging sequences) as an imaging biomarker in a prospective, blinded study of 56 patients with LVV (26/56 with TA and among these, 5 children).[97] Notably, 58% of PET scans in patients considered in clinical remission were interpreted as active vasculitis.[97] Increased ^{18}F-FDG uptake may persist for several years despite good response to treatment,

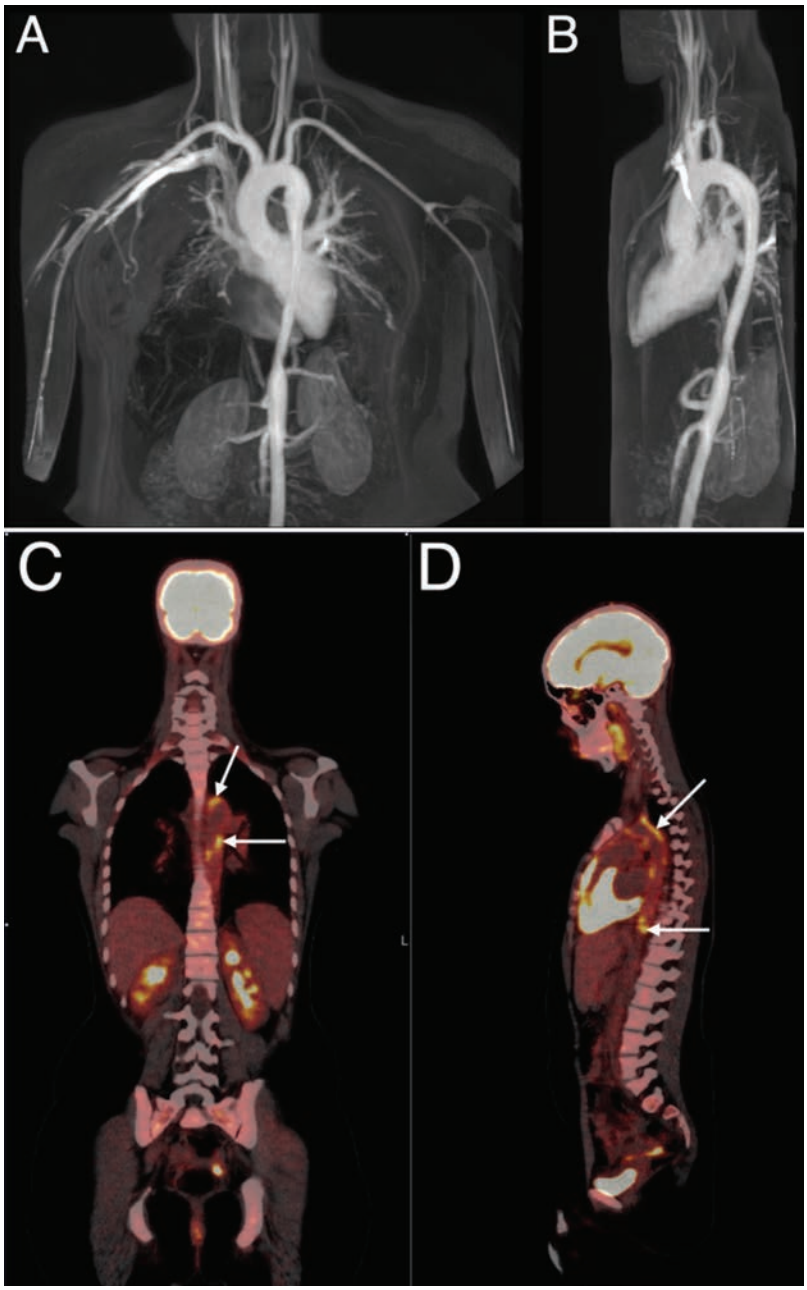

Figure 5. A 17-year-old female presented with a history of anemia, malaise, and lowered exercise tolerance. (A) Coronal and (B) sagittal maximum intensity projections of thoracic magnetic resonance angiogram show typical smooth elongated "hour-glass" narrowing of the descending thoracic aorta consistent with Takayasu arteritis. (C, D) PET scanning confirmed active disease in the narrowed segment (arrows). PET: positron emission tomography.

as it is not specific to active TA but can also be induced by a high metabolic rate during healing processes, fibrotic remodeling, and other inflammatory vascular diseases such as atherosclerosis.[98,99] This results in ambiguity as to whether tracer uptake in patients with clinically inactive TA represents subclinical vasculitis or nonspecific changes related to vascular damage. Interestingly, the global burden of ^{18}F-FDG uptake during clinical remission has been associated with future clinical relapse, suggesting that the variable ^{18}F-FDG uptake observed in clinically inactive patients reflects subclinical vasculitis.[97] Overall, the value of ^{18}F-FDG PET regarding evaluation of treatment response and prognosis remains limited and its definite role in the management of TA has yet to be determined.[98]

The combination of ^{18}F-FDG PET with CT or MRI allows more precise localization of pathologic changes.[100] A recent retrospective study investigating the role of ^{18}F-FDG PET/MRI in patients with aortitis for assessment of disease activity monitoring during immunosuppressive therapy suggested the

value of this hybrid imaging complementary to clinical and laboratory markers.[101] Of note, assessment of disease activity status between PET/MRI, clinical, and laboratory evaluation differed in 25% of cases. The utility of novel imaging modalities such as diffusion-weighted whole-body imaging with background body signal suppression remains to be validated.[58,102] Currently, ^{18}F-FDG PET plays a minor role in disease management of pediatric TA; aside from a few case reports,[103,104] 5 children were included in the prospective longitudinal study mentioned above.[97] To date, ^{18}F-FDG PET is not recommended for routine monitoring of disease activity in children due to the high radiation dose. It may be used on a case-to-case basis to assess disease activity when disease status remains unclear despite clinical, laboratory, and radiological assessment. When available, PET/MRI should be preferred over PET/CT.[18]

Joint procedural recommendations, published in 2018 by the European Association of Nuclear Medicine, Society of Nuclear Medicine and Molecular Imaging, and the PET Interest Group, provide guidelines for imaging specialists and clinicians for the request, performance, and result interpretation of FDG-PET imaging in patients with suspected LVV.[105] The statements conclude that FDG-PET/CT (angiography) plays an important role in the diagnosis of LVV, but also highlight the various open issues associated with diagnosis and disease monitoring, the lack of standardized protocols, and technical challenges.[105] PET is usually considered very sensitive in depicting active TA, but can adequately visualize neither pulmonary arteries[106] nor small vessels due to limited spatial resolution.[93] Other disadvantages of PET include the high costs, the limited availability, and the significant exposure to ionizing radiation, especially if combined with CT.

Conclusion

In summary, imaging modalities including MRI, CT, Doppler US, and ^{18}F-FDG PET reliably detect signs of suggestive vessel inflammation and allow recognition of TA even in the early prestenotic phase. However, despite advances in imaging techniques, there is no clear correlation with TA disease activity during follow-up monitoring; thus, the combination of clinical, laboratory, and imaging evaluation remains crucial for disease management and dosage of immunosuppressive medication. While MRI and CT both provide good visualization of vascular lesions and disease extent, MRI is often preferred and particularly recommended in children to minimize exposure to radiation. Doppler US is useful to diagnose and monitor TA in adults and children when affected vessels can adequately be assessed. Currently, the use of CA is principally limited to angiographic imaging prior to revascularization procedures. More recently, imaging was investigated as an outcome measure in an observational cohort and incorporated as an outcome measure regarding treatment response,[107,108,109] again highlighting the importance of a combined clinico-biological and radiological evaluation for disease activity assessment and disease management.

In the future, novel imaging techniques such as multimodality imaging systems, contrast-enhanced US, or the use of vasculitis/immune cell–specific tracers should be investigated.[36,105] To date, very few studies have evaluated the role of imaging in the prediction of angiographic and disease progression. However, imaging and novel imaging techniques may help to address the ongoing issues of accurate differentiation between active inflammatory lesions and nonspecific vascular remodeling observed during inactive disease phases, reliably monitor response to immunosuppressive therapy, and predict angiographic and disease progression.

ONLINE SUPPLEMENT

Supplementary material accompanies the online version of this article.

REFERENCES

1. Aeschlimann FA, Barra L, Alsolaimani R, et al. Presentation and disease course of childhood-onset versus adult-onset Takayasu arteritis. Arthritis Rheumatol 2019;71:315-23.
2. Kerr GS, Hallahan CW, Giordano J, et al. Takayasu arteritis. Ann Intern Med 1994;120:919-29.
3. Danda D, Goel R, Joseph G, et al. Clinical course of 602 patients with Takayasu's arteritis: comparison between childhood-onset versus adult onset disease. Rheumatology 2021;60:2246-55.
4. Seyahi E. Takayasu arteritis: an update. Curr Opin Rheumatol 2017;29:51-6.
5. Mirouse A, Biard L, Comarmond C, et al; French Takayasu network. Overall survival and mortality risk factors in Takayasu's arteritis: a multicenter study of 318 patients. J Autoimmun 2019;96:35-9.
6. Tombetti E, Mason JC. Takayasu arteritis: advanced understanding is leading to new horizons. Rheumatology 2019;58:206-19.
7. Terao C. Revisited HLA and non-HLA genetics of Takayasu arteritis--where are we? J Hum Genet 2016;61:27-32.
8. Renauer PA, Saruhan-Direskeneli G, Coit P, et al. Identification of susceptibility loci in IL6, RPS9/LILRB3, and an intergenic locus on chromosome 21q22 in Takayasu arteritis in a genome-wide association study. Arthritis Rheumatol 2015;67:1361-8.
9. Inder SJ, Bobryshev YV, Cherian SM, Lord RS, Masuda K, Yutani C. Accumulation of lymphocytes, dendritic cells, and granulocytes in the aortic wall affected by Takayasu's disease. Angiology 2000;51:565-79.
10. Mason JC. Surgical intervention and its role in Takayasu arteritis. Best Pract Res Clin Rheumatol 2018;32:112-24.
11. Moriwaki R, Noda M, Yajima M, Sharma BK, Numano F. Clinical manifestations of Takayasu arteritis in India and Japan--new classification of angiographic findings. Angiology 1997;48:369-79.
12. Hata A, Noda M, Moriwaki R, Numano F. Angiographic findings of Takayasu arteritis: new classification. Int J Cardiol 1996;54 Suppl:S155-63.
13. Lupi-Herrera E, Sánchez-Torres G, Marcushamer J, Mispireta J, Horwitz S, Vela JE. Takayasu's arteritis. Clinical study of 107 cases. Am Heart J 1977;93:94-103.
14. Arnaud L, Haroche J, Toledano D, et al. Cluster analysis of arterial involvement in Takayasu arteritis reveals symmetric extension of the lesions in paired arterial beds. Arthritis Rheum 2011;63:1136-40.
15. Goel R, Gribbons KB, Carette S, et al. Derivation of an angiographically based classification system in Takayasu's arteritis: an observational study from India and North America. Rheumatology 2020;59:1118-27.
16. Mukhtyar C, Guillevin L, Cid MC, et al; European Vasculitis Study Group. EULAR recommendations for the management of large vessel vasculitis. Ann Rheum Dis 2009;68:318-23.
17. Hellmich B, Agueda A, Monti S, et al. 2018 Update of the EULAR recommendations for the management of large vessel vasculitis. Ann Rheum Dis 2020;79:19-30.

18. de Graeff N, Groot N, Brogan P, et al. European consensus-based recommendations for the diagnosis and treatment of rare paediatric vasculitides - the SHARE initiative. Rheumatology 2019;58:656-71.
19. Mekinian A, Comarmond C, Resche-Rigon M, et al; French Takayasu Network. Efficacy of biological-targeted treatments in Takayasu arteritis: multicenter, retrospective study of 49 patients. Circulation 2015;132:1693-700.
20. Régnier P, Le Joncour A, Maciejewski-Duval A, et al. Targeting JAK/STAT pathway in Takayasu's arteritis. Ann Rheum Dis 2020;79:951-9.
21. Hoffman GS, Ahmed AE. Surrogate markers of disease activity in patients with Takayasu arteritis. A preliminary report from The International Network for the Study of the Systemic Vasculitides (INSSYS). Int J Cardiol 1998;66 Suppl 1:S191-4.
22. Dikkes A, Aschwanden M, Imfeld S, et al. Takayasu arteritis: active or not, that's the question. Rheumatology 2017;56:1818-9.
23. Ohigashi H, Haraguchi G, Konishi M, et al. Improved prognosis of Takayasu arteritis over the past decade--comprehensive analysis of 106 patients. Circ J 2012;76:1004-11.
24. Park JH. Conventional and CT angiographic diagnosis of Takayasu arteritis. Int J Cardiol 1996;54 Suppl:S165-71.
25. Fan L, Zhang H, Cai J, et al. Clinical course and prognostic factors of childhood Takayasu's arteritis: over 15-year comprehensive analysis of 101 patients. Arthritis Res Ther 2019;21:31.
26. Aeschlimann FA, Eng SWM, Sheikh S, et al. Childhood Takayasu arteritis: disease course and response to therapy. Arthritis Res Ther 2017;19:255.
27. Chen T, Mi J, Zhong MH, et al. Acute inferior myocardial infarction as the first manifestation of Takayasu arteritis in a young boy. Chin Med J 2015;128:2414.
28. Yang S, Dong K, Zheng S. Abdominal pain as the presenting symptom of Takayasu arteritis in an adolescent male: a case report. Medicine 2018;97:e11326.
29. Vijayvergiya R, Jindal AK, Pilania RK, et al. Complex interventions of abdominal aorta and its branches in children with Takayasu arteritis: clinical experience from a tertiary care center in north-west India. Int J Rheum Dis 2019;22:140-51.
30. Eleftheriou D, Varnier G, Dolezalova P, McMahon AM, Al-Obaidi M, Brogan PA. Takayasu arteritis in childhood: retrospective experience from a tertiary referral centre in the United Kingdom. Arthritis Res Ther 2015;17:36.
31. Jain S, Sharma N, Singh S, Bali HK, Kumar L, Sharma BK. Takayasu arteritis in children and young Indians. Int J Cardiol 2000;75 Suppl 1:S153-7.
32. Goel R, Kumar TS, Danda D, et al. Childhood-onset Takayasu arteritis -- experience from a tertiary care center in South India. J Rheumatol 2014;41:1183-9.
33. Fabi M, Brighenti M, Donti A, Lanari M. Tricky case of Takayasu arteritis in a young child presenting with heart failure and femoral pulses. Arch Dis Child 2019;104:507.
34. Park JH, Chung JW, Lee KW, Park YB, Han MC. CT angiography of Takayasu arteritis: comparison with conventional angiography. J Vasc Interv Radiol 1997;8:393-400.
35. Tullus K, Roebuck DJ. Renovascular hypertension in small children-is it Takayasu arteritis or fibromuscular dysplasia? J Am Soc Hypertens 2018;12:506-8.
36. Dejaco C, Ramiro S, Duftner C, et al. EULAR recommendations for the use of imaging in large vessel vasculitis in clinical practice. Ann Rheum Dis 2018;77:636-43.
37. Flamm SD, White RD, Hoffman GS. The clinical application of 'edema-weighted' magnetic resonance imaging in the assessment of Takayasu's arteritis. Int J Cardiol 1998;66 Suppl 1:S151-9.
38. Choe YH, Lee WR. Magnetic resonance imaging diagnosis of Takayasu arteritis. Int J Cardiol 1998;66 Suppl 1:S175-9.
39. Jiang L, Li D, Yan F, Dai X, Li Y, Ma L. Evaluation of Takayasu arteritis activity by delayed contrast-enhanced magnetic resonance imaging. Int J Cardiol 2012;155:262-7.
40. John RA, Keshava SN, Danda D. Correlating MRI with clinical evaluation in the assessment of disease activity of Takayasu's arteritis. Int J Rheum Dis 2017;20:882-6.
41. Desai MY, Stone JH, Foo TK, Hellmann DB, Lima JA, Bluemke DA. Delayed contrast-enhanced MRI of the aortic wall in Takayasu's arteritis: initial experience. AJR Am J Roentgenol 2005;184:1427-31.
42. Kato Y, Terashima M, Ohigashi H, et al. Vessel wall inflammation of Takayasu arteritis detected by contrast-enhanced magnetic resonance imaging: association with disease distribution and activity. PLoS One 2015;10:e0145855.
43. Tso E, Flamm SD, White RD, Schvartzman PR, Mascha E, Hoffman GS. Takayasu arteritis: utility and limitations of magnetic resonance imaging in diagnosis and treatment. Arthritis Rheum 2002; 46:1634-42.
44. Quinn KA, Ahlman MA, Malayeri AA, et al. Comparison of magnetic resonance angiography and 18 F-fluorodeoxyglucose positron emission tomography in large-vessel vasculitis. Ann Rheum Dis 2018;77:1165-71.
45. Sharma BK, Jain S, Radotra BD. An autopsy study of Takayasu arteritis in India. Int J Cardiol 1998;66 Suppl 1:S85-90.
46. Liu M, Liu W, Li H, Shu X, Tao X, Zhai Z. Evaluation of Takayasu arteritis with delayed contrast-enhanced MR imaging by a free-breathing 3D IR turbo FLASH. Medicine 2017;96:e9284.
47. Baumgartner D, Sailer-Höck M, Baumgartner C, et al. Reduced aortic elastic properties in a child with Takayasu arteritis: case report and literature review. Eur J Pediatr 2005;164:685-90.
48. Berman DP, Lewis AB, Kung GC. Case report of a 2-year-old boy with Takayasu's arteritis: an atypical, severe presentation of a rare disease. Pediatr Cardiol 2010;31:1089-92.
49. Alsaied T, Vasili Y, Moore R, McPhaul J, Javarayee P, Beekman R. Asymmetric pulses in a 5-year-old Asian female: is it worth further investigations? Clin Pediatr 2016;55:192-5.
50. Mitchell CS, Parisi MT. Magnetic resonance imaging of Takayasu's aortitis in an infant. J Am Osteopath Assoc 1997;97:607-9.
51. Bolin E, Moodie DS, Fraser CD, Guirola R, Warren R, Eldin KW. Takayasu arteritis presenting as severe ascending aortic arch dilation and aortic regurgitation in a 10-year-old female. Congenit Heart Dis 2011;6:630-3.
52. Aeschlimann FA, Grosse-Wortmann L, Benseler SM, Laxer RM, Hebert D, Yeung RS. Arterial dissection in childhood Takayasu Arteritis: not as rare as thought. Pediatr Rheumatol Online J 2016;14:56.
53. Aluquin VP, Albano SA, Chan F, Sandborg C, Pitlick PT. Magnetic resonance imaging in the diagnosis and follow up of Takayasu's arteritis in children. Ann Rheum Dis 2002;61:526-9.
54. Lam G, Kuller J, McMahon M. Use of magnetic resonance imaging and ultrasound in the antenatal diagnosis of placenta accreta. J Soc Gynecol Investig 2002;9:37-40.
55. Gotway MB, Araoz PA, Macedo TA, et al. Imaging findings in Takayasu's arteritis. AJR Am J Roentgenol 2005;184:1945-50.
56. Marinelli KC, Ahlman MA, Quinn KA, Malayeri AA, Evers R, Grayson PC. Stenosis and pseudostenosis of the upper extremity arteries in large-vessel vasculitis. ACR Open Rheumatol 2019;1:156-63.
57. Choe YH, Kim DK, Koh EM, Do YS, Lee WR. Takayasu arteritis: diagnosis with MR imaging and MR angiography in acute and chronic active stages. J Magn Reson Imaging 1999;10:751-7.
58. Tombetti E, Mason JC. Application of imaging techniques for Takayasu arteritis. Presse Med 2017;46:e215-23.
59. Yamada I, Nakagawa T, Himeno Y, Numano F, Shibuya H. Takayasu arteritis: evaluation of the thoracic aorta with CT angiography. Radiology 1998;209:103-9.

60. Park JH, Chung JW, Im JG, Kim SK, Park YB, Han MC. Takayasu arteritis: evaluation of mural changes in the aorta and pulmonary artery with CT angiography. Radiology 1995;196:89-93.
61. Kim SY, Park JH, Chung JW, et al. Follow-up CT evaluation of the mural changes in active Takayasu arteritis. Korean J Radiol 2007;8:286-94.
62. Kissin EY, Merkel PA. Diagnostic imaging in Takayasu arteritis. Curr Opin Rheumatol 2004;16:31-7.
63. Zhu FP, Luo S, Wang ZJ, Jin ZY, Zhang LJ, Lu GM. Takayasu arteritis: imaging spectrum at multidetector CT angiography. Br J Radiol 2012;85:e1282-92.
64. Soto ME, Meléndez-Ramírez G, Kimura-Hayama E, et al. Coronary CT angiography in Takayasu arteritis. JACC Cardiovasc Imaging 2011;4:958-66.
65. Abdel-Gawad EA, Housseini AM, Maged IM, Bozlar U, Norton PT, Hagspiel KD. Computed tomography angiography of type III Takayasu arteritis. J Rheumatol 2009;36:652-3.
66. Chung JW, Kim HC, Choi YH, Kim SJ, Lee W, Park JH. Patterns of aortic involvement in Takayasu arteritis and its clinical implications: evaluation with spiral computed tomography angiography. J Vasc Surg 2007;45:906-14.
67. Habib Geryes B, Calmon R, Donciu V, et al. Low-dose paediatric cardiac and thoracic computed tomography with prospective triggering: is it possible at any heart rate? Phys Med 2018;49:99-104.
68. Habib Geryes B, Calmon R, Khraiche D, Boddaert N, Bonnet D, Raimondi F. Radiation dose reduction in paediatric coronary computed tomography: assessment of effective dose and image quality. Eur Radiol 2016;26:2030-8.
69. Raimondi F, Warin-Fresse K. Computed tomography imaging in children with congenital heart disease: indications and radiation dose optimization. Arch Cardiovasc Dis 2016;109:150-7.
70. Warin Fresse K, Isorni MA, Dacher JN, et al. Cardiac computed tomography angiography in the paediatric population: expert consensus from the Filiale de cardiologie pédiatrique et congénitale (FCPC) and the Société française d'imagerie cardiaque et vasculaire diagnostique et interventionnelle (SFICV). Arch Cardiovasc Dis 2020;113:579-86.
71. Chan FP, Rubin GD. MDCT angiography of pediatric vascular diseases of the abdomen, pelvis, and extremities. Pediatr Radiol 2005;35:40-53.
72. Brenner DJ, Hall EJ. Computed tomography--an increasing source of radiation exposure. N Engl J Med 2007;357:2277-84.
73. Miglioretti DL, Johnson E, Williams A, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr 2013;167:700-7.
74. Aypar E, Celebi-Tayfur A, Keser M, et al. Takayasu arteritis in a 4-year-old girl: case report and brief overview of the pediatric literature. Turk J Pediatr 2012;54:536-9.
75. Pavić R, Blažeković R, Divković D, Marjanović K, Sipl M. Aggressive progression of Takayasu's arteritis in infancy: a case report. Acta Clin Croat 2019;58:535-9.
76. Mohan S, Poff S, Torok KS. Coronary artery involvement in pediatric Takayasu's arteritis: case report and literature review. Pediatr Rheumatol Online J 2013;11:4.
77. Feng Y, Tang X, Liu M, Zhou J, Zhao X, Li Q. Clinical study of children with Takayasu arteritis: a retrospective study from a single center in China. Pediatr Rheumatol Online J 2017;15:29.
78. Visrutaratna P, Srisuwan T, Sirivanichai C. Pediatric renovascular hypertension in Thailand: CT angiographic findings. Pediatr Radiol 2009;39:1321-6.
79. Ghembaza MEA, Boulenouar F, Lounici A. "Macaroni sign" in Takayasu arteritis. J Cardiovasc Imaging 2018;26:186-7.
80. Magnoni M, Dagna L, Coli S, Cianflone D, Sabbadini MG, Maseri A. Assessment of Takayasu arteritis activity by carotid contrast-enhanced ultrasound. Circ Cardiovasc Imaging 2011;4:e1-2.
81. Schmidt WA, Nerenheim A, Seipelt E, Poehls C, Gromnica-Ihle E. Diagnosis of early Takayasu arteritis with sonography. Rheumatology 2002;41:496-502.
82. Grotenhuis HB, Aeschlimann FA, Hui W, et al. Increased arterial stiffness adversely affects left ventricular mechanics in patients with pediatric Takayasu arteritis from a Toronto cohort. J Clin Rheumatol 2019;25:171-5.
83. Giordana P, Baqué-Juston MC, Jeandel PY, et al. Contrast-enhanced ultrasound of carotid artery wall in Takayasu disease: first evidence of application in diagnosis and monitoring of response to treatment. Circulation 2011;124:245-7.
84. Possemato N, Macchioni P, Germanò G, Pipitone N, Versari A, Salvarani C. Clinical images: PET-CT and contrast-enhanced ultrasound in Takayasu's arteritis. Rheumatology 2014;53:447.
85. Schinkel AF, van den Oord SC, van der Steen AF, van Laar JA, Sijbrands EJ. Utility of contrast-enhanced ultrasound for the assessment of the carotid artery wall in patients with Takayasu or giant cell arteritis. Eur Heart J Cardiovasc Imaging 2014;15:541-6.
86. Ma LY, Li CL, Ma LL, et al. Value of contrast-enhanced ultrasonography of the carotid artery for evaluating disease activity in Takayasu arteritis. Arthritis Res Ther 2019;21:24.
87. Germanò G, Macchioni P, Possemato N, et al. Contrast-enhanced ultrasound of the carotid artery in patients with large vessel vasculitis: correlation with positron emission tomography findings. Arthritis Care Res 2017;69:143-9.
88. Khemiri M, Douira W, Barsaoui S. Co-occurrence of Takayasu's arteritis and tuberculosis: report of a Tunisian pediatric case. Ann Pediatr Cardiol 2016;9:75-8.
89. Löffler C, Hoffend J, Benck U, Krämer BK, Bergner R. The value of ultrasound in diagnosing extracranial large-vessel vasculitis compared to FDG-PET/CT: a retrospective study. Clin Rheumatol 2017;36:2079-86.
90. Pipitone N, Versari A, Hunder GG, Salvarani C. Role of imaging in the diagnosis of large and medium-sized vessel vasculitis. Rheum Dis Clin North Am 2013;39:593-608.
91. Prieto-González S, Arguis P, Cid MC. Imaging in systemic vasculitis. Curr Opin Rheumatol 2015;27:53-62.
92. Henes JC, Müller M, Krieger J, et al. [18F] FDG-PET/CT as a new and sensitive imaging method for the diagnosis of large vessel vasculitis. Clin Exp Rheumatol 2008;3 Suppl 49:S47-52.
93. Andrews J, Al-Nahhas A, Pennell DJ, et al. Non-invasive imaging in the diagnosis and management of Takayasu's arteritis. Ann Rheum Dis 2004;63:995-1000.
94. Scheel AK, Meller J, Vosshenrich R, et al. Diagnosis and follow up of aortitis in the elderly. Ann Rheum Dis 2004;63:1507-10.
95. de Leeuw K, Bijl M, Jager PL. Additional value of positron emission tomography in diagnosis and follow-up of patients with large vessel vasculitides. Clin Exp Rheumatol 2004;6 Suppl 36:S21-6.
96. Stenová E, Mistec S, Povinec P. FDG-PET/CT in large-vessel vasculitis: its diagnostic and follow-up role. Rheumatol Int 2010;30:1111-4.
97. Grayson PC, Alehashemi S, Bagheri AA, et al. ^{18}F-fluorodeoxyglucose-positron emission tomography as an imaging biomarker in a prospective, longitudinal cohort of patients with large vessel vasculitis. Arthritis Rheumatol 2018;70:439-49.
98. Blockmans D, Bley T, Schmidt W. Imaging for large-vessel vasculitis. Curr Opin Rheumatol 2009;21:19-28.
99. Lehmann P, Buchtala S, Achajew N, et al. 18F-FDG PET as a diagnostic procedure in large vessel vasculitis-a controlled, blinded re-examination of routine PET scans. Clin Rheumatol 2011;30:37-42.
100. Kobayashi Y, Ishii K, Oda K, et al. Aortic wall inflammation due

to Takayasu arteritis imaged with 18F-FDG PET coregistered with enhanced CT. J Nucl Med 2005;46:917-22.
101. Einspieler I, Henninger M, Mergen V, et al. 18F-FDG PET/MRI compared with clinical and serological markers for monitoring disease activity in patients with aortitis and chronic periaortitis. Clin Exp Rheumatol 2020;38 Suppl 124:99-106.
102. Oguro E, Ohshima S, Kikuchi-Taura A, et al. Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS) as a novel imaging modality for disease activity assessment in Takayasu's arteritis. Intern Med 2019;58:1355-60.
103. Kwiatkowska J, Meyer-Szary J, Pawlaczyk R. Letter to the editor: some thoughts concerning dealing with an aneurysmal disease in children with Takayasu arteritis: a rare but aggressive vasculitis. Cardiol Young 2017;27:202.
104. Opoka-Winiarska V, Tomaszek MB, Sobiesiak A, et al. The importance of FDG PET/CT in the diagnostic process of the middle aortic syndrome in a 15-year-old boy patient with suspected systemic vasculitis and final diagnosis of Williams-Beuren syndrome. Rheumatol Int 2020;40:1309-16.
105. Slart RHJA; Writing group; Reviewer group; Members of EANM Cardiovascular; Members of EANM Infection & Inflammation; Members of Committees, SNMMI Cardiovascular; Members of Council, PET Interest Group; Members of ASNC; EANM Committee Coordinator. FDG-PET/CT(A) imaging in large vessel vasculitis and polymyalgia rheumatica: joint procedural recommendation of the EANM, SNMMI, and the PET Interest Group (PIG), and endorsed by the ASNC. Eur J Nucl Med Mol Imaging 2018;45:1250-69.
106. Addimanda O, Spaggiari L, Pipitone N, Versari A, Pattacini P, Salvarani C. Pulmonary artery involvement in Takayasu arteritis. PET/CT versus CT angiography. Clin Exp Rheumatol 2013;1 Suppl 75:S3-4.
107. Banerjee S, Quinn KA, Gribbons KB, et al. Effect of treatment on imaging, clinical, and serologic assessments of disease activity in large-vessel vasculitis. J Rheumatol 2020;47:99-107.
108. Nakaoka Y, Isobe M, Tanaka Y, et al. Long-term efficacy and safety of tocilizumab in refractory Takayasu arteritis: final results of the randomized controlled phase 3 TAKT study. Rheumatology 2020;59:2427-34.
109. Langford CA, Cuthbertson D, Ytterberg SR, et al; Vasculitis Clinical Research Consortium. A randomized, double-blind trial of abatacept (CTLA-4Ig) for the treatment of Takayasu arteritis. Arthritis Rheumatol 2017;69:846-53.