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Objective: To evaluate the clinical utility of time-resolved contrast-enhanced magnetic resonance angiography (MRA) in the evaluation of vascular orbital tumors.

Methods: Retrospective medical record review of patients with vascular orbital lesions imaged with Time-Resolved Imaging of Contrast KineticS (TRICKS; GE Healthcare [Chalfont St Giles, England]) MRA, a noninvasive dynamic imaging modality.

Results: Five patients with orbital vascular tumors were evaluated using TRICKS MRA. These included 1 patient with a cavernous hemangioma, 2 patients with orbital varices, 1 patient with an orbitocutaneous arteriovenous malformation, and 1 patient who had a solitary fibrous tumor with features of a hemangiopericytoma. In 2 patients, diagnoses were altered as a result of TRICKS MRA. In addition, a young patient with a large orbitocutaneous arteriovenous malformation involving the ophthalmic artery was followed perioperatively and noninvasively using TRICKS MRA, which produced exquisite images and added substantial value in the care of these patients.

Conclusion: Dynamic MRA in the form of TRICKS is a newly available imaging modality with great potential for improving the evaluation and management of patients with complex orbital tumors.

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Orbital Vascular Lesions

Orbital vascular lesions are common and include cavernous hemangioma, lymphangioma, varix, and arteriovenous malformations. These vascular abnormalities are classified according to their hemodynamic properties based on clinical and imaging criteria. A correct diagnosis is important because natural history and proper management are often dramatically different among no-flow, slow-flow, and higher-flow lesions.

An accurate clinical assessment remains the critical first step in the evaluation of patients with orbital tumors. However, reaching a diagnosis, or prioritizing the differential diagnoses, often remains a significant challenge. High-resolution imaging with computed tomography (CT) or magnetic resonance imaging (MRI) has become an invaluable adjunct to the clinical evaluation of orbital patients. For orbital vascular lesions, multiple imaging modalities exist. Conventional (ie, digital subtraction) angiography has been considered the gold standard for many years because of its ability to provide both spatial and temporal information about vascular lesions. Angiography can provide information about arterial blood supply, venous drainage, vessel caliber, collateral circulation, flow velocity, arteriovenous shunting, and presence of flow-related aneurysms. However, this technique is invasive and is associated with a small but definite risk of cerebral infarction and ophthalmic artery thrombosis or embolization. Conventional angiography is also less useful for assessing hemorrhagic changes or obtaining soft-tissue information. Contrast-enhanced CT imaging provides excellent spatial resolution, can be rapidly performed, is widely available, and its characteristics of orbital vascular lesions are well known because of extensive research and clinical experience during the past 2 to 3 decades.

Computed tomography angiography is another high-resolution imaging technique that can provide excellent visualization of large- and medium-sized blood vessels of the orbit. Computed tomography angiography can also be performed with a dynamic technique to provide information about blood flow to a vascular orbital lesion. A limitation of dynamic CT angiography, however, is its substantially higher...
doses of radiation to the lens (because multiple images must be acquired at the same slice location).

Magnetic resonance imaging can provide greater soft tissue detail about the internal architecture of vascular orbital lesions when compared with CT but is more susceptible to motion artifact from ocular movement owing to the longer scanning times. Magnetic resonance angiography (MRA) and venography can provide noninvasive static views of the orbital vasculature and some limited indirect information about blood flow. Dynamic MRA can be obtained with 3-dimensional time-of-flight and phase-contrast MRA. In time-of-flight MRA, repetitive pulses suppress stationary tissues while the protons of flowing blood create a signal. Hence, signal intensity depends on velocity and the characteristics of the surrounding tissues. Flow turbulence and the proximity of fat or subacute hemorrhage can lead to artifacts. Two-dimensional phase-contrast MRA, however, is not affected by these artifacts because it is only sensitive to moving protons. Magnetic resonance angiography is generally used for investigating venous flow because high-velocity arterial flow may cause phase-related artifacts. While traditional time-of-flight MRA provides excellent spatial resolution, it cannot adequately visualize smaller blood vessels and provides only indirect flow information about larger arterial vessels. Three-dimensional phase-contrast MRA evaluation can provide information regarding flow direction and flow velocity but is highly susceptible to motion artifacts from eye movement, making it impractical for routine orbit evaluation.

In 2003-2004, a new imaging modality was developed by GE Healthcare (Chalfont St Giles, England) based on research done in part at the Department of Medical Physics at the University of Wisconsin. This new imaging modality, known as Time-Resolved Imaging of Contrast KineticS (TRICKS), uses extremely rapid acquisition of MRIs to provide dynamic images of intravascular contrast flow. TRICKS delivers relatively high spatial resolution and also provides dynamic flow information that has not been previously available without more invasive studies, such as interventional angiography.

We present our initial experience with TRICKS MRA in the evaluation of orbital vascular lesions. TRICKS MRA provided critical information that improved our evaluation and management of certain patients with vascular orbital lesions.

METHODS

A retrospective medical record review was performed for patients who underwent TRICKS MRA of the orbits. Several illustrative cases were selected to highlight some characteristic findings of TRICKS MRA in orbital vascular lesions and to reveal how TRICKS MRA has improved diagnosis, patient counseling, and surgical planning for certain patients with such lesions.

High-resolution T1- and T2-weighted MRIs are initially obtained through the orbit prior to TRICKS MRA to aid in lesion localization and to assist in prescribing the best planes for flow acquisition. The TRICKS MRA study entails initial precontrast acquisition of a high-resolution map image. Approximately 20 to 30 TRICKS 3-dimensional MRA source-image time frames are acquired repeatedly over the area of interest in less than 1 minute during bolus injection of a gadolinium contrast agent. These low-contrast source images are then back projected onto the noncontrast image and digitally subtracted to
produce temporal images with improved anatomic information. Maximum-intensity projections of the 3-dimensional volume of data can then be generated for further vessel analysis.

Frame rates for TRICKS are approximately 2 seconds per acquisition, allowing evaluation of flow dynamics within lesions. Frame rates and number of acquisitions can be adjusted based on the expected flow dynamics of a lesion. Acquisitions are generally performed in the axial plane to initially evaluate the lesion; then a second acquisition is performed in a complementary orthogonal plane, either sagittal or coronal.

RESULTS

CASE 1

A 70-year-old man was referred to the oculoplastics clinic for evaluation of painless right-sided proptosis (eFigure 1, available at http://www.archophthalmol.com). His symptoms consisted of corneal dryness and ocular irritation on the proptotic side, with reflex tearing and epiphora. His examination revealed a visual acuity of 20/25 OU. Pupillary and extraocular motility examination results were normal. He had 2-mm inferior scleral show on the right. His Hertel exophthalmometry revealed 2.5 mm of exophthalmos on the right, with significant resistance to retropulsion. His proptosis did not change with a Valsalva maneuver. Magnetic resonance imaging of the orbits revealed a large right orbital lesion characteristic of a cavernous hemangioma (Figure 1A). TRICKS MRA revealed only a trace amount of contrast accumulation within the lesion, even in the late acquisition frames (Figure 1B). A diagnosis of cavernous hemangioma was made and observation was recommended.

CASE 2

A 49-year-old woman was referred to the oculoplastics clinic for evaluation of painless left-sided proptosis (Figure 2A, available at http://www.archophthalmol.com). She was asymptomatic. Her daughter noted the proptosis several months earlier, but review of older photographs revealed that the proptosis was present at least 2 years earlier. Her examination revealed visual acuities of 20/20 OD and 20/50 OS, with a mild relative afferent pupillary defect in the left eye. Her left extraocular motility was limited in supraduction and abduction. Hertel exophthalmometry revealed 9 mm of proptosis with resistance to retropulsion. A dilated fundus examination revealed mild disk edema. A CT scan from an outside facility demonstrated a large intraconal mass with imaging findings typical of a cavernous hemangioma (eFigure 2B, available at http://www.archophthalmol.com). An MRI scan (Figure 2A) additionally revealed significant intralesional hypervascularity. This finding argued against the initial diagnosis of cavernous hemangioma and suggested that a hypervascular neoplasm, such as a hemangiopericytoma, was more likely. TRICKS MRA confirmed that the mass was extremely vascular with rapid entry of contrast into the lesion (Figure 2B). This finding was felt to be inconsistent with cavernous hemangioma and more suggestive of a highly vascular neoplasm, such as hemangiopericytoma or possibly solitary fibrous tumor, metastasis, or sarcoma. Based on the TRICKS results, hemangiopericytoma was likelier the correct diagnosis. The differential diagnosis was discussed with the patient and her family and included the risks associated with excision of a higher-flow vascular neoplasm. A frontotemporal craniotomy approach was taken with the help of a skull-base neurosurgeon, with good exposure of the superior and lateral orbit. The intraconal mass was identified and excised completely in 1 piece. Postoperatively, the patient's visual acuity normalized and the afferent pupillary defect resolved.
Histopathologic evaluation revealed an encapsulated mass around uniform proliferation of rounded spindle cells admixed with vascular stroma containing sinusoidal spaces with staghorn configuration (Figure 2C). These histologic features are consistent with both hemangiopericytoma and solitary fibrous tumor, which exist along a morphologic and immunohistochemical spectrum.19,20 The main pathologic feature differentiating solitary fibrous tumor from hemangiopericytoma is that solitary fibrous tumor shows uniformly strong immunohistochemical staining with CD34, whereas hemangiopericytoma has weak and patchy staining.19 Based on the strongly positive CD34 signal on immunohistochemistry in our patient (eFigure 2C, available at http://www.archophthalmol.com), a diagnosis of a highly vascular solitary fibrous tumor was made. In this case, imaging with TRICKS pointed to the correct diagnosis and significantly affected treatment decisions.

CASE 3

A 9-year-old girl had an expanding area of red skin on her forehead and left periorbita since birth (eFigure 3A, available at http://www.archophthalmol.com). The patient denied vision changes or discomfort. Her lesion was initially treated elsewhere as a port-wine stain with multiple laser treatments but with no improvement. On physical examination, visual acuity was 20/15 OU. External examination revealed subcutaneous vascular pulsations, fullness, and localized warmth. Pupils, extraocular motility, and slit-lamp examination results were normal. Dilated fundus examination showed the posterior pole to be without choroidal folds, vascular lesions, or optic nerve abnormalities. A diagnosis of a cutaneous arteriovenous malformation was made. Magnetic resonance imaging (Figure 3A) and TRICKS MRA (Figure 3B) were used to evaluate the extent of the malformation, and revealed that arterial supply involved the ophthalmic artery as well as significant contributions by the superficial temporal and facial arteries bilaterally (eFigure 3B, available at http://www.archophthalmol.com). The dynamic MRA enabled preprocedure interventional planning, and staged intravascular embolization was pursued (Figure 3C). Following 3-stage embolization, a repeat TRICKS MRA showed recurrent ipsilateral and contralateral feeder vessels that continued to
enable communications among the ipsilateral and contralateral superficial temporal, facial, and ophthalmic arteries. Following additional embolization and confirmation of decreased blood flow in the malformation, a multidisciplinary surgical team, which included general and oculofacial plastic surgeons, debulked the vascular malformation at the radix and above the left brow (eFigure 3C, available at http://www.archophthalmol.com). At the completion of this series of interventions, MRI (Figure 3D) and TRICKS MRA (Figure 3E) revealed significant reduction in the size and flow of the arteriovenous malformation. The patient will continue to be observed both clinically and with TRICKS MRA. Because this technique is sufficiently sensitive for both arterial and venous flow, TRICKS MRA provides a way to noninvasively monitor the malformation.

CASE 4

A 37-year-old man was first seen with early-morning, spontaneous, left ocular pain associated with periorcular ecchymosis, eyelid edema, nausea, chills, and a headache (eFigure 4A, available at http://www.archophthalmol.com). A CT scan obtained at an outside hospital revealed an orbital apex intracanal mass. Examination revealed visual acuities of 20/20 OU with normal pupils and extraocular motility. Slitlamp examination results were unremarkable. Hertel exophthalmometry revealed 1 mm of proptosis. Magnetic resonance imaging of the orbits (eFigure 4B, available at http://www.archophthalmol.com) revealed a small orbital apex mass with well-defined borders, consistent with a cavernous hemangioma or possibly a lymphangioma. Because of the spontaneous hemorrhage, a diagnosis of lymphangioma was considered somewhat more likely. The patient was followed up during the next 7 years with no changes in lesion size. His most recent evaluation, at the age of 43 years, included TRICKS MRA, which revealed the orbital apex mass to have rapid midarterial phase opacification consistent with blood flow (data not shown). The diagnosis was changed to orbital varix, because early opacification is inconsistent with a cavernous hemangioma. The patient was advised of the change in diagnosis and counseled regarding the significance and features of this particular vascular entity.

CASE 5

A 59-year-old man had a history of a left orbital varix, which was initially diagnosed 15 years earlier after he noticed that his left eye protruded with bending or exertion. These episodes of intermittent proptosis were associated with orbital pain. The patient developed a habit of sleeping in a reclined position and avoiding activities that led to proptosis. His evaluation revealed visual acuities of 20/25 OD and 20/20 OS, with normal pupillary and extraocular motility examination results. Hertel exophthalmometry revealed measurements of 15.5 mm OD and 16 mm OS, with an increase of 4 mm OS following bending and the Valsalva maneuver (before and after, respectively; eFigure 5A, available at http://www.archophthalmol.com, and Figure 4A).21 He was followed up for the next 6 years with

Figure 4. Patient 5. A, Clinical photograph after the Valsalva maneuver, showing Valsalva-induced proptosis. B, Sagittal contrast-enhanced computed tomography scan demonstrated a large intracanal and extracanal mass. C, Oblique sagittal steady-state free procession images obtained with a 12-second scan time demonstrated enlargement of the mass with the Valsalva maneuver (left, rest; right, Valsalva). D, Early arterial to early venous phase images (left to right) from a dynamic Time-Resolved Imaging of Contrast Kinetics magnetic resonance angiography (TRICKS [GE Healthcare, Chalfont St Giles, England] MRA) demonstrated flow, with early blush of the mass (arrows), suggesting that the lesion is more likely a varix rather than a cavernous hemangioma. A fat-suppressed contrast-enhanced T1-weighted image obtained immediately after the TRICKS MRA revealed a contrast-blood layer in the mass, which further confirmed the diagnosis of a varix.
no changes in his condition and good control of his symptoms.

At 6 years, he underwent orthopedic operation on his right shoulder. Careful attention was paid to intraoperative positioning to reduce the risks of orbital complications. The patient awoke from general anesthesia with good vision and no proptosis in the left eye, but his sleeping position had been altered to accommodate his shoulder sling and the following morning he awoke with severe left orbital pain, severe proptosis, and loss of vision. His local ophthalmologist measured his intraocular pressure at 60 mm Hg, prescribed ocular hypertension drops and oral acetazolamide, and referred him for emergent care. An oculoplastic evaluation revealed severe loss of visual field in the left eye with an eccentric island of vision and a visual acuity of hand motions OS. At that point, there was minimal residual proptosis and no significant resistance to retropulsion. Orbital auscultation was negative for a bruit. A significant relative afferent pupillary defect was noted. A dilated fundus examination revealed juxtapapillary preretinal and intraretinal hemorrhages (eFigure 5B, available at www.archophthalmol.com) as well as disc pallor. A CT scan of the orbits revealed a large, enhancing lobulated mass surrounding the optic nerve (Figure 4B), suggestive of an orbital varix or an arteriovenous fistula, though a lymphangioma was also noted as a possibility. A diagnosis of severe acute compressive optic neuropathy was made. The patient was given 72 hours of corticosteroids with no improvement in visual function. Magnetic resonance imaging with contrast revealed a heterogeneous orbital mass that enlarged with the Valsalva maneuver (Figure 4C). TRICKS MRA revealed a large varix with early venous flow and opacification (Figure 4D) with identification of the venous access. The interventional neuroradiology service was consulted to consider the possibility of transorbital varix embolization. The patient elected to forgo any interventions. During the next 6 months, his visual acuity improved to 20/400 OS with eccentric viewing, but there were no changes in his severely constricted visual field.

The clinical evaluation of orbital disease primarily relies on a carefully obtained medical history and a complete examination of the eye and orbit. Noninvasive imaging of the orbit with CT and MRI can be extremely helpful, often providing critical information about the disease process. The role of noninvasive imaging in orbital and ocular evaluation has been the subject of numerous articles and editorials. Since imaging can be expensive, its justifiable use should provide unique information that may alter the course of treatment or provide special information that can help with patient counseling. Our experience with TRICKS MRA suggests that in certain cases of vascular orbital lesions, specifically when blood flow characteristics alongside high-resolution soft-tissue imaging are important for making the diagnosis, this modality can provide valuable information.

The topic of orbital vascular lesions, which include varices, lymphangiomas, hemangiomas, and arteriovenous malformations, has been the subject of heated debates, with recognition of both similarities and differences among these entities. Some orbital vascular lesions exist on a continuum with only subtle differences on conventional MRI and CT. An important element of categorization relies on the flow characteristics of a vascular lesion. A high-flow lesion is either an artery or an arterIALIZED vein in the context of an arteriovenous malformation. A lower-flow (venous) lesion with distention is characteristic of a varix, and lack of distention with moderate venous-phase flow would be consistent with a hemangiopericytoma. A no-flow lesion without distention and without contrast enhancement is characteristic of a lymphangioma. Cavernous hemangiomas typically have delayed contrast enhancement and have limited flow, and TRICKS images may reveal almost imperceptible and markedly delayed blushing, which may represent capillary enhancement.

Vascular lesions can hemorrhage, either spontaneously or following trauma. However, the likelihood of a hemorrhage and its association with certain activities is dissimilar among the different vascular lesions. The ability to distinguish noninvasively between them can be of critical importance in certain circumstances. In addition, the ability to assess flow and the presence of feeding vessels and/or collaterals can provide important information for surgical planning. In the case of arteriovenous malformations, this has typically been achieved through interventional angiography with arterial catheterization. The catheterization of small blood vessels, especially of the cranial and orbital circulation, can be risky. There is also a known risk (estimated at 1%-5%) of retinal ischemia following super-selective ophthalmic artery catheterization. This risk increases when the orbit contains abnormal vascular elements.

In our small series, we used a newly commercialized imaging modality to evaluate both known and unknown orbital vascular lesions. In the cases with known diagnoses, we attempted to acquire new information about the lesion that could be helpful with management. In the cases of lesions of an indeterminate diagnosis, we hoped that this new imaging modality might help provide a more definitive diagnosis. Based on our small series, TRICKS MRA has tremendous potential for providing critical new information about orbital vascular lesions. Despite the small size of our series, TRICKS provided us with information that caused us to change 2 diagnoses based on blood flow characteristics. In patient 4, the diagnosis was changed from presumed lymphangioma to varix. In patient 2, a presumed diagnosis of cavernous hemangioma was changed to a greatly increased likelihood of a vascular neoplasm, such as hemangiopericytoma. The altered diagnosis, along with lesion size and location, led to a frontotemporal craniotomy approach in conjunction with neurosurgery, in the hope of maximizing the likelihood of complete excision of a lesion with the potential for malignant transformation and metastatic spread. In both cases, our ability to inform and counsel patients was greatly enhanced by the information provided by the TRICKS MRA. Traditional MRA would not have provided the blood flow information that proved so critical to making the correct diagnoses.
In addition, even in cases with a known diagnosis, TRICKS MRA proved to be valuable in counseling our patients and planning future interventions. In patient 3, who had orbitocutaneous arteriovenous malformation, the dynamic images obtained with this noninvasive technique allowed the interventional neuroradiologist to develop precise plans for subsequent intervention based on the evaluation of blood flow through the various aspects of the malformation. TRICKS MRA also provided vascular assessment to determine the success of each stage of embolization therapy without the necessity of invasive angiography. In patient 5, who had large distensible varix and suffered a catastrophic hemorrhage, the images revealed the venous access and provided information that was useful both for counseling and for assessing interventional options. A traditional MRA would not have been able to identify the venous access of this lesion.

Imaging soft tissue alongside vascular blood flow can be obtained through 1 of 3 different approaches: (1) combining separate soft-tissue imaging with invasive angiography, (2) dynamic CT angiography, or (3) dynamic contrast-enhanced MRA, such as TRICKS MRA. The advantages of TRICKS MRA center on 3 attributes: (1) the combination of vascular blood flow assessment with high-resolution soft-tissue imaging, (2) the ability to obtain this information noninvasively, and (3) the safety profile of MRI technology compared with CT technology, which involves both ionizing radiation and iodinated contrast. Unlike iodinated contrast materials, gadolinium is generally better tolerated, though acute renal failure can rarely still occur.29-31 In cases of severe renal dysfunction, gadolinium-based contrast has been associated with a devastating complication, nephrogenic systemic fibrosis, though other risk factors, such as recent operation and the use of erythropoietin, have also been implicated.32-39 As with any other medical imaging modality, the use of gadolinium-based imaging should be carefully weighed against the potential risk to the particular patient. Compared with invasive angiography, MRA with or without contrast represents a significantly improved safety profile. Still, the decision to use dynamic contrast-enhanced MRA should be based on a complete clinical evaluation and the need to differentiate it from among several diagnostic possibilities. We believe that if the diagnosis is uncertain or if the clinical evaluation is inconsistent with the presumed diagnosis of a particular vascular lesion, dynamic contrast-enhanced MRA can provide invaluable information.

The potential of contrast-enhanced dynamic MRA extends to many other medical and surgical specialties, and promising studies have been reported in the fields of cardiovascular and neurologic operation.17,40-45 The ability to combine accurate and noninvasive assessment of blood flow with high-resolution images has tremendous potential. The cost of TRICKS MRA is only slightly higher than the cost of MRA without contrast and is significantly cheaper than interventional angiography, though it still represents a significant expense. Given cost constraints and the desire for cost-effective health care, we believe that contrast-enhanced dynamic MRA should be used when soft-tissue imaging is needed, hemodynamic considerations are judged to be very important, and the risks and costs of invasive angiography in the orbit are not warranted. We believe that the evaluation of orbital vascular lesions may be particularly well suited to this new imaging modality.

Our study is significantly limited by the small number of cases and the lack of well-defined parameters for performing and evaluating contrast-enhanced dynamic MRA. Our experience is also limited to TRICKS. Other hospitals may use a different system, such as the Syngo TWIST system (Siemens Medical Solutions, Malvern, Pennsylvania) or 4D-TRAK (Philips Medical Systems, Best, the Netherlands). These systems may be different in small but important ways from TRICKS. Orbital specialists are encouraged to familiarize themselves with the specific imaging systems available to them.

In conclusion, noninvasive dynamic angiography in the form of TRICKS MRA provided valuable information that was useful for making diagnoses, counseling patients, planning surgical interventions, and assessing the success of such interventions. As the availability of noninvasive dynamic angiography increases, we believe that this modality will become a very useful tool in the assessment of orbital vascular tumors and possibly other orbital lesions as well.

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REFERENCES

eFigure 1. Patient 1. Clinical photograph revealing marked unilateral proptosis with no signs of inflammation.

eFigure 2. Patient 2. A, Clinical photograph revealing marked unilateral proptosis with no signs of inflammation. B, Contrast-enhanced computed tomography scan revealing a large enhancing intraconal mass with medial displacement of the optic nerve. C, Immunohistochemistry with anti-CD34 antibodies (dark stain, original magnification ×20) reveals a strong uniform signal somewhat more consistent with a solitary fibrous tumor than a hemangiopericytoma.
eFigure 3. Patient 3. A, Clinical photograph revealing cutaneous involvement over the radix, left periorbita, and forehead. B, Coronal Time-Resolved Imaging of Contrast KineticS (TRICKS; GE Healthcare, Chalfont St Giles, England) magnetic resonance angiography revealed that the arteriovenous malformation was primarily supplied by branches of the superficial temporal arteries, the left facial artery, and the ophthalmic artery. A large arterialized vein is noted in the brow area. C, Intraoperative photograph of vascular debulking.

eFigure 4. Patient 4. A, Clinical photograph showing resolving periorbital ecchymosis. B, Coronal T1-weighted fat-suppressed magnetic resonance imaging scan demonstrated a small-enhancing intraconal mass (arrow) at the orbital apex, which was initially read as a lymphangioma by the neuroradiologist, but is actually more consistent with a cavernous hemangioma. Subsequent Time-Resolved Imaging of Contrast KineticS (TRICKS; GE Healthcare, Chalfont St Giles, England) magnetic resonance angiography revealed flow that was more consistent with a small varix (not shown).
Figure 5. Patient 5. A, Clinical photograph before the Valsalva maneuver. B, Fundus photograph revealing peripapillary retinal hemorrhages.