Published in final edited form as:

Clin Radiol. 2014 October ; 69(10): e381–e391. doi:10.1016/j.crad.2014.06.009.

Computed tomography arthrography with traction in the human hip for three-dimensional reconstruction of cartilage and the acetabular labrum

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Abstract

AIM—To develop and demonstrate the efficacy of a computed tomography arthrography (CTA) protocol for the hip that enables accurate three-dimensional reconstructions of cartilage and excellent visualization of the acetabular labrum.

MATERIALS AND METHODS—Ninety-three subjects were imaged (104 scans); 68 subjects with abnormal anatomy, 11 patients after periacetabular osteotomy surgery, and 25 subjects with normal anatomy. Fifteen to 25 ml of contrast agent diluted with lidocaine was injected using a lateral oblique approach. A Hare traction splint applied traction during CT. The association between traction force and intra-articular joint space was assessed qualitatively under fluoroscopy. Cartilage geometry was reconstructed from the CTA images for 30 subjects; the maximum joint space under traction was measured.

RESULTS—Using the Hare traction splint, the intra-articular space and boundaries of cartilage could be clearly delineated throughout the joint; the acetabular labrum was also visible. Dysplastic hips required less traction (~5 kg) than normal and retroverted hips required (>10 kg) to separate the cartilage. An increase in traction force produced a corresponding widening of the intra-articular joint space. Under traction, the maximum width of the intra-articular joint space during CT ranged from 0.98–6.7 mm (2.46 ± 1.16 mm).

CONCLUSIONS—When applied to subjects with normal and abnormal hip anatomy, the CTA protocol presented yields clear delineation of the cartilage and the acetabular labrum. Use of a Hare traction splint provides a simple, cost-effective method to widen the intra-articular joint space during CT, and provides flexibility to vary the traction as required.

Introduction

Hip pathoanatomy, caused by disorders such as hip dysplasia, acetabular retroversion, and femoroacetabular impingement (FAI), is currently considered the primary cause of hip osteoarthritis (OA).¹ The ability to evaluate cartilage and bone morphology and the progression of OA is beneficial to diagnose and treat these conditions.^{2–7} For example, peri-acetabular osteotomy (PAO) corrects dysplasia and retroversion by reorienting the socket to more effectively distribute cartilage contact stresses. However, PAO is not recommended if the cartilage to be rotated into a load-bearing region is not of sufficient thickness.⁸ Similarly, it is critical to stage OA in FAI patients as they have poor outcomes when surgery is performed following the onset of osteoarthritic changes.^{9,10}

The three-dimensional geometry of the pathoanatomical hip is complex and often includes concomitant deformities.^{11,12} Measurements from radiographs only address bone morphology. Further, radiographs may fail to identify out-of-plane deformities and can be misleading.¹³ For example, the presence or absence of the cross-over sign, used in the diagnosis of acetabular retroversion, is not specific as it depends on pelvic tilt and obliquity.¹⁴ Conversely, volumetric imaging permits visualization of hip deformities in multiple planes. Both computed tomography (CT) and magnetic resonance imaging (MRI), with or without intra-articular contrast medium, have become increasingly common methods to screen for hip pathoanatomy (e.g.^{2,15–18}).

Volumetric imaging affords opportunities for translational research, such as the development of computer models that can quantify femoral head coverage¹⁹ and asphericity for preoperative planning.²⁰ In addition, finite element (FE) models that include bone and soft-tissue geometry from CT arthrography (CTA) can provide insight into the relationship between abnormal anatomy and mechanical causes of cartilage and labrum degeneration in pre-osteoarthritic hips.^{21–23} However, accurate representations of bone and cartilage morphology are essential to obtain realistic FE predictions of cortical bone strains²⁴ and soft-tissue contact mechanics.^{25,26}

The accuracy of cartilage thickness reconstructions from CTA has previously been quantified,^{27,28} first using a phantom,²⁸ and then with cadaveric hips.²⁷ Results from these studies demonstrate excellent accuracy for imaging hip cartilage and bone using CTA. However, in practice, numerous technical challenges have been identified that make it difficult to visualize the intra-articular space and corresponding cartilage boundaries as separate structures using CTA in live subjects. In particular, the hip is a close-fitting, congruent, and nearly-spherical joint, with relatively thin cartilage. Traction in the setting of arthrography has been used as a means to widen the intra-articular joint space and visualize cartilage.^{8,29–35} However, only custom, complicated traction devices have been described. Further, there is no consensus on the amount of traction necessary; reports range from 6–25 kg.^{8,29–35}

CTA for the hip can image bone, cartilage, and labrum in a single setting, and could, therefore, become a standard technique to diagnose hip pathoanatomy. As the awareness of conditions such as FAI increases, there becomes a compelling need to develop a

standardized CTA protocol for the hip. The objective of the present study was to develop and demonstrate the efficacy of a CTA protocol for the hip that enables accurate three-dimensional reconstructions of cartilage and excellent visualization of the acetabular labrum. Specifically, a method to apply traction, guidelines on the amount of traction required, comparison of the maximum joint space width resulting from traction during CT, and discussion of possible solutions to common pitfalls associated with CTA of the hip are described.

Materials and methods

There was some variation in the protocol over the course of 8 years of development and application. The final protocol, outlined in Fig 1, is described below.

Patient and subject recruitment

Between February 2005 and October 2013, 93 subjects (56 male, 37 female) underwent CTA, yielding a total of 104 CTA examinations (Table 1): 68 with abnormal anatomy (acetabular retroversion, FAI, hip dysplasia), 11 post-operation (7 male, 4 female subjects with abnormal anatomy who underwent CTA before and after PAO), and 25 volunteer subjects. One subject in the volunteer group was asymptomatic for hip pain, but was found to have abnormal anatomy. The 68 patients with abnormal anatomy were scanned as a standard of care. Five of the subjects had bilateral CTA scans (four preoperatively bilateral, one postoperative bilateral). Images of the postoperative patients and normal subjects were acquired for research purposes only. Informed consent was obtained from all subjects; the protocols were approved by the local ethics committee (University of Utah IRB #10983 and IRB #43600; the procedures followed were also in accordance with the Declaration of Helsinki). All female patients and subjects participated in a urine pregnancy test (QuickVue, Quidel Corporation, San Diego, CA USA) prior to fluoroscopy and CT.

CTA

A musculoskeletal radiologist prepared a solution of 20 ml of 1% lidocaine (Hospira, Lake Forest, IL, USA), 10 ml of 61% iopamidol (Isovue 300 mg iodine/ml, Bracco Diagnostics, Monroe Township, NJ, USA) and 0.1 ml of 1:1000 epinephrine 1 mg/ml (Hospira, Lake Forest, IL, USA) in a 30 ml lure lock syringe. The hip was positioned in neutral rotation while the patient was supine. External or internal rotation was prevented by a sandbag placed on the lateral or medial border of the malleoli, respectively. The mid-cervical femur was chosen as the point of capsular penetration thus avoiding any injection of the labrum or incidental injection/damage to the femoral neurovascular bundle, as confirmed under fluoroscopy (Fig 1). A lateral oblique approach was used to avoid the ilioinguinal nerve and to facilitate capsular penetration about the femoral neck.³⁶ Prior to accessing the joint, soft tissue at the injection site was anaesthetized using a 2 inch 25 G needle with 2–5 ml of lidocaine. After approximately 2–5 min, a 3 inch 22 G spinal needle was inserted at the marked position and was slowly advanced until it contacted bone on the femoral neck. The location of the needle was verified under fluoroscopy. The radiologist then injected a small amount (<5 ml) of contrast mixture to confirm that contrast medium entered the hip capsule, outlining the zona orbicularis (Fig 1). After approximately 10 ml had been injected, light

manual traction was applied by pulling the subject's ankle inferiorly as he/she relaxed muscles of their lower limb and grasped the headboard of the fluoroscopy bed. Traction was released, and additional fluid was injected until a total of 15–25 ml had entered the capsule. The needle was removed. Next, manual traction was applied as fluoroscopy video was acquired to verify whether contrast medium covered the femoral head. The subject was told to make a mental note of the peak traction applied. Total fluoroscopy time did not exceed 30 s. With experience, total fluoroscopy time for the procedure was reduced to less than 10 s.

CT scan and traction

CT images were acquired following arthrography; generally within 15 min. Exudation of contrast medium prior to CT was avoided by the epinephrine in the contrast mixture and by transporting the subject via a wheelchair to avoid weight-bearing on the injected hip.

A Hare traction splint applied traction during the CT examination (Figs 1, 2). The subject was in a supine position (Fig 2). Taller subjects were placed feet first in the detector ring to ensure the CT machine could obtain a scout to cover the length of the proximal portion of the pelvis to the tibial tuberosity (see next paragraph). The proximal padded bar of the traction device was placed directly inferior to the ischial tuberosity (Fig 2b). A strap was secured about the ankle, immediately proximal to the medial malleolus (Fig 2c). The device was winched to approximately the same force applied during the injection, as confirmed by the subject.

A scout image, which encompassed the proximal portion of the pelvis to the tibial tuberosity, was acquired after traction to ensure adequate joint distraction and to determine the appropriate imaging window. If contrast medium did not completely cover the femoral head, traction was reapplied and an additional scout image was acquired. With sufficient traction confirmed as a visible line of contrast medium covering the femoral head, the scan area was adjusted to a field of view that encompassed both hips (the distance between the lateral borders of the proximal femur). After imaging parameters were finalized and the bed was indexed to the first scan section, the traction device was tightened once more to account for relaxation or slippage as the imaging window was defined. Images were immediately acquired with a 128-section single-source CT machine (SOMATOM Definition™; Siemens Healthcare, Munich, Bavaria, Germany) with the following settings: 120 kVp, 100–400 mAs, 512 × 512 matrix, 1.0 pitch, 300–400 mm FOV, 0.7–1 mm section thickness.

Bilateral CTA

Bilateral CTA data were acquired during a single scan in five subjects with hip pathoanatomy to visualize cartilage in both hips (four preoperatively, one postoperatively). Both sides were injected as described previously. However, the final contrast mixture was diluted with saline to avoid cardiac dysrhythmia from excessive lidocaine (10 ml each of saline, lidocaine and iopamidol, and 0.1 ml epinephrine with the same concentrations noted above). Two Hare traction splits applied bilateral traction.

Postoperative CTA

CTA data were also acquired postoperatively in 11 subjects for research purposes (Table 1). The aforementioned protocol was used with special considerations. Specifically, the needle often penetrated firm scar tissue, making initial needle placement within the capsule more challenging. However, the same CT settings were utilized; screw artefact was minimal in the images that visualized articular cartilage.

Influence of traction force

The association between traction force and joint space width was assessed qualitatively in four subjects with varying presentations (normal anatomy, postoperative traditional dysplasia, traditional dysplasia, FAI). First, a hand scale was attached to the ankle strap. Next, manual traction was applied in ~2 kg increments from 0–18 kg as fluoroscopy images were acquired at each increment. The joint space width was visually assessed between successive images.

Joint space width measurements

Cartilage geometry was semi-automatically segmented from the images of 30 subjects selected for FE modelling studies.^{21,22,37} Subjects were divided equally into three groups: normal, traditional dysplasia, and acetabular retroversion. The distance between opposing bodies of reconstructed cartilage was calculated using a custom algorithm that used the local surface normal to determine the distance between two surfaces over the entire structure, as previously used for cortical bone thickness calculations.³⁸ The maximum distance was recorded as the maximum joint space width. Maximum joint width was compared between the three groups using one-way ANOVA on ranks with Tukey's post-hoc corrections. Significance was set at $p = 0.05$.

Results

The developed protocol consistently produced high-quality images that delineated the intra-articular joint space, both cartilage bodies and the acetabular labrum throughout the hip joint. CTA images were found to be valuable in the diagnosis of intra-articular pathology (Fig 3). In particular, it was possible to diagnose tears to the acetabular labrum, cartilage lesions, hypertrophic labra, and osteochondral cysts from the CTA images. As opposing boundaries of cartilage were visible throughout the articulating surface, CT data could be reconstructed into subject-specific FE models (Fig 4a–b) of normal hips, dysplastic hips, and hips with retroverted acetabula.^{21,22,37} From these reconstructions, it was possible to create fringe plots of cartilage thickness (Fig 4c–d). Although the accuracy of cartilage reconstructions for these FE models could not be evaluated directly, prior phantom and *in-vitro* studies demonstrated that the chosen protocol yielded faithful representations of cartilage.^{27,28} Specifically, cartilage thicker than 1 mm was reconstructed with <10% error in the phantom study.²⁸ Cartilage geometry semi-automatically segmented from CTA images of cadaver hips demonstrated similar accuracy, with good inter- and intra-observer repeatability (ICCs of 0.90 and 0.88, respectively).²⁷

The amount of contrast agent injected varied according to the subject's hip anatomy. Joints of subjects with dysplasia and postoperative patients accepted the largest volume of contrast medium (20–25 ml). Normal hips required less contrast medium (15–20 ml). Hips with acetabular retroversion and pincer type FAI accepted the smallest volume of contrast (~15 ml).

Generally speaking, patients with hip dysplasia and postoperative patients required less traction force (~5 kg) to widen the intra-articular space than normal subjects (~10 kg). Patients with acetabular retroversion and FAI required even larger traction force (~10–15 kg). For the four subjects monitored under fluoroscopy, as the force was increased incrementally, more contrast agent entered the joint space (Fig 5). In the absence of traction, or with insufficient traction, it was difficult to delineate opposing bodies of cartilage (Fig 6).

The joint space width for all 30 cartilage reconstructions ranged from 0.98–6.70 mm and averaged 2.46 ± 1.16 mm. The average $\pm$ standard deviation of the normal, traditional dysplastic, and retroverted groups was 2.64 ± 1.16 , 2.97 ± 1.75 , and 1.77 ± 0.59 mm, respectively. Normal hips had a significantly larger maximum joint space than retroverted hips ($p = 0.048$). There was a trend towards larger maximum joint space in traditional dysplastic hips than in retroverted hips ($p = 0.053$). There was no significant difference between normal and traditional dysplastic hips ($p = 0.622$).

Pitfalls and challenges encountered during the development of this protocol included injection of contrast medium into the psoas tendon and injection of air into the capsule (Fig 7a–b). Although a small volume of the contrast agent in the psoas tendon did not substantially affect images of cartilage, larger amounts made it difficult to visualize the articulating surface. Failure to remove air bubbles prior to injection also made it difficult to visualize the entire cartilage surface. Finally, it was difficult to visualize posteroinferior cartilage in a small number of subjects (Fig 7c).

The total radiation dose from the fluoroscopy procedure and CT was estimated to be 9.62 mSv. This dose calculation assumes 30 s of fluoroscopy time, a scout that encompasses the entire pelvis to the tibial tuberosity, and CT of the pelvis and knee.

Discussion

The ability to clearly delineate the intra-articular joint space and boundaries of hyaline cartilage in the hip has many applications. Images can be used to measure cartilage thickness,^{27,39} and thus evaluate the progression of hip OA or evaluate the integrity of the cartilage prior to surgery. Images can also be used for translational research, including reconstruction into three-dimensional models to measure hip morphometrics^{20,40} and estimation of the mechanical forces applied to the cartilage and labrum to study the origins of hip OA.^{21–23,37} For biomechanical models, the entire articulating surface must be visible as accurate representations of hip cartilage geometry are required to obtain realistic predictions of hip joint contact mechanics.^{25,26}

Although the previous phantom and *in-vitro* studies documented the accuracy of CTA,^{27,28} it was difficult in practice to delineate both acetabular and femoral cartilage without the

application of traction during the examination. The developed CTA protocol includes a simplistic and cost-effective method to apply traction. This method reliably produced high-quality images in a population of young subjects with normal and abnormal hip anatomy.

The present CTA protocol for the hip is not the first to report the use of traction. However, the present protocol is novel as it utilizes a device available to the public, provides a method to verify the necessary traction force required to separate cartilage, and was demonstrated to be efficacious for subjects with differing presentations of hip anatomy. Previous studies have reported traction forces of 6–20 kg during MRI^{8,29–32,35} and 10–25 kg during CT.^{33,34} However, justification for the chosen applied load was not provided in these previous studies. For example, in one study, only 6 kg was used to distract hips in patients with groin pain,²⁹ which was subsequently questioned by another research group as being insufficient.³⁵ In the present study, the traction force required to distract individual hips was variable and depended on the underlying anatomy. Although 5–6 kg was sufficient for lax, dysplastic hips, upwards of 10–15 kg of traction force was necessary for hips with normal anatomy or hips with FAI. Fortunately, using the described protocol, the traction force need not be known before CTA. Rather, it can be estimated on a per-subject basis by manual application of traction while the patient is under fluoroscopy. Although the present approach of “teaching” the patient the required force at the time of fluoroscopy is not precise, it was found to be effective.

Previous studies have described the use of flexion/extension, walking, and active exercise in both MR arthrography (MRA) and CTA to distribute contrast agent throughout the joint.^{33,41,42} In the present study, subjects were asked not to perform loading-bearing exercises and the hip was not manipulated passively. This difference in approach may be due, in part, to the amount of contrast agent injected. Previous studies have reported using 10–15 ml of contrast medium in CTA and MRA,^{29,33,34} whereas the present study used 15–25 ml. Combined with traction, the increased volume injected in the present protocol likely provided the coverage necessary without the need to exercise or passively manipulate the hip. Although the chosen volume of contrast medium represents the high end of that reported in the literature, there was no difficulty in injecting 15–25 ml of contrast medium into the joints and, besides mild discomfort, no adverse events were reported.

Although use of a Hare traction splint represents a simplistic approach to applying traction during CT, there was a learning curve associated with its use. For example, in the first 10 hips that were scanned, cartilage bodies could be delineated over the whole joint for only two of the hips. Conversely, in the most recent 10 hips, cartilage could be visualized over the entire articulating surface for all 10 hips. It was imperative to position the cushioned end of the splint directly distal to the ischial tuberosity. The CT scout image provided a useful tool to confirm the position of the splint and presence of a distracted hip. Traction was also hampered when subjects did not relax their lower limb muscles, especially the gluteal muscles. Besides estimating the necessary traction force prior to CT, application of manual traction during fluoroscopy helped participants better understand what to expect from the Hare traction splint during CT. Therefore, it is recommended that the purpose of traction is discussed with the patient so that they may understand the importance of relaxing their muscles.

It is possible that the protocol applied herein could be extended successfully to MRA. However, CT of the hip generally last <30 s, which allows the use of relative large traction forces comfortably. Conversely, the long scan time in MRA may limit the applied traction force. Furthermore, the method to apply traction does not apply a constant force as tissues can elongate, which may cause motion artefact in the MRA images. Llopis et al.³⁰ used only 6–9 kg of traction due to the long scan time and Mechlenburg⁸ limited the applied traction to 10 kg as the most that could be tolerated for a 10 min MRA examination. Regardless, current clinical MRI protocols for the hip are based on two-dimensional image acquisitions with thick sections, which may not allow for faithful representations of cartilage thickness to be determined over the entire articulating surface, as is possible with CTA.⁴³

Pitfalls were encountered using the present CTA protocol, such as injection of contrast medium into the psoas and injection of air into the joint capsule (Fig 7a–b). Also, in some instances it was difficult to delineate thin cartilage, especially in the posteroinferior acetabulum (Fig 7c). Injection into the psoas was likely the result of the needle not puncturing completely through the tendon. Using a 22 G needle, it can be difficult to cleanly penetrate chronically injured or fibrotic psoas tendons as this tissue may palpate similar to bone. Additionally, capsular fibrosis and psoas bursal adhesions contribute to incomplete penetration of the short beveled spinal needle into the synovial space. When there is perceived increased resistance to injection after contacting the femoral neck, the bevel can be partially or wholly blocked by tough capsular tissue trapped against the femoral neck. Clean penetration can be assured by spinning the needle and allowing the needle tip to cut through the fibrosis, thus releasing the capsule. In this scenario, injecting a nominal amount of contrast media to verify correct positioning is especially important. When in psoas tendon (and not capsule), contrast media will appear as long, striated lines that run in the cranial to caudal direction (Fig 7b). Injection of air into the joint space could be avoided by first exuding fluid through the tip of the syringe, into the tubing, and placing several drops into the hub of the spinal needle prior to attaching the tubing to the spinal needle and injecting contrast medium.

There are limitations to the presentation of this protocol that warrant discussion. Because the traction force was not standardized between subjects, the comparisons of maximum joint space width obtained for the 30 FE models could not be analysed with respect to the underlying traction force. However, the purpose of the joint space width data was to demonstrate that traction sufficient to delineate opposing bodies of cartilage throughout the entire surface can be achieved in subjects with a variety of diagnoses. The simplistic approach of applying traction manually during fluoroscopy and then confirming this relative degree of traction with the patient at the time of CT helps to ensure the deployment of this protocol by other institutions. In addition, the association between known traction force and resulting joint space width was assessed only qualitatively using fluoroscopy on four subjects. However, the fluoroscopy images clearly demonstrated that an increase in traction force caused a corresponding widening of the joint space for subjects with differing presentations (normal anatomy, hip dysplasia, FAI, post-operative hip dysplasia); therefore, these results are generalizable. Because the present protocol was developed for and implemented on a relatively young, healthy, and fit population of adults, there could be challenges associated with applying this protocol to overweight, obese, or unhealthy

patients. Any application of traction during CT causes obvious pelvic obliquity. However, pelvic obliquity can be corrected on most commercial CT machines by multiplanar oblique reconstructions to restore the standard coronal/sagittal/radial configuration read by radiologists. Finally, the use of CT includes exposure to ionizing radiation. The risk of this exposure must be weighed carefully against the benefits to the patient.

In conclusion, the CTA protocol presented herein provides delineation of the intra-articular joint space and both bodies of cartilage through the entire joint in hips with normal and abnormal anatomy. The resulting images can be used to measure cartilage thickness, diagnose soft-tissue disease, and bony pathoanatomy, and can be reconstructed to create geometrically accurate computer models to study anatomy and hip contact mechanics. Use of a Hare traction splint provides a simple and cost-effective method to distract the hip during the CT examination. Normal hips or patients with acetabular retroversion and FAI will likely require greater traction force than patients with hip dysplasia. Application of manual traction during fluoroscopy can inform the patient of the force to be applied at the time of CT. Confirmation of correct placement of the Hare traction splint and presence of sufficient traction can both be made by visual inspection of the CT scout image prior to the full scan.

Acknowledgments

Financial support from NIH #R01AR053344 is gratefully acknowledged. The funding agency had no role in study design, data collection, analysis or interpretation, manuscript writing, or the decision to submit the manuscript.

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Figure 1.

Flowchart of the CTA protocol. Details of the injection procedure are outlined. Additionally, the iterative process of obtaining sufficient traction during fluoroscopy and prior to CT acquisition is demonstrated. Use of this protocol reliably provided image data with clear delineation of the intra-articular space and cartilage bodies throughout the hip joint.

Figure 2.

Positioning of patient in CT scanner and placement of Hare traction splint. (a) Oblique sagittal view with arrow indicating the direction of the scan. (b) The padded end of traction split should be placed directly distal to the ischial tuberosity as indicated in this sagittal view. Note that the patient has leaned toward the contralateral pelvis only to visualize proper placement splint pad. (c) Oblique distal view showing the ankle wrap and direction of traction force (F_T). Although not shown here, the toes of the left and right foot may be taped together to facilitate equal anatomical alignment between the limbs.

Figure 3.

The CTA protocol yielded images that clearly delineated boundaries of cartilage and enabled the diagnosis of various disease entities. (a) Labral hypertrophy in the coronal plane (female, 30 years old, left hip, diagnosed with dysplasia). (b) Labral tear in the coronal plane (male, 20 years old, left hip, diagnosed with cam FAI). (c) Subchondral cyst and extensive labral tear with labroacetabular separation extending into chondral delamination in the sagittal plane (female, 31 years old, left hip, diagnosed with bilateral dysplasia).

Figure 4.

Three-dimensional reconstructions segmented from the CTA data and associated cartilage thickness plots (male, 32 years old, right hip, normal anatomy). (a) Three-dimensional reconstructions of the pelvis and femur bones (yellow), femoral cartilage (dark blue) and acetabular labrum (green); the acetabular cartilage is not shown. (b) Sagittal cross-section of three-dimensional reconstructions with the acetabular cartilage (light blue). (c) Thickness plot for femoral cartilage. (d) Thickness plot for acetabular cartilage. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Figure 5.

Anteroposterior fluoroscopy image of a right hip with mixed FAI in a 26-year-old woman with various traction forces applied: (a) no traction applied; (b) 2 kg of traction applied; (c) 9 kg of traction applied; (d) 18 kg of traction applied. Approximately 18 ml contrast medium was injected. The images qualitatively demonstrate the relationship between applied force and resulting joint space width.

Figure 6.

CTA sections demonstrating the importance of sufficient traction for delineating the articular cartilage boundaries in the axial (left), coronal (middle) and sagittal (right) planes. (a) Hip with insufficient traction applied. (b) Hip with sufficient traction.

Figure 7.

Common pitfalls encountered during CTA of the hip. (a) Air introduced into the joint space in the axial plane (female, 26 years old, left hip, 31 months after peri-acetabular osteotomy to correct acetabular retroversion). (b) Contrast medium injected into surrounding musculature, such as the psoas tendon in the sagittal plane (male, 23 years old, right hip, diagnosed with acetabular dysplasia). (c) Difficulty delineating the boundary of cartilage in posteroinferior acetabulum in the sagittal plane (female, 22 years old, right hip, normal hip anatomy).

Table 1

Summary of subjects who have undergone CTA protocol.

Diagnosis	Male							Female						
	n	Age	# Right	# Bilateral	Mass (kg)	Height (cm)	BMI (kg/m ²)	n	Age	# Right	# Bilateral	Mass (kg)	Height (cm)	BMI (kg/m ²)
No hip disease	16	25.8 ± 3.2	4	0	76.6 ± 13.7	180.0 ± 6.3	23.5 ± 3.4	9	25.8 ± 4.1	3	0	62.2 ± 9.4	168.1 ± 4.6	22.0 ± 3.4
Abnormal anatomy (asymptomatic)	1	22	0	0	90	195.5	23.5	0						
Traditional acetabular dysplasia (preoperative)	9	27.3 ± 3.8	5	1	96.7 ± 21.0	180.3 ± 8.8	29.6 ± 5.6	19	28.2 ± 7.1	7	3	65.2 ± 14.4	166.5 ± 6.3	23.5 ± 5.1
Acetabular retroversion (preoperative)	13	25.2 ± 6.8	8	0	80.8 ± 11.1	182.2 ± 8.8	24.3 ± 2.7	3	25.0 ± 2.8	1	0	52.5 ± 2.1	168.5 ± 6.4	18.5 ± 0.7
Acetabular retroversion and cam FAI (preoperative)	12	24.4 ± 6.7	7	0	82.4 ± 11.3	181.3 ± 7.5	25.0 ± 2.9	3	29.0 ± 7.2	1	0	96.3 ± 15.0	174.3 ± 2.1	31.7 ± 4.8
Cam FAI (preoperative)	3	29.0 ± 6.1	0	0	75.9 ± 8.4	174.7 ± 4.7	24.8 ± 1.6	1	19	1	0	66	161.5	25.3
Pincer and cam FAI (preoperative)	1	19	1	0	95	190	26.3	2	24.5 ± 2.1	0	0	60.1 ± 4.8	170.5 ± 3.5	20.8 ± 2.5
Abnormal anatomy, no clear diagnosis (preoperative)	1	28	1	0	58	168	20.5	1	18	0	0	51	169.5	17.8
Traditional acetabular dysplasia (postoperative)	1	34	1	0	100	197	25.8	3	30.3 ± 8.3	2	0	61.7 ± 9.3	171.3 ± 6.5	20.9 ± 1.7
Acetabular retroversion (postoperative)	2	28.0 ± 5.7	2	0	79.0 ± 11.3	184.3 ± 2.4	23.2 ± 2.7	1	26	0	0	46	164	17.1
Acetabular retroversion and cam FAI (postoperative)	4	21.5 ± 1.7	2	1	76.3 ± 14.0	179.9 ± 9.9	23.4 ± 2.1	0						

FAI, femoroacetabular impingement; ±, SD; BMI, body mass index.