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Three-dimensional CT angiography for surgical planning in congenital hand malformations: a case series presentation

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Abstract

Between January 2000 and December 2019, three-dimensional computer tomographic (CT) angiography was used in a total of 140 hands (116 patients, mean age 6.8 years) with congenital hand malformation to assess the vascular and bony structures. Analysis showed overall satisfactory three-dimensional CT images for operative planning, including detailed abnormal vascular patterns and bony malformations. Among the 116 patients, six patients with typical findings of a few malformations are reported in detail. Pitfalls in interpretation of the images and the use of three-dimensional CT angiography in surgical planning are discussed. We conclude that three-dimensional CT angiography is useful for preoperative planning of complex congenital hand malformations.

Level of evidence: IV

Keywords

CT, three-dimensional, CT angiography, paediatric, hand, congenital malformation, preoperative planning

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Introduction

For patients with congenital hand malformations, preoperative assessment is mostly performed with plain X-rays, which can detect almost all bone malformations, but is limited in depiction of growth plates and cartilaginous structures. A computer tomographic (CT) scan can show more complex changes in bones and joints (Nakasone et al., 2018); and three-dimensional (3-D) CT angiography is noninvasive and is widely used in preoperative planning for microsurgical reconstruction in evaluating both donor and recipient vascular supply (Chen et al., 2016; Duymaz et al., 2009). Three-dimensional CT angiography can be a helpful tool in surgical decision making for congenital hand malformations (Askari et al., 2016; Holten et al., 1997a; Kilinc et al., 2018), but it still does not see routine use. The purpose of this study was to determine the value of the method in complex congenital hand malformation for precise operative planning.

Methods

Patients

This is a retrospective analysis of multi-detector CT (MDCT) angiography obtained in patients with congenital forearm and hand malformations between January 2000 and December 2019. Babies and toddlers, as well as children who were unable to stay calm during the CT scan, were examined under short-term general anaesthesia. In every case,

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informed consent was obtained from the parents before radiographic examinations were performed.

MDCT angiography

A 4-MDCT scanner (LightSpeed QX/i, GE Healthcare, Milwaukee, WI, USA) was used until May 2006. From June 2006 to November 2011, a 64-MDCT (LightSpeed VCT, GE Healthcare) was used, and since December 2011, a 64-MDCT (Discovery, GE Healthcare) was used. Patients were positioned supine, and the involved extremity was immobilized with adhesive tape during the scan. The 4-MDCT angiography images were acquired using 1.25 mm collimation and 0.9 mm reconstructed slice thickness. The 64-MDCT images were acquired using 0.625 mm collimation and 0.5 mm reconstructed slice thickness in a proximal-to-distal direction. To improve image quality, we used a low-pitch (4-MDCT: 0.75; 64-MDCT: 0.5) to optimize axial resolution to the smallest possible scan field of view, and the display field of view captured only the involved extremity.

In all children we used an X-ray tube voltage of 80 kV. The current in the 4-MDCT with a 0.6-sec gantry rotation period ranged from 80 mA to 200 mA. In the 64-MDCT, with a possible rotation time down to 0.35 sec, we used a fixed noise index of 12, with automatic adaptation of current. Depending on the patient's weight and scan duration, we administered non-ionic contrast material at a rate of 0.8–2.0 ml/second according to the following formula: maximum contrast volume (ml) = body weight (kg) × 2. Scan delay, which is of particular importance for an ideal contrast of the arteries without venous overlay, was determined with a bolus-tracking technique (SmartPrep software, GE Healthcare) until November 2011 and with a test bolus thereafter. The latter is based on the injection of a small amount of contrast material (15% to 20% of the main bolus; flow rate equal to angiographic scanning) during the acquisition of a series of dynamic low-dose images (80 kV; 20 mAs) while monitoring scans at the level of the vessel or region of interest in the distal forearm arteries.

Acquisition of the dynamic monitoring scan started 5 seconds after beginning to inject intravenous contrast material at a rate of one scan per second. The time to first enhancement of the forearm arteries was the delay applied for the angiographic scanning. Using the bolus-tracking technique, scan delay was determined by the SmartPrep software, which allows continuous monitoring of the attenuation values in the vessel of interest. Dynamic low-dose monitoring scanning began 5 seconds after starting the intravenous contrast material injection. When the arterial attenuation value increased to 140–160 HU after contrast material injection, helical scanning was manually initiated under the radiologist's supervision. After pressing the start button, the table moved to the cranial start position, which takes at least 5 seconds (transitions delay). This means a possible venous overlay because of the fast blood circulation in children, and it requires accordingly a prolonged injection of contrast material. This was the reason for switching to the test bolus-tracking technique.

After acquisition, MDCT data sets were transferred to a PACS (IMPAX EE, Agfa HealthCare; Bonn, Germany) and 3-D rendering workstation running Advantage Windows software (GE Healthcare) to create 3-D reconstructions, meaning multiplanar reformations and volume-rendered views of the bones, vascular structures and flexor tendons.

Assessment of the image quality

The quality, including overall image quality, vessel depiction and artefacts, of the MDCT angiogram of all 74 patients until July 2007 were assessed by a radiologist as described elsewhere (Rieger et al., 2006). Thus, the quality was classified in the following grades: (1) very good demonstration of vascular anatomy enabling comprehensive and reliable evaluation; (2) good demonstration of vascular anatomy enabling adequate evaluation; (3) reasonable demonstration of vascular anatomy with inadequate evaluation; and (4) unsatisfactory, barely visible vascular anatomy.

Results

Between January 2000 and December 2019, a total of 140 hands of 116 patients with a mean age of 6.8 years (54 females of mean age of 7 years, range: 5 months to 30 years, and 62 males with a mean age of 5 years, range: 5 months to 27 years), underwent MDCT angiography.

Quality of the images

Evaluation revealed good quality of grade 1 (24.7%) grade 2 (43.8%), and grade 3 (26%). Only 5.5% of cases showed unsatisfactory depiction of vessel anatomy (grade 4). No additional invasive angiography was performed for grade 4 patients. None of the patients required additional conventional angiography to enable surgical planning.

Case presentations for selected hand malformations

Figures 1 to 5 present the use of the technique in different pathologies of the hand and the usefulness

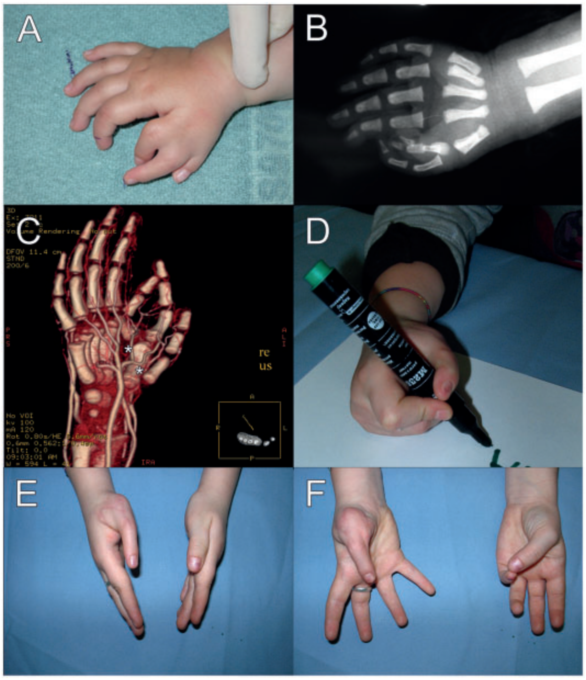

Figure 1. (a) An 11-month-old girl with a triplicated thumb, Wassel Type VII, the radial thumb being hypoplastic, Blauth type IIIB. (b) Plain X-rays were not useful for surgical planning because of marked overlay of bony structure, which did not provide additional information beyond the clinical examination. (c) MDCT angiography (Online Video Supplement 1) showed that the radial artery (asterisks) supplied exclusively the triplicated thumb and the radial side of the second digit. No connection between radial and ulnar arteries making up the superficial or deep palmar arch was detected. The radial artery and its branches exclusively supplied the thumb triplication. The knowledge of arterial anatomy permitted precise vessel preparation during surgery ((c), asterisks). The hypoplastic radial thumb and the ulnar thumb were resected, followed by pollicizing the middle triphalangeal thumb. (d)–(f) The result after secondary reposition and stabilization of the metacarpal head, indicating excellent thumb position and function 5 years later.

for surgical planning. Figure 6 shows typical pitfalls of the technique.

Discussion

Our results show that 3-D CT angiography is useful for treatment planning for complex congenital hand malformations. For these anomalies, CT scans and MRI have been suggested (Holten et al., 1997a, 1997b). CT-angiography is more useful as it depicts all tissues and additionally provides exact knowledge of the vascular anatomy and its abnormalities. Flexor tendons can also be depicted accurately. The

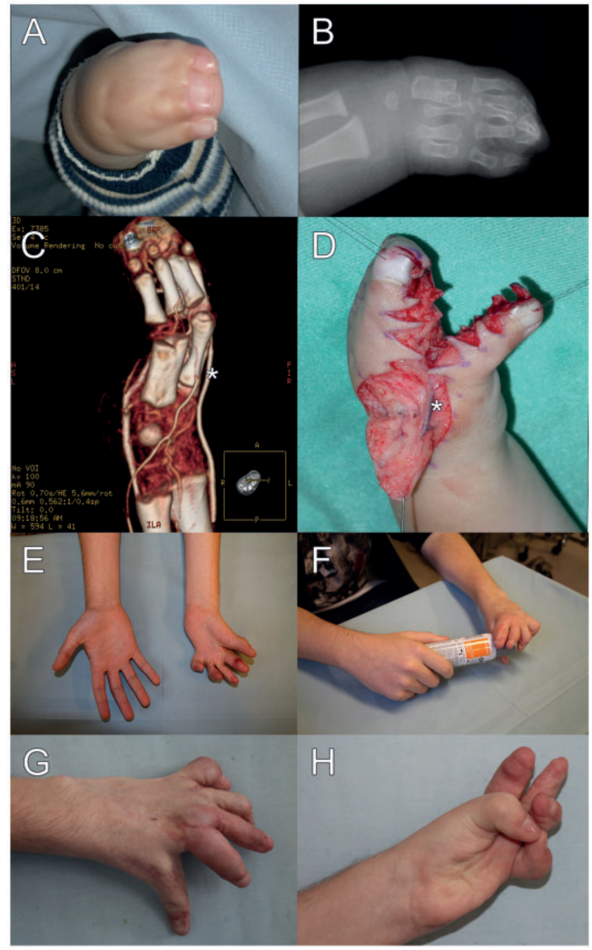

Figure 2. (a) This 15-month-old boy had a rare non-syndromal Apert-like malformation of the left hand, Upton Type III, without associated malformation of the feet or skull. (b) X-ray examination hinted at bony fusion of the distal phalanges of the central rays and partial osseous syndactyly of the fourth and fifth metacarpal bones. (c) MDCT showed that the main vessel supplying the hand was a strong ulnar artery, dividing into two main branches at the level of the third metacarpal head after supplying the fifth digit. The hypoplastic radial artery divided to a small superficial palmar arch and a princeps pollicis artery, travelling to the dorsum of the hand (asterisk). (d) This knowledge was useful for planning a well-supplied local rotation advancement flap to line the first webspace (asterisk) correcting syndactyly with interdigitated ulnar- and radial-based mirror image Z flaps. At the age of 12 years (e and f) and 15 years (g and h), the result is aesthetically pleasing and functional.

angiographic pictures show a high correlation with intraoperative vascular anatomy in most cases. Thus, the smallest vessels, such as connection vessels between the digital arteries, can be identified, or the larger of two digital arteries can be selected

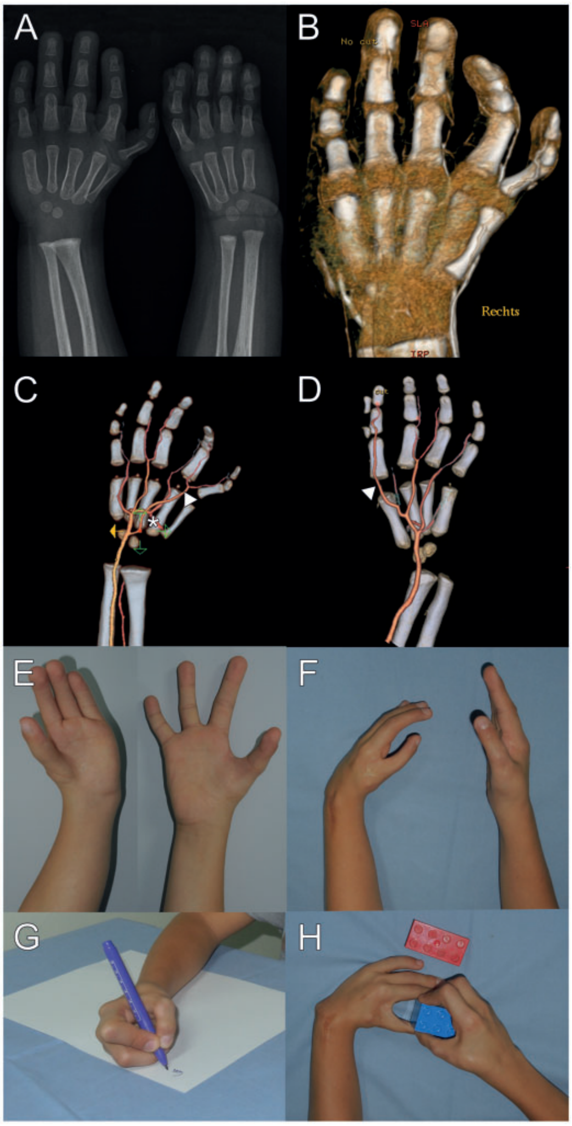

Figure 3. (a) The patient had Holt-Oram syndrome with bilateral radial clubhand Bayne and Klug Type I on the right, Type II on the left forearm. Radial ray deficiency showed a hypoplastic right thumb (Blauth Type 3 b), left thumb (Blauth Type 4). (b) X-rays showed a typical short radius on the right side and a hypoplastic radius with radial and palmar deviation of the carpus on the left forearm. (c) MDCT at age of 26 months showed that only the ulnar artery was present in both sides, leaving a deep palmar arch in the right (asterisk), but not the left hand (d). Bilaterally, a branch to the first and second digit was identified ((c and d), arrows). (e)–(h) The right side was corrected with pollicization of the second digit after resection of the hypoplastic thumb at the age of 28 months. Bilateral radial deviation was corrected by tendon transfer of flexor carpi radialis and extensor carpi radialis longus to the extensor carpi ulnaris and temporary K-wire transfixation. The hand and arm were functional 11 years after surgery.

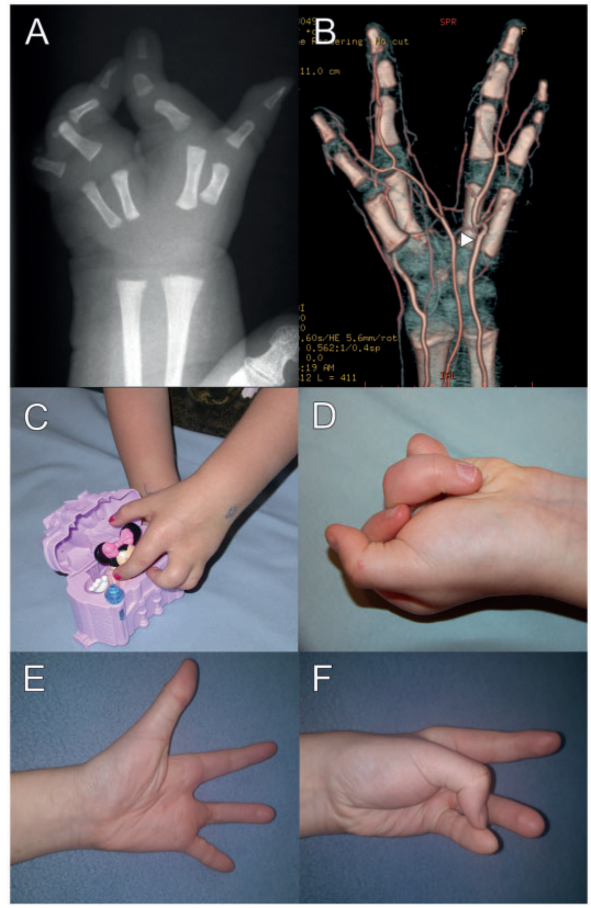

Figure 4. (a) A girl had a cleft hand Type I with hypoplastic thumb on the left side. (b) The deep cleft reached to the metacarpal base. On the right side, only two fingers were evident (Type 3). MDCT for surgical planning was done (Online Video Supplement 2; age: 15 months). A strong median artery and radial artery supplied the two radial rays, the ulnar rays were exclusively supplied by the ulnar artery. A thin deep palmar arch was identified (arrow). Correction was performed using the procedure of Snow and Littler. Knowledge of the presence of the anterior interosseous artery allowed use of an axial transposition flap to create a first web space. Webspace deepening was not limited by the connection vessel between radial artery and the third finger artery because the index was known to have three supplying branches. Transposition of the second ray to the central position created a functional, pleasing result after 2 years (c), 9 years(d) and 16 years (e and f).

beforehand. Also, small crossing vessels in complex cases are easily identified.

3-D MDCT allows syndactyly release of adjacent fingers in a single-stage procedure (Harvey et al., 2012). Even central digits can be released at the same time as border digits, and the number of operations needed in these patients can be decreased

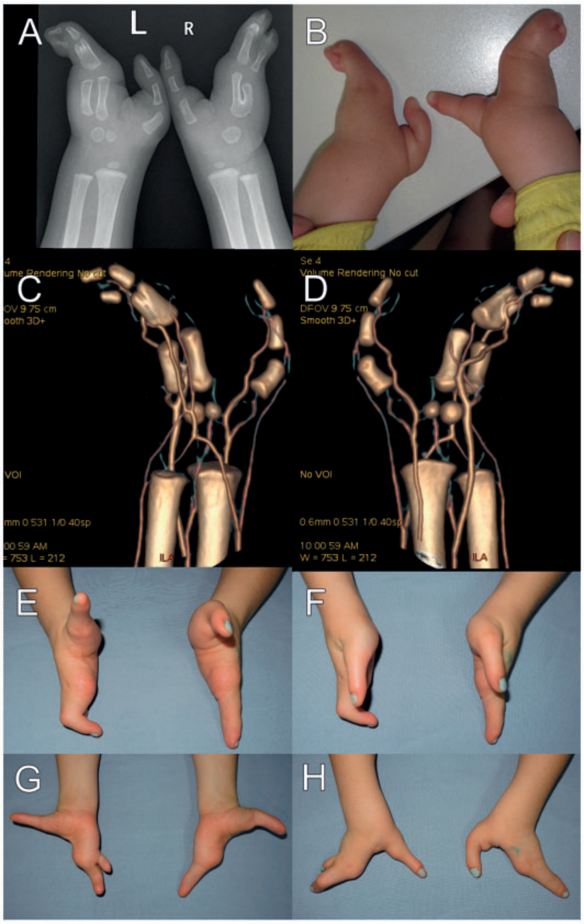

Figure 5. (a) and (b) A girl had a Type I bilateral cleft hand as part of split hand/split foot malformations due to a TP63 gene mutation. (c) and (d) MDCT for both hands and feet at age of 11 months. At the age of 17 months, the right hand was treated by resolving the syndactyly of the ulnar rays and stabilizing the index finger by reconstructing the radial collateral ligament of the second metacarpophalangeal joint. Eight months later, the left hand was treated by resecting the rudimentary small digit, reinserting the abductor digiti minimi and tightening the radial MCP joint collateral ligament to prevent further ulnar deviation. A strong median artery was found on each side. As typical in this malformation, the superficial volar arch was absent. Exact visualization of the arterial vessels was possible to the mid-level of the proximal phalanx in this patient, most likely attributable to the timing of contrast material administration. (e)–(h) Good functionality of both hands at 3.8 years (right hand) and 3.2 years (left hand) postoperative.

(Fearon, 2003; Zucker et al., 1991), which is particularly helpful in children with associated malformations requiring surgical procedures for correction (Piza-Katzer et al., 2008). Tendons can be identified in 3-D MDCT scans with volume rendering

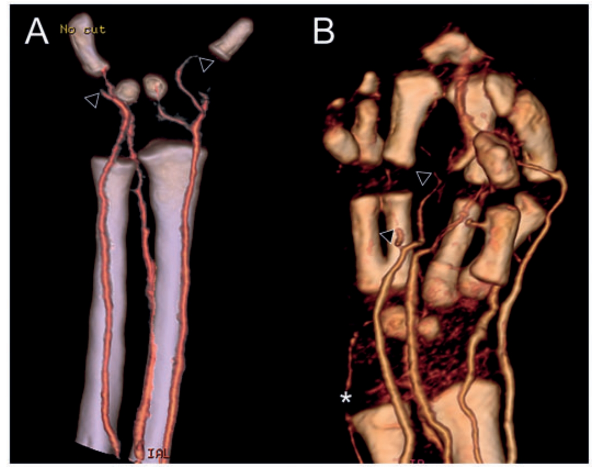

Figure 6. Pitfalls. (a) A 14-month-old girl with symbrachydactyly Type III in Poland's syndrome. Arrows show the distal end of the correctly contrasted arteries, followed by uncontrasted digital vessel segments due to incorrect scan delay. (b) The MDCT scan of a 5-month-old girl with Apert's syndrome performed on a 4-MDCT scanner. Arrows indicate the distal end of the correctly contrasted arteries, while the asterisk marks venous overlay likely due to the transitions delay. Additionally, scan field and display field of view have not been adjusted to scan volume, which impairs image resolution.

(Sunagawa et al., 2003). In paediatric imaging, however, flexor tendons are depicted as clearly defined round structures embedded into the relatively high amount of fat tissue in the palm. It might, however, be impossible to differentiate both the flexor digitorum profundus and superficialis tendons in children (Sunagawa et al., 2003), but the presence of the tendon tissue can be depicted and thus be considered for surgical planning. Extensor tendons are more difficult to detect because of their low volume and the much lower content of surrounding fat on the dorsal aspect of the hand.

Care should not only be taken when planning surgery but even before that, namely when planning preoperative imaging, to avoid unnecessary or redundant examinations. In more complex cases, such as Apert's syndrome, the MDCT of the hands is done at the same time as the craniofacial planning CT is done for craniosynostosis surgery. In split hand/split foot malformations (Gane and Natarajan, 2016), for instance, all four distal extremities can be depicted in the same scanning sequence. Usually, the patient is supine with the arms positioned above the head in order to keep the radiation dose at the maximum possible distance from the abdominal organs. Also, using only the arterial phase is sufficient in surgical planning, thus further decreasing the radiation dose (Harvey et al., 2012). In our experience, 3-D CT angiography is a fast and comprehensive technique for analysing soft tissues and neurovascular structures in children.

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Informed consent All patients gave their written informed consent for both the surgical procedure as well as for documentation, including the photographs, and their use in scientific publications.

Supplemental material Supplemental material for this article is available online.

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