Aortic Arch Mapping by Computed Tomography for Actual Anatomic Studies in Times of Emerging Endovascular Therapies

Manuel Wilbring,[1] Maximilian Rehm,[1] Tamer Ghazy,[1] Marc Amler,[2] Klaus Matschke,[1] and Utz Kappert,[1] Dresden, Germany

Background: The latest advances in treatment of aortic arch pathologies increasingly included endovascular technologies. For those purposes, more detailed knowledge about the specific anatomic features are of particular interest, especially with regard on the need for better suitable stent grafts or even development of "off-the-shelf" stents.

Methods: The study enrolled patients undergoing computed tomography of the chest for other reasons than screening for aortic disease. Patients with aortic pathologies were excluded. Finally, 118 patients were included. Anatomic features of the aortic arch, the supra-aortic branches, distances and takeoff angles as well as specific diameters were assessed and analyzed with respect to the patients height, weight, age, and sex.

Results: A significant variability of all measurements was observed. Nonetheless, 4 recurrent types of aortic arch geometry were identified: (1) Classic arch (39%), (2) Gothic arch (39%), (3) Rectangle arch (11.9%), and (4) Plain arch (8.5%). Furthermore, the aortic diameter continuously decreased from the beginning of the ascending aorta during the after 200 mm by 24.8% (31.8 ± 3.6 mm to 23.9 ± 3.1 mm in mean). Distances from the aortic annulus to the supra-aortic branches takeoff points showed significant gender- and age-related differences with larger distances in the older and male ($P < 0.001$). Observed takeoff angles were 44.9 ± 15.9° for the brachiocephalic trunk, 25.7 ± 15.5° for the left common carotid artery, and 28.8 ± 14.5° for the left subclavian artery.

Conclusions: Observed anatomic features were highly variable. It seemed that a "standard aortic arch" does not exist. Until today, the aortic arch as a dynamic and 3-dimensional entity is not fully understood. The development of "off-the-shelf" stents in the near future will be limited by this complexity and variability.

INTRODUCTION

Pathologies of the ascending aorta and aortic arch potentially are one of the most demanding problems a surgeon can be faced with. Despite the excellent results reported by experienced surgeons, open aortic and aortic arch surgery are still affected from relevant morbidity, particularly in the older and substantially diseased patients. For those reasons, development of endovascular strategies is warranted.[1-5]

In 1991, Nikolay Volodos[6,7] reported successful hybrid aortic arch repair in a patient, whom was reported to be still alive in 2013. Newer and

M.W. and M.R. contributed equally to this work.

[1]Department of Cardiac Surgery, University Heart Center Dresden, Dresden, Germany.

[2]Department of Radiology, Supraregional Office of Radiology Dresden, Dresden, Germany.

Correspondence to: Manuel Wilbring, MD, Department of Cardiac Surgery, University Heart Center Dresden, Fetscherstrasse 76, 01307 Dresden, Germany; E-mail: manuel.wilbring@gmail.com

Ann Vasc Surg 2016; 30: 181–191
http://dx.doi.org/10.1016/j.avsg.2015.07.018

Manuscript received: March 30, 2015; manuscript accepted: July 10, 2015; published online: September 12, 2015.

innovative developments recently likewise included debranching of the aortic arch for generating an adequate landing zone, allowing to perform thoracic endovascular aortic repair (TEVAR). For those purposes, an antegrade or retrograde placement of an endovascular stent graft in a staged or 1-step procedure is possible.

Until today, acceptable clinical results of first experiences are reported, simultaneously revealing technical concerns and relevant morbidity of this young technique.[8–10] In our own experience, one particular limitation of TEVAR is the development of endoleaks, potentially being a consequence of the deficiencies of presently available stent grafts.[9] Proximal and distal sealing of the aorta for exclusion of the diseased segment remains crucial for procedural success and satisfying long-term outcome.

For reliable sealing, authoritative knowledge of aortic and aortic arch anatomy is needed. The 3-dimensional, dynamic and tortuous construct with the supra-aortic branches, being indispensable for life, result in a challenging surgical anatomy.

Presently, most anatomic knowledge of the aortic arch comes from cadaveric studies. But nowadays, computed tomography (CT) is an essential tool for preoperative planning and should also be used for anatomic studies. For those reasons, the present study used CT data for mapping the aortic anatomy. A comparable study was performed by Finlay et al.[11] They provided detailed information about arch anatomy, hereby focusing on the supra-aortic branches.[11] The present study additionally adds, beside a larger patient cohort, a classification of arch geometry based on CT.

Main purpose of suchlike studies is to support the development of ‘‘off-the-shelf’’ thoracic stent grafts by providing basic anatomic knowledge. Presently, ‘‘off-the-shelf’’ devices are still in their infancy. Further development and improvement of the presently available grafts are desired for precluding time delays and further reducing costs.[11] For further improvement of the presently available devices, detailed basic information and geometrical mapping of the ascending aorta and aortic arch are deemed necessarily.

Objective of the present study was a detailed analysis of the anatomy of the ascending aorta, the aortic arch and the supra-aortic branches using CT. The description of the ‘‘normal case’’ shall be the basis for further studies describing the diseased aorta and corresponding changes to the normal case.

PATIENTS AND METHODS

Patient Population

The study enrolled patients undergoing CT of the chest for extracardiac reasons. Between May and July 2013, consecutive 120 patients were screened. Two patients with an aortic aneurysm as an incidental finding were excluded. The remaining 118 patients were enrolled. CT was performed using a GE Optima™ 660 (64 slice; slice thickness, 0.625 mm; pitch, 20 mm/rotation). The data were anonymized and subsequently prospectively included into the present study. Mean patient’s age was 63 ± 15 years, ranging from 22 to 85 years; 62 patients (52.5%) were male. The recorded body weight ranged from 50 to 95 kg with a mean of 70 ± 11 kg. The body height averaged 164 ± 5 cm, ranging from 154 to 170 cm. The corresponding body-mass-index was 27.4 ± 4.3 kg/m^2 with a range from 18 to 32 kg/m^2.

Because of the complete retrospective design and secondary analysis of anonymized data, a separate review process by the institutional review board was not mandatory. All patients gave informed consent for the CT. There existed no conflict of interest.

Primary Outcome Measures

Surveying and mapping of the ascending aorta, the aortic arch and parts of the descending thoracic aorta included continuous recording of (1) aortic diameters, (2) configuration of the aortic isthmus (spot on the aorta distal the left subclavian artery [LSA] at the site of the ductus arteriosus), (3) configuration of the aortic arch, (4) distance from the aortic valve level to the takeoff points of the supra-aortic branches and coronary arteries, (5) takeoff angulation of the supra-aortic branches, (6) distribution of atherosclerotic plaques, and (7) the corresponding aortic course, depicted in a 3-dimensional coordinate system. Hereby, takeoff points were defined as the center of the branch at the outer curvature. The angle at takeoff was defined as the angle between the branch plumb line and the aortic tangent in standard vertical axis. To avoid bias caused by the significant tapering between branch takeoff point and further vessel course, the branch diameters were determined 1 cm after takeoff. Subsequently, the gathered information was analyzed with respect to sex, age, weight, and height.

Data Assessment

The anonymized primary Digital Imaging and Communications in Medicine-data were imported