Artery Research (2014) 8, 66—72

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/artres

Cardiovascular aging: Insights from local and regional measures of aortic stiffness using magnetic resonance imaging

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Available online 14 March 2014

KEYWORDS
Cardiovascular aging;
Magnetic resonance imaging;
Aortic stiffness;
Distensibility;
Pulse wave velocity

Abstract Aortic stiffness is now established as an independent marker of cardiovascular aging and cardiovascular risk. However, the specific role of the proximal aorta, specifically the ascending aorta, remains understudied. Magnetic resonance imaging (MRI), a non-invasive technique has recently been proposed to measure new local and regional imaging biomarkers of stiffness in the thoracic aorta. We will here review recent data on aortic stiffness assessed by MRI. We will discuss the methodological advantages and challenges of MRI, combined with applanation tonometry, to evaluate local aortic distensibility and pulse wave velocity (PWV) and summarize available results concerning the age related distribution of such parameters.

Aortic distensibility has been shown to be an early subclinical marker of vascular target organ damage in the general population and expected ranges for ascending aortic distensibility and aortic arch pulse wave velocity assessed in MRI have been described. Changes in aortic distensibility and arch PWV have been related to age-related geometric changes, specifically lengthening, enlargement and unfolding of the thoracic aorta. Increased proximal aortic stiffness measured by MRI has also been related to decreased systolic and diastolic function and concentric remodeling of the left ventricule in healthy individuals.

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1872-9312/$ — see front matter
http://dx.doi.org/10.1016/j.artres.2014.01.005

Background

The increasing burden of cardiovascular disease in aging world populations associated with increased systolic and pulse pressures has been related to two main factors: arterial stiffness and wave reflections. Aortic stiffness has emerged clinically as an important integrated marker of large arterial vessel damage over a lifetime, whereas measures such as blood pressure or biological markers are indirect and instantaneous measures of aortic stiffness furthermore highly modifiable by drugs.[1] Furthermore, age-related changes in blood pressure which are only indirect measures of aortic stiffness appear to be significant only later in life.

Along the arterial tree, the proximal aorta is responsible for most of the buffering and immediate conduit function of the pulsatile systolic flow from the heart to the peripheral vasculature and end organs. Alterations of these two components of aortic function lead to inefficiency of the circulatory system and potential vascular—ventricular uncoupling eventually deleterious to the heart through increased workload.

One of the great challenges in this field of research is to untangle the relative effects of age and disease including cardiovascular risk factors when both the age-driven vascular alterations and atheroslcerosis-driven disease continuum share similar mechanisms such as hypertrophy, remodeling, ischemia, fibrosis and generate the same complications such as heart failure and sudden death. However, this overlap between age-related alterations and disease may differ along the arterial tree which is highly heterogenous regarding its viscoelastic properties. Indeed, the ascending aorta differs from the descending aorta both embryologically and in its natural history as it is less prone to atheroma, thrombus and calcification but more to dilatation secondary to fragmentation and alteration of its important elastic component.[2] Consequently, local and direct indices of aortic stiffness may have increased relevance as they may be more specifically related to aging vs. a disease process and also because they may be more sensitive to early infra clinical alterations than more global or surrogate markers of arterial stiffness.

However, the challenge is to determine the robustness of such markers, their distribution and correlates in the general population and in patients with cardiovascular disease and finally their predictive value for adverse events beyond the available and established indices of aortic stiffness.

The non-invasive assessment of aortic stiffness schematically relies on the assessment of either pulse wave velocity or local cross sectional changes in vessel area driven by local pulse pressure (distensibility). The reference method to assess global aortic stiffness is the measurement of carotid to femoral pulse wave velocity by applanation tonometry (cf-PWV). This technique benefits from a large experience, wide cohort applications and reported distribution in the general population and patients, particularly in hypertension. Furthermore, cf-PWV is a recognized independent risk factor for mortality and hard cardiovascular events in the general population. More recently, magnetic resonance imaging (MRI) has been proposed to provide a comprehensive non-invasive study of the aorta. One of the strengths of this method is indeed to provide simultaneously a thorough three-dimensional exploration of aortic anatomy as well as local wall dynamics and flow. Assessment of cardiac structure and function or peripheral arteries and organs can also be performed in the same setting. We will here discuss the methodological advantages and challenges of MRI, combined with applanation tonometry, to evaluate aortic biomechanics and geometry and summarize available data concerning the age-related distribution of such parameters compared with established measures of aortic stiffness.

Assessing structure and function of the thoracic aorta using MRI: methods and results in cardiovascular aging

MRI, a reference technique to evaluate cardiac structure and function also uniquely provides non-invasive depiction of aortic anatomy, wall motion and flow in any given anatomical localization or spatial direction. Electrocardiogram gating and segmented acquisition techniques over several heartbeats are used to generate anatomic images corresponding to different phases of the cardiac cycle. The resulting cine acquisitions can be used to track aortic wall motion with high spatial (0.7 mm) and temporal resolution (10 ms—30 ms) depending on the heart rate and breath holding ability. Moreover, the intrinsic sensitivity of magnetic resonance to motion and flow can be used to produce velocity and flow maps using phase-contrast acquisition sequences (Fig. 1).

Aortic structure and geometry

Aortic wall thickness

MRI allows to visualize the aortic wall in any plane orientation (Fig. 1). Most studies are based on black-blood spin echo T1-weighted acquisitions which generate a sharp contrast between the signal from the wall and the blood. An age-related increase in average wall thickness of the descending aorta was reported in 1053 general population individuals aged 45—85 years (average 2.35 $\pm$ 0.5 mm) but was not found for the ascending aorta (average 2.8 mm).[3,4] In this study SBP and hypertension were also independent correlates of increased wall thickness. Good reproducibility for this measurement has been reported.[5,6] However, the spatial resolution of most acquisitions (0.7—1 mm) being about half of the expected thickness for the aortic wall (1.5—2.5 mm) we believe that partial volume remains a major drawback that will require higher spatial resolution and refined automated quantification methods to be accurate. No large MRI studies are available on the wall thickness of young and healthy individuals.

Static cross sectional aortic dimensions

Numerous MRI methods allow to measure aortic size. We will not review them here extensively. One of the strengths of MRI is to provide a 2D or 3D approach allowing to