Diagnostic imaging in the management of patients with metabolic syndrome

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Metabolic syndrome (MetS) is the constellation of metabolic risk factors that might foster development of type 2 diabetes and cardiovascular disease. Abdominal obesity and insulin resistance play a prominent role among all metabolic traits of MetS. Because intervention including weight loss can reduce these morbidity and mortality in MetS, early detection of the severity and complications of MetS could be useful. Recent advances in imaging modalities have provided significant insight into the development and progression of abdominal obesity and insulin resistance, as well as target organ injuries. The purpose of this review is to summarize advances in diagnostic imaging modalities in MetS that can be applied for evaluating each components and target organs. This may help in early detection, monitoring target organ injury, and in turn developing novel therapeutic target to alleviate and avert them.

Abbreviations: ASL = arterial spin labeling; BMI = body mass index; BOLD = blood oxygen level-dependent; BP = blood pressure; CAD = coronary artery disease; CIMT = carotid intima-media thickness; CT = computed tomography; D = dimensional; DCE = dynamic contrast-enhanced; DTI = diffusion tensor imaging; DWI = diffusion-weighted imaging; DXA = dual-energy x-ray absorptiometry; FDG = fluorodeoxyglucose; GFR = glomerular filtration rate; HU = Hounsfield units; IMCL = intramyocellular lipid; IVUS = intravascular ultrasound; LV = left ventricle; LVH = left ventricular hypertrophy; MetS = metabolic syndrome; MRE = magnetic resonance elastography; MRI = magnetic resonance imaging; MRS = magnetic resonance spectroscopy; MTI = magnetization-transfer imaging; NAFLD = non-alcoholic fatty liver disease; NAFPD = non-alcoholic fatty pancreatic disease; NASH = non-alcoholic steatohepatitis; OCT = optical coherence tomography; PET = positron emission tomography; PWV = pulse wave velocity; SAT = subcutaneous adipose tissue; SPECT = -photon emission computed tomography; TCD = transcranial Doppler; US = ultrasonography; VAT = visceral adipose tissue

INTRODUCTION

Metabolic syndrome (MetS) is the constellation of metabolic risk factors that might foster development of type 2 diabetes and cardiovascular disease. According to the NCEP-ATPIII 2005, 3 or more of the following 5 traits define MetS: (1) bbdominal obesity by waist circumference; (2) elevated triglyceride levels or drug treatment for elevated triglycerides; (3) low levels of high-density lipoproteins or drug treatment for low high-density lipoproteins cholesterol; (4) elevated blood pressure (BP) or drug treatment for elevated BP; and (5) Elevated fasting glucose or drug treatment for elevated blood glucose. These traits might be inter-related; therefore, whether MetS merely reflects the additive effects of the individual traits or stratifies distinct risk of cardiovascular disease remains controversial.

Abdominal obesity and insulin resistance play a particularly prominent role among all metabolic traits of the MetS.[1] Duration and severity of obesity are positively associated with incident MetS, as well as increased risk for other MetS components, suggesting that

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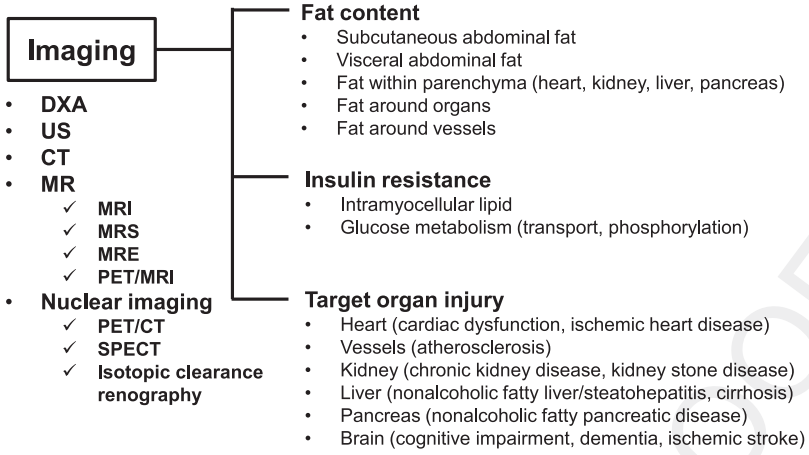

Fig 1. Schematic illustrating evaluation of the metabolic syndrome using imaging modalities. CT, computed tomography; DXA, dual-energy x-ray absorptiometry; MRE, magnetic resonance elastography; MRI, magnetic resonance; MRS, magnetic resonance spectroscopy; PET, positron emission tomography; SPECT, single-photon emission computed tomography; US, ultrasonography.

metabolically healthy obesity is a transient state in the pathway to cardiometabolic disease.[2] Obesity leads to increased morbidity including cardiovascular disease and type 2 diabetes,[3,4] and is significantly correlated with increased mortality.[5,6] Interventions and lifestyle modifications have been shown to reduce morbidity and mortality in MetS.[7,8] Obesity, especially abdominal obesity, can also instigate or worsen insulin resistance in MetS. Excessive fatty acids in MetS increase lipid accumulation, inhibit insulin-mediated glucose uptake, and thereby reduce insulin sensitivity in several organs including adipose tissue, skeletal muscle, and liver.[9] Additionally, insulin resistance affects sodium reabsorption, sympathetic nervous system activation, and nitric oxide bioavailability, and is thus implicated in target organ injury.[10] Therefore, the ability to detect and monitor development and progression of abdominal obesity and insulin resistance and their consequences in target organs is important to stratify the risk and apply effective preventive and therapeutic intervention in individuals with MetS.

Recent advances in imaging modalities have provided significant insight into understanding the pathogenesis of 2 major components of MetS, abdominal obesity, and insulin resistance. In addition, diagnostic imaging is essential for early detection of target organ injury and characterization of complications of MetS.

The purpose of this review is to summarize advances in diagnostic imaging modalities in MetS that can be applied for evaluating the features of MetS and its target organs. Timely use of imaging modalities may help in the diagnosis, prediction of target organ injuries, and development of novel therapeutic targets to alleviate and avert them.

EVALUATING COMPONENTS OF METABOLIC SYNDROME

Abdominal obesity. Abdominal obesity is one of the most central factors for the development of MetS.[11] Abdominal obesity is often clinically expressed as waist circumferences at the umbilical level,[12] yet this measure cannot discriminate between visceral abdominal tissue (VAT) and subcutaneous adipose tissue (SAT). Visceral obesity is known as a major cause of insulin resistance, and is closely associated with the other 4 features of MetS through an imbalance between adipokines and insulin.[12] Recent studies have shown that VAT is strongly associated with carotid intima-media thickness (CIMT) and contributes to early development of atherosclerosis.[13,14] Ultrasonography (US), computed tomography (CT), and magnetic resonance (MR) imaging have been shown to be useful to assess the VAT (Fig 1). In particular, a previous study using CT to assess MetS reported that accumulation of VAT is the best predictor for MetS in women, and a good predictor for MetS in men.[15]

The imaging methods used for quantification of adipose tissue include dual-energy x-ray absorptiometry (DXA). DXA measures the attenuation of 2 x-ray photon energies to distinguish fat, lean, and bone mineral content measures with low radiation exposure (~1 mSv/scan[16]), short scanning time (5–13 minutes), high precision, and low cost.[17] DXA estimation of fat tissue may be somewhat influenced by the degree of hydration or edema.[18] Although it does not discriminate between VAT and SAT, recent studies have developed algorithms for segmenting fat within the torso.[19,20] DXA-measured VAT shows a good correlation with CT-measured VAT volume ($r^2 = 0.89–0.96$ for females and 0.84–0.95 for males)[19,20] and may provide clinically useful information to