A contemporary review of non-invasive methods in diagnosing abdominal aortic aneurysms

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Abstract

Background: Currently, the impact of abdominal aortic aneurysm may be changing despite the aging population, but may be ambiguous given the decline in smoking, the use of screening methods, and integration of non-surgical treatment. **Objective:** This review aimed to assess the most common currently used non-invasive methods to identify abdominal aortic aneurysm, namely ultrasound and computed tomography. **Methods:** PRISMA guidelines were utilized to retrieve original articles from the past five years. All retrospective and prospective studies/trials were included, but limited to US and CT abdominal aortic aneurysm diagnostic imaging methods. Qualitative assessment of study quality is described. **Results:** Three of the six studies reported abdominal aortic aneurysm screening data. The estimated prevalence of abdominal aortic aneurysm for the three studies ranged from 4.5% to 6.2%. CT had slightly higher sensitivity and US had higher specificity for abdominal aortic aneurysm diagnosis. Two of the described studies assessed technical issues and problems with contemporary imaging of abdominal aortic aneurysm. The final article described measuring abdominal aortic aneurysm function of aortic distensibility and its pulse wave velocity for a comprehensive assessment of the abdominal aortic aneurysm via standard CT imaging. **Conclusions:** Both US and CT are useful diagnostic imaging modalities for abdominal aortic aneurysm, but remain with unique pitfalls and propensity for errors, notwithstanding patient-related errors. Technical issues in imaging with both ultrasound and CT are not straightforward. The potential value of an integrated CT protocol with CT-US fusion and/or assessment of aortic function rather than solely aortic anatomy may further diminish diagnostic complexities.

Introduction

An abdominal aortic aneurysm (AAA) is a localized dilation of 50% greater than the normal diameter of the adjacent healthy aorta. Recent estimates of AAA-associated complications demonstrate significant mortality responsible for over 4900 deaths, or an equivalent of crude rate of 1.5 deaths per 100,000 population, despite its overall decline during the past two decades[1,2]. Despite this decrease, future prevalence of AAA could change substantially when taken together with the incidence of AAA being known to rise sharply in individuals over 60 years of age, in conjunction with the ongoing aging of the general population at large. Most AAAs go undetected until they rupture. The risk of rupture depends largely on the size of the AAA. The larger the size, the greater risk of rupture, with the risk of death of up to 81%[3,4]. The aim of this literature review is to describe the most common non-invasive imaging methods used for AAA.

Background

The U.S. Preventative Services Task Force (USPSTF) recommends that men between ages 65–75 years with a history of smoking be screened, while men between ages 65–75 years who have never smoked be screened selectively as deemed by a clinician[5]. However, screening women 65–75 years of age who have never smoked or have a family history of AAA is not recommended[5]. The Society for Vascular Surgery (SVS) recommends screening both men and women 65–75 years of age with a history of smoking or family history of AAA, and also screening men and women over 75 years of age in good overall health, but with a history of smoking[6]. AAAs appear ten years later in women than in men[7]. Other factors to consider besides age include history of coronary artery disease, current smoking, hypercholesterolemia, obesity, peripheral artery disease, and varicose veins[7].
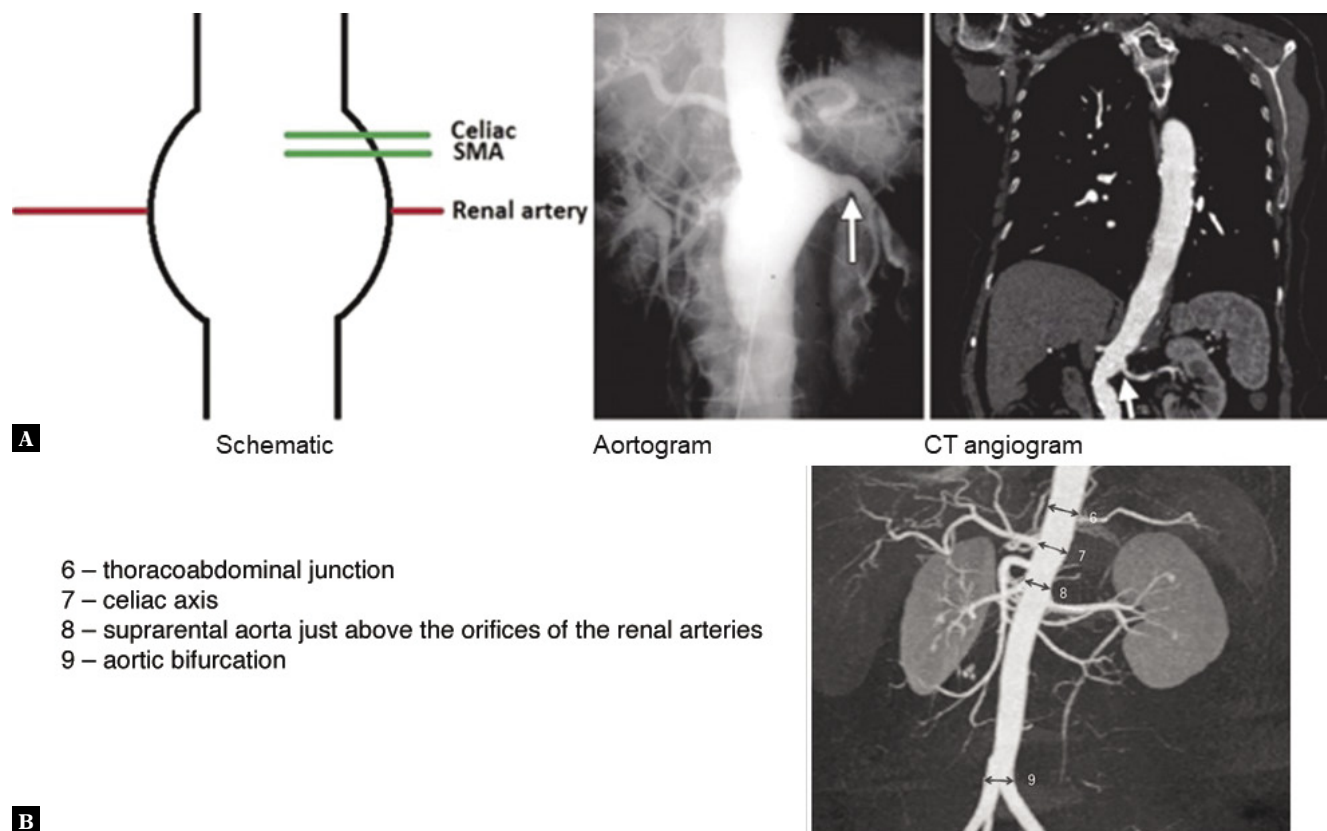
6 – thoracoabdominal junction
7 – celiac axis
8 – suprarenal aorta just above the orifices of the renal arteries
9 – aortic bifurcation

Fig. 1. A. *Suprarenal aortic aneurysm (aneurysm extending above the renal arteries (arrows)[10]* **B.** *Maximum intensity image of the entire "normal" abdominal aorta shows the suprarenal aorta at level "8" (arrows)[35]*
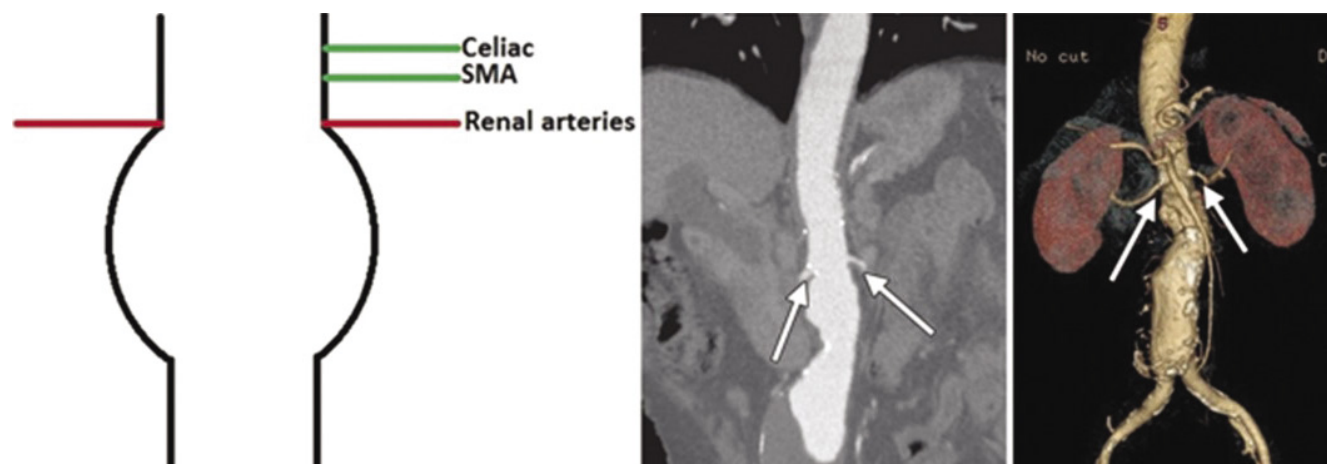

Fig. 2. *Juxterenal aortic aneurysm. Schematic diagram (left), CT angiogram (middle), and three-dimensional rendition (right) of an AAA in the same patient demonstrate the aneurysm extending just to the level of the renal arteries (arrows)[10]*

There seem to be differences in USPSTF and SVS opinions on who should or should not be screened. Nevertheless, it remains clear that AAA screening is important to prevent an avoidable death. The USPSTF recommends screening by US[5] and it is also the preferred screening tool of the SVS[6]. Ultrasound has a high sensitivity (94–100%) and specificity (98–100%)[3]. It is noninvasive, easy to perform, and does not require exposure to radiation. CT is a very accurate imaging modality, but not recommended as a screening tool due to potential harm from exposure to radiation[3]. Physical examination is also not recommended as a screening tool due to its low sensitivity (39–68%) and specificity (75%)[8].

Specifically, AAAs may be described relative to the involvement of the renal or visceral vessels. A pararenal aneurysm involves the aorta at the level with the renal arteries appearing as originating from an aneurysmal aorta. A suprarenal AAA involves the renal arteries and
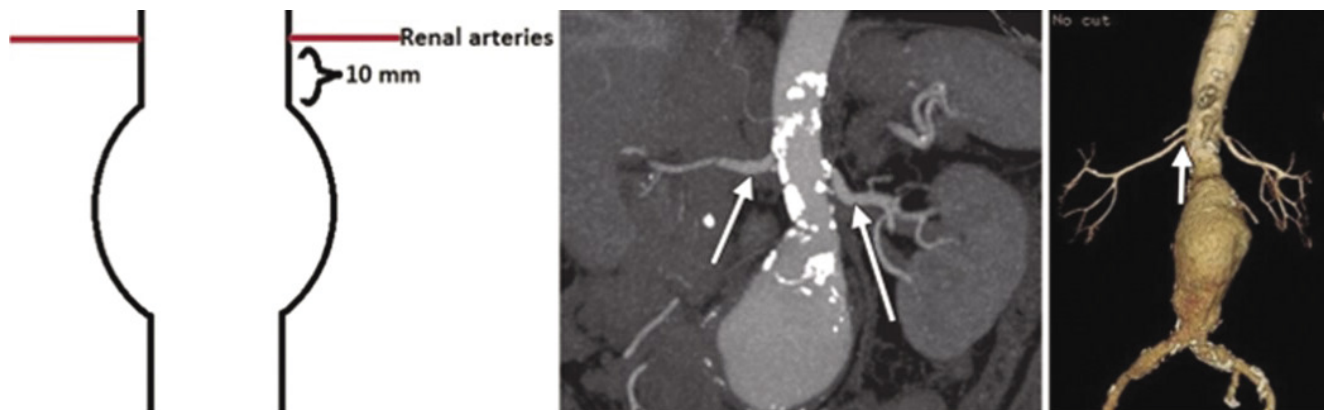
Fig. 3. *Intrarenal aortic aneurysm. Schematic diagram (left), CT angiogram (middle), and three-dimensional rendition (right) of an AAA in the same patient demonstrate the aortic aneurysm extending 1 cm below the level of the renal arteries (arrows)[10]*

extends superiorly so that the superior mesenteric artery and celiac arteries arise from the aneurysmal aorta (Fig. 1)[9]. Suprarenal aneurysms are uncommon, but may develop late following AAA repair. Juxta renal aneurysms originate essentially at the level of the renal arteries, but the aorta remains normal superiorly (Fig. 2)[9]. Approximately 15% of AAAs are juxtarenal. An infrarenal AAA arises at least 10 mm below the renal arteries (Fig. 3)[9]. The most common site in the abdominal aorta is primarily the segment of the infrarenal aorta, the segment below the renal arteries[10].

Methods

This literature review was performed with the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Fig. 4)[11]. An online systematic search with language restricted to English for prospective and retrospective original studies or trials on AAA imaging was performed. The search term "AAA screening" was paired with "ultrasound" and "CT". A five-year filter was applied to only include the most recent studies. Relevant journal publications were retrieved from Medline/Pubmed and Google Scholar from
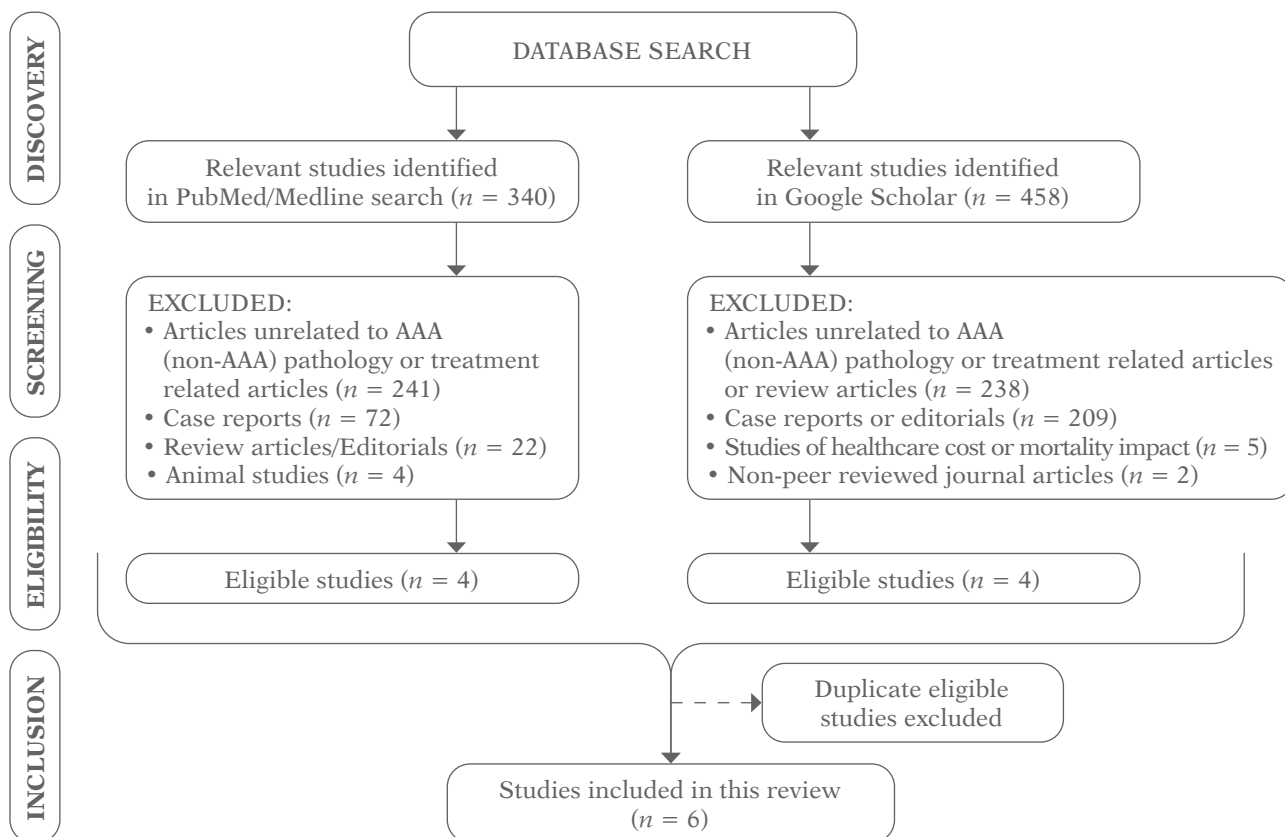

Fig. 4. *PRISMA Diagram*

Tab. 1. *Study selection and characteristics of included studies*

	First author	Journal (year)	Study type	US imaging data utilized	CT imaging data utilized
AAA screening studies	Claridge *et al.*	*J Vasc Surg* (2017)	Retrospective	No	Yes
	Liisberg *et al.*	*BMC Med Imag* (2017)	Prospective	Yes	Yes
	Ruff *et al.*	*Vasc Med* (2016)	Retrospective	Yes	Yes
Studies optimizing technical AAA imaging aspects	Shalan *et al.*	*J Clin Diag Res* (2018)	Retrospective	No	Yes
	Zur *et al.*	*Am J Roentgenol* (2019)	Prospective	Yes	Yes
Novel AAA imaging study data	Zha *et al.*	*Biomed Res Int* (2017)	Prospective	No	Yes

Tab. 2. *AAA screening studies*

First author (year)	Sample size analyzed	% Female	Mean age	Mean measurements (AP axial aortic diameter)	Estimated AAA prevalence	Sensitivity	Specificity
Claridge (2017)	3332	52.4	70.5 ± 10.8 y	2.17 ± 0.64 cm	5.80%	65.20%	98.80%
Liisberg (2017)	533	0	69.4 ± 10.8 y	2.13 ± 0.53 cm (CT) 2.12 ± 0.50 cm (US)	4.50%	82.6–88.9% (CT) 57.1–70.4% (US)	97.7–98.4% (CT) 99.2–99.6% (US)
Ruff (2016)	265	–[a]	–[b]	–[c]	6.20%	97.20%	99.20%

[a] sex distribution not reported
[b] mean age not reported; screened "all patients" >50 undergoing either US or CT abdomen
[c] did not quantify aortic dimension/used radiologists' report confirming presence or absence of AAA

Tab. 3. *Studies optimizing technical AAA imaging aspects*

First author (year)	Sample size analyzed	% Female	Mean age	AAA measurement reported
Shalan *et al.* (2018)	212	15.5	76 ± 8.6 y	mean US AP diameter: 5.4 ± 1.05 cm mean CT AP diameter: 5.7 ± 1.13 cm mean difference in CT – US diameter: 0.329*
Zur *et al.* (2019)	14	21	70.8 y	mean difference in: CT – US diameter: 0.50 mean difference in: CT – CT/US fusion diameter: 0.13‡

* paired t-test: $p < 0.001$
‡ paired t-test: $p < 0.0005$

Tab. 3. *Studies optimizing technical AAA imaging aspects*

First author (year)	Sample size analyzed	% Female	Mean age	Mean AAA diameter (range)	AAA distensibility (10-5 Pa-1)	AAA PWV (m/s)
Zha (2017)	54	29	67.2 ± 6.8 y	3.9 cm (3.2–5.9 cm)	1.05 ± 0.22 (Level 1) 0.49 ± 0.18 (Level 2)*	9.68 ± 1.09 (Level 1) 14.96 ± 4.01 (Level 2)‡

* Wilcoxon signed rank test: $p < 0.01$
‡ Wilcoxon signed rank test: $p < 0.01$

all data available through February 2021. Exclusion criteria included: case reports, reviews articles, editorials, AAA treatment, healthcare costs/economic analyses, AAA mortality studies, other associated AAA pathology, animal studies, and publications in non-peer reviewed journals. After screening, eligible studies were accumulated, any duplicate articles, or sub-studies a part of a larger study were identified and removed.

Results

Study selection and characteristics of included studies

A total of 798 published articles were identified (Fig. 4 and Tab. 1). Pubmed/Medline yielded 340 articles from which 241 were excluded because of reporting of peripheral (non-AAA) pathology and treatment related articles; 72 were

case reports; 22 were review articles/ editorials; and 1 animal study. A total of 4 eligible studies were identified after the screening process. A total of 458 articles were found on Google Scholar. A total of 238 articles were excluded due to irrelevant pathology/ review articles; 209 case reports/ editorials; 5 studies specific to healthcare cost/ mortality; and 2 non-peer reviewed journal. A total of 4 eligible studies were identified after the screening process. Also, articles were excluded if they were a precursor to a larger study published later. There were two duplicate articles identified and excluded. A total of six original studies on AAA imaging methods and their effectiveness were then compiled and evaluated.

There were 3 ultrasound studies that fulfilled the criteria, 5 CT studies that fulfilled the criteria and one study that incorporated both US and CT ("CT-US fusion") to diagnose AAA. There were 3 retrospective and 3 prospective studies (Tab. 1). Of these six articles selected for the final review, three were AAA screening studies, two compared
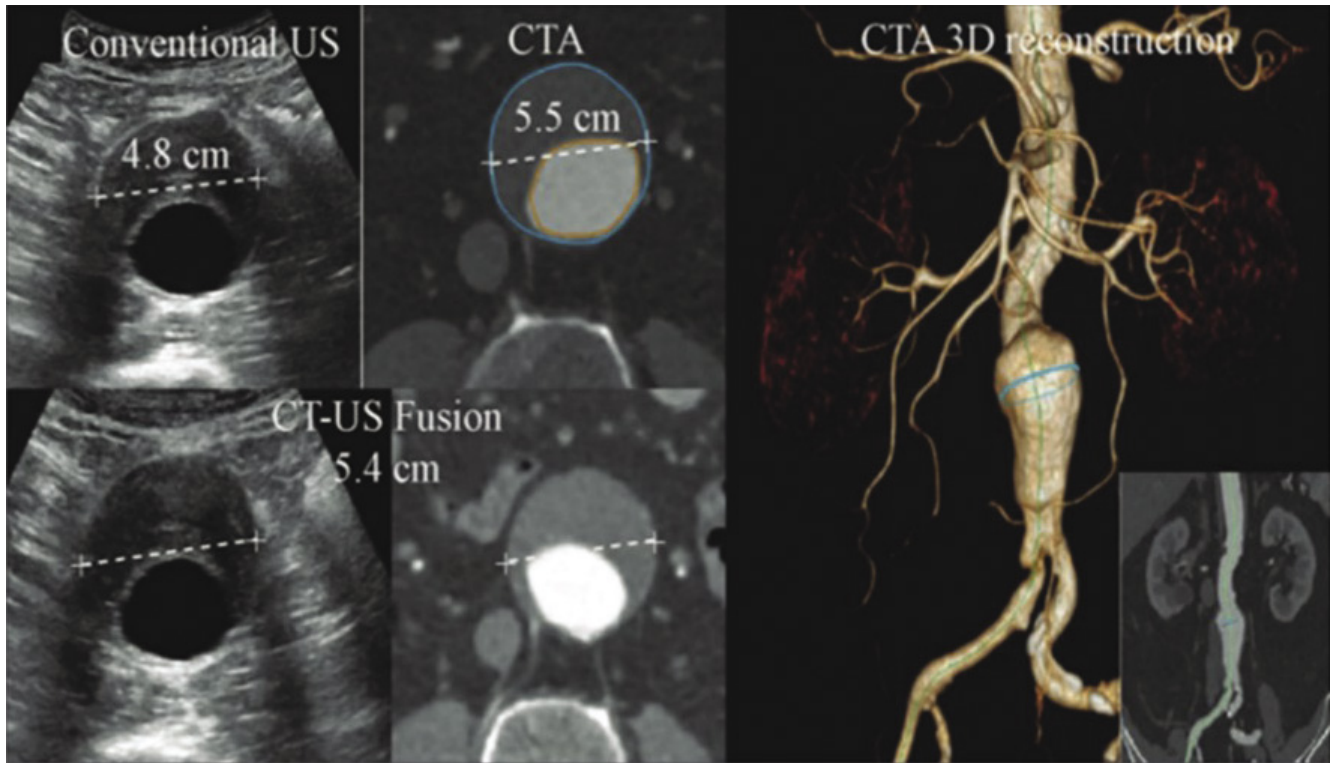
Fig. 5. *Above is an example of CT-US fusion measurements with corresponding images along the same plane of the vessel[17]*
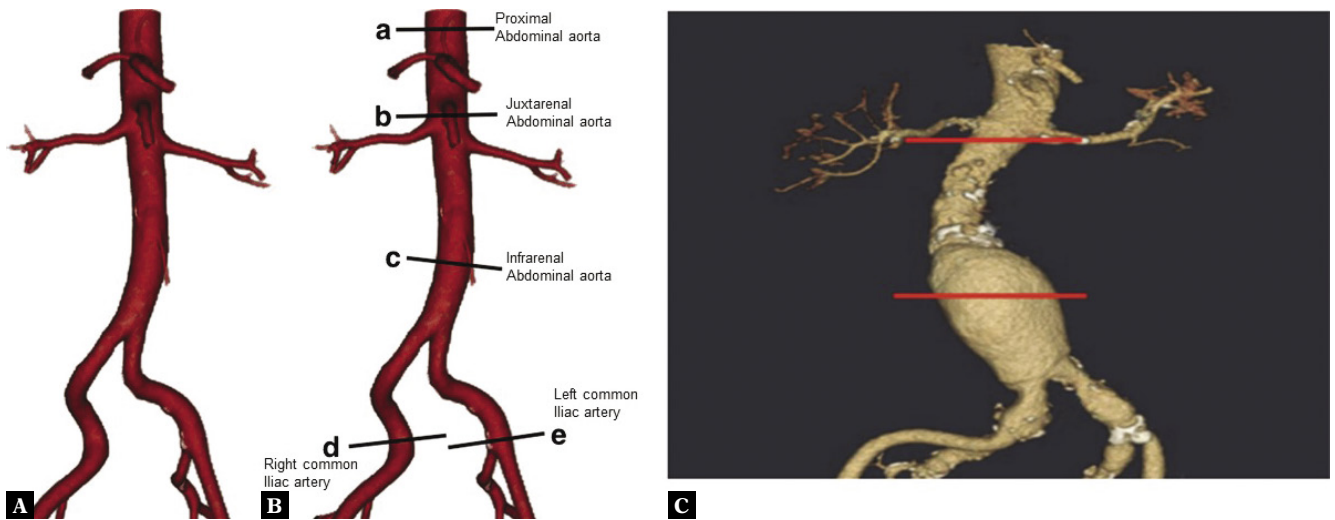

Fig. 6. A. *Volume rendered normal aorta[36]* **B.** *Standard sites of measurement[36]* **C.** *Aortic distensibility CT image[36]. The more superior level (Level 1): below the level of the renal arteries. The more interior level (Level 2): at the maximum aneurysm diameter*

the technical issues and factors with AAA measurements via US/ CT, and finally one article described an emerging complementary technology of deriving the aortic aneurysm's distensibility and its associated pulse wave velocity (PWV) using conventional CT imaging of the AAA (Tab. 1).

Reported data from the included studies

Among the studies that utilized imaging to diagnose AAAs in a population not previously known to have this diagnosis, prevalence estimates as well as sensitivity/specificity values of the imaging modality utilized were key objectives. The prevalence of AAA for the three studies appeared similar, ranging from 4.5% to 6.2% (Tab. 2). Notably, however, Ruff *et al.*[12] did not specify the age or sex distribution of the population and though they utilized both US and CT, they did not report the quantitative measures of AAA dimensions and their calculated sensitivity/specificity values were estimated with CT imaging after initial screening with US. Claridge *et al.*[13] incorporated the largest sample size, but utilized only CT for

their sensitivity/specificity estimates. Whereas Liisberg *et al.*[14] incorporated both US and CT and their sensitivity/specificity values were calculated using each method as a reference standard for the other. CT sensitivities reported ranged from 65.2 to 97.2 and CT specificities ranged from 97.7 to 99.2, and the associated US sensitivity ranged from 57.1 to 70.4% and its specificity was 99.2 to 99.6% (Tab. 2).

Among the two studies analyzing technical issues with the measurement of AAA, Shalan *et al.*[15] demonstrated that the mean measured difference in AP diameter measured by US versus CT was statistically different (Tab. 3), even though both CT and US showed significant correlation (correlation coefficient [cc] 0.938/p <0.001) with each other. Additionally, when the authors assessed the limits of agreement between CT and US via Bland-Altman analysis, the plot indicated only weak agreement with a persistent bias for larger reading on all CT measurements in comparison to US. Though there was no disagreement between CT and US with increasing AAA size, larger-size AAAs showed significant but weak correlation (lower cc) between CT and US (cc 0.27/ p <0.001). Zur *et al.*[16] demonstrated that the mean difference between conventional US and CT was 0.50 cm, but when utilizing CT-US fusion imaging, the difference dropped to 0.13 cm (Fig. 5). This finding was statistically significant, demonstrating that CT-US imaging was significantly more accurate than conventional US alone for aneurysm measurement when using CT as the reference standard (Tab. 3).

Unlike the other studies looking at aortic anatomical dimensions, Zha *et al.*[17] also integrated that of aortic function as characterized by the aneurysmal stiffening as measured by aortic distensibility and its corresponding pulse wave velocity (PWV) to comprehensively evaluate the patients' AAA. These values were derived by measuring the aortic cross-sectional area changes at two positions: (level 1) immediately below the lowest renal artery and (level 2) at the level of the AAA's maximal diameter (Fig. 6). From these measurements, and by incorporation of the patient's pulse pressure, they utilized literature definitions to calculate aortic distensibility and from this value, they likewise converted aortic distensibility to the corresponding PWV as defined in the literature. The main findings of their study were that aortic aneurysmal stiffening as measured by aortic distensibility and PWV was significantly increased in AAA as compared to the non-aneurysmal parts of the abdominal aorta (Tab. 4).

Discussion

The impact of AAA on morbidity and mortality appears to be changing. AAA-associated mortality has decreased by nearly 50% since the early 1990s[18–20]. Although the specific reasons for this decline are unknown, the declining prevalence of cigarette smoking in the adult population, the increasing awareness and the impact of screening programs on early identification of disease, and an increase in non-surgical repair of AAA, all may

have partially played a role in this decline[20,21]. Some authors suggest that estimates of aneurysm mortality may also come from over-reporting of the burden of the disease[20]. Furthermore, accurate diagnosis of AAA, particularly among the asymptomatic population, may often be challenging and may impart distressful repercussions. Despite limited evidence quantifying the harm of overdiagnosis, it appears that approximately 45% of patients will be overdiagnosed, where only aneurysms of clinically important size will be considered for surgery and smaller aneurysms will be monitored, which is potentially associated with a significant level of anxiety, and consequently underscores the utility of a timely yet accurate diagnosis[22].

To this regard, this literature review attempted to describe the present-day data from AAA imaging studies. Diagnostic US continues to be considered the mainstay for AAA screening but in general, its sensitivity is slightly lower than that of CT in the screening studies as described in this review. The reported results revealed that the diagnostic sensitivity of US is effective for AAA screening, as recommended by current guidelines. For asymptomatic AAA, abdominal US, which has adequate sensitivity but also specificity approaching 100% for an aortic diameter >3.0 cm, remains the long-standing imaging test of choice[23]. Abdominal US is convenient, devoid of ionizing radiation, and is ideal for serial imaging in patients with small- and medium-sized aneurysms who are being conservatively managed. The recent screening studies reviewed here demonstrated that US has lower sensitivity than that of CT, but it has very high specificity. However, it is well acknowledged that ultrasound is often operator-dependent, with additional limitations deriving from increased patient adiposity, large waist circumference or intestinal gas diameters, all of which can contribute to difficulty in proper assessment of abdominal US, and hence its lower sensitivity[24]. These issues make CT the imaging method of choice for symptomatic AAA[24]. Although contrast-enhanced CT is generally not needed to establish a diagnosis of ruptured AAA, it is recommended if surgical repair is being considered. Prevalence estimates in the imaging screening AAA studies ranged from 4.5–6.2%. This is consistent with prior prevalence estimates ranging between 4 to 8%[25–28].

The technical issues of AAA imaging are not straightforward for either US or CT. An important limitation of abdominal ultrasound imaging is that it is operator-dependent[29]. Specifically, if the US transducer is not oriented perpendicular to the midline, the AP diameter of the aorta may be overestimated[29]. There remains debate over the optimal method of measuring the diameter of the abdominal aorta (outer-to-outer, inner-to-inner, or leading-edge to leading-edge[30–32]). Currently, it appears leading-edge measurements were the most reproducible, but all methods showed a high degree of variability[30].

Likewise, even though guidelines for CT AAA suggest that the maximum aneurysm diameter should be based

on an outer wall measurement perpendicular to the path of the aorta for CT scanning[6]. It has been recognized that this imaging modality benchmark may often represent an oblique slice of the AAA, and in doing so, overestimate maximal aneurysm diameter in cases of vessel tortuosity[33]. The reported study in this review investigating AAA measurements in US and CT and their discrepancies mentioned that measurements of both modalities are made in different axes with CT usually with maximum diameter. Whereas with US, the AP and transverse planes are reported. In cases where the AAA is asymmetric, it will produce a CT measurement that is greater than the US measurement. Should the course of the aorta be tortuous as well, CT will further overestimate aortic dimensions. Consequently, investigators have proposed that US can correct for aortic angulation, because the US probe is adjusted by the technologist to maintain a view of the aorta perpendicular to blood flow[33]. For this reason, US may allow for a true cross-sectional, or orthogonal to flow, measurement that is more accurate than the oblique slice of an axial CT[34]. One of the studies in this review by Zur et al.[16] further applied this concept to demonstrate CT-US fusion imaging which they feel may further resolve errors in short axis imaging with both CT and US. Their results described that CT-US fusion is a more accurate method for AAA measurement and surveillance compared with conventional US (or CT) alone. Despite this, current CT post-processing software incorporate techniques to avoid these potential errors with 3D reconstruction and oblique reformatted processed images which are far easier to achieve in busy clinical centers than the rigorous and cumbersome fusion techniques.

The final article integrates CT imaging with the principles of cardiovascular mechanics, where aneurysmal rupture is known to occur when AAA wall stress exceeds the strength of the aortic wall[18,19]. Accordingly, if knowledge of the aortic aneurysmal wall's distribution of distensibility is known, its susceptibility to rupture may be better predicted. This study found that aortic distensibility and PWV was significantly increased when compared to non-aneurysmal segments of the aortic wall. Their reported results showed that the non-aneurysmal aortic segment was more distensible, whereas the wall of the aneurysm was stiffer, which consequently delivered a greater PWV in these "stiffer" wall segments compared to more "normal" wall segments. However, the potential for aortic distensibility as a reliable predictor of the risk of progression to AAA rupture still needs further investigation. Additionally, derived parameters of aortic distensibility and PWV are not easily derived parameters in the clinical setting. Zha et al.[17] described meticulous raw measurements from CT imaging and brachial arterial blood pressure readings, which then had to be incorporated into research software, Matlab (MathWorks, Natwick, MA USA), as well as the use of programming software with Visual C++ (Microsoft, Redmond, WA USA) before multiple contour iterations, and the final contour was adequately defined prior to being able to derive the actual distensibility and PWV measurements.

These procedures are probably all too cumbersome and arduous for practical application in the current clinical setting.

Strengths and limitations

This literature review has the merits of utilizing a comprehensive, expert, peer-reviewed and up-to-date search. Also, it included relevant studies after duplicate study withdrawal and categorized potentially relevant items by manuscript selection that approximated the format of the PRISMA checklist as much as possible. Limitations of this systematic review are that it did not formally assess the quality of sources for included items, though a qualitative summary was included. Additionally, it is possible, potentially relevant items from work yet to be published may not have identified. Three of our included studies were retrospective, making them predisposed to confounding errors and selection bias. Similarly, there is an element of referral bias that is also incorporated as most centers first utilize abdominal US to rule out AAA. Clinicians may likely refer to a vascular lab if they have a higher clinical index of suspicion for AAA, making these referrals higher risk for AAA than the general population. Similarly, it may also be possible that US studies have been ordered in response to prior CT findings. While most studies incorporated multidetector CT for their image acquisition, details of the US equipment used were not detailed. However, given that this review incorporated contemporary published studies, most centers are likely to have utilized 2.5–5 MHz transducers with standard sonography equipment.

Conclusion

This review summarized data from six studies on AAA imaging. It found both US and CT to be useful imaging modalities to screen for AAA despite changing trends in the natural history and pathogenesis of AAA – such as that of the aging population and the decline in traditional risk factors such as smoking. At the same time, other risks, such as obesity, may be increasing. This latter risk can pose obvious challenges to imaging and such technical issues in imaging with both US and CT are not straightforward. Studies utilizing CT-US imaging may further mitigate the AAA complexities that currently may be commonplace. Finally, also presented was a study that demonstrated the potential value of an integrated CT protocol that looked at aortic function rather than solely aortic anatomy to characterize aortic distensibility and its PWV. The potential to use these markers clinically will need further investigation in a larger study population, as well as appropriate technology to rapidly calculate these measurements in a clinically timely, yet reliably reproducible and accurate manner.

Conflict of interest

Authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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