



# Abdominal aortic aneurysm measurement at CT/MRI: potential clinical ramifications of non-standardized measurement technique and importance of multiplanar reformation

Joseph R. Leach<sup>#^</sup>, Chengcheng Zhu<sup>#^</sup>, Dimitrios Mitsouras<sup>^</sup>, David Saloner<sup>^</sup>, Michael D. Hope<sup>^</sup>

University of California, San Francisco Veterans Affairs Medical Center, San Francisco, CA, USA

<sup>#</sup>These authors contributed equally to this work.

*Correspondence to:* Joseph R. Leach, MD, PhD. San Francisco Veterans Affairs Medical Center, University of California, San Francisco, 4150 Clement St, Building 200, Office 2D-008, San Francisco, CA 94121, USA. Email: joseph.leach@ucsf.edu; Chengcheng Zhu, PhD. University of California, San Francisco, 1959 NE Pacific Street, Seattle, WA 98195-7117, USA. Email: zhucheng043@gmail.com.

**Abstract:** Accurate and reproducible measurement of abdominal aortic aneurysm (AAA) size is an essential component of patient management, and most reliably performed at CT using a multiplanar reformat (MPR) strategy. This approach is not universal, however. This study aims to characterize the measurement error present in routine clinical assessment of AAAs and the potential clinical ramifications. Patients were included if they had AAA assessed by CT and/or MRI at two time points at least 6 months apart. Clinical maximal AAA diameter, assessed by non-standardized methods, was abstracted from the radiology report at each time point and compared to the reference aneurysm diameter measured using a MPR strategy. Discrepancies between clinical and reference diameters, and associated aneurysm enlargement rates were analyzed. Two hundred thirty patients were included, with average follow-up  $3.3 \pm 2.5$  years. When compared to MPR-derived diameters, clinical aneurysm measurement inaccuracy was, on average, 3.3 mm. Broad limits of agreement were found for both clinical diameters [ $-6.7$  to  $+6.5$  mm] and aneurysm enlargement rates [ $-4.6$  to  $+4.2$  mm/year] when compared to MPR-based measures. Of 78 AAAs measuring 5–6 cm by the MPR method, 21 (26.9%) were misclassified by the clinical measurement with respect to a common repair threshold (5.5 cm), of which 5 were misclassified as below, and 16 were misclassified as above the threshold. The clinical use of non-standardized AAA measurement strategies can lead to incorrect classification of AAAs as larger or smaller than the commonly accepted repair threshold of 5.5 cm and can induce large errors in quantification of aneurysm enlargement rate.

**Keywords:** Abdominal aortic aneurysm (AAA); multiplanar reformat (MPR)

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<sup>^</sup> ORCID: Joseph R. Leach, 0000-0002-6800-0790; Chengcheng Zhu, 0000-0001-6898-549X; Dimitrios Mitsouras, 0000-0003-4023-0823; David Saloner, 0000-0002-6989-8547; Michael D. Hope, 0000-0001-9832-5732.

## Introduction

Abdominal aortic aneurysm (AAA), a dilation of the abdominal aorta to  $>3$  cm or  $>1.5\times$  the normal aortic diameter, is common, often asymptomatic, and can be associated with significant morbidity and mortality, particularly if aneurysm rupture occurs (1). The key aneurysm feature by which patients are risk-stratified and which guides clinical decision-making is maximal aneurysm diameter. Multiple large trials have shown the outcomes benefit of AAA screening, which allows for early diagnosis and initiation of surveillance of smaller aneurysms (3–5 cm) and prompt referral to open or endovascular repair of larger (commonly  $>5.5$  cm) aneurysms (2). In addition to the maximal diameter of an aneurysm and other clinical factors including gender and symptoms referable to the AAA, the rate of aneurysm enlargement is also considered when deciding on timing of intervention, with a rate of expansion of  $>1$  cm/year considered higher risk (3). Measuring AAA diameter accurately and reproducibly is important in the selection of patients for intervention and in quantification of aneurysm expansion rate to guide patient management and surveillance strategy.

Although simple in concept, AAA diameter assessment in the clinical setting is complicated by several factors. Screening and surveillance are commonly performed with ultrasound (US), an operator dependent modality with well described limitations in measurement accuracy and reproducibility (4,5). Although reliable and reproducible, AAA assessment by CT is complicated by a lack of measurement standardization (6–9). In CT, anteroposterior, transverse and “any direction” maximal diameter measurements are most commonly made in the axial, sagittal, and coronal planes out of convenience, when in principle multiplanar reformat (MPR) based measurements are preferred (3,10–12). MPR methods permit aneurysm analysis in planes perpendicular and parallel to the local vessel axis and an accurate assessment of maximal aneurysm diameter can be made regardless of vessel tortuosity. This is particularly important in the assessment of aneurysm enlargement, where vessel tortuosity can change between initial and follow-up exams and inaccuracies at each time point are compounded (12,13).

Despite the clear advantages of MPR based methods, MPR is not always performed, and may in fact be rarely performed. According to a recent meta-analysis (8), only 2/10 longitudinal studies on the CT assessment of AAA used MPR. There are several possible reasons for this: (I)

multiplanar reformations cannot be readily made in all radiology PACS systems; (II) MPR-capable software additions to the PACS environment can be unfamiliar or difficult to use for many radiologists, as they are not routinely used to assess other pathologies; (III) MPR assessment of AAAs takes more time than measurements made on standard axial, sagittal, and coronal planes; (IV) perhaps most importantly, while MPR has been shown to be technically superior (13), there has been a lack of studies demonstrating the clinical ramifications of relying on the wide variety of less accurate and reproducible measurement techniques.

Previous studies of MPR based AAA assessment at CT have been limited by small sample sizes and/or lack of longitudinal data. Our study aims to evaluate the importance of MPR methods and potential clinical ramifications of non-standardized AAA measurement techniques in a large ( $>200$  subjects) cohort followed for an average of 3 years. We sought to compare MPR and non-standardized clinical AAA measurements to understand how patient referral for aneurysm repair (diameter  $>5.5$  cm) could be affected, and how growth rate estimates could differ.

## Methods

### *Study population*

Retrospective review of anonymized medical imaging data, with waiver of written patient consent, was approved by the institutional review board of the San Francisco Veterans Affairs Medical Center.

A database of clinical radiology reports generated from January 2004 to December 2018 was queried, identifying patients with AAA observed at CT, high-resolution black blood MRI, or PET/CT. From these patients, final study inclusion criteria were: (I) presence of AAA at first contrast-enhanced CT, and (II) availability of a follow-up CT or MRI scan at least 6 months after the initial study. Exclusion criteria were: (I) AAA repair, open or endovascular, prior to or within the imaging interval. (II) Poor image quality precluding a reliable measurement of aneurysm diameter. (III) Aneurysms thought mycotic in etiology or with concomitant dissection.

### *Image acquisition and data abstraction*

All CT exams were acquired helically on multidetector scanners, using a variety of standard institutional protocols for contrast-enhanced CT, including CT angiography,

routine portal-venous phase CT, and multiphase CT evaluation of hepatic, pancreatic, and renal masses. Accordingly, a wide range of CT techniques are represented in the data, reflecting changes in scanners and imaging technologies over the 14-year period. CT exams were performed on a variety of platforms but the great majority, approximately ninety percent, were performed on GE scanners with 120 kVp tube potential. Automatic tube current modulation was applied on all exams. Axial images were reconstructed at 1- to 5-mm thickness. A sample of represented CT techniques is provided in Table S1.

Black blood MRI data were acquired at 3T (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) using a 3D T1 weighted fast spin echo acquisition with DANTE blood suppression with an 18-channel body coil during free breathing. Scan parameters were as follows: TR/TE = 800 ms/20 ms;  $32 \times 32$  cm<sup>2</sup> field of view (FOV); 52 coronal slices; echo train length 60; resolution was 1.3 mm isotropic with a scan time of 7 minutes (during free breathing). Further details on the MR imaging protocol can be found in references (14,15).

The clinically measured maximal AAA diameter ( $D_C$ ) was extracted from each radiology report. The overwhelming majority of clinical reports made no mention of how maximal AAA diameter was measured, and MPR was never cited as a measurement strategy. Clinical measurements may have been made in any plane, by radiology residents at various stages of training, by abdominal imaging fellows, and/or by faculty radiologists with a broad range of experience. For these reasons, we refer to these measurements as “non-standardized”.

### Image analysis

Imaging datasets were transferred to an offline workstation in DICOM format, and analysis was performed with commercial medical imaging software (Horos, version 3.0). Two reviewers (JRL and CZ) with more than 6 years of experience in reviewing vascular CT and MRI performed the image review and AAA measurements. A double-oblique MPR method was used to measure the maximal diameter ( $D_{MPR}$ ) of each AAA inclusive of the vessel wall thickness, which was assumed to be the reference standard measurement. The double oblique method comprises a set of manually performed rotations of the orthogonal MPR planes such that a reconstructed “true axial” image of the aneurysm perpendicular to the vessel centerline can be reliably established, as described previously in both the AAA

and aortic root/aortic valve replacement literature (16-18). An automated resampling of data to isotropic resolution matching the native in-plane resolution and interpolation of displayed images within the Horos 3D MPR viewer greatly reduces the stair-stepping artifact common to reformatted lower-resolution data, and no cases reviewed were deemed uninterpretable. For 30 cases, both reviewers independently made AAA measurements, and the inter-reader agreement was evaluated. To assess aneurysm progression over each patient's follow-up period, the AAA diameter at the earliest time point ( $D_{C,1}$  or  $D_{MPR,1}$ ) and the latest time point ( $D_{C,2}$  or  $D_{MPR,2}$ ) were recorded, and the annual growth rate (mm/year) of each AAA was calculated as  $(D_{*,2} - D_{*,1}) / \text{follow-up duration (years)}$ , where “\*” denotes either the clinical diameter measurements or MPR-based diameter measurements.

### Statistical analysis

Data normality was assessed using the Shapiro-Wilk test. Continuous data was summarized using the mean  $\pm$  standard deviation or median [inter-quartile range]. Categorical data were expressed as counts or percentages. Continuous data were compared using either a Mann-Whitney U test or Student's *t*-test. In 30 randomly selected datasets, both reviewers measured the AAA diameter. The reproducibility of measurements was evaluated by intraclass correlation coefficient (ICC) and coefficient of variation ( $CV = SD \text{ between measurements} / \text{mean} \times 100\%$ ).

A P value of less than 0.05 was considered statistically significant. All tests were two-sided. Data analysis was performed with SPSS (version 26.0).

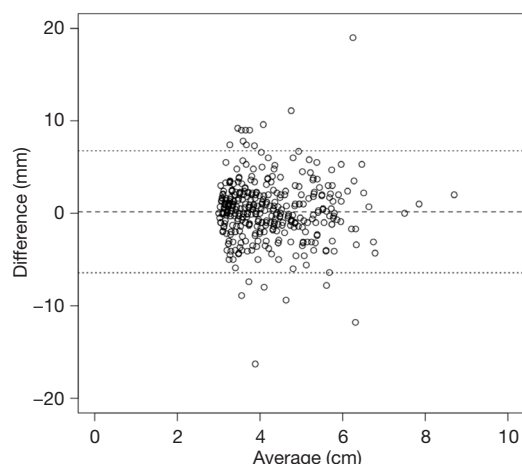
### Results

Two hundred thirty patients (all male, age  $73 \pm 9$  years) were included in this study, each with a baseline and follow-up exam for review, resulting in 460 imaging datasets (441 CT and 19 MRI) for comparison of clinical diameter measurements and MPR-based measurements. Average follow-up duration was  $3.3 \pm 2.5$  years (range 0.5 to 9 years).

Agreement between the two reviewers was excellent for measurement of maximal AAA diameter using the double-oblique MPR approach ( $4.5 \pm 0.9$  vs.  $4.5 \pm 0.8$  cm,  $P=0.26$ , ICC = 0.991), with measurement error 1.2 mm.

For the entire cohort, the absolute difference in AAA diameters measured by the MPR approach and reported clinically was  $2.3 \pm 2.4$  mm ( $P<0.001$ ), and the measurement

error for clinically reported maximal diameter was 3.3 mm. A graph of the Bland Altman analysis for maximal diameter measurements is shown in *Figure 1*, highlighting the broad limit of agreement  $[-6.7$  to  $6.5$  mm] between the clinically reported diameters and the MPR-based reference standard. Examples are shown in *Figures 2,3* for AAAs measuring 5.0 and 3.4 cm, respectively, demonstrating the magnitude of error that can arise using a non-MPR measurement strategy. In *Figure 2*, the clinical measurement of 5.9 cm was made in the axial plane and is greater than the typical repair threshold of 5.5 cm. Subset analyses of 195 CT datasets with slice thicknesses 5 and  $\leq 2.5$  mm demonstrated

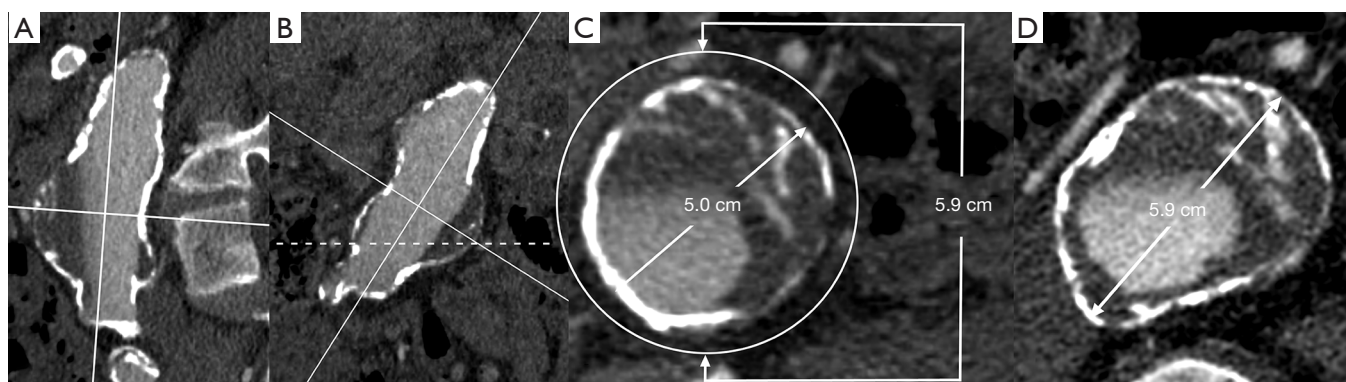


**Figure 1** Bland Altman plot of abdominal aortic aneurysm (AAA) maximal diameter measurements using multiplanar reconstruction (MPR) compared to clinical measurements ( $n=460$ ).

no dependency of measurement error on slice thickness (2.8 vs. 2.9 mm) for the clinically reported AAA diameter. Bland Altman plots showing the similar spread of measurement difference for these two groups are shown in *Figure S1*.

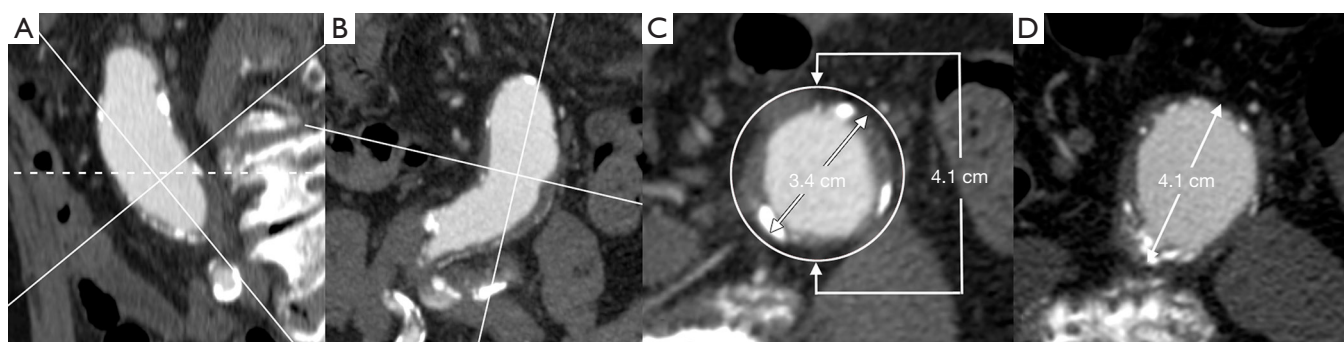
For the entire cohort, the absolute difference in AAA enlargement rate calculated with MPR-measured and clinically reported AAA diameters was  $1.4 \pm 1.7$  mm/year ( $P < 0.001$ ). The measurement error for clinically derived aneurysm enlargement rate was 2.2 mm/year. A graph of the Bland Altman analysis for aneurysm enlargement rates is shown in *Figure 4*, highlighting the broad limit of agreement  $[-4.6$  to  $4.2$  mm/year] between the clinically reported enlargement rates and the MPR-based reference standard.

The classification of AAA diameter as  $\geq 5.5$  or  $< 5.5$  cm by MPR and clinical measurement is shown in *Tables 1,2*. From the 460 exams, 22 AAAs (4.8%) were misclassified in the clinical report as being larger or smaller than 5.5 cm, a threshold diameter at which aneurysm repair is generally recommended. For AAAs measuring 5–6 cm by the MPR method, a size range where accurate measurement is essential for repair decision and planning, the specificity and negative predictive value of a clinically reported measurement with regard to the 5.5 cm threshold drop significantly, to 64.4% and 82.9%, respectively. Of the 78 AAAs that measured 5–6 cm by the double oblique MPR method, 21 (26.9%) were misclassified in the clinical report with respect to the repair threshold, with 5 AAAs misclassified as smaller than 5.5 cm and 16 misclassified as larger than 5.5 cm.

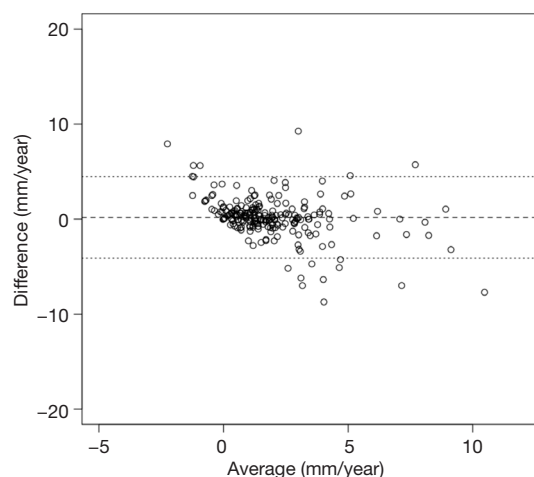


**Figure 2** (A) sagittal oblique and (B) coronal oblique images showing abdominal aortic aneurysm irregularity and tortuosity. (C) The true aneurysm cross section normal to the vessel axis showing the equivalent error of the clinical  $D_{\max}$  measurement, 5.9 cm, when compared to the multiplanar reconstruction (MPR) measurement of 5.0 cm. (D) Axial image at the location indicated by the dashed line in (B), showing how the aneurysm was measured clinically.





**Figure 3** (A) sagittal oblique and (B) coronal oblique images showing abdominal aortic aneurysm tortuosity. (C) The true aneurysm cross section normal to the vessel axis showing the equivalent error of the clinical  $D_{\max}$  measurement, 4.1 cm, when compared to the multiplanar reconstruction (MPR) measurement of 3.4 cm. (D) Axial image at the location indicated by the dashed line in (A), showing how the aneurysm was measured clinically.



**Figure 4** Bland Altman plot of abdominal aortic aneurysm (AAA) growth rate measurements using multiplanar reconstruction (MPR) compared to clinical measurements (n=230).

## Discussion

For asymptomatic AAAs, clinical management decisions are largely based upon a single simple metric: maximal aneurysm diameter. In clinical practice, however, this metric is not typically based on a standardized measurement method, and discrepant values of maximal diameter can be reported by different radiologists for the same aneurysm due to the wide variety of measurement methodologies (6,12,13). Some radiologists report the anteroposterior diameter, while others report the transverse diameter, and still others report the maximal diameter in any direction. Even the plane of measurement can vary, with axial, sagittal,

and coronal planes all cited in radiology reports depending on aneurysm shape and tortuosity.

Despite several detailed analyses showing the relatively limited accuracy and reproducibility of non-MPR-based measurement techniques compared to MPR-based methods (10-13), the more robust measurement strategy using multiplanar reformations is not universally used for AAA measurement. In a review by Hendy, 5 of 10 studies describe measuring aortic diameter using a non-MPR method, while another 3 studies did not describe the measurement technique employed (8). There are likely several reasons why MPR based AAA measurements are not universally used, including the need for and familiarity with special software not available in every PACS system, the extra time needed for MPR measurements [Dugas *et al.* (12) report an average required time of 1 min and 40 seconds], and possibly the lack of literature demonstrating a real clinical impact of using less accurate diameter measurement methods. It is this last reason that we have attempted to address in this work.

To do this, we compared clinically reported maximal AAA diameters from 460 cross sectional exams to an assumed reference standard diameter as measured using a double-oblique MPR technique. We also compared aneurysm progression for the 230 distinct aneurysms as assessed by both clinically reported diameters and the assumed reference standard. Our results both compare well with, and add valuable clinical perspective to the existing literature. First, in agreement with prior studies we found that the clinically reported diameters had a larger measurement error than the MPR based diameters (3.3 *vs.* 1.2 mm), resulting in broad limits of agreement (12,13).

**Table 1** Classification of all abdominal aortic aneurysm (n=460) with regard to the common intervention threshold of 5.5 cm using multiplanar reconstruction (MPR) and reported clinical measurements

AAA classification	>5.5 cm by MPR	<5.5 cm by MPR	Total
Reported >5.5 cm	51	16	67
Reported <5.5 cm	6	387	393
Total	57	403	

Sensitivity (95% CI): 89.47%(78.48% to 96.04%); specificity (95% CI): 96.03% (93.63% to 97.71%); PPV 76.12% (66.17% to 83.86%); NPV 98.47% (96.80% to 99.28%); accuracy 95.22% (92.85% to 96.98%). CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

**Table 2** Classification of >5 cm aneurysms (n=102) with regard to the common intervention threshold of 5.5 cm using multiplanar reconstruction (MPR) and reported clinical measurements. In aneurysms of this size, highly accurate aneurysm measurement is often desired to assess the need for and to plan a surgical or endovascular repair. As shown below, the specificity and negative predictive value (NPV) drops significantly

AAA classification	>5.5 cm by MPR	<5.5 cm by MPR	Total
Reported >5.5 cm	51	16	67
Reported <5.5 cm	6	29	35
Total	57	45	

Sensitivity (95% CI): 89.47%(78.48% to 96.04%); specificity (95% CI): 64.44% (48.78% to 78.13%); PPV 76.12% (68.05% to 82.67%); NPV 82.86% (68.74% to 91.40%); accuracy 78.43% (69.19% to 85.96%). CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

A discrepancy of 5 mm or more between the clinically reported and MPR-based diameters was seen in 50 of 460 (11%) cases. Importantly, in 21 of 78 (26.9%) AAAs that measured 5–6 cm by MPR, the clinical assessment misclassified the AAA as either larger or smaller than 5.5 cm when the opposite was true, as shown for example in *Figure 2*, similar to the findings of Kontopodis *et al.* in a smaller series (13). Such misclassification could be clinically impactful, as a patient may be inappropriately referred to either repair or continued imaging surveillance.

Additionally, our results show that the error of clinically assessed aneurysm progression rates (at least in this sample from our institution), is not insignificant, at 2.2 mm/year. This error is comparable to the average AAA progression rate of 2 mm/year, and thus typical and potentially clinically relevant aneurysm progression may be masked by the inaccuracies and inconsistencies of clinical aneurysm diameter measurement. This point is critically important for studies investigating the deleterious or protective effects on AAA progression of a variety of therapies, risk factors, medical comorbidities, and aneurysm features or biomechanical factors (19–22). For such studies, it is clear that MPR based assessment of aneurysm progression is not only superior but could reduce the required sample size to

show differences with statistical significance.

Our study has a number of strengths. First, the large cohort size allows us to confidently assess differences in measurement methodologies and associated aneurysm progression rates which might otherwise be masked by random measurement variation. Second, we chose to compare MPR-based aneurysm diameter measurements to the diameters reported clinically rather than with diameters measured by two reviewers as done in prior studies. In this way, we naturally compare to clinical practice, thereby reflecting both the lack of standardization and the broad range of measurement techniques. Clinically determined aneurysm progression rates capture not only the range of measurement strategies, but also the realistic situation of different readers, as our dataset spans 14 years and clinical reports were generated by dozens of trainees and no fewer than 15 attending radiologists. Third, rather than constrain our analysis to a specific type of exam (CT Angiography, for example) performed with a technique optimized for vascular analysis, we included the realistically broad array of exams on which aneurysm size and progression are assessed clinically. At our institution high resolution black-blood MRI is sometimes used for AAA surveillance, and so these studies were also included. Our prior work has

demonstrated this MRI method is equivalent to CT in terms of accuracy and reproducibility of aneurysm diameter measurement (14), and a subset analysis of only the CT datasets (n=441) showed no significant change in our results or conclusions. A bland Altman plot from this subset analysis is shown in [Figure S2](#).

Our study has a few limitations. First, only male patients are represented in the data, due to the practice conditions of the Veterans Affairs healthcare system. This is considered a minor limitation, however, as the estimated prevalence of AAA in the general population is six times higher for males than females (19). Second, this is a single-center retrospective study, and despite the large number of readers generating clinical measurements, some forms of bias cannot be excluded. Third, very few large AAAs (>5.5 cm) were included in the dataset, as most aneurysms of this size underwent intervention rather than surveillance imaging.

In conclusion, our study provides clinical context for the importance of MPR-based AAA assessment, which remains unrecognized in prior reviews comparing MPR methods to other standardized measurement techniques. The clinical use of non-standardized measurements can lead to incorrect classification of AAAs as larger or smaller than the commonly accepted repair threshold of 5.5 cm, and can induce large errors in quantification of aneurysm enlargement rate.

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## Footnote

**Conflicts of Interest:** All authors have completed the ICMJE uniform disclosure form (available at <http://dx.doi.org/10.21037/qims-20-888>). The authors have no conflicts of interest to declare.

**Ethical Statement:** Retrospective review of anonymized medical imaging data, with waiver of written patient consent, was approved by the institutional review board of the San Francisco Veterans Affairs Medical Center.

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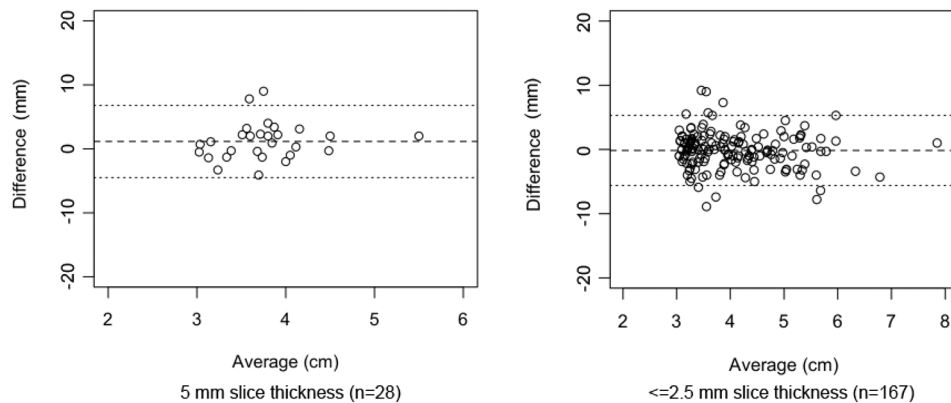
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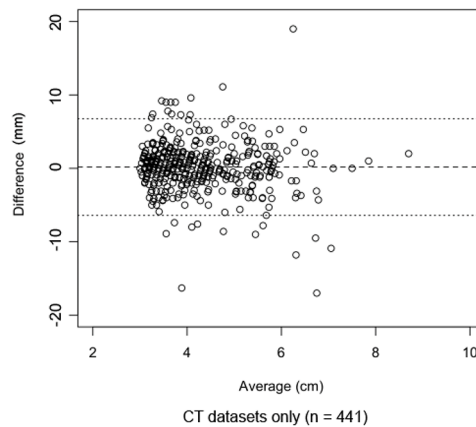
## Supplementary

**Table S1** List of CT protocols represented in the more recent imaging data included for analysis. Portions of protocols with variable anatomic coverage are included only if the AAA would have been included within the field of view, and multiphase exams list only technique used during the phase that would best depict a AAA. Please note that these protocols are our current implementation and differences from historical scans (due to scanner differences and optimizations) are likely.

Protocol	Contrast, injection, scan delay	Coverage	Tube potential (kV)	Tube current (mA)	Scan Mode/Pitch	Detector Configuration	Slice Thickness (mm)	FOV (cm)
Aorta	IV, 4 mL/sec (120 mL), SmartPrep threshold set at 150HU with ROI on proximal abdominal aorta	Top of diaphragm to the symphysis pubis	120	Auto mA – Min. 150 to Max. 750	0.984:1 – 39.37 mm/rot	0.625 mm x 64 = 40 mm coverage, Noise Index 36	1.25	28-50
Routine	IV, 3 mL/sec (120 mL), 75 sec	Top of diaphragm to the symphysis pubis	120	Auto mA – Min. 150 to Max. 750	0.984:1 – 39.37 mm/rot	0.625 mm x 64 = 40 mm coverage, Noise Index 36	2.5	28-50
Ischemic Bowel/GI Bleed	IV, 3.5 mL/sec (120 mL), SmartPrep: ROI over proximal abdominal aorta with 150 HU threshold and 15 sec trigger delay, 75 sec	Top of diaphragm to the symphysis pubis	120	Auto mA – Min. 150 to Max. 750	0.984:1 – 39.37 mm/rot	0.625 mm x 64 = 40 mm coverage, Noise Index 36	2.5	28-50
Multiphase (Liver, Pancreas, Renal)	IV, 5 mL/sec (120 mL), delay adjusted per timing bolus time to peak	Top of diaphragm to the symphysis pubis	120	Auto mA – Min. 150 to Max. 750	0.984:1 – 39.37 mm/rot	1.25 mm x 64 = 80 mm coverage, Noise Index 36	2.5	28-50
CT Urography	IV, 3 mL/sec (120 mL), 110 sec	Top of diaphragm to the symphysis pubis	120	Auto mA – Min. 150 to Max. 750	0.984:1 – 39.37 mm/rot	.625 mm x 64 = 40 mm coverage, Noise Index 36	2.5	28-50
Renal Stone	None	Top of diaphragm to the symphysis pubis	120	Auto mA – Min. 150 to Max. 750	0.984:1 – 39.37 mm/rot	.625 mm x 64 = 40 mm coverage, Noise Index 36	1.25	28-50
CT Colonography	None	Top of colon to anus, supine and prone	120	50 mAs	1.375:1 55 mm/rot	.625 mm x 64 = 40 mm coverage	0.625	28-50



**Figure S1** Bland Altman plots of abdominal aortic aneurysm (AAA) diameters from 195 CT cases, as measured using the double-oblique MPR method and as reported clinically, stratified by slice thickness (left – 5 mm slice thickness, right –  $\leq 2.5$  mm slice thickness). Note the similar spread of measurement difference for each slice thickness group.



**Figure S2** Bland Altman plot of abdominal aortic aneurysm (AAA) diameters from only the 441 CT scans, as measured using the double-oblique MPR method and as reported clinically. The measurement error of the clinically reported diameters is 3.3mm, identical to that when the entire CT+MRI dataset is analyzed.