Association Between Aortic Imaging Features and Impaired Glucose Metabolism: A Deep Learning Population Phenotyping Approach

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Rationale and Objectives: Type 2 diabetes is a known risk factor for vascular disease with an impact on the aorta. The aim of this study was to develop a deep learning framework for quantification of aortic phenotypes from magnetic resonance imaging (MRI) and to investigate the association between aortic features and impaired glucose metabolism beyond traditional cardiovascular (CV) risk factors.

Materials and Methods: This study used data from the prospective Cooperative Health Research in the Region of Augsburg (KORA) study to develop a deep learning framework for automatic quantification of aortic features (maximum aortic diameter, total volume, length, and width of the aortic arch) derived from MRI. Aortic features were compared between different states of glucose metabolism and tested for associations with impaired glucose metabolism adjusted for traditional CV risk factors (age, sex, height, weight, hypertension, smoking, and lipid panel).

Results: The deep learning framework yielded a high performance for aortic feature quantification with a Dice coefficient of 91.1 ± 0.02. Of 381 participants (58% male, mean age 56 years), 231 (60.6%) had normal blood glucose, 97 (25.5%) had prediabetes, and 53 (13.9%) had diabetes. All aortic features showed a significant increase between different groups of glucose metabolism ($p \leq 0.04$). Total aortic length and total aortic volume were associated with impaired glucose metabolism (OR 0.85, 95%CI 0.74–0.96; $p = 0.01$, and OR 0.99, 95%CI 0.98–0.99; $p = 0.02$) independent of CV risk factors.

Conclusion: Aortic features showed a glucose level dependent increase from normoglycemic individuals to those with prediabetes and diabetes. Total aortic length and volume were independently and inversely associated with impaired glucose metabolism beyond traditional CV risk factors.

Key Words: Aorta; Magnetic Resonance Imaging; Diabetes.

Abbreviations: **BMI** Body- mass-index, **CV** Cardiovascular, **CVD** Cardiovascular disease, **CI** Confidence interval, **KORA** Cooperative Health Research in the Region of Augsburg, **HDL** High-density lipoprotein, **LDL** Low-density lipoprotein, **OGTT** Oral glucose tolerance test, **OR** Odds ratio, **SD** Standard deviation, **VIBE** Volumetric interpolated breath-hold examination

Acad Radiol 2025; 32:2509–2516

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https://doi.org/10.1016/j.acra.2025.01.032

INTRODUCTION

Type 2 diabetes is a known risk factor for vascular disease (1). While a large body of research has detailed its adverse effects on peripheral, coronary and cerebral arteries, its association with aortic features is less well studied (2). Yet, with recently published guidelines on diagnosis and treatment of acute and chronic aortic syndromes the aorta becomes an increasingly notified organ system (3).

Moreover, approximately 30–40% of individuals with diabetes are undiagnosed (4) with an estimated latency of 6 years between onset and final diagnosis (5), bearing the risk of serious complications with a major economic impact (6).

With millions of radiologic images acquired every year of which a significant portion also displays the aorta (7) and deep learning algorithms for high-throughput image assessment on the rise, leveraging imaging data as an opportunistic screening tool might help to narrow this gap.

The KORA (Cooperative Health Research in the Region of Augsburg) is a prospective epidemiological study of participants with prediabetes, diabetes, and normal controls. In an magnetic resonance imaging (MRI) substudy, MRI images were acquired allowing the assessment of the thoracic aorta (8).

Thus, aim of this study is to 1) develop and test a fully automated deep learning framework for aortic segmentation and quantification in MRI, 2) extract aortic phenotypes and describe their difference in participants with prediabetes, diabetes, and normal glucose controls and 3) investigate associations between aortic phenotypes and impaired glucose metabolism (prediabetes plus diabetes) beyond traditional cardiovascular (CV) risk factors.

MATERIAL AND METHODS

Ethics and Approval

This study was approved by the Bavarian Chamber of Physicians and the institutional review board of the XXX. It respects the Helsinki declaration of human rights and its later amendments. All participants provided written informed consent.

Study Population

This analysis used data from the cross-sectional MRI substudy of the KORA (Cooperative Health Research in the Region of Augsburg) trial, a prospective epidemiological study. Participants for the MRI substudy were recruited from June 2013 to September 2014 and underwent whole-body MRI. For this research, we relied on outcome data from the FF4 survey. Subjects with known cardiovascular disease (CVD) were excluded (8,9).

MRI Protocol

Whole-body MRI was performed using a 3 T scanner (Magnetom Skyra, Siemens Healthcare GmbH, Erlangen, Germany) in supine position using an 18-channel body surface coil and a spine matrix coil. The protocol was detailed previously (8). For the evaluation of aortic phenotypes, water images of a two-point T1-weighted isotropic Volumetric interpolated breath-hold examination (VIBE)-Dixon gradient-echo technique were used. Acquisition parameters were as follows: 1.7 mm slice thickness, 1.7 × 1.7 mm^2 in-plane resolution, 488 × 716 mm field of view with a 256 × 256 mm matrix, repetition time 4.06 ms, echo time 1.26 × 2.49 ms, flip angle 9° (8).

Risk Factors and Glucose Metabolism

Baseline demographics and CV risk factors were assessed per study protocol (9). CV risk factors were defined as follows: age, sex, body mass index (BMI) (kg/m^2), cholesterol levels (mg/dl), high-density lipoprotein (HDL) (mg/dl), low-density lipoprotein (LDL) (mg/dl), triglycerides (mg/dl), hypertension (systolic blood pressure >=140mmHg, diastolic blood pressure >=90 mmHg or current treatment with antihypertensive medication), smoking status (regular, occasional, former, never).

Persons without known diabetes received a standard 75 g oral glucose tolerance test (OGTT) after an overnight fast of at least 8 h.

Prediabetes was defined as impaired glucose tolerance (2 h serum glucose concentration between ≥140 and < 200 mg/dL) and/or impaired fasting glucose concentration between ≥110 and 125 mg/dL. Type 2 diabetes was defined as a 2 h serum glucose concentration≥200 mg/dl and/or a fasting glucose level ≥126 mg/dl according to World Health Organization (WHO) criteria (10). Individuals with previously established diagnosis of type 2 diabetes did not receive additional OGTT (8,9).

Outcome

The primary outcome was impaired glucose metabolism defined as either having prediabetes or type 2 diabetes as detailed above to increase sample size.

Development and Testing of the Deep Learning Framework

To quantify aorta phenotypes, we developed a fully automated deep learning framework. The framework consists of two steps: 1) segmentation model for volumetric aorta segmentation, where the only input is a T1-weighted isotropic VIBE-Dixon gradient-echo sequence with water contrast, and the output is a 3D segmentation mask of the thoracic aorta; 2) the quantification of aortic phenotypes based on the 3D aorta segmentation mask generated by the segmentation model. All model tasks were implemented in the open-source medical imaging platform NORA (www.nora-imaging.com). An example is displayed in Figure 1.

Development: The model was trained using the recently introduced DNP segmentation architecture based on hierarchical and nested stacking of patch-based 3D networks of

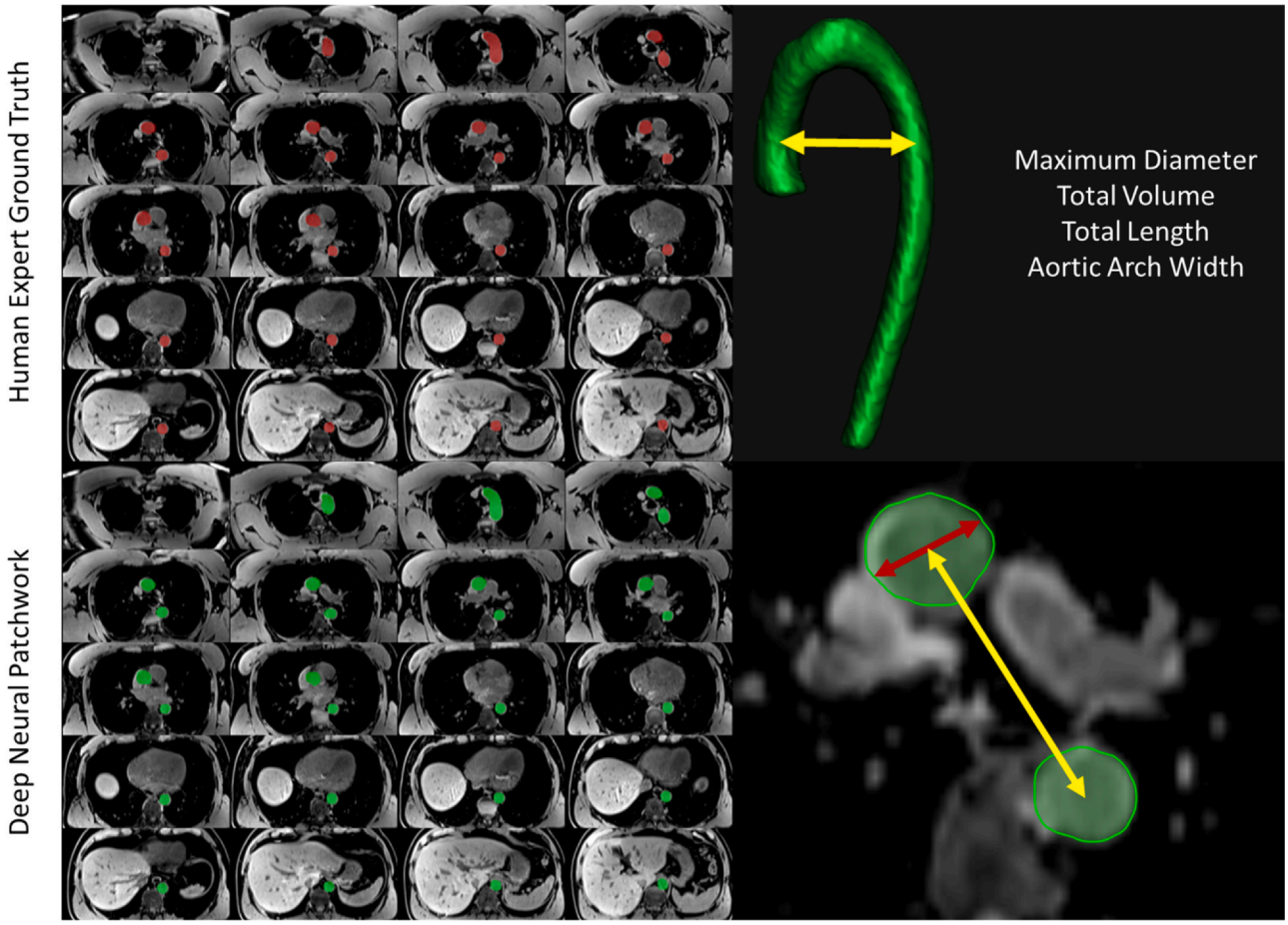

Figure 1. Example of aortic segmentation and phenotype extraction. T1w VIBE Dixon water image with manual ground truth segmentation (top left, red) and deep learning segmentation (bottom left, green) of the thoracic aorta. From the segmentation mask, the maximum aortic diameter (red arrow), total volume, total length, and the maximum width of the aortic arch were obtained. (Color version of figure is available online.)

fixed matrix size but decreasing physical input size, which allows for addressing the dilemma between global context and memory limitation in high-resolution 3D data (11). The size of the five-layer hierarchical pyramid was chosen to allow for a reasonable 3D field-of-view of each dimension of 80% of the whole matrix size in the coarsest layer and a high spatial resolution in the smallest layer with $1.5 \times 1.5 \times 3$ mm. The matrix size of 323 voxels was selected in a way that would map representative portions of the anatomy. The architecture of the basis U-Net employed was close to the default U-Net configuration with feature dimensions (8,12),32,64) and maximum pooling in the encoding layers and transposed convolutions in the decoding layers. The network was trained for 5 million patches with the Adam optimizer and a learning rate of 0.001. As a loss function, a binary cross-entropy variant of the top-K loss was used. The training took around 20 h with a batch size of 200 images in the graphic unit 's memory. Training was performed on a GPU-accelerated server system using an RTX A6000 graphics processing unit (NVIDIA, Santa Clara, CA, USA). During training, patches were randomly sampled so that approximately 80% of the finest patches contained at least one label. No systematic tuning was done with the settings adapted to prior established values (13,14).

For model training, a random subset of 150 KORA participants was chosen. Manual segmentations were generated by an experienced radiology resident and proof-read/corrected by a board-certified radiologist based on freely adaptable multiplanar reformats of the T1-weighted isotropic VIBE-Dixon sequence with water contrast. For all training samples, the aorta was segmented from the aortic root to the center of the twelfth thoracic vertebra.

Independent testing: The model was independently tested on $n = 50$ random samples not seen during any part of model development. Manual segmentations were generated in a similar way as the training dataset. For further quality control, manual assessment of the segmentation masks was performed in all participants.

Aortic phenotypes: Aortic phenotypes were quantified as follows: first, the centerline of the segmentation mask was determined, which was defined as a line along the segmentation mask with equidistant distance from the edges in an orthogonal level at any given point. From this, the *maximum aortic length (cm)* was obtained ranging from the aortic root to

the center of the twelfth vertebra. The *maximum diameter (cm)* was calculated as the maximum distance between the edges of the segmentation mask orthogonally to the centerline. *Aortic volume (mL)* was calculated as voxel volume by summing all voxels within the segmentation mask. The *aortic width (cm)* was defined as the maximum distance between the ascending and descending aorta on axial reformats.

Statistical Analysis

Data are presented as mean ± standard deviation (SD) or median and interquartile ranges (IQR) for continuous variables and as absolute frequencies and percentages for categorical variables in participants with prediabetes, diabetes, and normoglycemic individuals. Group differences were assessed by the Chi-squared test and ANOVA as appropriate.

To determine differences in baseline characteristics on aortic parameters, we performed a median split of each aortic parameter into a "low" and a "high" value group and calculated mean values (± SD) or frequencies (%) of each characteristic. Differences were assessed using t-test or Wilcoxon rank sum test as appropriate.

The association between the different aortic phenotypes and impaired glucose metabolism (prediabetes plus diabetes) was assessed using unadjusted and multivariable logistic regression analyses adjusted for following age, sex, height, weight, smoking status, and lipid panel as specified above.

All p-values are two-sided and considered to indicate statistical significance if < 0.05. All statistical analyses were performed using R (version 4.2.1, https://www.R-project.org/).

RESULTS

Deep Learning Framework

The performance of the deep learning framework in the independent test set was high with a Dice coefficient of 91.1 ± 0.02 and a 95% Hausdorff distance of 3.5 ± 1.2 for aortic segmentations. For the individual aortic phenotypes Pearson's correlation coefficients between the manual and deep learning generated phenotypes were r = 0.85 ($p < 0.001$) for maximum diameter, r = 0.99 ($p < 0.001$) for volume, r = 0.94 ($p < 0.001$) for length and r = 0.94 ($p < 0.001$) for arch width, respectively.

During visual assessment, no systematic failures of the deep learning framework were observed.

Study Population, Demographics and Cardiometabolic Risk Factors

Of the 400 included participants of the MRI substudy of the KORA study, 11 were excluded due to incomplete imaging data and another 8 due to incomplete clinical information resulting in a final study cohort of 381 participants (221 male, 58%) with a mean age of 56 years. A total of 231 participants (61%) had normal blood glucose, 97 participants (25%) had prediabetes, and 53 participants (14%) had type 2 diabetes.

There were differences in age and CV risk factors including BMI, HDL and triglycerides, and blood pressure between the groups (all $p < 0.001$). Smoking status or alcohol consumption did not significantly differ (p = 0.60 and 0.25, respectively).

In general, percentage of male participants, age, triglycerides and percentage of participants with hypertension increased from normal to prediabetes to diabetes, HDL decreased in the same order. (Table 1).

Aortic Imaging Features

ANOVA revealed significant associations of glucose metabolism (normal, prediabetes, and diabetes) on all aortic phenotypes with an increase in diameter (mean maximum diameter 3.35 cm vs. 3.47 cm vs. 3.53 cm; F (1, 379) = 13.52, $p < 0.001$), total length (31.93 cm vs. 32.55 cm vs. 32.79 cm; F (1, 379) = 6.17, p = 0.01), volume (0.15 l vs. 0.17 l vs. 0.18 l; F (1, 379) = 34.02, $p < 0.001$), and a larger aortic arch width (7.21 cm vs. 7.75 cm vs. 8.21 cm; F (1, 379) = 43.3, $p < 0.001$) with increasing blood glucose levels. An example of different aortic phenotypes by glycemic state is given in Figure 2.

Distribution of Demographics and Cardiometabolic Risk Factors by Aortic Phenotypes

There were statistically significant differences in sex, age, BMI, HDL, LDL, triglycerides and hypertension between the "low" and "high" value groups for each aortic feature with a lower percentage of women, an increase in age, BMI, hypertension, and an adverse lipid profile (high LDL and triglycerides, low HDL) in the "high" value group. All values are demonstrated in the supplemental Table 1.

Association Between Aortic Phenotypes and Impaired Glucose Metabolism

In univariable logistic regression analyses, maximum overall aortic diameter, total aortic length, total aortic volume, and width of the aortic arch were significantly associated with impaired glucose metabolism (OR 3.07, 95% CI 1.68, 5.74; OR 1.1, 95% CI 1.02, 1.2; OR 1.01, 95% CI 1.01, 1.02) and type 2 diabetes (OR 3.49, 95% CI 1.51–8.33, p = 0.00; OR 1.02, 95% CI 1.01–1.03, $p < 0.001$; OR 1.80, 95% CI 1.47–2.23, $p < 0.001$). (Table 3) In multivariable models, total aortic length (OR 0.85, 95%CI 0.74, 0.96) and total aortic volume (OR 0.99, 95%CI 0.98, 0.99) showed an inverse association with impaired glucose metabolism after adjustment for CV risk factors (age, sex, height, weight, hypertension status, smoking status, total cholesterol, LDL, HDL, triglycerides). (Table 3).

DISCUSSION

In this study, we developed and tested a fully automated deep learning framework to extract aortic phenotypes from MRI,

TABLE 1. Descriptive Baseline Data in Participants with Normal Blood Glucose, Prediabetes, and Diabetes Type 2

Variable	Overall (*n* = 381)	Normal (*n* = 231)	Prediabetes (*n* = 97)	Diabetes (*n* = 53)	p
Women	160 (42%)	112 (49%)	34 (35%)	14 (26%)	0.00
Age (years)	56.34 ± 9.26	54.26 ± 8.99	58.39 ± 8.88	61.6 ± 8.28	< 0.001
BMI (kg/m2)	28.19 ± 4.95	26.7 ± 4.24	30.69 ± 5.08	30.15 ± 5.15	< 0.001
Total cholesterol (mg/dl)	217.94 ± 36.36	216.07 ± 35.6	224.14 ± 31.81	214.74 ± 45.74	0.15
HDL (mg/dl)	61.86 ± 17.62	65.26 ± 17.83	58.33 ± 14.09	53.45 ± 18.66	< 0.001
LDL (mg/dl)	139.64 ± 32.97	138.49 ± 31.88	145.03 ± 30.03	134.77 ± 42.23	0.13
Triglycerides (mg/dl)	132.52 ± 86.01	107.55 ± 64.52	153 ± 81.8	203.85 ± 120.64	< 0.001
Mean systolic blood pressure (mmHg)	120.64 ± 16.90	116.49 ± 15.06	124.78 ± 15.25	131.12 ± 20.85	< 0.001
Mean diastolic blood pressure (mmHg)	75.24 ± 10.07	73.64 ± 9.18	77.74 ± 9.68	77.62 ± 12.91	< 0.001
Hypertension (n, %)	133 (34.91%)	181 (78.4%)	45 (46.4%)	38 (71.7%)	< 0.001
Smoking (n, %)					0.60
Regular	65 (17%)	44 (19%)	14 (14.4%)	7 (13.2%)	
Occasional	12 (3.2%)	8 (3.5%)	3 (3.1%)	1 (1.9%)	
Former	167 (43.8%)	92 (39.8%)	47 (48.5%)	28 (52.8%)	
Never	137 (36%)	87 (37.7%)	33 (34%)	17 (32.1%)	
Alcohol Consumption > 20 g/d (*n*, %)	127 (33.33%)	69 (29.9%)	38 (39.2%)	19 (35.8%)	0.25

Values are given in mean ± SD, median[range] or *n* (%); p < 0.05 considered significant. BMI, body-mass Index; HDL, high-density lipoprotein; LDL, low-density lipoprotein

in a population of participants with normal blood glucose as well as in those with prediabetes and diabetes. Our data shows an association of maximum aortic diameter, total volume, total length, and distance of the aortic arch with impaired glucose metabolism. When adjusted for CV risk factors, only the total volume and total length of the thoracic aorta remained associated with impaired glucose metabolism but with an inverse effect.

1. Aortic phenotype and changes of the aortic organ during disease development
   The recently published "guidelines for diagnosing and treating acute and chronic syndromes of the aortic organ" bring up the new "perception" (3) of the aorta as an organ itself while at the same time stating that this vital organ is in wide parts poorly understood due to a lack of longitudinal data (3).
   Our data allows a general description of aortic phenotypes of those with an increased risk of developing type 2 diabetes (e.g., those with prediabetes) and of those who have developed type 2 diabetes in comparison to a healthy population.
   We observed an increase of maximum diameter, length, volume, and distance of the aortic arch from 'normal' to prediabetes and further to diabetes. However, we likewise noticed a significant increase in CV risk factors (e.g., male

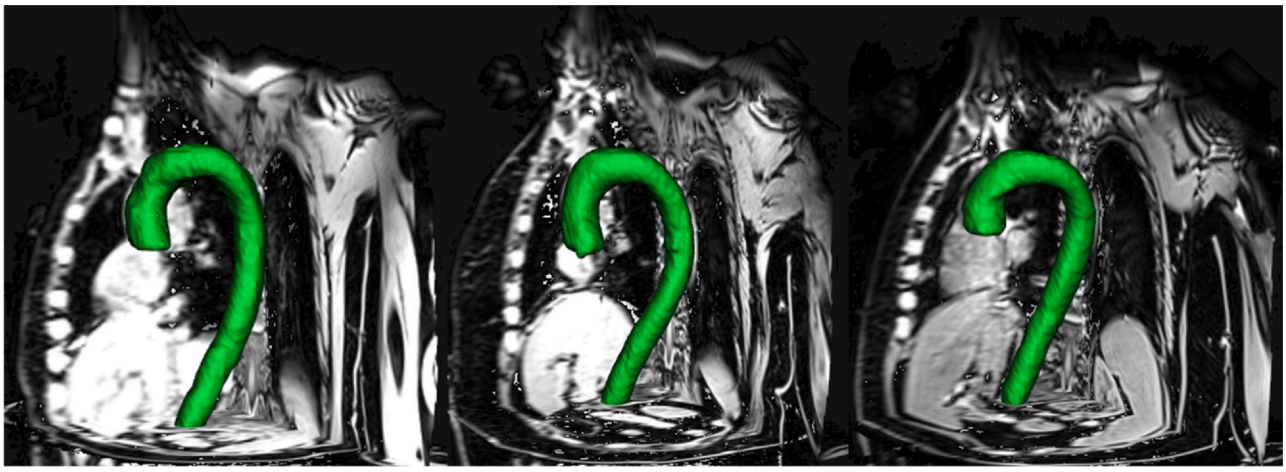

Figure 2. Exemplary model segmentations of the thoracic aorta by glycemic state. Exemplary model segmentations of the thoracic aorta in a normoglycemic participant (left, 70 years old female), impaired glucose metabolism (middle, 64 years old female), and diabetes (right, 63 years old female).

TABLE 2. Aortic Phenotypes in Participants with Normal Blood Glucose, Prediabetes, and Diabetes Type 2

Variable	Overall (n = 381)	Normal (n = 231)	Prediabetes (n = 97)	Diabetes (n = 53)	p
Maximum overall diameter (cm)	3.41 ± 0.35	3.35 ± 0.35	3.47 ± 0.31	3.53 ± 0.4	< 0.001
Total length (cm)	32.22 ± 2.65	31.95 ± 2.75	32.55 ± 2.43	32.79 ± 2.45	0.04
Total volume (ml)	0.16 ± 0.04	0.15 ± 0.04	0.17 ± 0.03	0.18 ± 0.04	< 0.001
Arch width (cm)	7.49 ± 1.15	7.21 ± 1.14	7.75 ± 0.92	8.21 ± 1.17	< 0.001

Descriptive statistics and results of ANOVA for the different aortic phenotypes in individuals with different states of glucose metabolism. Values are given in mean ± SD; p < 0.05 considered significant

sex, age, BMI, increased mean systolic and diastolic blood pressure, triglycerides) over these three groups.

It is generally understood that clinical risk factors as well as parameters indicating an adverse lifestyle (e.g., increase in BMI, presence of hypertension, high blood lipids) are the precursors for disease onset and are highly present once type 2 diabetes is manifest. These parameters in return have an influence on the aortic organ and are known risks for the development of aortic dilatation and ultimately aneurysm formation (3,15,16) also demonstrated by our data. Thus, there is likely a large confounding effect, which determines this 'aortic phenotype'.

2. Associations between aortic phenotypes and impaired glucose metabolism

In unadjusted logistic regression, each aortic phenotype was associated with impaired glucose metabolism (with ORs > 1) suggesting an increased odds for the presence of impaired glucose metabolism with an increase in diameter, volume, length, or arch width of the thoracic aorta.

Interestingly, in multivariable analysis, only total volume and total length remained statistically significantly associated with impaired glucose metabolism with an inverse association. When adjusting for CV risk factors, a decreased total length and volume remained associated. Moreover, a reduced maximum diameter demonstrated a trend towards statistical significance (and may be considered clinically relevant).

As previously mentioned, type 2 diabetes and CV have many common risk factors (3,15,16). This in mind, the inverse association of length, volume and diameter may seem paradoxical at first. However, this is in line with previous reports describing an association of lower aortic diameters in diabetic patients when compared to those with normal blood glucose (2,12,17,18) - even going as far as calling diabetes protective for aortic aneurysm rupture (2,17). There are several underlying pathomechanisms which might contribute to this effect including Mönckeberg`s arterial medial calcification which are particularly prevalent in persons with diabetes (19). In a murine study with experimentally induced abdominal aortic aneurysms, a reduced progression of aortic aneurysms in mice with hyperglycemia vs. normoglycemia was described (20). The authors suggest an inhibitory effect of diabetes on aneurysm progression on the basis of "reduced mural neovascularization, macrophage infiltration, and medial elastolysis" (20).

Similarly, clinical studies in diabetic individuals have reported a correlation of a downregulation of inflammatory mediators in the aortic wall and slower progression of thoracic and abdominal aortic aneurysms [18–20]. Hospitalization rate for thoracic aortic aneurysm and dissection was furthermore associated with a 40-80% reduction in persons with diabetes (2).

Another recently published study investigated amongst other things the association of diabetes type 1 and 2 and CV imaging traits using Mendelian randomization in a large cohort of the UK Biobank. Their data likewise shows a link between type 2 diabetes and a decreased diameter of the ascending aorta, along with a reduced distensibility of the descending thoracic aorta. Interestingly, an inherited tendency towards diabetes type 1 had the opposite effect and correlated with an increased aortic distensibility. Li and colleagues conclude a direct

TABLE 3. Univariable and Multivariable* Association of Aortic Phenotypes and Impaired Glucose Metabolism (Prediabetes + Diabetes Type 2)

	Univariable		Multivariable*	
Variable	OR (95% CI)	p	OR (95% CI)	p
Maximum overall diameter (cm)	3.07 (1.68–5.74)	< 0.001	0.44 (0.17 - 1.07)	0.07
Total length (cm)	1.10 (1.02–1.2)	0.01	0.85 (0.74 - 0.96)	0.01
Total volume (ml)	1.01 (1.01–1.02)	< 0.001	0.99 (0.98 - 1.00)	0.02
Arch width (cm)	1.80 (1.47–2.23)	< 0.001	0.88 (0.65 - 1.16)	0.35

CI, confidence intervals; OR, odds ratio, p < 0.05 considered significant. *adjusted for age, sex, height, weight, hypertension status, smoking status, lipid panel.

relationship of altered glucose metabolism and vascular remodeling (18).

Thus, our results are in line with literature describing a more 'benign' aortic phenotype in (pre-)diabetic individuals despite the presence of CV risk factors.

The importance of the parameter 'diameter' and 'length' of the thoracic aorta is stressed in a recent publications indicating that diameter and length of the ascending aorta (however, in this case, an increase from normal) are independent risk factor for acute aortic events and powerful predictors (21) and recent guidelines advocate for both parameters to be specifically stated in radiology reports (3). Moreover, a decreased distensibility has been linked to an increase in all-cause death and the occurrence of CV events potentially due to increased strain on the left ventricle caused by a diminished 'Windkessel' effect (22). While our findings need to be confirmed in a larger prospective analysis, they may demonstrate another clinically relevant reason to report aortic dimensions from cross-sectional imaging as smaller aortic diameter and reduced aortic length and volume especially in patients with an elevated CV risk but no known CV disease (as in our cohort) may indicate abnormal blood glucose levels and could serve as an imaging biomarker for further diagnostic work-up.

3. Future perspective for opportunistic screening

Millions of radiologic images are acquired every year with a significant portion encompassing the aorta (7). With the utilization of artificial intelligence (e.g., the method proposed by us) it is feasible to extract aortic parameters within seconds and assess an individual risk for the presence of altered glucose metabolism opportunistically. These algorithms could be integrated into the clinical workflow to automatically extract aortic parameters from cross-sectional MRI encompassing the thoracic aorta and thus deliver additional diagnostic and prognostic information. Individuals who might otherwise go undiagnosed and may face downstream complications of their untreated diabetes could be channeled to seek appropriate help early. This could help cut future treatment costs which are estimated to reach 2.1 trillion US$ in 2023 for the treatment of diabetes and its complications alone (6).

LIMITATIONS

There are several limitations to our study. First, the KORA cohort included predominantly participants of Caucasian descent without known CV disease. If our results can be generalized to participants of different race/ethnicity or those with presence CV disease needs to be confirmed in future studies. Secondly, sample size especially in the subgroup of diabetic individuals was rather small (n = 53). Thus, generalizability may not be given. Also, imprecise estimate findings need to be interpreted with care and larger cohort studies would be desirable to confirm results. Furthermore, we only assessed imaging features of the thoracic aorta. However, features of the abdominal aorta may contribute further to better understand our results and other studies revealed an associated of diabetes with a decreased prevalence of abdominal aortic aneurysms (23). Thus, the association of impaired glucose metabolism and imaging features of abdominal aorta should be evaluated in future research. Furthermore, an assessment of presence/severity of atherosclerosis in this population may add further insights into pathogenesis. Thirdly, our deep learning model was not validated externally. This would need to be done to apply the network to other more diverse populations. Lastly, there is an established clinical routine regarding the diagnosis and monitoring of prediabetes and diabetes. The acceptance/impact of a potential opportunistic screening result is unclear.

CONCLUSION

While the general aortic phenotype in participants with prediabetes and diabetes is likely driven by the presence of other CV risk factors, reduced aortic length and volume show an association with impaired glucose metabolism beyond CV risk factors.

DECLARATION OF COMPETING INTEREST

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jana Taron reports a relationship with Onc AI that includes: consulting or advisory. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENTS

AR was supported by the Berta-Ottenstein-Programme for Clinician Scientists, Faculty of Medicine, University of Freiburg.

APPENDIX A. SUPPORTING INFORMATION

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.acra.2025.01.032.

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