Aortic wave intensity analysis using CMR and non-invasive central BP

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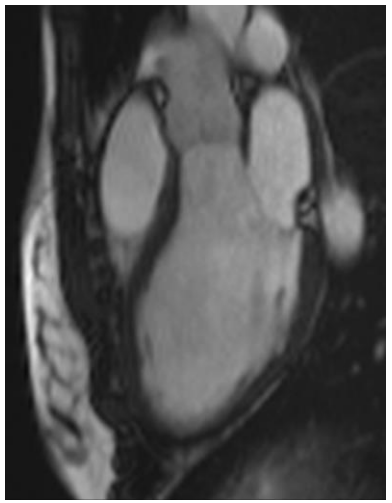
Conflict of interest: none declared

Integrated cardio-vascular function



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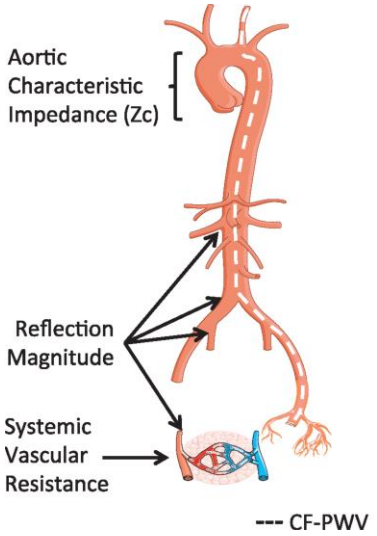


Pulsatile haemodynamics

Wave Intensity Analysis

- Arterial stiffness
- Wave reflection
- ?normal population
- Ventricular remodeling
- Myocardial fibrosis
- Contractile dysfunction

Integrated function

Kim P, CJ J. Forward and Backward Running Waves in the Arteries *J Biomech Eng*. 1990;112:322-326.
Pulsatile arterial haemodynamics in heart failure EHJ 2018 doi:10.1093/eurheartj/ehy346

Study aim

In a population of healthy volunteers, we aimed to:

- Assess the feasibility of non-invasive aortic WIA
  - gold-standard velocity and pressure assessments;
  - sequentially acquired.
- Validate local wave speed against PWV.
- Understand the influence of age on WIA.

Wave intensity (WIA): data analysis

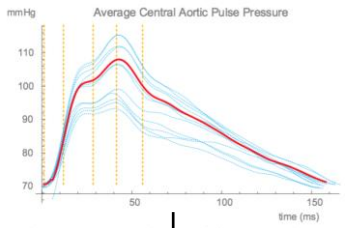
Healthy volunteers over age 18

Free of cardiovascular disease

n = 206

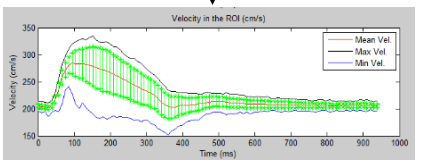
Pressure (P) acquisition (pre-scan)

Brachial suprasystolic oscillometry (200Hz)



Velocity (U) acquisition

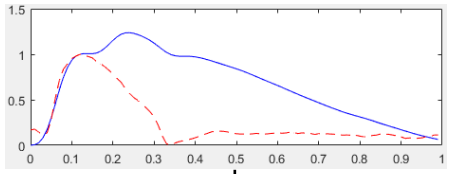
Velocity measured at each time point (100Hz at 60bpm)



Data preparation

Linear interpolation to 100Hz for direct comparison to U

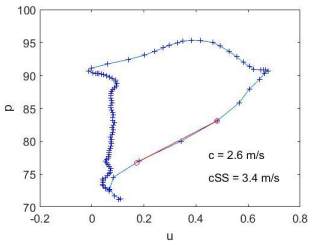
foot-foot alignment



Wave speed estimation

Sum of squares estimation (cSS)

$$cSS = \frac{1}{\rho}\sqrt{\frac{\sum dP^2}{\sum dU^2}}$$



Wave intensity analysis

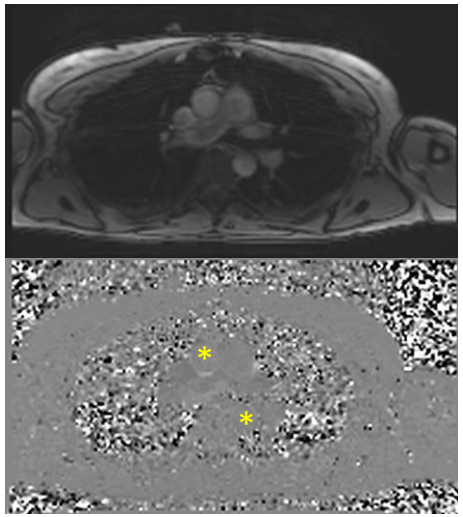
Calculation of forward (WI_+) and backward (WI_-) wave intensity at each timepoint:

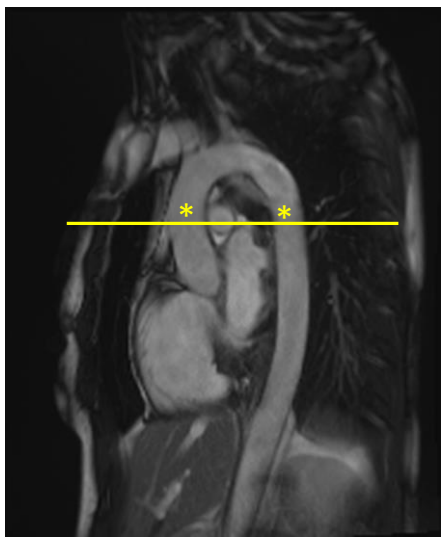
$$WI_+ = \frac{1}{4\rho c}\left(\frac{dP}{dt} + \rho c \frac{dU}{dt}\right)^2$$

$$WI_- = -\frac{1}{4\rho c}\left(\frac{dP}{dt} - \rho c \frac{dU}{dt}\right)^2$$

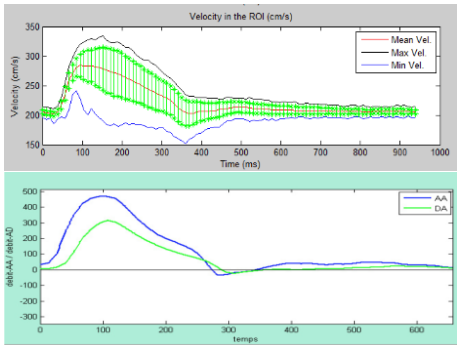
p = 1.05 g/cm^3, WIA using c not cSS

Wave speed validation vs PWV by transit time

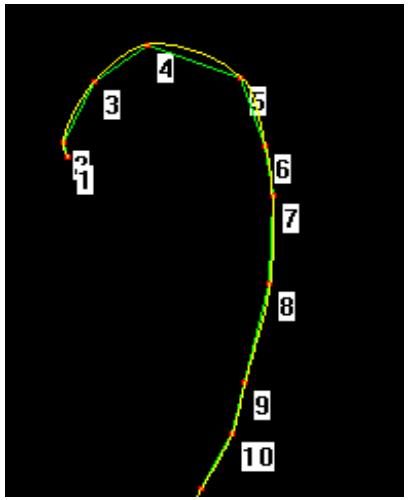




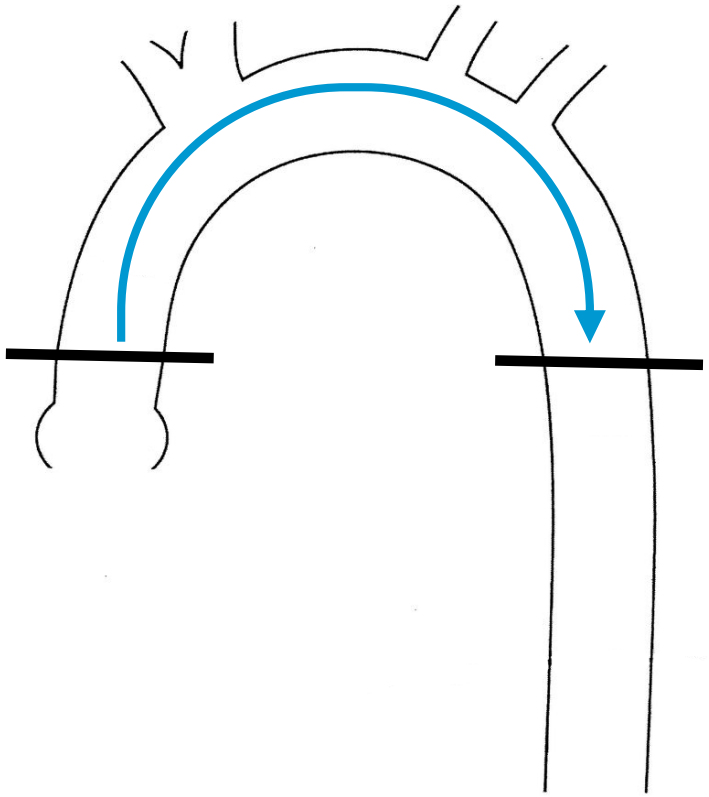
Resolution 9.2ms; 1.97 x 1.77mm^2



Transit time



True aortic geometry

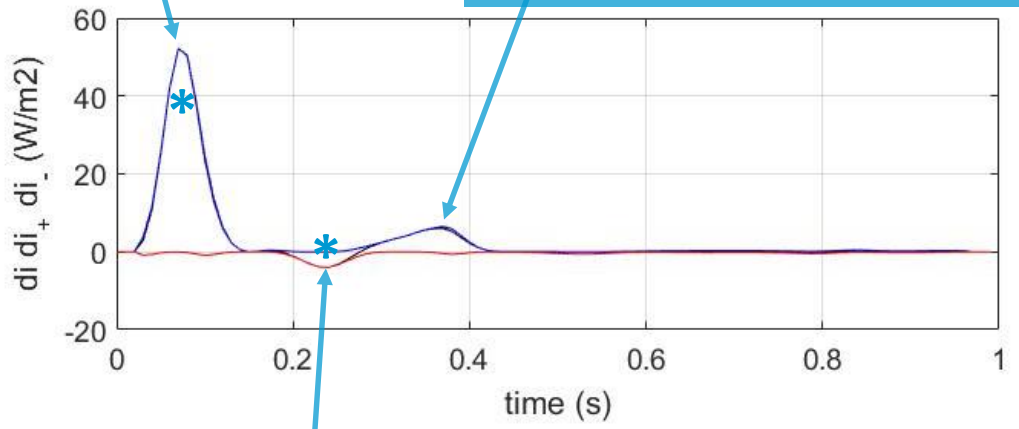


Aortic arch pulse wave velocity (PWV-tt)

WIA quantification: wave peak and timing

Initial compression wave (S)

Protodiastolic decompression wave (D)



Backward compression wave (R)

Reflection index (R:S)

Analysis stratified by age

Results

- All subjects analysed
- Age 37 years (range: 21-73)
- BP >140/90mmHg: 17 (8%)

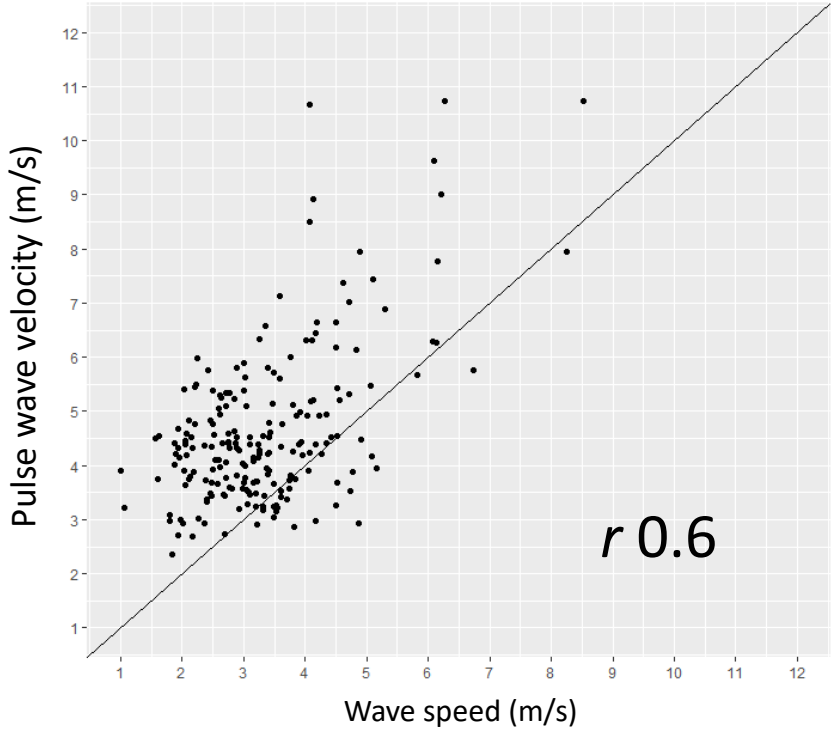
Baseline characteristics	
n (female)	206 (101)
Age	37(29-44)
BMI kg/m^2	25±4
Weight (kg)	74±14
Body Fat (%)	26±9
Peak ($V0_2$/ml/kg/min)	34±8

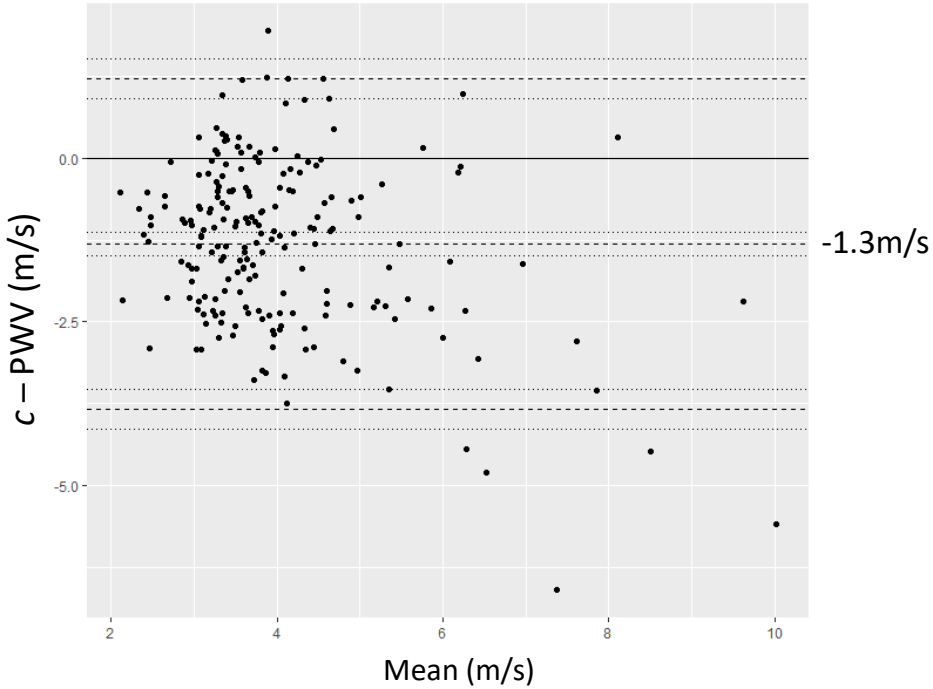
Data presented as mean±SD or median (IQR)

Results - Wave speed (*c*)

Wave speed		PWV-tt (m/s)
3.4±1.2	vs	4.7±1.5

- Good correlation (r 0.6)
- c underestimates PWV

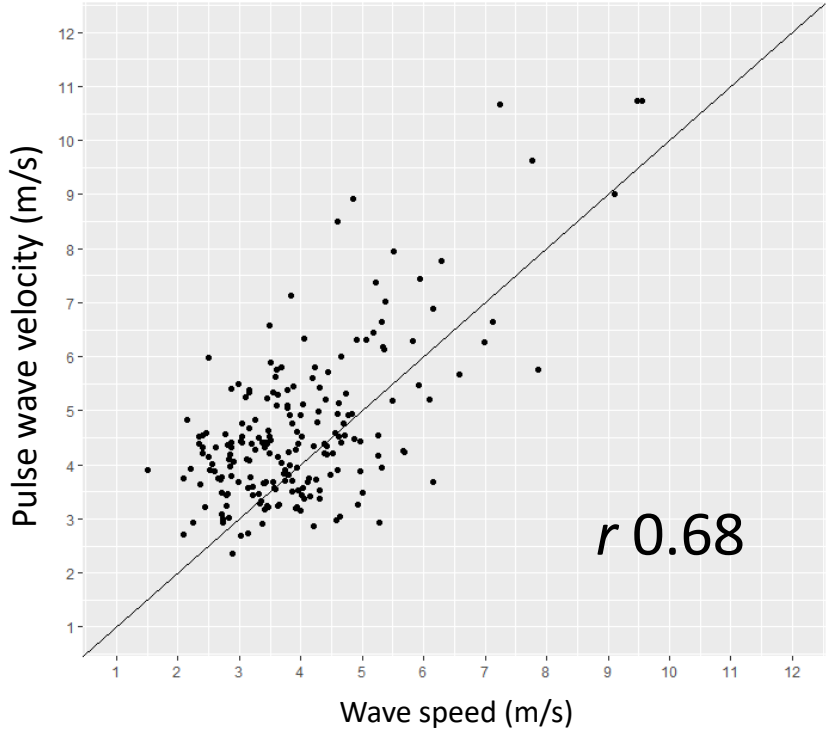


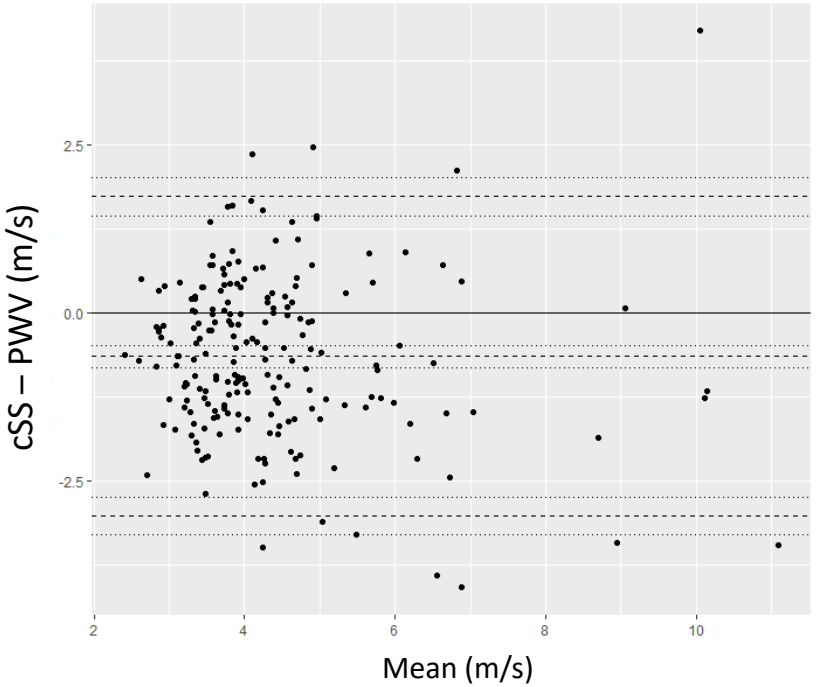


Results - sum of squares

Wave speed		PWV-tt (m/s)
4.0±1.5	vs	4.7±1.5

- Stronger correlation (r 0.68)
- Less bias

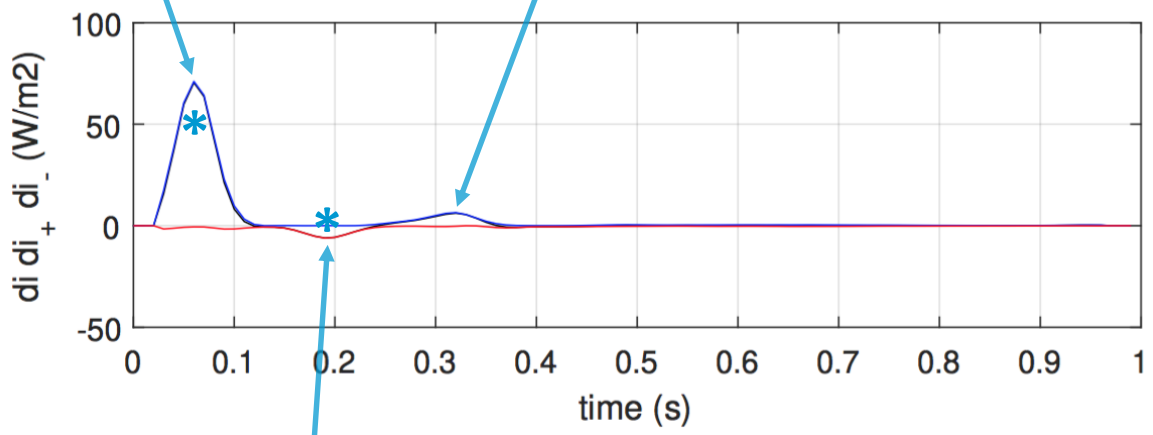




Results – wave intensity analysis

Initial compression wave (S)
64 (49-87) W/m^2
60±1 ms

Protodiastolic decompression wave (D)
5.8 (4-7) W/m^2
320±5 ms

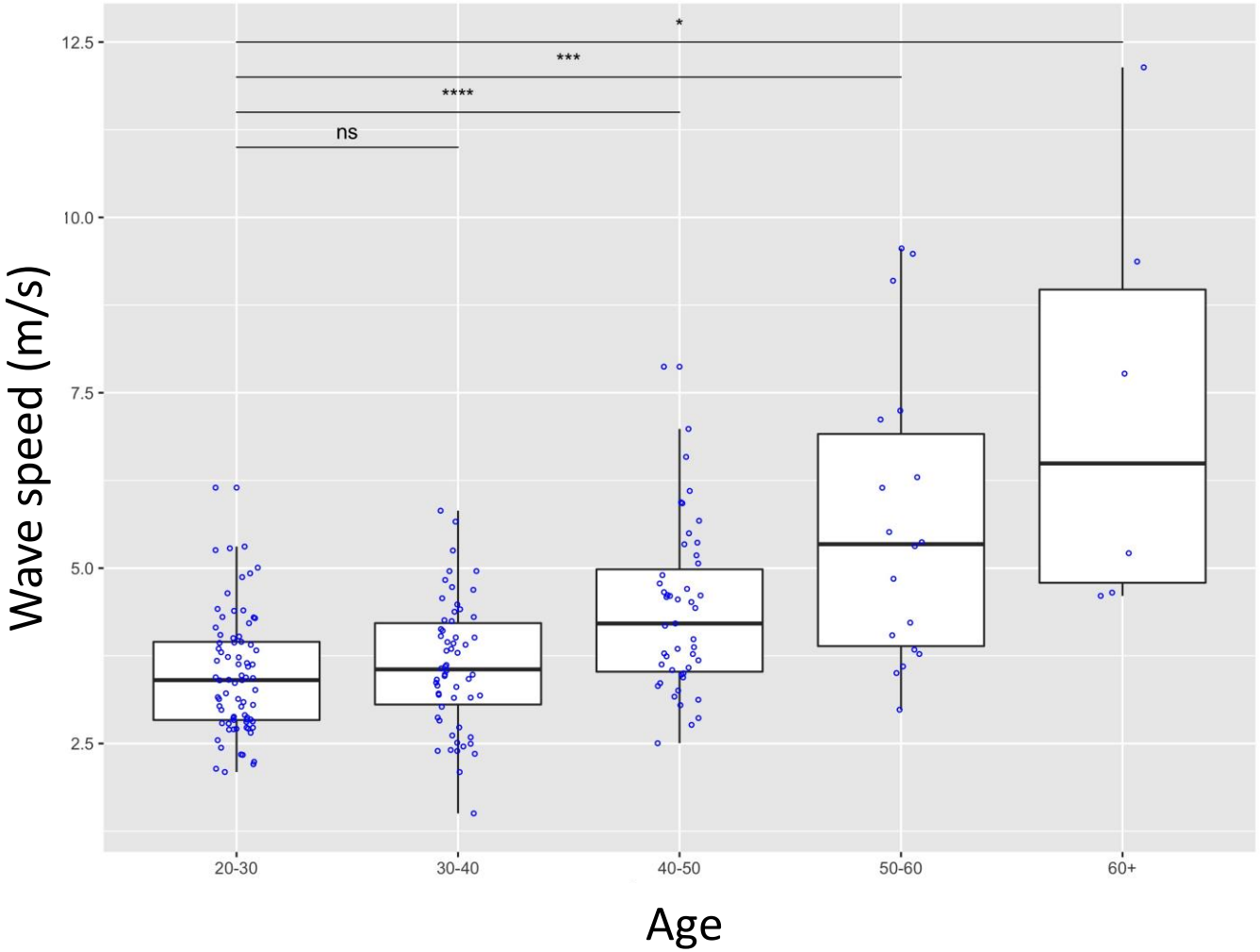


Backward compression wave (R)
5.3 (4-8) W/m^2
190±4 ms

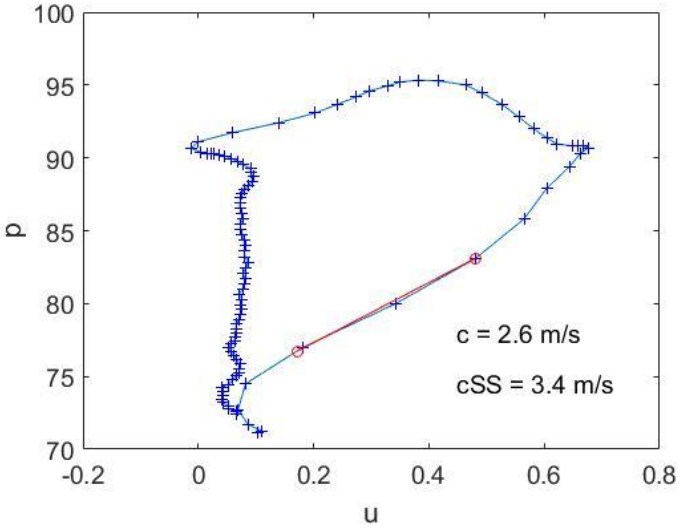
*** Reflection index (R:S)**
8% (6-12%)

Measured at peak wave

Results – local wave speed vs age

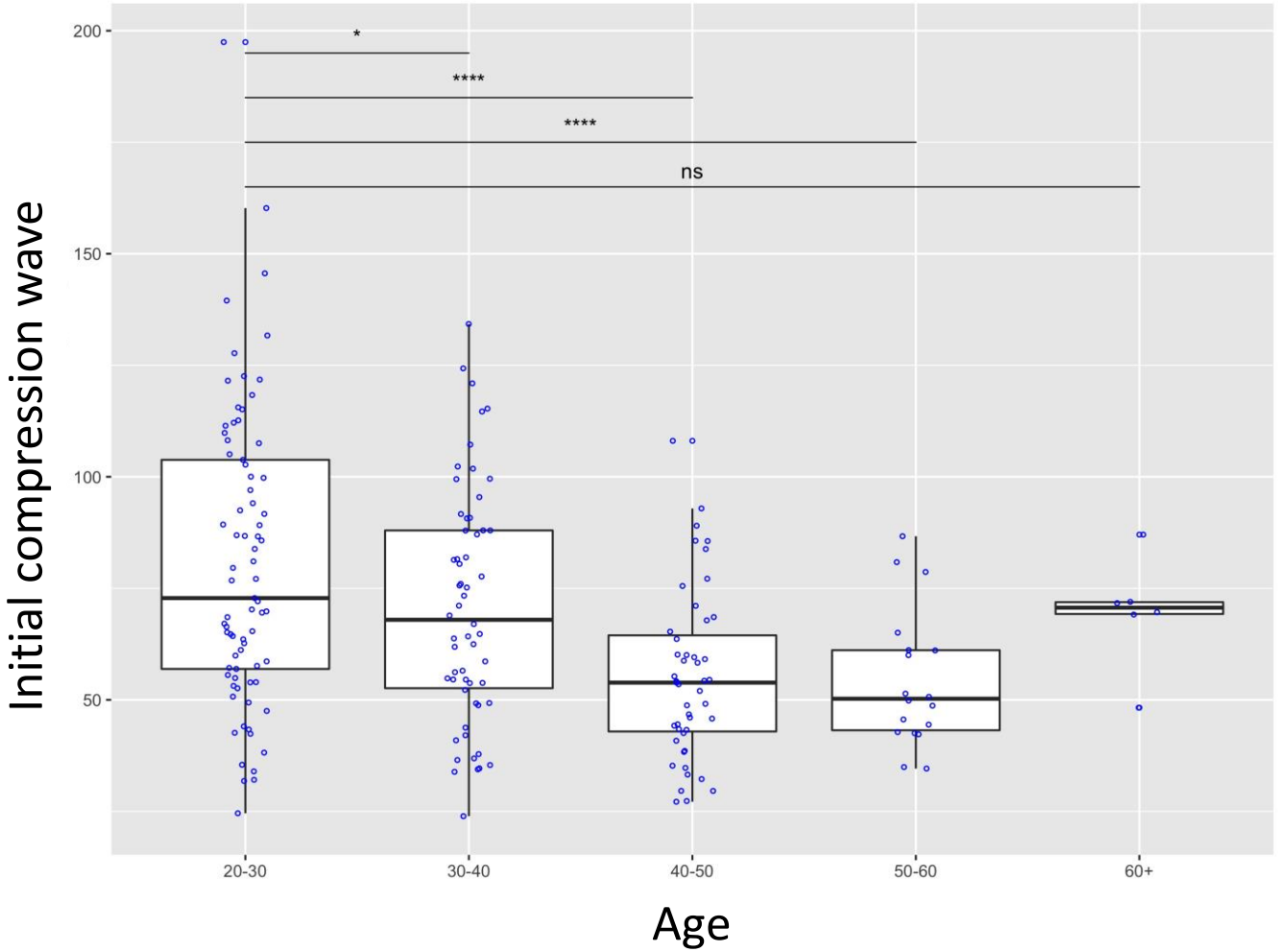


- Increases after age 40

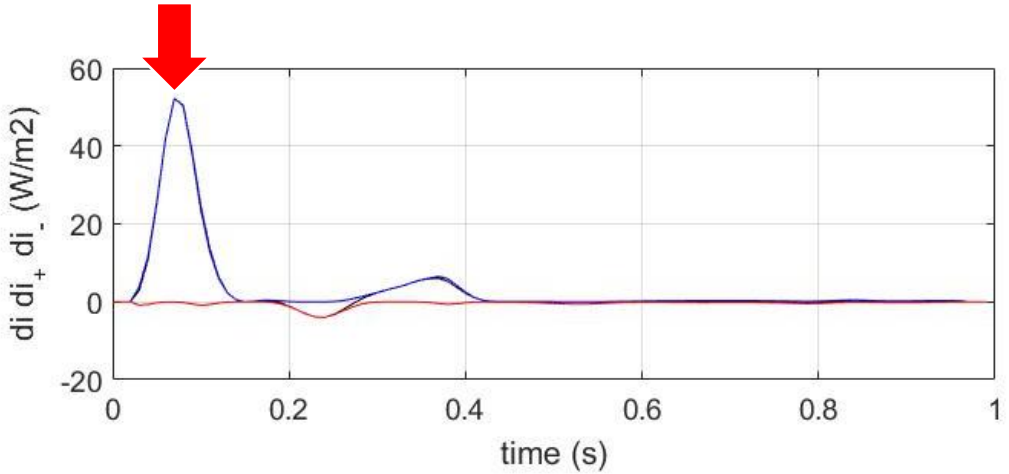


* p < 0.05 ** p < 0.01 *** p < 0.001 **** p < 0.0001; wave speed measured as c*SS*

Results – S wave vs age

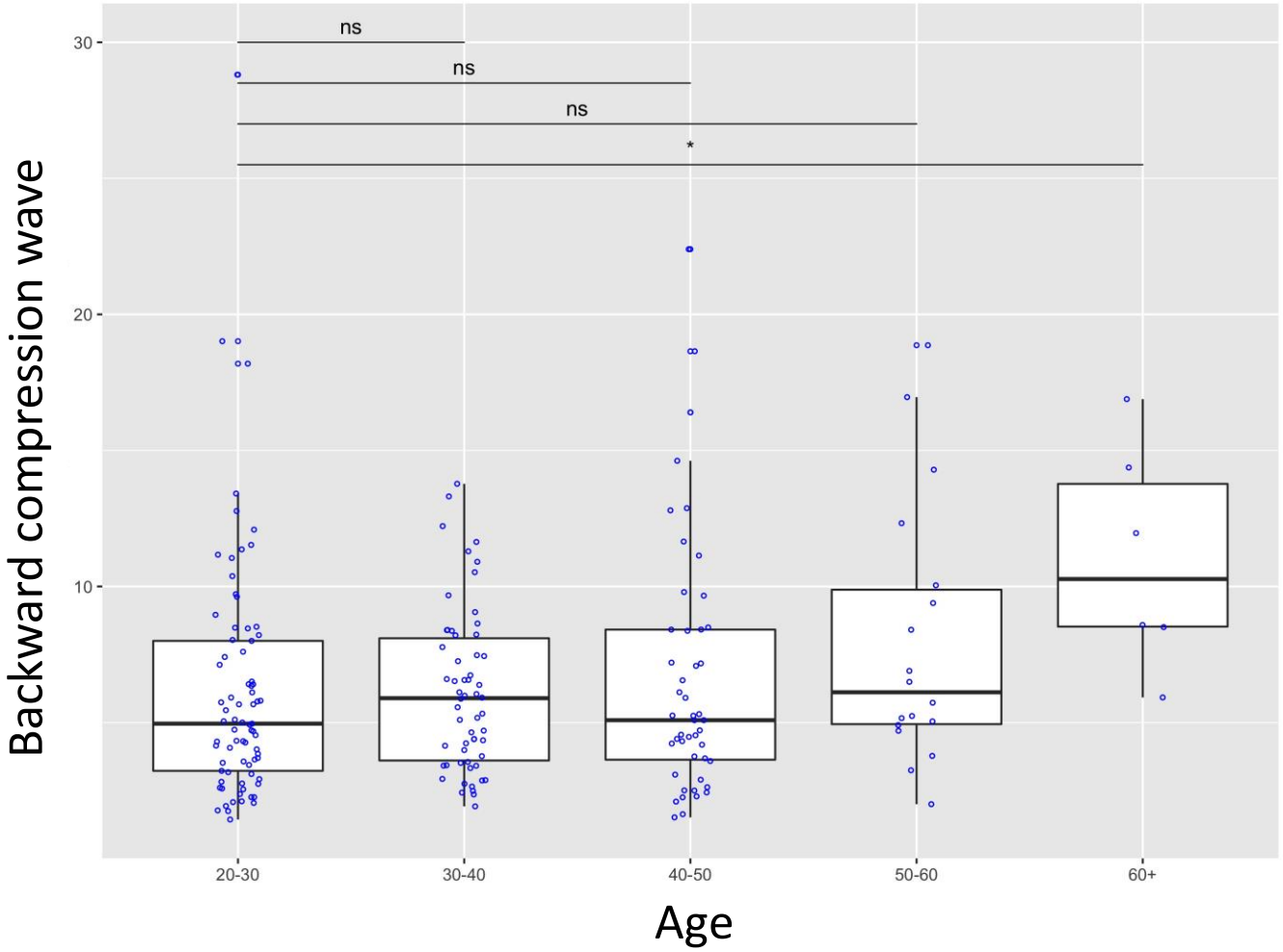


- Decreases after age 30

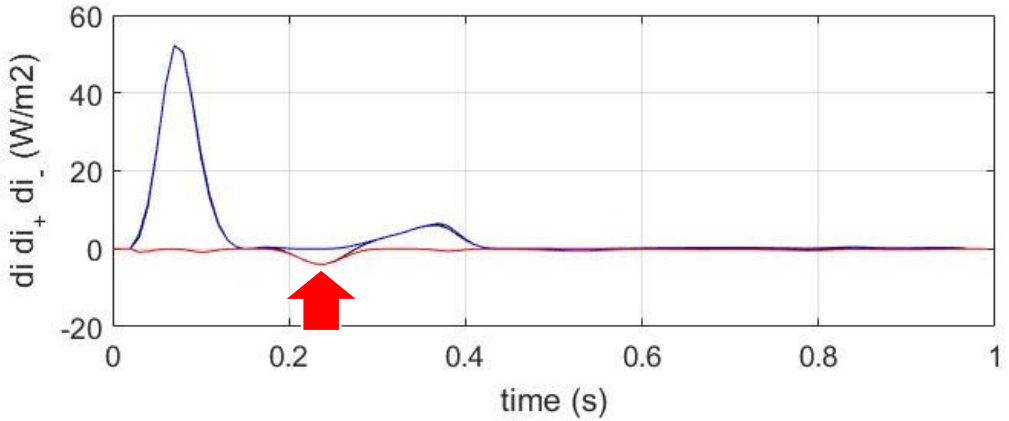


* p < 0.05 ** p < 0.01 *** p < 0.001 **** p < 0.0001

Results – R wave vs age



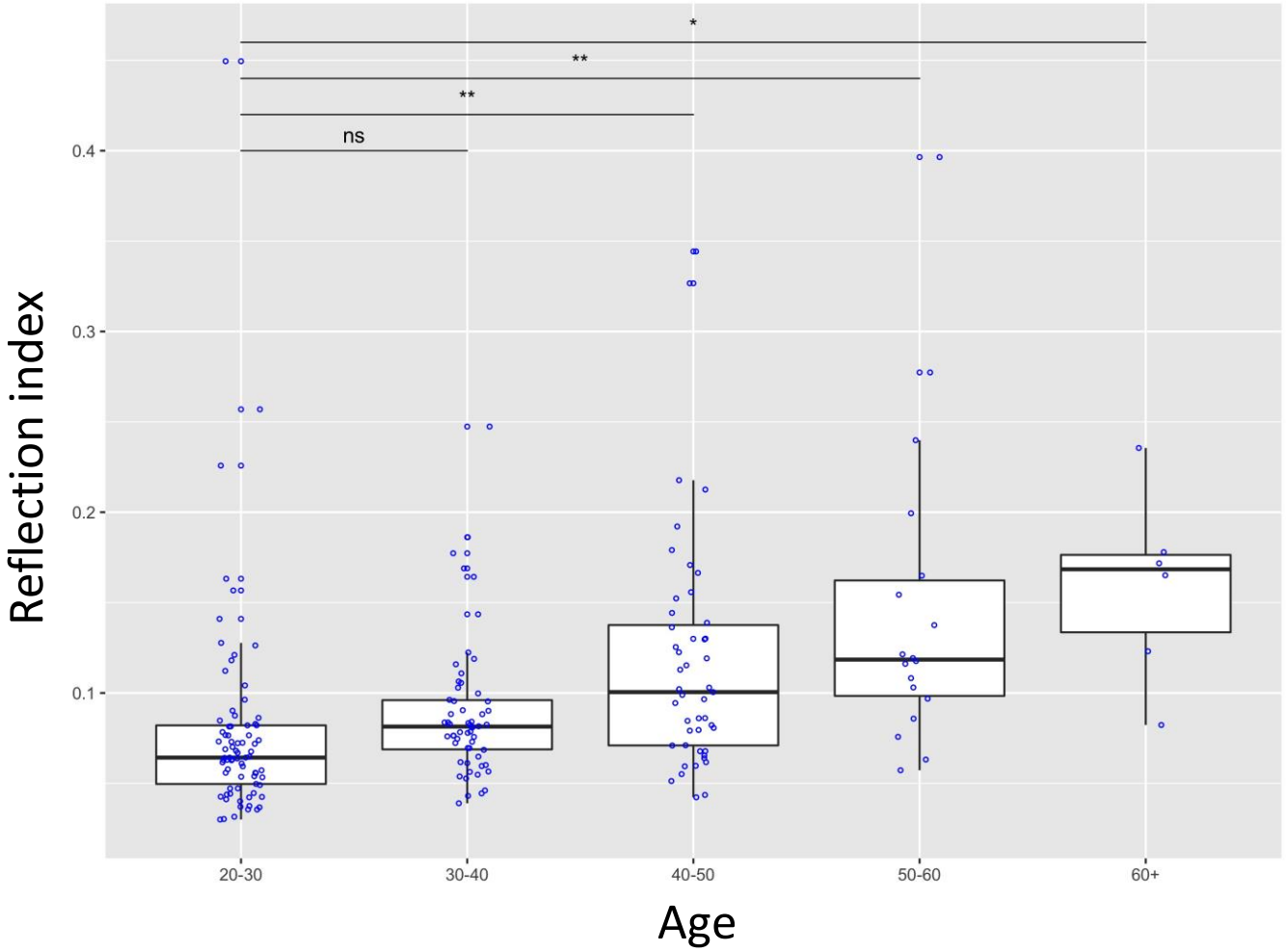
- Increases after age 60



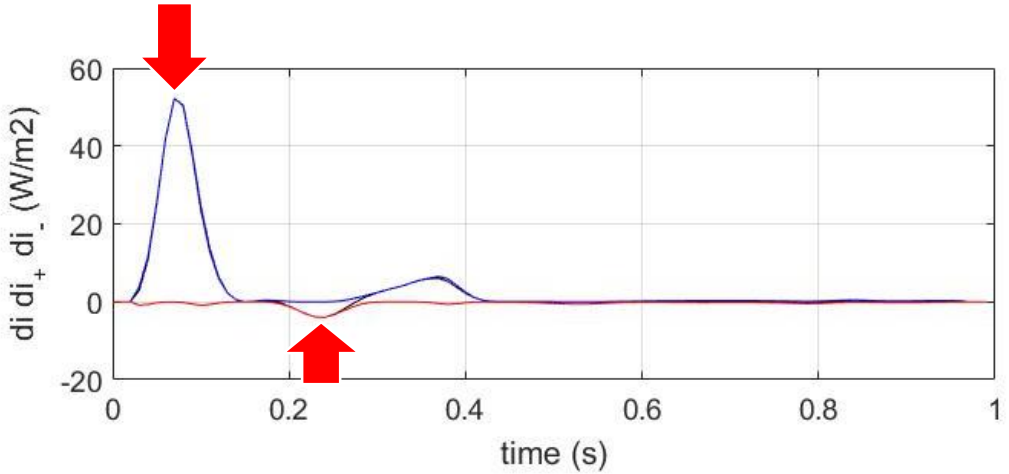
No change in reflecting timing

* p < 0.05 ** p < 0.01 *** p < 0.001 **** p < 0.0001

Results – Reflection index vs age

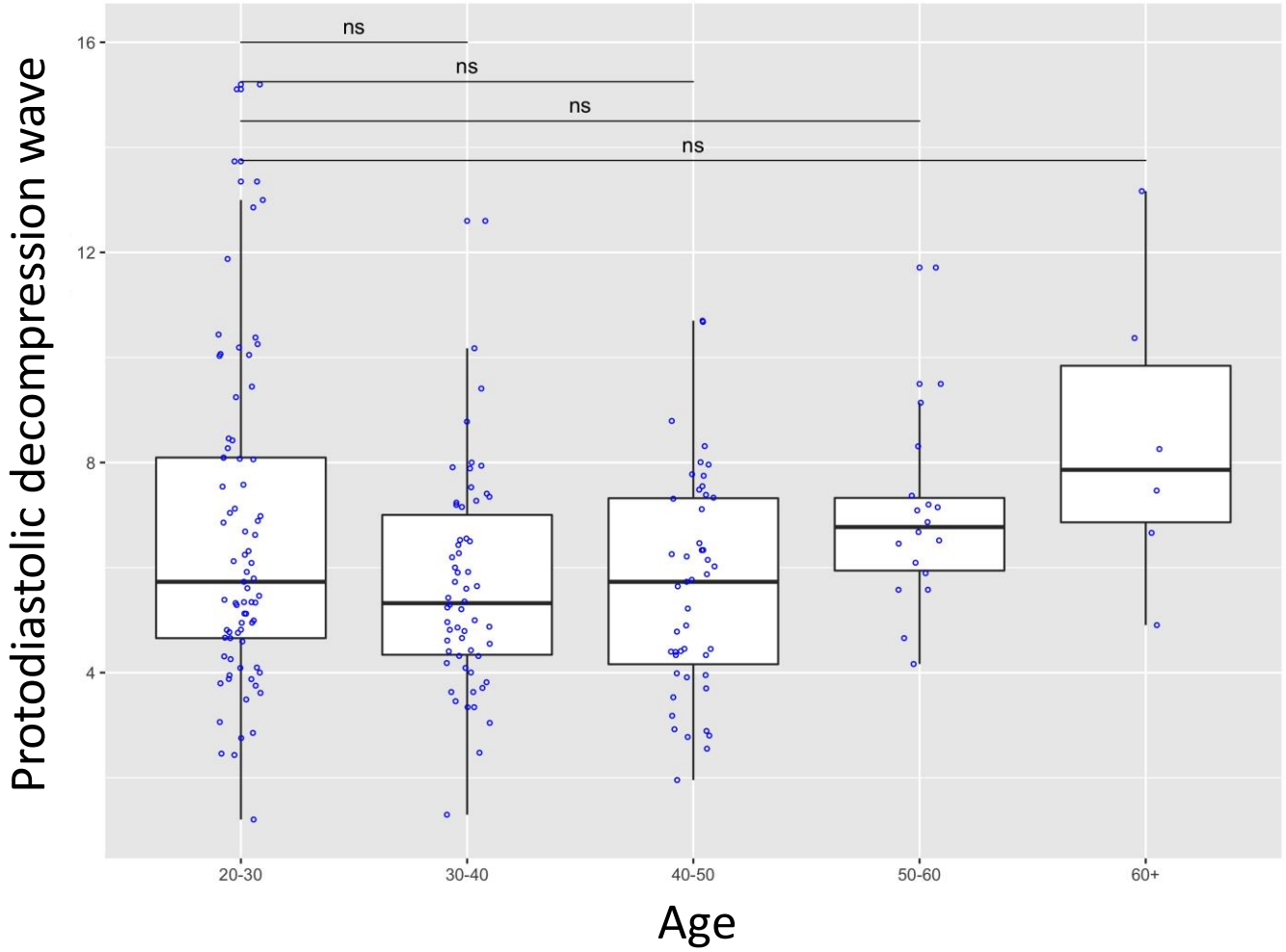


- Increases after age 40

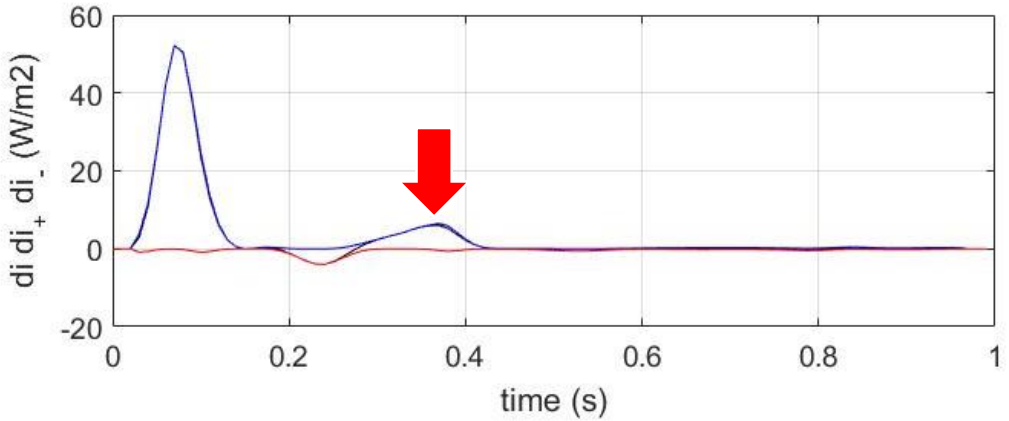


* p < 0.05 ** p < 0.01 *** p < 0.001 **** p < 0.0001

Results – D wave vs age



- No relationship



* p < 0.05 ** p < 0.01 *** p < 0.001 **** p < 0.0001

Results – multivariate linear regression

Age v	Standardized β	p
S wave	-0.28	0.002
R wave	0.19	0.049
R:S	0.34	<0.001
D wave	-0.03	0.79

	Heart rate	Peak V02	Male gender	Mean arterial pressure	PWV-tt
↑ S wave	↓	ns	↑	↑	ns
↑ R wave	↓	ns	↓	↑	ns
↑ R:S	↓	ns	↓	↑	ns
↑ D wave	↓	ns	↑	↑	ns

Conclusions

- Aortic wave intensity analysis is possible at scale.
- Patterns and magnitude are similar to invasive methods.
- Ageing results in increased reflected wave magnitude.
- Local wave speed is less biased using the sum of squares method.

Thank you

Professor Alun Hughes
Dr Charlotte Manisty
Professor James Moon

Siana Jones
Hannah Taylor

Paul Scully
Kris Knott
Katia Menacho
Clem Lau
Stefania Rosmini
Tom Treibel
Heeraj Bulluck
Louise McGrath
Sandy Gardner

The Marathon Study Team
Andy D'Silva
Professor Sanjay Sharma
Camilla Torlasco
Niro Nadarajan
Giulia Benedetti
Jet Van Zalen

All the study group from Barts Health NHS Trust and St George's University of London including:
Radiographers
Echocardiographers
Sports Scientists
Call Centre team

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Contributions

- In 2015: wrote and submitted the grant application
- 2015-2017: acquired the data and coordinated the team
  - CMR scans >300 scans myself
  - Echo and CPEX >20 studies
  - Consent, phlebotomy, BP, bioimpedance including storage
- 2017- present: analysed data
  - CMR segmentation
  - Matlab analysis- data preparation, alignment and waveform quantification
  - Statistical analysis

Future Work

- Validation against:
  - Diastolic function
  - Ventricular systolic function
  - Distensibiliity derived measures

- Reflected wave timing with age & sex differences
- Compare parameters in health against disease (Bariatric patients, Hypertension, Anderson-Fabry's disease, veteran athletes)

- Is ageing related to other physiological parameters eg. SVR

Age group	*n*
20-30	*77*
30-40	*58*
40-50	*47*
50-60	*18*
60+	*6*

Results – multivariate linear regression

Age is associated with:

- S wave ↓
- R wave ↑
- Reflection magnitude ↑ ↑
- D wave =

Age v	Standardized β	p
S wave	-0.28	0.002
R wave	0.19	0.049
R:S	0.34	<0.001
D wave	-0.03	0.79

When accounting for
Heart rate
Peak V02i
Gender
Mean arterial pressure
Aortic arch pulse wave velocity

Increase S wave: Lower HR; Lower Age; Male sex; Higher MAP
Increase R wave: Lower HR; Higher Age; Female sex; Higher MAP
R:S wave: Lower HR; Higher Age; Female sex; Higher MAP
D wave: Lower HR; Male sex; Higher MAP
No paraeter influenced by local PWV