GHENT UNIVERSITY

UCL

Arterial hemodynamics and wave reflections

Patrick Segers and Alun Hughes

bioMeda ibitech

FACULTY OF ENGINEERING AND ARCHITECTURE

GHENT UNIVERSITY

UCL

Background

Artery Research (2017) 18, 75–80

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/artres

Review

Towards a consensus on the understanding and analysis of the pulse waveform: Results from the 2016 Workshop on Arterial Hemodynamics: Past, present and future

Patrick Segers [a,*], Michael F. O'Rourke [b], Kim Parker [c], Nico Westerhof [d], Alun Hughes [e] on behalf of the Participants of the 2016 Workshop on Arterial Hemodynamics: Past, present and future

GHENT UNIVERSITY

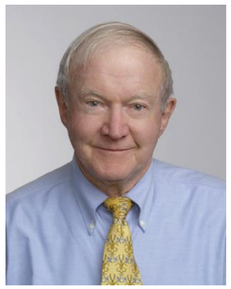
UCL

Background

- Artery Society has prominent “eminence grises” among its members (think of our McDonald lecturers)
- Their legacy is to some extent preserved in books and papers but McDonald lectures, for instance, have not been recorded and there was little or no audiovisual material.
- The idea to organize a workshop to audio-visually document seminal work in arterial hemodynamics and discuss contentious aspects was born in a coffee-break of the Artery 2013 meeting in London.

Background

- We organized the 2-day *Workshop on Arterial Hemodynamics: Past, present and future* in 2016 (June 14-15) in London
- Keynote speakers (with 45 min – 1hr lectures) by:
  - Michael O'Rourke
  - Nico Westerhof
  - Kim Parker



- Integral recording of their talks: http://www.arterysociety.org/arterial-hemodynamics-download-videos-from-meeting/
- Highly valued contributions from several other colleagues

GHENT UNIVERSITY

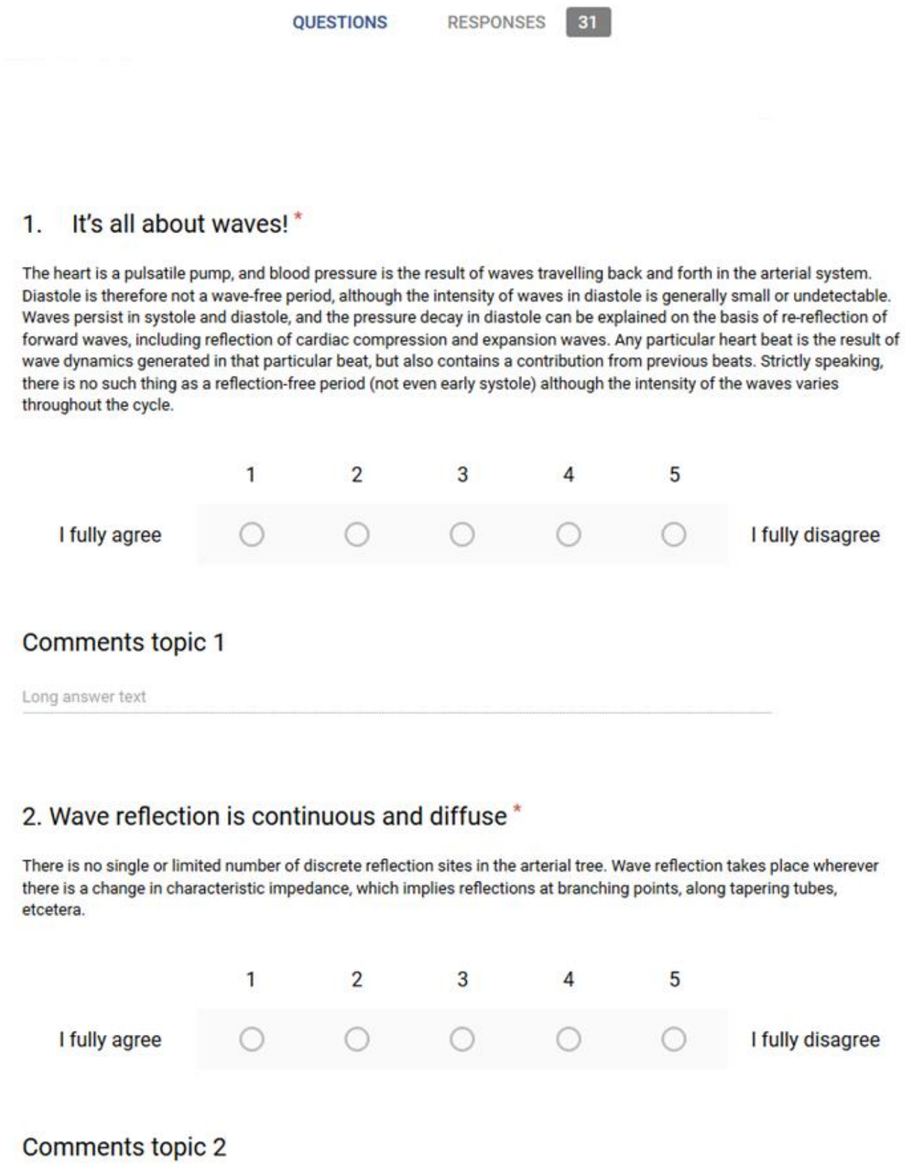
UCL

Aim of this presentation

- Advertise the available audio-visual material
- Share and discuss methodology (and its pros and cons)
- Share some results
- Prepare the floor for a continued open discussion

Methodology

- Poll via Google Forms
- 9 (broad) statements
- Participants could express their level of agreement using a Likert scale (a score of 1 indicating full agreement, and a score of 5 indicating full disagreement)
- Not anonymous (coupled to co-authorship on paper)
- Participants were permitted to make unattributable comments for inclusion in the manuscript, or comments not for publication
- 31/51 participants + NW/KP/MOR filled out the survey



QUESTIONS RESPONSES 31

1. It's all about waves! *

The heart is a pulsatile pump, and blood pressure is the result of waves travelling back and forth in the arterial system. Diastole is therefore not a wave-free period, although the intensity of waves in diastole is generally small or undetectable. Waves persist in systole and diastole, and the pressure decay in diastole can be explained on the basis of re-reflection of forward waves, including reflection of cardiac compression and expansion waves. Any particular heart beat is the result of wave dynamics generated in that particular beat, but also contains a contribution from previous beats. Strictly speaking, there is no such thing as a reflection-free period (not even early systole) although the intensity of the waves varies throughout the cycle.

	1	2	3	4	5	
I fully agree	○	○	○	○	○	I fully disagree

Comments topic 1

Long answer text

2. Wave reflection is continuous and diffuse *

There is no single or limited number of discrete reflection sites in the arterial tree. Wave reflection takes place wherever there is a change in characteristic impedance, which implies reflections at branching points, along tapering tubes, etcetera.

	1	2	3	4	5	
I fully agree	○	○	○	○	○	I fully disagree

Comments topic 2

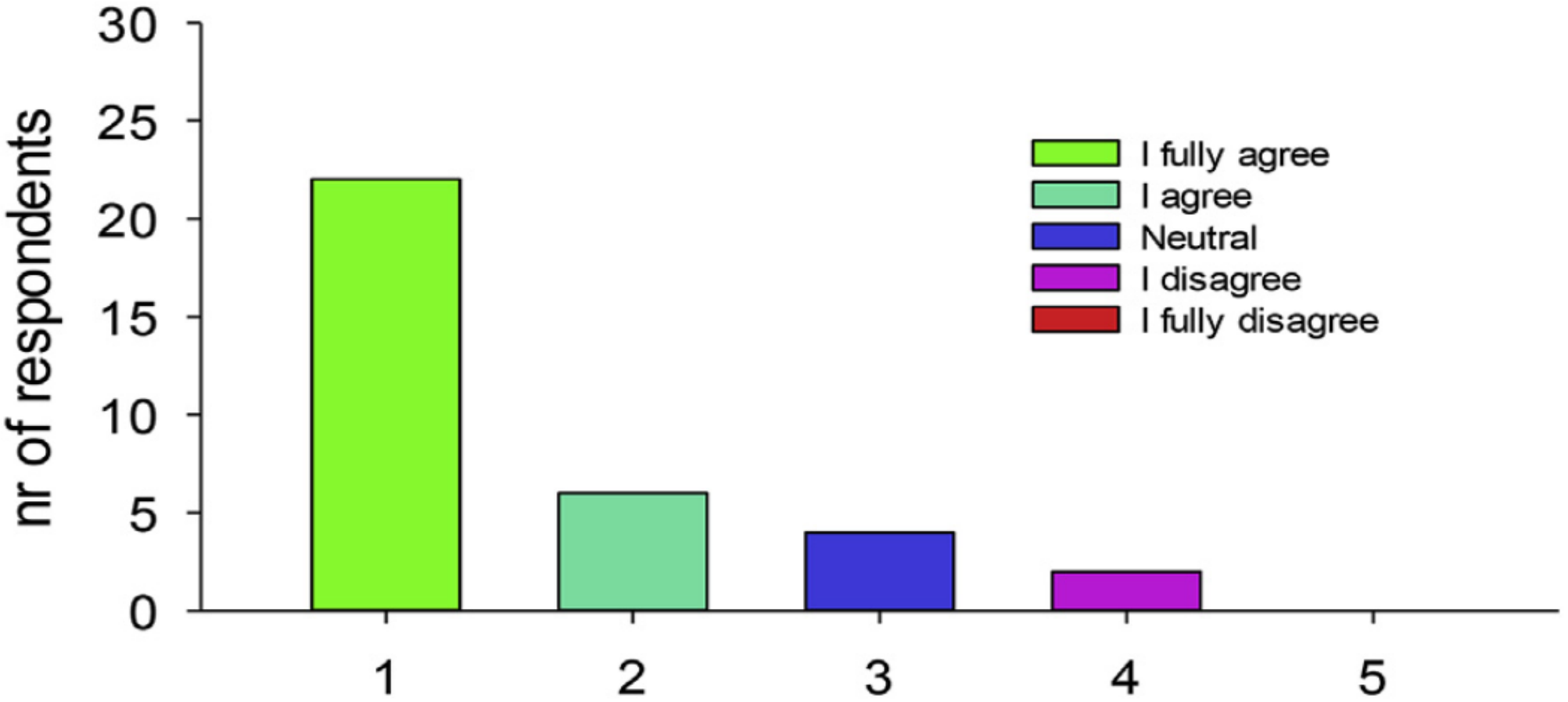
GHENT UNIVERSITY

UCL

Statement 1 – it's all about waves

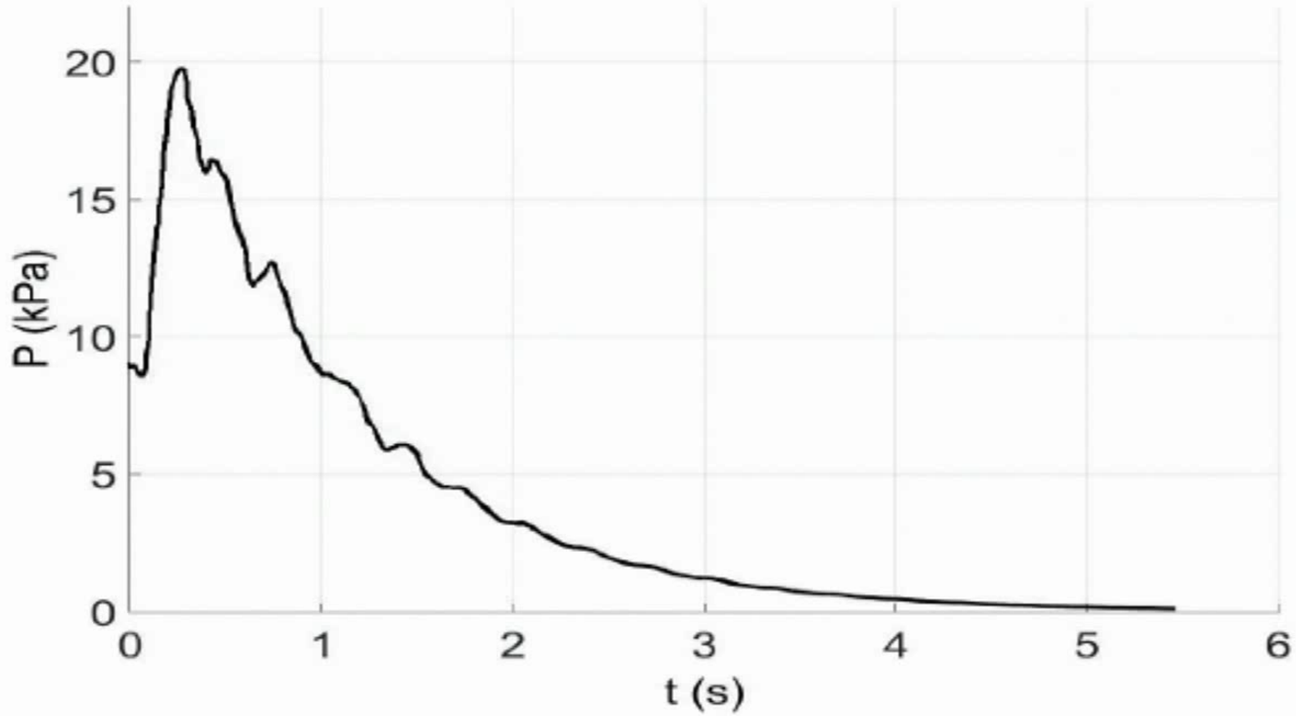
Statement 1 – it's all about waves

The heart is a pulsatile pump, and blood pressure is the result of waves travelling back and forth in the arterial system. Diastole is therefore not a wave-free period,



Statement 1 – it's all about waves

numerical results



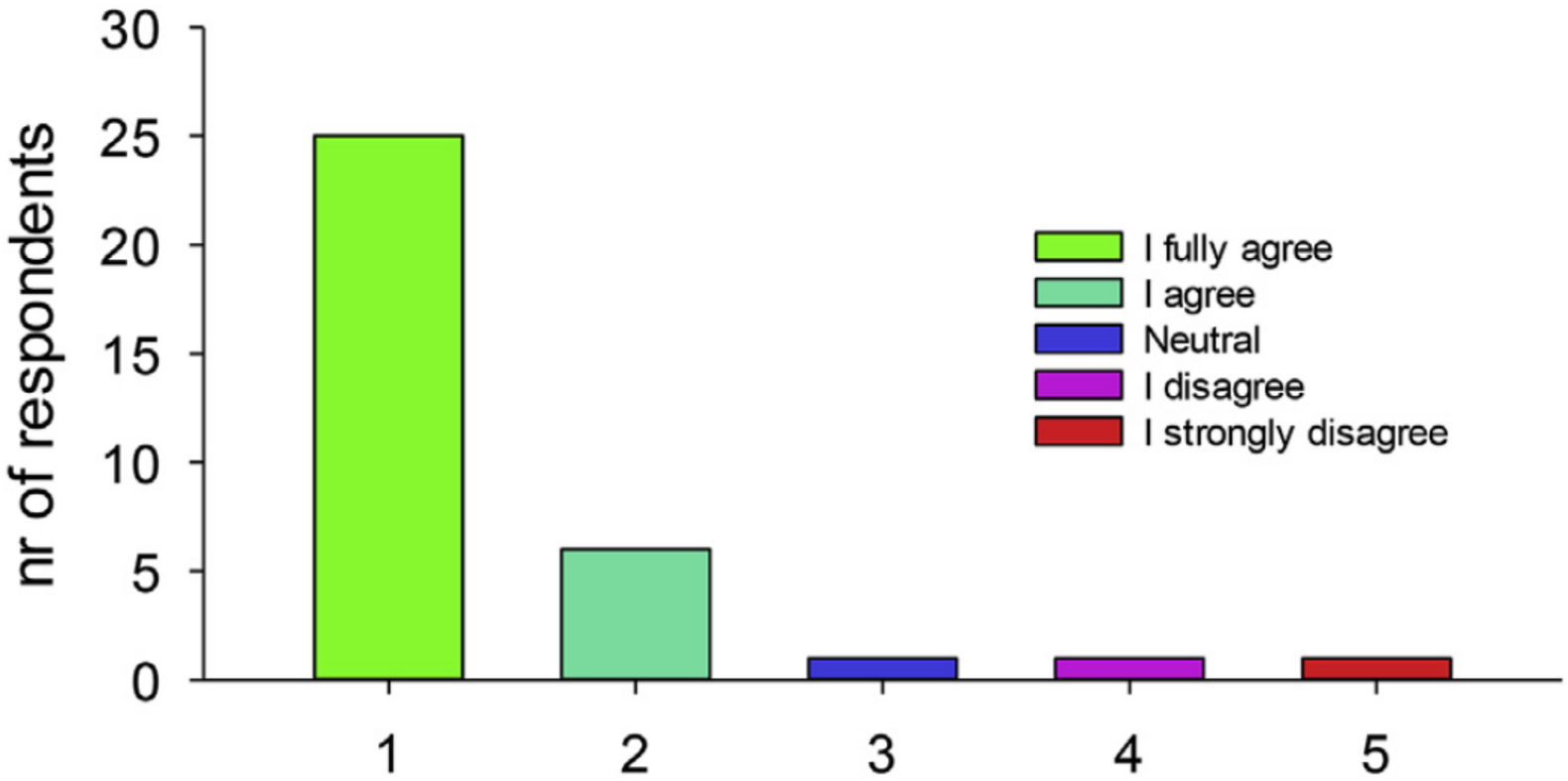
computed pressure during extended diastole (J. Alastruey)

$$\tau_{computed} = 1.02\ s \qquad \tau_{thoery} = -\frac{2\langle T \rangle}{ln(\lambda_{max})} = 1.22\ s$$

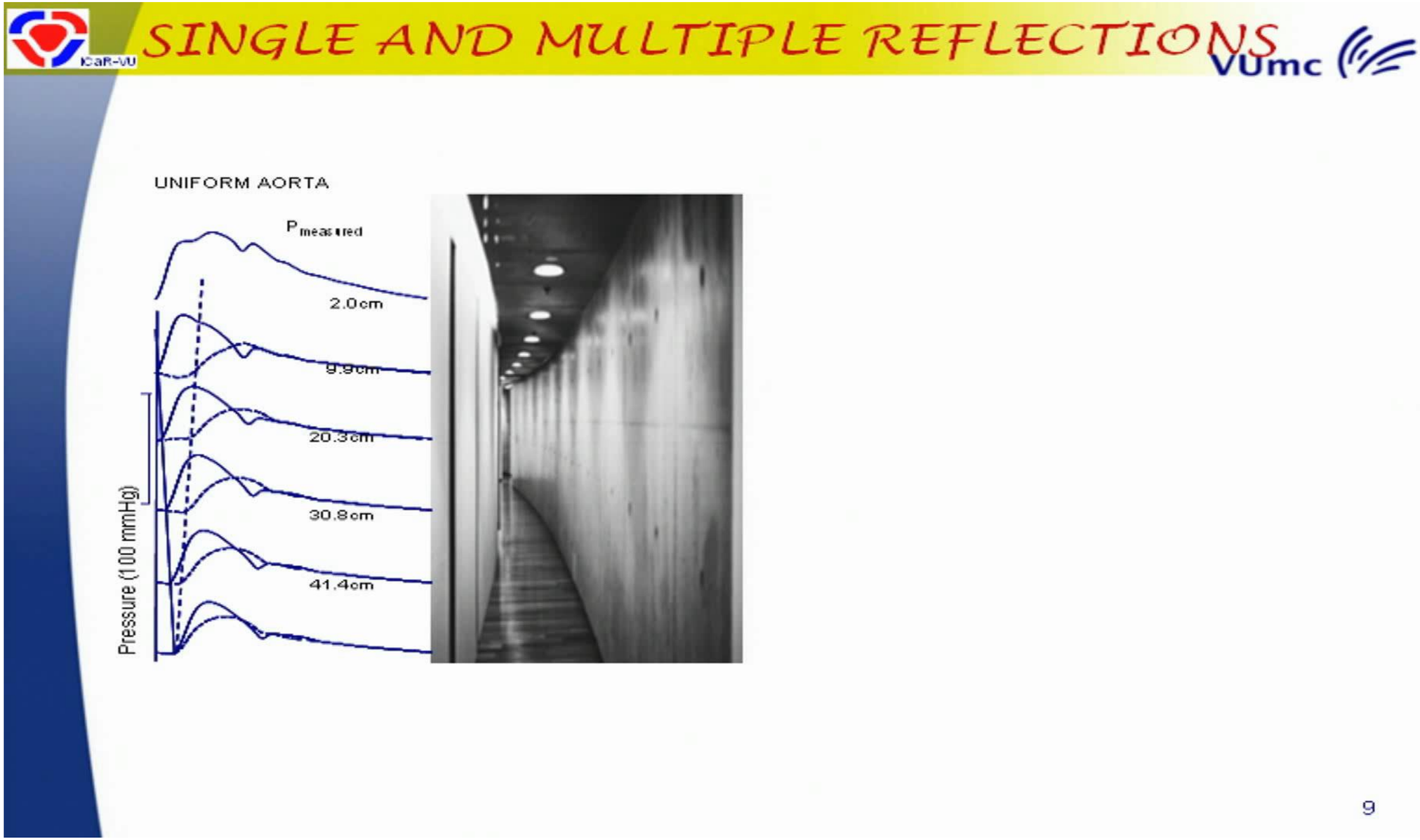
… even the origin of mean arterial pressure

Statement 2. Wave reflection is continuous and diffuse

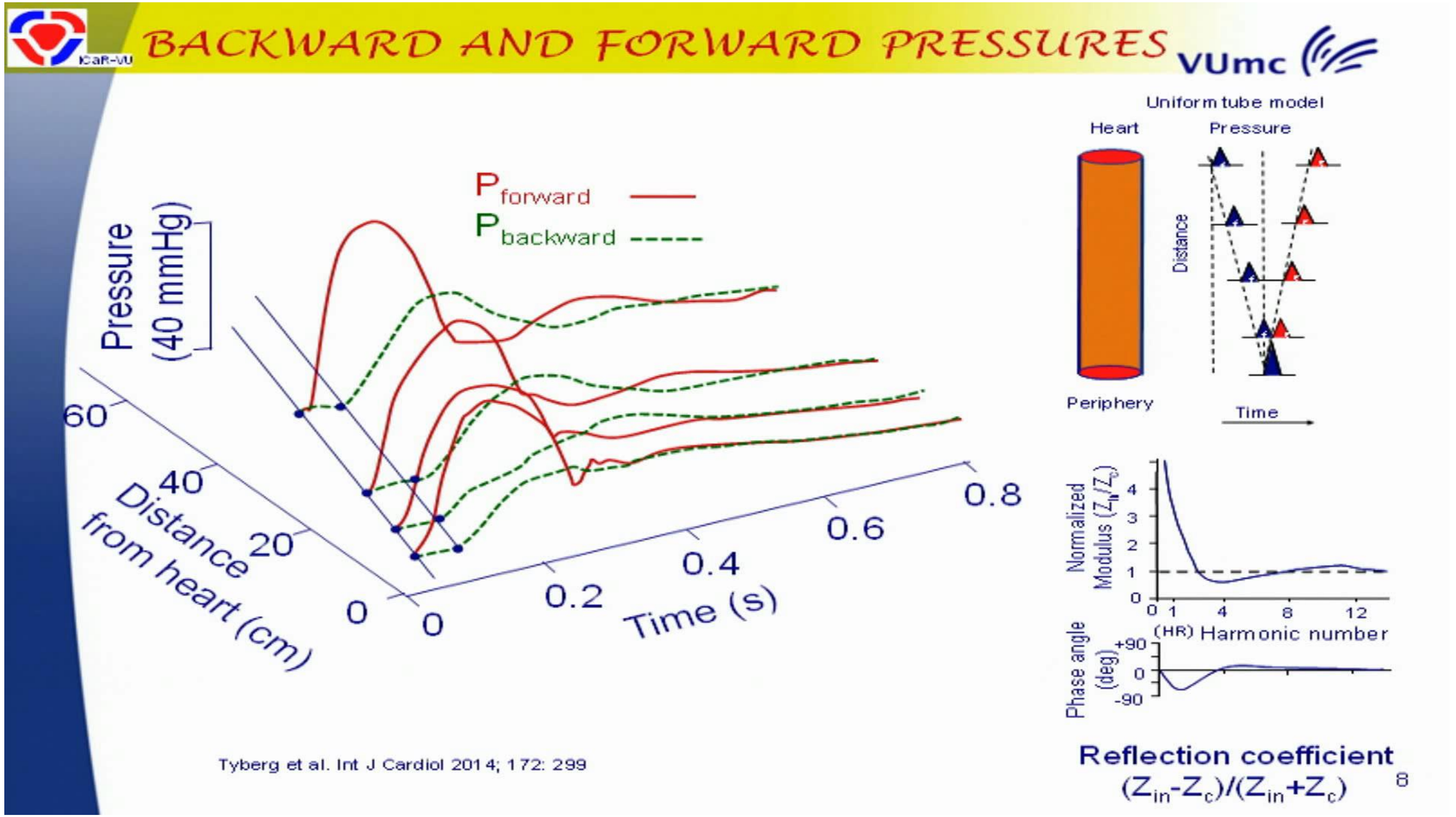
There is no single or limited number of discrete reflection sites in the arterial tree. Wave reflection takes place wherever there is a change in characteristic impedance, which implies reflections at branching points, along tapering tubes, etcetera.



Statement 2. Wave reflection is continuous and diffuse

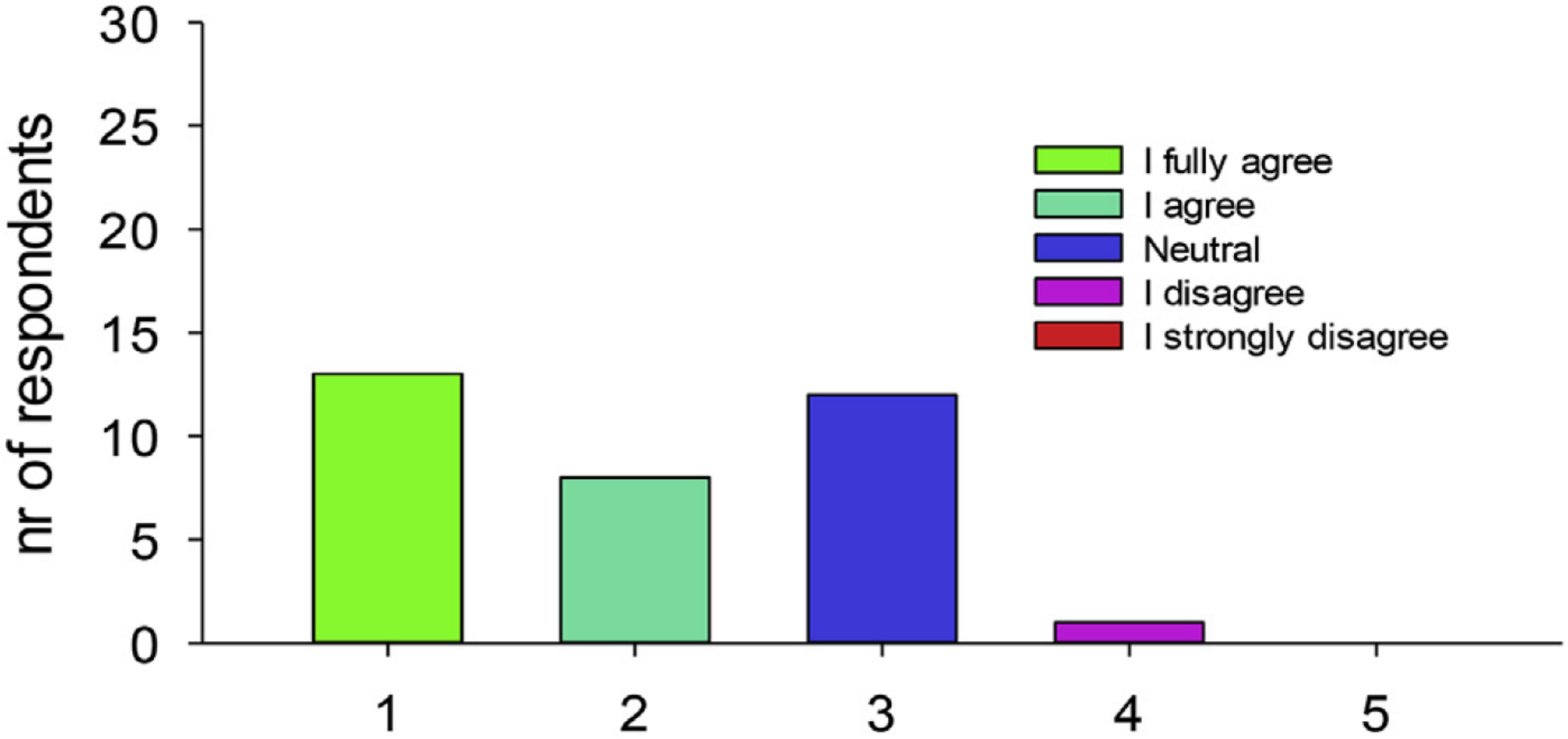


Statement 2. Wave reflection is continuous and diffuse



Statement 9. The reservoir-wave concept

The reservoir-wave model is a conceptual model/paradigm, just as the Windkessel, uniform tube and T-tube models. As for all simplified models, it



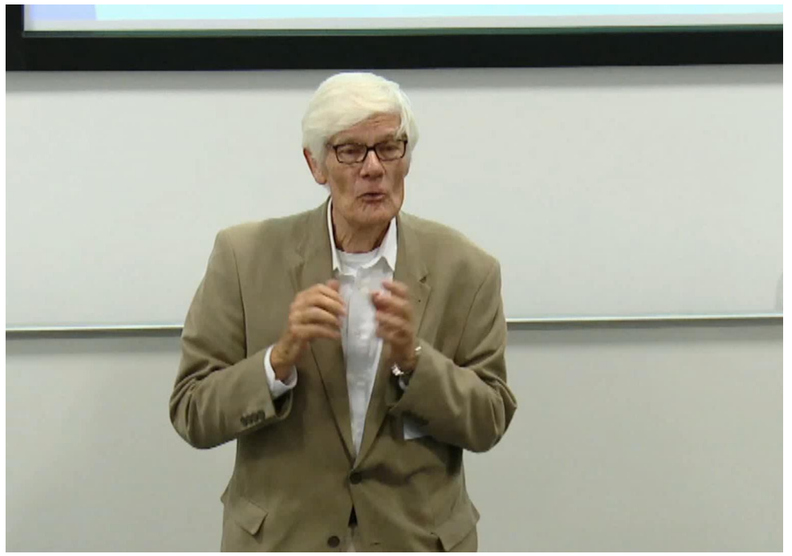
GHENT UNIVERSITY

UCL

Statement 9. The reservoir-wave concept

Concluding remarks

- Workshop was quite successful, with lots of space for debate and discussion
- Google Form approach to poll for opinion of attendees worked very well.

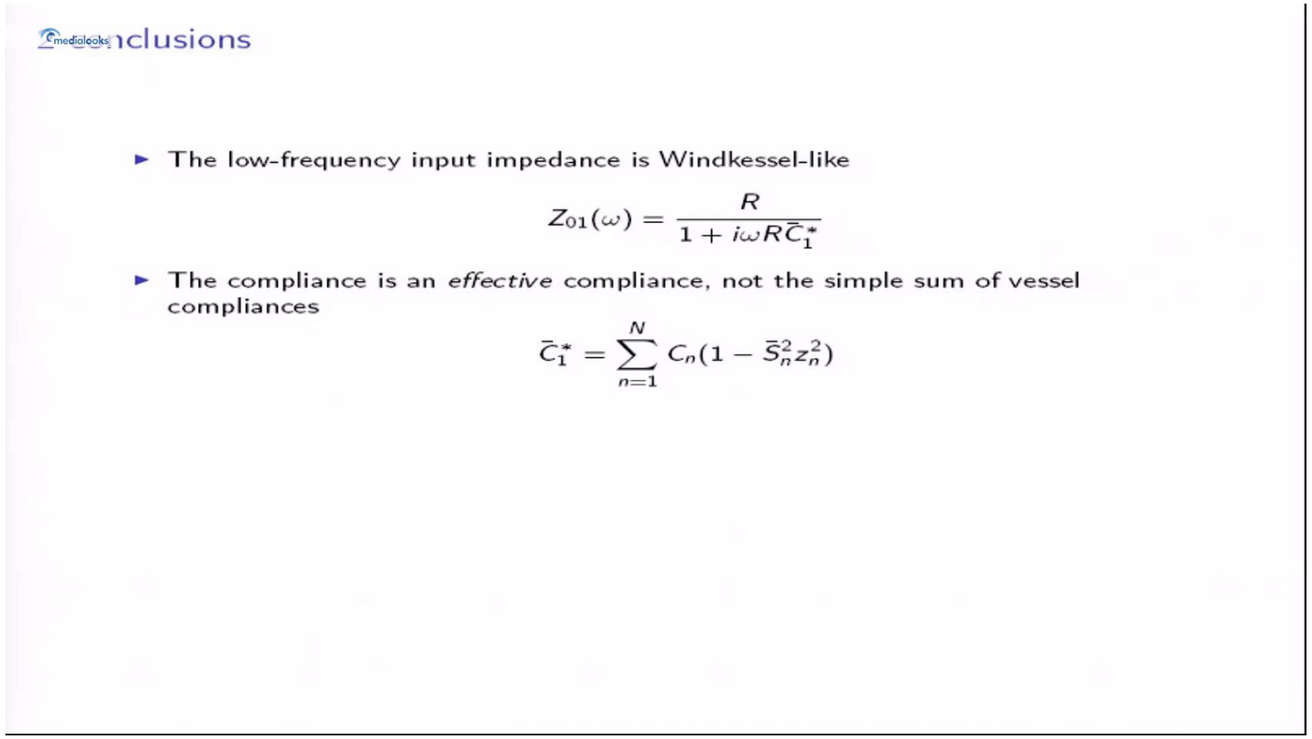


Concluding remarks

- Statements formulated by only 2 people (intrinsic bias?) and intentionally broad, making it hard to obtain clear-cut conclusions
- Not all participants to the poll have the same degree of expertise on all of the topics. Responses were not weighted by expertise
- Useful basis for proceeding with a more detailed and comprehensive consensus document on the current understanding and approaches to analysis of the pulse waveform

Concluding remarks

Future efforts should be directed at identifying remaining areas of dispute and future topics for research



Acknowledgements

- British Heart Foundation and National Institute for Health
- Tom Carson and UCL staff

Invitation to submit papers in special issue

Physiological Measurement

IPEM Institute of Physics and Engineering in Medicine

Focus on analysis and measurement of the arterial pulse wave waveform

Alun Hughes *UCL, UK*
Patrick Segers *Ghent University, Belgium*
Koen Reesink *Maastricht University Medical Center, Netherlands*

Scope

The field of pulse wave analysis has a long history but there are a number of new developments and continuing controversy. The emergence of easy-to-use cuff-based and wearable devices that record the pulse waveform has broadened the reach of these techniques and opened the realistic possibility of pulse wave analysis being adopted as a measure in the clinic.

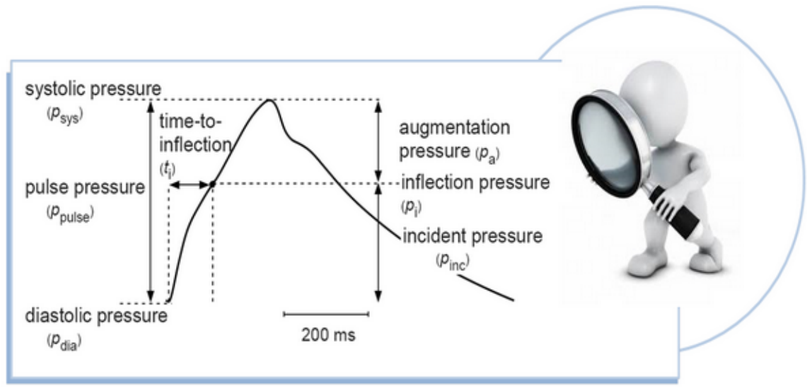


Figure. 'Pulsology' - what are we learning from our signals? **Image credit:** Pulse wave and annotations: Maarten Heusinkveld, MSc; puppet with looking glass: nl.freepik.com; arrangement: Koen Reesink, PhD

At the same time, more conceptual issues, such as the importance of waves and wave reflections in shaping the arterial pulse, and how to explain the Windkessel-like behaviour of the arterial system in diastole, remain the subject of scientific debate. The aim of this collection is to address methodological

JOURNAL LINKS
Journal home
Scope and key information
Editorial board
Abstracted in
Author benefits
Highlights of 2016
IOP Publishing Reviewer Awards 2016
Focus issues
Letters
Martin Black Award
Related links
Developing country access
Open access information
Prices & ordering

Submission remains open until 28 February 2018