Echocardiography is one of the most useful and powerful diagnostic tools in the assessment of cardiac function. It remains a rapidly expanding modality, with new techniques constantly developing and maturing. Building on the success of the original work, the second edition of Making Sense of Echocardiography: A hands-on guide provides an up-to-date, accessible overview for those learning echocardiography for the first time as well as an accessible handbook that experienced sonographers can refer to throughout their careers.

The strong clinical focus and concentration on real-life scenarios make this book especially relevant in day-to-day practice. New chapters in this edition discuss myocardial mechanics and speckle tracking and 3D echo. The book also contains significantly expanded and updated material on:

- Contrast echo
- Tissue Doppler imaging
- Intravascular ultrasound and epicardial echo
- The left ventricle and its systolic function
- Left ventricular diastolic function
- The left atrium

Supplying the latest guidelines and evidence-based clinical advice, this edition is also supplemented with new illustrations and an updated website. Fully updated key references for further reading are provided for each chapter. This accessible yet comprehensive text will ensure readers are up to date on the essentials in the field and can confidently integrate new procedures into their everyday practice.
MAKING SENSE of Echocardiography
A hands-on guide
Second Edition
MAKING SENSE of Echocardiography
A hands-on guide
Second Edition
Andrew R Houghton
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Despite the blossoming of cardiac imaging techniques over recent years, echocardiography remains one of the bedrocks upon which modern cardiology is built. The benefits are obvious of an imaging technique with high spatial and temporal resolution, but which is also portable enough to be delivered in environments as diverse as the cardiac operating theatre or a field camp in rural India. But the ubiquitousness of echocardiography also brings with it some major challenges. It remains a rapidly expanding modality, with new techniques constantly developing and maturing. Appropriate integration of these into everyday practice remains a challenge. Complementary, and sometimes competing, technologies mean that it is no longer appropriate to train in one modality without some understanding of the alternatives. Quality is the new watchword in healthcare. It is no longer acceptable for an individual or a healthcare provider to simply claim competence. This must be verifiably evidenced, and various schemes in the UK, in Europe and across the globe provide accreditations for both individuals and departments.

The second edition of Andrew Houghton’s book is therefore extremely welcome, taking many of these issues head on. Together with his collaborators, he has penned an excellent primer for those learning echocardiography for the first time. The strong clinical focus and concentration on real life scenarios means the book always feels relevant in day to day clinical practice. The basics are covered in detail and areas that prove constantly challenging to those who are training (and some who have been practicing a little longer!), such as the physics of ultrasound, are concisely and clearly explained. But the simple style does not mean that this book is not relevant to those already working in echocardiography or in clinical cardiology who want an insight into the scope of assessment that echo can offer. Newer technologies such as the tissue Doppler derived and speckle track based strain analysis are clearly described; this is an area that causes many echocardiographers some discomfort. Likewise the chapter on the conduct and integration of 3D technology into the standard transthoracic workflow is timely. Three dimensional echo has been slow to take off in routine clinical care and the chapter in this book will provide a very valuable introduction to the subject. The chapter on departmental quality assurance and audit is particularly important, incorporating both the principles involved and practical advice on undertaking audit in echo. Although much discussed, even when performed, this is often done poorly and it is good to see a chapter given equal weight to other more practical aspects of scanning such as how to conduct an M-mode examination or undertake Simpsons biplane assessment of systolic function. Both the technical and the reliability aspects are ultimately of equal importance to the large volumes of patients undergoing echocardiography every day across the world.
So congratulations to the authors for producing such a concise yet comprehensive text book. It will be of great value to those learning echo for the first time, but also will sit very happily on the shelf of any echo department or in the personal libraries of existing sonographers and cardiologists.

Guy W L Lloyd MD FRCP
Consultant Cardiologist
East Sussex Healthcare NHS Trust
President of the British Society of Echocardiography
Since the publication of the first edition of *Making Sense of Echocardiography*, there have been many advancements in the field of echo. The quality and sophistication of echo technology continues to improve, and techniques such as 3D echo and speckle tracking are increasingly ‘mainstream’. To reflect these changes, the book has been thoroughly revised and updated and, in particular, sees the addition of specific chapters on the newer echo technologies by expert contributors.

There have also been major updates of many of the key echo guidelines, and these updates have been incorporated throughout the text. Key references for further reading are provided for each chapter, and these reflect the latest guidelines and papers in each field. Many new figures have been included, and several chapters have been restructured to provide even greater clarity to the text.

The primary aim of this second edition of *Making Sense of Echocardiography* remains the same as the first – to provide the echo trainee with a comprehensive yet readable introduction to echo, and to provide more experienced sonographers with an accessible handbook for reference when required. Information not just on performing echo but also on the supporting topics of ultrasound physics, anatomy, physiology and clinical cardiology is interwoven throughout the book.

The approach to echo studies taken in this book is based on guidelines published by national echo societies, principally the British Society of Echocardiography (BSE), and I am particularly grateful to the BSE and the British Heart Foundation for their permission to use their recommended reference ranges throughout the book. I am also grateful to everyone who has taken the time to comment on draft copies of the text and to all those who have provided echo images for this book. Finally, I would like to thank all of the staff at CRC Press, formerly Hodder Arnold, who have contributed to the success of the *Making Sense*… series of books.

Andrew R. Houghton
2013
I would like to thank everyone who provided suggestions and constructive criticism while I prepared the second edition of *Making Sense of Echocardiography*. I am particularly grateful to Dr Grant Heatlie at the University Hospital of North Staffordshire in Stoke on Trent for writing the chapter on myocardial mechanics and speckle tracking, and to Dr Thomas Mathew at the Trent Cardiac Centre, Nottingham, for writing the chapter on 3D echo.

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Catherine Goul    Upul Wijayawardhana
Prathap Kanagala   Bernadette Williamson
Jeffrey Khoo

I am indebted to Rick Steeds and Guy Lloyd at the British Society of Echocardiography (BSE) and to Heidi Mayhew and Anu Mukherjee at the British Heart Foundation (BHF) for their permission to quote their recommended echo reference ranges which, where applicable, form the basis of the reference ranges used in this book. Further details of the BSE/BHF reference ranges can be found at the end of the book (see ‘Echo resources’).

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Dr Andrew R. Houghton studied medicine at the University of Oxford and undertook postgraduate training in Nottingham and Leicester. He was appointed as consultant cardiologist at Grantham & District Hospital in Lincolnshire, UK, in 2002. His subspecialty interest is in cardiac imaging, and he is clinical head of echocardiography. He has been a member of the British Society of Echocardiography’s working group on revalidation, and is a regular lecturer at BSE meetings.

Dr Houghton has co-authored a number of textbooks, including Making Sense of the ECG (winner of the Royal Society of Medicine’s Richard Asher prize for best first textbook, and commended at the BMA Book Awards) and its companion volume Making Sense of the ECG: Cases for Self-Assessment. He is co-editor of Chamberlain’s Symptoms and Signs in Clinical Medicine (13th edition). The first edition of Making Sense of Echocardiography was highly commended at the BMA Medical Book Awards in 2010.
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<thead>
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<th>Abbreviation</th>
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<td>two-dimensional</td>
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<tr>
<td>3D</td>
<td>three-dimensional</td>
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<tr>
<td>A</td>
<td>peak A wave velocity</td>
</tr>
<tr>
<td>ACE</td>
<td>angiotensin-converting enzyme</td>
</tr>
<tr>
<td>$A_{dur}$</td>
<td>duration of atrial reversal in pulmonary vein flow</td>
</tr>
<tr>
<td>$A_{dur}$</td>
<td>duration of A wave in left ventricular inflow</td>
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<td>AF</td>
<td>atrial fibrillation</td>
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<td>$A_m$</td>
<td>atrial contraction velocity on tissue Doppler imaging of mitral annulus (also known as $A'$)</td>
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<td>Ao</td>
<td>aorta</td>
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<td>aortic regurgitation</td>
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<td>ARVC</td>
<td>arrhythmogenic right ventricular cardiomyopathy</td>
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<td>AS</td>
<td>aortic stenosis</td>
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<td>ASD</td>
<td>atrial septal defect</td>
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<td>ASE</td>
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</tr>
<tr>
<td>AV</td>
<td>aortic valve or atrioventricular</td>
</tr>
<tr>
<td>BSA</td>
<td>body surface area</td>
</tr>
<tr>
<td>BCS</td>
<td>British Cardiovascular Society</td>
</tr>
<tr>
<td>BHF</td>
<td>British Heart Foundation</td>
</tr>
<tr>
<td>BSE</td>
<td>British Society of Echocardiography</td>
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<tr>
<td>CI</td>
<td>cardiac index</td>
</tr>
<tr>
<td>CO</td>
<td>cardiac output</td>
</tr>
<tr>
<td>CRT</td>
<td>cardiac resynchronization therapy</td>
</tr>
<tr>
<td>CSA</td>
<td>cross-sectional area</td>
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<tr>
<td>CW</td>
<td>continuous wave (Doppler)</td>
</tr>
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<td>Cx</td>
<td>circumflex (coronary) artery</td>
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<tr>
<td>DCM</td>
<td>dilated cardiomyopathy</td>
</tr>
<tr>
<td>E</td>
<td>peak E wave velocity</td>
</tr>
<tr>
<td>EACVI</td>
<td>European Association of Cardiovascular Imaging</td>
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<td>ECG</td>
<td>electrocardiogram</td>
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<td>EDV</td>
<td>end-diastolic volume</td>
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<tr>
<td>EF</td>
<td>ejection fraction</td>
</tr>
<tr>
<td>$E_m$</td>
<td>early myocardial velocity on tissue Doppler imaging of mitral annulus (also known as $E'$)</td>
</tr>
<tr>
<td>ESC</td>
<td>European Society of Cardiology</td>
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<tr>
<td>ESV</td>
<td>end-systolic volume</td>
</tr>
<tr>
<td>ET</td>
<td>ejection time</td>
</tr>
<tr>
<td>FS</td>
<td>fractional shortening</td>
</tr>
<tr>
<td>HCM</td>
<td>hypertrophic cardiomyopathy</td>
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<tr>
<td>HFPEF</td>
<td>heart failure with preserved ejection fraction</td>
</tr>
<tr>
<td>HFREF</td>
<td>heart failure with reduced ejection fraction</td>
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<tr>
<td>HID</td>
<td>half-intensity depth</td>
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<tr>
<td>HO{\text{CM}}</td>
<td>hypertrophic obstructive cardiomyopathy</td>
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</tbody>
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HR        heart rate
ICD       implantable cardioverter defibrillator
ICT       isovolumic contraction time
INR       international normalized ratio
IRT or IVRT isovolumic relaxation time
IV        intravenous
IVC       inferior vena cava
IVNC      isolated ventricular non-compaction
IVS       interventricular septum
IVSd      interventricular septal wall dimension – diastole
IVSs      interventricular septal wall dimension – systole
JVP       jugular venous pressure
LA        left atrium
LAA       left atrial appendage
LAD       left anterior descending (coronary artery)
LCA       left coronary artery
LCC       left coronary cusp
LLPV      left lower pulmonary vein
LMS       left main stem
LUPV      left upper pulmonary vein
LV        left ventricle
LVEDV     left ventricular end-diastolic volume
LVEF      left ventricular ejection fraction
LVESV     left ventricular end-systolic volume
LVH       left ventricular hypertrophy
LVIdd     left ventricular internal dimension – diastole
LVIds     left ventricular internal dimension – systole
LVOT      left ventricular outflow tract
LVPW      left ventricular posterior wall
LVPWd     left ventricular posterior wall dimension – diastole
LVPWs     left ventricular posterior wall dimension – systole
MI        mechanical index or myocardial infarction
MR        mitral regurgitation
MS        mitral stenosis
MV        mitral valve
NCC       non-coronary cusp
NSTEMI    non-ST elevation myocardial infarction
OM        obtuse marginal (coronary artery)
P½T       pressure half-time
PA        pulmonary artery
PADP      pulmonary artery diastolic pressure
PASP      pulmonary artery systolic pressure
PBMV      percutaneous balloon mitral valvuloplasty
PDA       persistent ductus arteriosus or posterior descending artery
PFO       patent foramen ovale
PG        pressure gradient
PISA      proximal isovelocity surface area
P max     peak pressure
P mean    mean pressure
PR        pulmonary regurgitation
<table>
<thead>
<tr>
<th>Abbreviation</th>
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<tr>
<td>PRF</td>
<td>pulse repetition frequency</td>
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<tr>
<td>PS</td>
<td>pulmonary stenosis</td>
</tr>
<tr>
<td>PV</td>
<td>pulmonary valve or pulmonary vein</td>
</tr>
<tr>
<td>PVₐ</td>
<td>peak atrial reversal (‘A’ wave) velocity in pulmonary vein</td>
</tr>
<tr>
<td>PV₁₀</td>
<td>peak diastolic (‘D’ wave) velocity in pulmonary vein</td>
</tr>
<tr>
<td>PV₅</td>
<td>peak systolic (‘S’ wave) velocity in pulmonary vein</td>
</tr>
<tr>
<td>PW</td>
<td>pulsed wave (Doppler)</td>
</tr>
<tr>
<td>RA</td>
<td>right atrium</td>
</tr>
<tr>
<td>RAP</td>
<td>right atrial pressure</td>
</tr>
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<td>RCA</td>
<td>right coronary artery</td>
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<tr>
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<td>regurgitant fraction</td>
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<td>RLPV</td>
<td>right lower pulmonary vein</td>
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<tr>
<td>RUPV</td>
<td>right upper pulmonary vein</td>
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<tr>
<td>RV</td>
<td>regurgitant volume or right ventricle</td>
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<tr>
<td>RVDP</td>
<td>right ventricular diastolic pressure</td>
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<tr>
<td>RVOT</td>
<td>right ventricular outflow tract</td>
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<td>RVSP</td>
<td>right ventricular systolic pressure</td>
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<td>SD</td>
<td>stroke distance</td>
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<td>SV</td>
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<td>ST elevation myocardial infarction</td>
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<td>superior vena cava</td>
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<td>SVI</td>
<td>stroke volume index</td>
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<tr>
<td>TAVI</td>
<td>transcatheter aortic valve implantation</td>
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<td>tissue Doppler imaging</td>
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<td>time-gain compensation</td>
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<td>transoesophageal echo</td>
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<td>tricuspid regurgitation</td>
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<td>tricuspid stenosis</td>
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<td>transthoracic echo</td>
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<td>peak velocity</td>
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<td>mean velocity</td>
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<tr>
<td>VSD</td>
<td>ventricular septal defect</td>
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<td>VTI</td>
<td>velocity time integral</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>Zva</td>
<td>valvular-arterial impedance</td>
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PART 1

Essential principles
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The first application of diagnostic ultrasound in medicine was in the late 1930s, when Karl Dussik, an Austrian psychiatrist and neurologist, became interested in the potential use of ultrasound for brain imaging. Ultrasound was already in use at that time by mariners for underwater imaging and also by engineers for flaw detection in metals. The piezoelectric effect was already well known, having been discovered more than half a century earlier, and the concept of using a piezoelectric crystal both to transmit and receive ultrasound was described in 1917.

Dussik’s brain imaging technique was different to today’s ultrasound, in that it was based on the transmission of ultrasound waves through an object, rather than detecting waves reflected from an object. His technique, which he called hyperphonography, involved placing a transmitter on one side of the head and a receiver on the other, and using this apparatus he was able to produce images of the ventricles of the brain. Echotransmission was also the first ultrasound technique used for cardiac imaging, by the German physiologist Wolf-Dieter Keidel, in order to make measurements of the heart and thorax.

Echoreflection was first used by Inge Edler and Carl Hellmuth Hertz in Sweden. One weekend in 1953 they borrowed an industrial device, used to detect flaws in metals by the Kockum shipyard in Malmö, to conduct their work on human subjects. By a fortunate coincidence the frequency of the echo transducer happened to be one that was suitable for cardiac imaging. The image of the heart they produced was known as an A-mode scan and was thought to show the posterior wall of the left ventricle (LV). They were soon granted an ultrasound machine of their own and began to produce M-mode scans, with which they were able to examine the mitral valve and also detect atrial thrombus, myxoma, and pericardial effusion.

Nonetheless, it was not until the early 1960s that the potential value of cardiac ultrasound became more widely recognized. The first dedicated cardiac ultrasound machine, developed by Jack Reed and Claude Joyner, appeared at this time and the term ‘echocardiography’ was coined for the first time.

Real-time 2D echo followed in the 1960s, spurred on by advances in electronics, and by the early 1970s mechanical transducers were available that could produce 2D images by steering the transducer back and forth, sweeping the ultrasound beam across the heart. Phased-array transducers soon followed, in which the mechanical beam-steering mechanism was replaced by solid-state electronics.

The 1970s also saw rapid developments in the use of Doppler techniques, and by the early 1980s colour Doppler imaging was becoming a common feature of echo studies. During the 1980s, the technique of transoesophageal echo started to enter clinical practice, initially with monoplane probes but later with biplane probes, multiplane probes and, ultimately, the use of 3D transoesophageal imaging.

The 1990s saw a gradual change in archiving methods, with a move away from recording studies on videotape towards more versatile digitally based archiving.
There were also refinements in the quality of echo, with the introduction of harmonic imaging and the growing use of echo contrast agents to enhance endocardial border definition. Tissue Doppler imaging entered mainstream practice towards the end of the 1990s, adding a new modality that has proven particularly valuable in the assessment of LV diastolic function.

The new millennium saw the increasing adoption of 3D/4D echo, both in transthoracic and transoesophageal studies. The use of speckle tracking echo has provided valuable insights into myocardial mechanics and is gradually moving from the research setting into routine clinical practice. Meanwhile, echo machines have gradually shrunk, initially to the size of laptop computers, and subsequently to the size of handheld devices, greatly increasing the portability and availability of echo technology.

The growing use of echo has reinforced the need for professional regulation, and the past few years have seen the publication of many key national and international guidelines that set clear quality standards for the performance of echo in the years ahead.

Further reading

An excellent and detailed overview of the history of medical ultrasound can be accessed at: www.ob-ultrasound.net/history.html.


History of echocardiography
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Cardiac anatomy and physiology

Physics and instrumentation

Doppler physics

Service provision

The standard transthoracic echo study

Transoesophageal echo
Stress echo

Contrast echo

Tissue Doppler imaging

Myocardial mechanics and speckle tracking
3D echo

Intravascular ultrasound and epicardial echo

Alternative cardiac imaging techniques

The left ventricle and its systolic function
Lang R.M. , Bierig M. , Devereux R.B. , et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005; 18: 1440-1463.

Coronary artery disease and regional left ventricular function
Left ventricular diastolic function

Lang R.M., Bierig M., Devereux R.B., et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography’s Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005; 18: 1440-1463.


The left atrium

Lang R.M., Bierig M., Devereux R.B., et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography’s Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005; 18: 1440-1463.


The aortic valve


The mitral valve


The right heart
Lang R.M., Bierig M., Devereux R.B., et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography’s Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr 2005; 18: 1440–1463.

Heart valve repair and replacement

Endocarditis

The cardiomyopathies
The pericardium

The aorta

Cardiac masses
277 Bruce C.J. Cardiac tumours: diagnosis and management. Heart 2011; 97: 151-60.

Congenital heart disease

Common echo requests