PRINCIPLES OF PRACTICAL THREE-DIMENSIONAL ECHOCARDIOGRAPHY

The picture on the cover page was generously donated by the artist, Mrs. Shoshana Feiglstein from Ashkelon, Israel. 12/2016. Titled "The Mystery Lady", it shows a praying woman covered by a scarf.

Acknowledgments

This book is dedicated to my beloved wife Mina and our children, Or, Shoval, Ziv, and Yahel.

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Sincerely yours,

Chaim Yosefy MD

PRINCIPLES OF PRACTICAL THREE DIMENSIONAL ECHOCARDIOAGRAPHY

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Chapters

Introduction

What are the factors that are crucial for successful implementation of a new method?

Three-Dimensional Echocardiography (3D echo) is a relatively new echocardiographic technique that is still searching for its correct place as a tool for the acquisition of live echocardiography images based on millions of studies conducted every day by many thousands of operators around the world. It is a tool that greatly enhances diagnosis and improves quantification and, above all, plays a pivotal role in clinical decision making.

The enthusiasm of echo operators (technicians and physicians) about a new technique is dependent on how efficient, user-friendly, and accurate the new procedure is, and no less important, how much speedier and less time consuming it is compared to the well-known, easily performed, and well-trusted 2D echocardiography. Each of these operators, I believe, will face the current 3D echo with some reasonable initial fear (Figure I.1) followed by great enthusiasm that will ultimately result in their routine use of this technique. This transition from rare to frequent volume of use is also dependent on self-confidence and learning skills and knowledge. We ask ourselves – "To what boundaries will it reach?" This depends on who answers. In my opinion, it will be an inseparable part of daily echocardiography lab work.

There are three possibilities regarding the extent of the future use of 3D echo in clinical cardiology:

- 2D echo will remain the only modality used
- 3D echo will replace 2D echo
- A combination of 2D and 3D echo will be used.

I believe that the last option, i.e., some degree of integration of both technologies, will prevail – combining 2D echo and 3D echo in various volumes, either transthoracic echocardiography (TTE) or transesophageal echocardiography (TEE), or both, in tailored amounts for each patient. In our practice, we have already reached this goal by integrating 2D echocardiography with 3D echo during TEE and TTE procedures as have many echo labs worldwide.

Many are concerned about their ability to think and work with 3D echo. I am sure that this ability to think in 3D can be taught and gradually improved with practice, accuracy, standardization, and reproducibility. However, for 3D echo to be implemented in routine clinical practice, a full understanding of its technical principles and a systematic approach to image acquisition and analysis are required. Thus, the main goal of this book is to provide a comprehensive state-of-the-art review of live/real-time 3D echo illustrating both normal and pathological cardiovascular findings. We also aim to provide a practical guide on how to acquire, analyze, and display the various heart structures, as well as present the limitations of the technique.

This book predominantly describes our experience with this new modality in the clinical setting in our echocardiography laboratories in Israel.

In this book operators/readers can learn about the heart structures and function using real-time 3D echo. Physicians, including cardiologists, anesthesiologists, cardiovascular surgeons, and internists as well as sonographers, will find this book an outstanding opportunity to expand their knowledge of 3D echo.

Disc-on-key:

Since learning echocardiography needs images, we have attached to this book a disc-on-key that has hundreds of clips and images specially prepared to be used as a learning aid to help the reader better understand each of the subjects in a simple and clear manner. Thus we call this book a "cook book", which takes the reader step by step through the amazing trip of learning 3D echo.

Three-dimensional glasses:

Attached to each book are three-dimensional glasses, to observe 3-dimensional clips recorded from the operating room perspective. The option to compare operating room real 3D anatomy and pathological heart structures with 3D echo windows and clips enables the reader to enhance 3-dimensional understanding with a high level of reality.

This I believe will potentially ensure in the readers mind the three rules I believe in: 1) Think in 3D, 2) Work in 3D, 3) Measure in 3D.

The book is arranged in a "How to" learning sequence. The 28 chapters start with a chapter detailing the 3D anatomy of each 3D echo "window" (different from the 2D echocardiography "view" by showing the third dimension), to familiarize the reader with the basic normal anatomy before studying the pathological clips and images.

The following three chapters cover the technical aspects of 3D acquisition. These important chapters are dedicated to the three manufacturers of echo machines with which we have experience (Philips, General Electric, and Siemens). The reader will be able to identify the machine with which he is most familiar and will also have the opportunity to be exposed to other methods. This concept, I believe, was successfully implemented in two national echocardiography courses (two full days each) that took place in Ashkelon, Israel. The lecturers in these two courses were my colleagues from Israeli echo labs who courteously agreed to write the chapters in this book. Each of the 28 chapters was written to clearly describe the steps required to acquire, crop, and optimize the display of different aspects of the cardiac chambers using figures, tables, and videos and the dynamic nature of 3D.

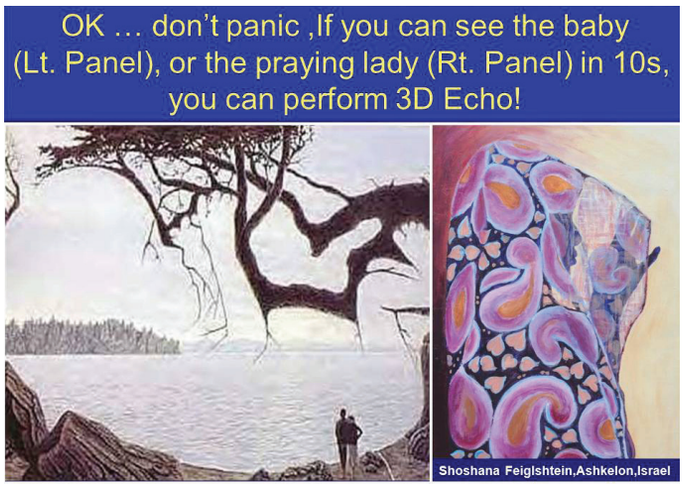

figure I.1

Following these technically oriented chapters, the reader is guided through the left and right ventricles, left atrium, and left atrial appendage. Next in order are the chapters on valvular heart disease and treatments (mitral, aortic, and tricuspid valves) and artificial valves, the aorta, and endocarditis. Special consideration is given to new diagnostic modalities including 3D strain and contrast 3D echo, some treatment modalities including cardiac resynchronization therapy, and atrial septal deflects in children. The book concludes with the view point of those who we serve and require our echo results, including the electrophysiology operators, the cardiovascular surgeons, and colleagues from other imaging modalities such as computed tomography (CT) and cardiovascular magnetic resonance (CMR).

Throughout the book, we will help the reader learn the complex steps required to successfully overcome the hardships of the learning curve period, while thinking, working, measuring, and diagnosing in three dimensions. I am sure it will not be easy, but nevertheless possible and rewarding. The implications of this amazing new technique will open the doors to a new and dynamic insight for both patients and their healers.

Sincerely yours,

Chaim Yosefy MD

Preface

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A NEW DIMENSION, A NEW CHAPTER

"I will remove the heart of stone … and give you a living heart." – Yechezkel 36:26
"And the three-fold chord is not easily broken." – Kohelet 4:12

Let us celebrate this magnificent work! Innovation requires champions who translate concept to practice while educating and disseminating information. This definitive text of three-dimensional echocardiography, organized and orchestrated by Chaim Yosefy, is a tribute to all the contributors who have made this vision real in characteristically Israeli fashion. It is fitting as well to recognize Margot Einstein, a passionate advocate for Israel, who raised the core contributions in Boston, Massachusetts, for the 3D scanner that was the focus of the First Israeli Course in Three-Dimensional Echocardiography, organized by Chaim Yosefy, that implanted the seeds for this text.

Echocardiography is a constantly evolving discipline in which clinical need drives engineering advance. This process began with Hertz and Edler's application of metallurgical ultrasound to the heart, Nakamura's studies with the Doppler shift, Harvey Feigenbaum's first applications in the US, Arthur Weyman's extensive exploration and teaching of two-dimensional echocardiography, Liv Hatle's partnership with Bjorn Angelsen to derive cardiac hemodynamics by applying fluid mechanics to the heart, and the work of countless engineers worldwide to move from A-mode to M-mode to 2D and Doppler color flow mapping, all in response to clinical motivation.

For years, we asked: since we think of the heart as a three-dimensional object, can we look at the beating heart in 3D? The answer to the 3D question had long been no, since scanning a full 3D volume with existing technology would typically require at least a full heart beat, yielding a blurred image. We were seeking both pictures and numbers: roadmaps to valve and congenital heart disease diagnosis and repair, and quantification of chamber size and function and valve areas based on full three-dimensional information and image standardization.

Two alternative approaches have overcome this fundamental limitation of volumetric scanning: integration of registered 2D images and true volumetric acquisition. Ensembles of traced 2D images yielded 3D constructs without changes in the basic sector scan technology, beginning with Alan Pearlman's 3D volumes of the RV. Mark Handschumacher ingeniously combined spatial and image information in decodable frames, leading to a range of volumetric validation by Mark, Michael Picard, and others that helped convince industry to forge ahead. It also enabled demonstration of the saddle shape of the mitral valve as the basis for diagnostic specificity and recent genetic discoveries in mitral valve prolapse.

True volumetric acquisition has required nothing short of a technological revolution, based on phased-array parallel processing from multiple "eyes" scanning the full 3D volume simultaneously. This began with the partnership

of Olaf von Ramm and Joseph Kisslo. Since then, unsung engineering heroes have filled in the early blank spaces and miniaturized the process from a full room to a palm-sized probe to increasingly facile and small transesophageal and intracardiac probes, with processing beginning in the transducer head, much like a retina working as an extension of the central nervous system. Champions such as Roberto Lang, working with Victor Mor-Avi, have driven the development and clinical use of these methods, proving their worth in improving spatial appreciation, standardization, accuracy and reproducibility – ideal methods for the interaction of echocardiography with surgery, intervention, cardiac resynchronization, clinical trials, and much more.

In reading these chapters, it will be helpful to keep in mind several perspectives:

1. While the focus is three-dimensional imaging, it is most valuable to think of an integrated, versatile echocardiographic study. Three-dimensional acquisitions permit precise standardization of two-dimensional slices to optimize quantification. Even when rendered three-dimensional images are used to guide mitral valve repair, they can provide a more detailed appreciation from extracted two-dimensional views.

2. This integrated exam demands programs for visualization and analysis, such as rapid standardization of orthogonal planes to measure stenotic and regurgitant orifice areas. Mark Handschumacher's Omni4D analysis suite, for example, simplifies navigation in three dimensions, multimodality comparisons of clinical data, truly three-dimensional tracking of cardiac contraction, and hypothesis testing ranging from papillary muscle tethering geometry in functional mitral regurgitation to the adequacy of mitral, aortic, and tricuspid leaflet adaptation in heart disease by uniquely measuring total open leaflet areas.

3. We eagerly anticipate continuing advances in this evolving field. The power of the matrix array has yet to be fully realized – for example, in accurately measuring regurgitant flow rate by power-velocity integration at the vena contracta that overcomes the limitations inherent to single-frame measures of a dynamic orifice. Can we achieve the dream of three-dimensional volumes without borders, eliminating the need to fight physics in imaging non-specular boundaries parallel to the beam? These and other developments will be fueled by active engagement between engineers, echocardiographers, and the increasing range of clinical specialists with whom we interact.

Keeping these perspectives in mind, please enjoy the journey of three-dimensional echocardiography in this living text!

Robert A. Levine, MD

Preface

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Over the past several decades, technological advances have significantly contributed to the development of echocardiography as an invaluable diagnostic tool, which is used to monitor cardiac performance. Although the concept of the three-dimensional (3D) echocardiography was first introduced in the 1970's, it has only recently gained widespread clinical use and appropriate recognition with the development of real-time transthoracic and transesophageal 3D imaging. Today, 3D echocardiography provides more than just pretty pictures. Its ability to improve the diagnostic confidence of the echocardiographic examination and help quantify cardiac chambers is well established and, as a result, the use of this technique is rapidly expanding as it is being incorporated into mainstream clinical imaging protocols in laboratories worldwide.

The advantages of 3D echocardiography stem from the fact that with the preservation of spatial and temporal resolution, the addition of the third dimension of depth contributes to our understanding of, and ability to, accurately quantify complex anatomy and functional geometry of cardiac chambers, valves, and great vessels. Consequently, 3D echocardiography greatly enhances diagnosis and quantification, while facilitating interpretation, communication, education, and clinical decision making.

This Comprehensive 3D Echocardiography volume entitled "PRINCIPLES OF PRACTICAL 3D ECHOCARDIOGRAPHY uses the advantages of a multimedia format to address the unique dynamic nature of this new imaging technique. In each chapter, the authors clearly describe the steps required to acquire, crop and display the different aspects of the cardiac chambers using a combination of figures, tables and videos. The significant number of case studies in this book demonstrates the advantages of 3D echocardiography in terms of its unique quantitative and qualitative analyses that far exceed what can be accomplished using standard two-dimensional techniques. The format of this book is very user friendly. Every echocardiographer should be able to quickly find rapid answers to his/her questions. Importantly, all the chapters have been written in a uniform format by echocardiography experts working in laboratories around Israel.

I share the confidence that this book will be of great use to all echocardiography professionals, including sonographers, anesthesiologists, intensivists, cardiac surgeons, and cardiologists.

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