CONGENITAL HEART DISEASE

先天性心脏病

——心血管造影学

TEXTBOOK OF ANGIOCARDIOGRAPHY

VOLUME 2

ROBERT M. FREEDOM, MD
JOHN B. MAWSON, MB, CHB, (NZ)
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Chinese Edition

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Congenital Heart Disease
Textbook of Angiocardiography

Volume II

by

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Foreword by

G.A. Trusler, MD

With 2703 illustrations

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Futura Publishing Company, Inc.
Armonk, NY

For those whose lives are affected
by congenital heart disease

Foreword

I am privileged to write a brief foreword for this magnificent work, *Congenital Heart Disease: Textbook of Angiocardiography.* It is fitting that it should emanate from the Hospital for Sick Children in Toronto where cardiac angiography has been an art form in the diagnosis of congenital heart disease for so many years, and from which so many publications on the angiocardiography of congenital heart disease have emanated. This started with John Keith, the first head of cardiology, and continued with Dick Rowe (both now deceased) and reached a pinnacle with the redoubtable Bob Freedom, Head of the Division of Cardiology for more than the past decade. *Congenital Heart Disease: Textbook of Angiocardiography* emphasizes morphological descriptions of each anomaly and its many anatomic variations. The natural history of each condition is clearly depicted and is extensively portrayed by a beautiful compilation of angiocardiography. The great usefulness of the interventional catheter, which has developed so much over the past 10 years, and its symbiosis with angiocardiography is well described by Lee Benson. The careful details of catheter and angiographic techniques and their indications provide the science of angiocardiographic imaging, but the art of this text comes from the extensive experience of the authors.

My relationship with cardiology extends back over 35 years when John Keith was the head of cardiology and Bill Mustard, head of cardiac surgery. In those early years every child and every operation was potentially new and different. It was a great learning experience. Happily, there was a feeling of mutual help and trust between cardiologists and surgeons. That feeling was carried forward by Dick Rowe and subsequently by Bob Freedom. Conferences continue to be maintained with a refreshingly friendly spirit of collegiality where the prime interest is the long-term welfare of the child. As surgeons we were and continue to be aware of our good fortune in having the support of an outstanding cardiology team.

The present leader of the team, Bob Freedom, a dear friend and colleague over many years, is and has been a tremendous strength and resource with a prodigious memory and a great knowledge of both morphology and angiography, combined with excellent skills with a catheter. I suspect that Bob sometimes wishes he had become a cardiac surgeon, but perhaps he has the best of both worlds. Despite a heavy clinical and administrative load, he remains extraordinarily productive. As witness herein, Bob and his co-authors, John Mawson, Shi-Joon Yoo, and Lee Benson have produced a text on angiocardiographic imaging destined to become a classic.

George A. Trusler, MD, FRCS(C)

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Preface

When one of us (RMF) was asked: Why write an entirely new book dedicated almost entirely to angiocardiography? Has the subject changed that dramatically? The answer was an unhalting ***yes.*** Congenital heart disease seemingly is becoming more complex; we are becoming aware of profound changes in cardiac form and function as we week to treat all different expressions of congenitally malformed hearts in patients, many of whom were once considered inoperable and condemned to an early death. One can list operations that weren't routinely being conducted 10 to 15 years ago: the bidirectional cavopulmonary connection to stage toward the Fontan; the palliative arterial switch procedure for some forms of univentricular atrioventricular connection; the double switch procedure for some forms of hearts with discordant atrioventricular and ventriculoarterial connections; arterial switch operation for the patient treated with a previous atrial repair and now with either a failing right ventricle or pulmonary hypertension from pulmonary venous obstruction, etc. Cross-sectional echocardiography, with Doppler and color flow imaging has rightly assumed its mantle of importance in our field, but echocardiographic imaging hasn't supplanted angiocardiographic imaging. Indeed, for many kinds of congenitally malformed hearts, these imaging modalities are not mutually exclusive; rather they are complementary.

Once I had decided to take on this task, I asked Lee Benson, colleague, friend, and Director of the Hospital for Sick Children's Variety Club Cardiac Catheterization Laboratories, to share with me the 'ownership' of the book. I asked Lee to contribute sections on intervention and the angiographic aftermath of those activities. While this work will have a Toronto flavor, it is enhanced by the contributions of John Mawson and Shi-Joon Yoo. John is the Senior Cardiovascular Radiologist at the Hospital for Sick Children, and it is worth noting that he received much of his initial training in pediatric cardiovascular radiology from the late Peter Brandt—one of the pioneers in this arena—in Auckland, New Zealand, with subsequent training from a dear friend and former colleague, Gordon Culham, in Vancouver, British Columbia. Some years ago when in Singapore on a speaking engagement, I had the good fortune of meeting Shi-Joon Yoo. We chatted briefly, and he presented me with a small gift. Back at the hotel, I opened the package ot find his wonderful textbook, *Angiocardiograms in Congenital Heart Disease. Teaching File of Sejong Heart Institute* (Yoo S-J, Choi Y-H. Oxford Medical Publications, Oxford, 1991). This is a book of remarkable clarity with beautiful illustrations. A year later, Joon was conducting a sabbatical here at the Hospital for Sick Children, and it was at that time I asked him to become involved with this project. For those around the world who know Shi-Joon Yoo, they understand why I asked him to join in this cooperative effort. Both John, here, and Joon, now back in Korea, have added so much to the clarity and comprehensive character of this work.

From the perspective of angiocardiography, this textbook is meant to be complete, and while we could not show examples of every image, we hope that we have provided angiocardiographic and clinical references to most forms of congenitally malformed hearts, both common and rare. This is obviously an unenviable task, and clearly there will be errors of omission. Most of the angiocardiograms used in this work are from patients studied at the Hospital for Sick Children, with some from New Zealand and Korea (the latter contributed by our co-authors). Our colleagues and friends from around the world have given us permission to use some of their material as well. These specific contributions are, of course, acknowledged in the figure legends, but we would like to express our gratitude to them here for their generosity. Because of limitations of space, we could not dedicate as much space to those changes in form and function that result from surgical intervention. There is, however, much in this work ad-

dressing these important changes, but in a more focused format. This effort is more, however, than an atlas. It is not just a 'show' but rather a 'show-and-tell'. We have tried to put into a clinical perspective those images that we have portrayed. What management issue(s) should be considered from the images that you see, and what angiocardiographic information you should seek to best enhance patient care. Furthermore, the narrative in the text is not just directed toward the art and science of angiocardiography. Rather we have tried to place certain issues of morphology and image into management and outcome, and thus the essence of this 'show-and-tell'. As the senior author, I will share with my colleagues any praise for this work. However, I alone will shoulder any fault for error.

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Acknowledgments

This herculean effort could not have been completed without contributions and support from many sources. Dr. Robert H.A. Haslam, Professor and Chair of Paediatrics of the University of Toronto Faculty of Medicine, and Paediatrician-in-Chief of the Hospital for Sick Children, provides the academic milieu for clinical research. With his nurturing and mentoring style, his academic leadership and with his wisdom gleaned from years of pediatric leadership, he understands and appreciates clinical and outcome research. The former Chair of the Department of Pathology of the Hospital for Sick Children, Dr. M.J. Phillips, and the current Chair, Dr. Larry Becker, have provided access to pathological material and resources for display and photography. In this regard, Dr. Don Perrin (Pathologists' Assistant) and Michael Starr, Staff Photographer, both of the Department of Pathology have been so helpful to RMF over the years, lending their art and skill to the dissection and photography of congenitally malformed hearts.

We have been privileged to work on a daily basis with a superb group of cardiovascular surgeons. We all benefited from the pioneering work, dedication, and great humor of the later William T. Mustard, the first Director of Paediatric Cardiovascular Surgery at the Hospital for Sick Children. Dr. Mustard's successor, George A. Trusler, just retired in December, 1994, after a long and distinguished career. George, a dear friend and colleague provided for all of us an academic, meticulous, and nurturing career, and his patients benefited tremendously from his skill. His successor, Dr. William G. Williams is currently joined in surgical endeavors by Drs. John Coles, Glen Van Arsdell, Michael Black and Ivan Rebeyka, now in Alberta, Canada.

The collaboration with our cardiovascular radiology colleagues has meant so very much to our patients and to us. Dr. J.A.G. Culham, a cardiovascular radiologist, now at the British Columbia's Children's Hospital was a co-author of the first textbook of angiocardiography emanating from this institution. Dr. C.A.F. Moes, Professor of Radiology Emeritus of the University of Toronto Faculty of Medicine, contributed to the present textbook and also was a co-author of our earlier textbook of angiocardiography. Dr. Cathy MacDonald joined the Department of Radiology some years ago and has contributed several chapters to this effort. We appreciate the leadership of Dr. Derek Harwood-Nash (now deceased) and Dr. Alan Daneman, former Chairs of the Department of Radiology of the Hospital for Sick Children who both foster and support such academic collaboration. Dr. David Nykanen who joined the staff of the Division of Cardiology several years ago with a focus on interventional cardiac catheterization procedures contributed a number of chapters and specific sections on intervention, and this effort is all the better for his contributions.

The overwhelming number of angiocardiograms used in this textbook were performed at the Hospital for Sick Children in Toronto, and the majority of those used for this textbook were performed in the past decade. We must acknowledge the contributions of our colleagues within the Division of Cardiology who along with RMF and Lee Benson performed these studies. These colleagues include Drs. Ian Adatia, Christine Boutin, Robert Gow, Robert Hamilton, Teruo Izukawa (now retired), Brian McCrindle, and Jeffrey Smallhorn. We have used some angiocardiograms performed prior to 1985 by colleagues who have left the Hospital for Sick Children, including Drs. John Dyck, Peter Hesslein, B.S.L. Kidd, Peter Olley, and the late Richard D. Rowe. The Variety Club Cardiac Catheterization laboratories have been staffed with nurses and technicians of extraordinary dedication. These include Kathy Hunter, Sandra Bogdon, Susan Hoey, Angie Basciano, and Frank Hamilton, and we thank them for their talent.

The authors are particularly indebted to those friends and colleagues throughout the world who at our request made available their own material for inclusion in this textbook. Some of these materials were figures from their publications, while other material was in the

form of color 35-mm slides or black-and-white prints of angiograms. We have reformatted much of this material to be consistent with the graphic format of most of the angiograms reproduced herein.

The ability to define cineangiocardiograms of consistent textbook quality necessitates knowledge of congenital heart disease, axial angiocardiography, film processing, contrast agents, catheter size, and flow rates, etc. The authors must acknowledge the unique contributions of Mr. Haverj Mikailian to this effort, the senior radiology technician who has worked with the Division of Cardiology in the catheterization laboratories for more than two decades. a bright and dedicated individual, Haverj's greatest delight is producing angiocardiograms of world-class quality. Totally professional and motivated only by the desire for excellence, Haverj was central to the review of all angiocardiograms used in this textbook. He and RMF reviewed the overwhelming number of angiocardiograms performed since 1983, to this date, marking the completion of a comprehensive angiocardiographic review for *Angiocardiography of Congenital Heart Disease* (R.M. Freedom, J.A.G. Culham, C.A.F. Moes. MacMillan Publishing, New York, 1984). Haverj's radiology technical staff includes or has included Marie Craven-Turner, Marlene Baily, Albert Aziza, Gayle Nystrom, Deidre Milne, and Ellen Charcot.

A tremendous effort to provide consistency in the photographic reproduction of the 35-mm cine films was provided by Tiiu Kask, director of the Graphics Centre, and her staff. This staff includes Diogenes Baena and Ian Douglas, both photographers in the Graphics Centre, and Philip Dakin, graphic artist. Without their dedication to this seemingly never-ending task and consummate professionalism, we would not have been able to complete this work. We must single out Phil Dakin for his unending dedication to the completion of this work. His skill and knowledge, tempered by a great sense of humor and understanding, proved invaluable. This work could not have been accomplished without his tremendous input.

Much of the hard- and software used in the production of this textbook from the perspective of the Division of Cardiology, the Hospital for Sick Children, is based on MacIntosh format. In this regard, for a number of years, Mr. Don Klees and his Avanet Data Corporation has served as computer consultants to the authors and to the Division of Cardiology. Mr. Klees and his colleague, Mr. Ian Free, have worked tirelessly on our behalf, and we are deeply appreciative of their efforts.

Funding for completion of this work has been derived from several sources. Supportive of Divisional Clinical Research activities over many years are Mr. and Mrs. Dov. Lidor and the Bestbuy Corporation. This family and their corporate family and friends have been very important to the funding of these textbook activities. In addition, The Hospital for Sick Children Foundation was most generous in providing financial support for this effort and we are most appreciative of the time and interest the Foundation president, Dianne Lister, and her predecessor, Claus Wirsig have taken in this project.

For many years, the Division of Cardiology of the Hospital for Sick Children has utilized Siemens angiocardiographic imaging technology. This has been so important to the acquisition of the excellent images displayed in this textbook. We acknowledge the generosity of the Siemens Company in supporting some of the cost of this project. Specifically, we are indebted to both Mr. Don Ramsay, technical sales representative of the Diagnostic Imaging Products, and Mr. Gerd Baer, Vice President of the Medical Systems Division who both endorsed and supported this effort. The authors also would like to acknowledge the support of Mr. Ravi Anand, the senior technical representative from Siemens who has worked with us for more than 8 years. On those occasions when technical problems occur, Ravi is always available, providing us with his technical excellence and knowledge.

The former President and CEO of the Hospital for Sick Children, Mr. David Martin, and the current President and CEO, Mr. Michael Strofolino were and continue to be supportive of those activities that support and endorse patient care. While neither physicians nor scientists, they value basic and clinical research as the lifeblood of any institution dedicated to patient care, education, and research. We appreciate their ongoing efforts to provide an environment to conduct these activities.

The authors must acknowledge the important roles of all the trainees in the Division of Cardiology who over the years have participated in clinical care and research and who daily stimulate and motivate us as their teachers. We know soon the 'student' will become the teacher and caregiver, and indeed, this is the 'genetics' of what we do.

The authors must acknowledge the contributions of their secretaries, those unflappable individuals who provide day-to-day direction to our professional activities. Drs. Benson and Nykanen's lives are put into order by Sandra Gretto, and Dr. Freedom by Mrs. Lisa Berejiklian-Cullen, Ms. Therese Benoit, Administrative Coordinator for the Division of Cardiology, Tiziani Lolli, his secretary for patient activities and Teresa Tota.

The authors are most indebted to their editor, Ann Kerr of Futura. She provided tremendous professionalism, laced with great humor and collegiality. We all found it just a delight to work with Ann. And what about Steven Korn, President of Futura Publishing Company? With his knowledge, charm, wit, and dedication, who would not want to to do a book with him, or even a second book? Futura is devoted to the production of excellent textbooks, figure-heavy, and we appreciate their dedication to this educational forum.

The Authors

Individual Acknowledgments

More than 30 years ago when as a medical student at the UCLA School of Medicine, I had the good fortune, indeed privilege to meet and work with Drs. Arthur Moss, Forrest Adams, George Emmanouilides, Herbert Ruttenberg, Leonard Linde, Sam Sapin, Stan Goldberg, Bill Vincent, and Harrison Latta. They encouraged a then young, impetuous medical student to pursue his interest in pediatric cardiology and cardiac morphology. During a year devoted to cardiac morphology, I wrote to and received advice and encouragement from Dr. Jesse Edwards. In those early years, his two red volumes became my 'bible'. I will always remember the generosity and kindness that Jesse showed me, and I am honored that Jesse and I became and have remained friends and collaborators. The faculty at UCLA next supported me in my desire to take an elective with Richard Van Praagh shortly after he had moved from Chicago to Boston. The time spent with Dick, a Toronto native and alumnus of the University of Toronto School of Medicine and the Hospital for Sick Children and Stella at the Cardiac Registry at the Boston Children's Hospital was one of the most exhilarating times of my life, solidifying my desire to become a pediatric cardiologist. Finishing medical school, I journeyed to Boston, completing my pediatric training at the Children's Hospital and was fortunate to be selected into the cardiology training program headed by Dr. Alexander S. Nadas.

Those were exciting years and Alex Nadas, Don Fyler, Curt Ellison, Bill Plauth, and Amnon Rosenthal proved to be wonderful role models, demonstrating on a daily basis, the best in patient care, teaching, and clinical research. While a senior fellow in Boston, I had the good fortune of meeting Richard Rowe, then director of the Division of Cardiology at Johns Hopkins, and Dick recruited me when I completed my training to come to Baltimore to become head of the diagnostic cardiac catheterization laboratory. While in Baltimore, I forged friendships with Catherine Neill, Bob Gingell, Dan Pieroni, Glenn Rosenquist, Bob White, Donald Harrington, and Jerry Krovetz, and those years 'under the dome' proved maturing and stimulating. I was only in Baltimore several years when Dick Rowe was recruited back to the Hospital for Sick Children in Toronto to succeed John Keith (now deceased) as the Director of Pediatric Cardiology. How excited I was when Dick asked me to join him in Toronto and I accepted a staff position here in December, 1973, officially landing on Canadian soil in August, 1974. The more than two decades here at the Hospital for Sick Children have been wonderful and productive years. Dick Rowe of Christchurch, New Zealand meant so much to his family and friends, to his academic community, to pediatric cardiology and to me, that perhaps one of my deepest personal sadnesses was the untimely death of Dick Rowe in January, 1988, just weeks before his planned retirement.

The massive efforts to produce these kinds of textbooks require extraordinary dedication, not just of the authors, but of their families. I appreciate the humor, dedication, and absolute professionalism of my co-authors. However, the solace necessary to conceive and complete this work could not have been accomplished without the love and understanding of Penny and Jonathan. They ask so little, but give so much. Finally, for my twin brother, Gary, we know about that special bond between twins.

Robert M. Freedom, MD
Granville Ferry, Nova Scotia & Cheju Island,
South Korea

I was privileged to begin my Cardiac Radiology training at Green Lane Hospital in Auckland, New Zealand working with Drs. Peter Brandt and John Ormiston, (Cardiac Radiologists), and Drs. Louise Calder and John Neutze, (Paediatric Cardiologists). Dr. Brandt was one of the pioneers of cineangiocardiography, particularly in his application of a "projections" approach to imaging and "segmental approach" to interpretation. To him I owe a particular debt for his patience, encouragement and teaching. Mr. Darren Brown is thanked for photographing the Green Lane Hospital angiocardiograms that have been used in this book.

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My wife Claudia's support and love during this endeavour has been of the utmost importance.

John B. Mawson, MD
Toronto, Ontario, Canada

I would like to express my gratitude to Professors Man Chung Han and Kyung Mo Yeon who taught me cardiac radiology when I was a resident at the Seoul National University from 1978 until 1982. Special thanks must be given to Dr. Young Kwan Park, the President of the Sejong General Hospital in Pucheon, Korea, late Dr. Yung Kyoon Lee, the former Chief of the Sejong Heart Institute, and Dr. Yong Ho Auh, the Chief of the Department of Diagnostic Radiology, the Asan Medical Center/the University of Ulsan in Seoul, Korea for their constant advice, encouragement, and enthusiasm.

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Finally, I would like to thank my wife and daughters for their patience and consideration. I would like to dedicate this book to my mother and father.

Shi-Joon Yoo, MD
Seoul, Korea

The lineage of a textbook is varied and represents not only the collective knowledge of its authors, but a quilt work of their experiences. Throughout my academic life, it has been my medical colleagues, particularly at the Hospital for Sick Children, who have had and continue to have, the greatest influence on my work, direction and goals, and for their collective support, each is acknowledged. However, there have been three individuals in particular, who have had a unique impact on the direction I have taken. Appreciation goes to Dr. Robert M. Freedom, senior cardiologist, professor and head of the division of pediatric cardiology at the Hospital for Sick Children, Toronto. Bob was (and remains) my teacher and mentor. He conceived of this project, having created the environment which allowed its realization, and was the driving force who saw it to completion. He is selfless in this generosity, and the ultimate clinician. In this era of 'high-tech' diagnosis, there is lost at times the perspective of clinical relevance and the understanding of the pathologic anatomy of pediatric cardiovascular disorders. Bob is the master teacher of these critical skills which are the foundation of our profession, and I am honored to call him my friend. Dr. Richard D. Rowe, was associated with the Hospital for Sick Children throughout his career until his untimely death in 1988. He will be remembered as a gentle and thoughtful clinician whose contributions to pediatric cardiology remain with us today, not only through his clinical skills and research, but in the hundreds of trainees who had the opportunity to work with him and learn from him. Dick Rowe supported and encouraged my early sojourn into the little known field of interventional cardiology, which is the focus of my career to this day. Dr. William F. Friedman, professor and former head of pediatrics at

the University of California, Los Angeles, introduced me to the scientific footings of pediatric cardiovascular medicine, emphasizing the relevance of basic research to clinical practice, and the reliance of one on the other. For this important prospective on clinical medicine I will always be grateful.

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Leland N. Benson, MD
Toronto, Ontario, Canada

The Onsite Production of *Congenital Heart Disease: Textbook of Angiocardiography*

Philip Dakin

This discussion outlines some of the methodologies used by the authors in conjunction with the Graphic Centre of the Hospital for Sick Children in Toronto to produce the *Congenital Heart Disease: Textbook of Angiocardiography.* There were striking departures in the onsite technical 'production' of this textbook when compared with others authored or co-authored by one or more of the present writers.[1–3] The text and references were formatted on MacIntosh equipment networked throughout the Division of Cardiology and Department of Radiology. Reference manager software such as Endnote and Endlink (Niles and Associates, Berkeley, CA) provided the capability to deal with the many thousands of references. All written material was eventually focussed through the office of RMF. But it was the large number of images and the desire of the authors to provide images of striking clarity with consistent labeling, that provided the biggest challenge.

This text contains more than 2700 figures, the vast majority obtained from 35-mm cineangiocardiograms performed from 1975 to 1996 at the Hospital for Sick Children in Toronto. Early in the formulation of the size, scope and format of *Congenital Heart Disease: Textbook of Angiocardiography,* we decided that virtually all the images used would be manipulated and stored digitally (Fig. 1). This step into the computer age was taken initially to replace the labeling system "Letraset" (Letraset International Ltd., England), a sheet of adhesive letters and symbols that are transferred onto a photograph by rubbing with an instrument such as a pencil. Labeling each figure, in duplicate, in this manner is a time consuming and expensive process that in the past produced acceptable, albeit inconsistent results at best. The Letraset technique had been used by the authors to label the images for their previous publications.[1–3] However, an image editing program such as Adobe PhotoShop (Adobe Systems Incorporated, Mountain View, CA) allows the labeling of images, as well as the removal of any existing Letraset (or other adhesive) labels when photographing the original cine film was impractical (or impossible). Apart from time management, there are many additional benefits to handling the images digitally including consistency and clarity of labeling, image cropping, manipulation of density and contrast, removal of scratches and dust. Once the image is stored in a digital form, it is available for teaching and talks using slides, and can be married to electronic text, CD-ROM, real-time video sequences, etc.

Ideally, one would be able to transport a digitally-acquired angiographic image directly to a database and thence to a document such as a book chapter or paper or presentation. (Fig. 1D). However, current technology cannot yet produce digital images comparable to the resolution and tonal range of photographic film. Additionally, the vast majority of the more than 20,000 angiograms reviewed for this text were acquired prior to digital catheter laboratories being available and thus are stored as 35-mm cine film; only a fraction of the images used have been selected from digital angiocardiograms.

Traditionally, as many as seven photographic steps are needed to take an image from the original cine film to the pages of this book (Fig. 1A). Just as an old story becomes distorted (or enhanced) as it gets passed from generation to generation so too are photographic images. Every time a different form of image is needed another generation of film must tell the story of the image subject to variables such as exposure and lens quality. Most of the originals were submitted for digitizing in the form of 5 × 7 in. black and white prints and had therefore already gone through at least three photographic stages as described above. Digitizing the images at this stage will only produce results as good as the print itself. Because scanning the analogue images into

digital format would have been done during the final production phases for their placement in the book, we were not adding another stage but merely moving the digitizing to an earlier point in the production process (Fig. 1B and 1C). Only after the cine film is processed and developed can the assessment of angiographic quality and both diagnostic and 'artistic' excellence be determined. Frames of interest are marked by the authors and the cineangiocardiogram is then sent to the Graphics Centre to have negatives and the prints made of the frames. Modifications were made to a slide duplicating machine (Charles Beseler Co., Florham Park, NJ) enabling it to advance through the hundreds of feet of cine film to expose specific frames onto 35-mm negative film. A 5 × 7 print is made from the negative that would be labeled by hand.

Before the tremendous task of digitizing, labeling, and storing the images could begin, testing was needed to calculate the amount of data that would be generated by 2700 images and the kind of computer system needed to effectively process this amount of data. We realized that we would probably scan and label more images than we would eventually use. Our existing equipment, consisting of a 33-megahertz, Macintosh Quadra 950 (Apple Computer, Inc, Cupertino, CA) with 64 megabytes of RAM and a 1-gigabyte hard drive was used for the testing along with an Agfa Arcus II scanner (Agfa-Gevaert, NV, Germany). By scanning 50 images @ 400 dpi amd five line drawings @ 1000 dpi with this system, we were able to calculate the average image size at around four megabytes requiring a hard drive with a storage capacity of 12 gigabytes. It was decided that four Quantum Grand Prix hard drives of 4.3 gigabytes each would be used. This configuration provided some data security and most importantly, allowed us to perform multitasking using up to four computers simultaneously.

The Quadra 950's 33-megahertz co-processor chip was adequate for scanning, but proved to be much too slow to process images efficiently. A Macintosh PowerPC 9500 with a fast 132-megahertz co-processer and 32 megabytes of RAM was added to the team and provided the main image processing work station. Both computers were set up side by side and connected via an Ethernet network to the output devices. One of the drives was SCSI connected to the Quadra 950 for use with the scanner, and the remaining three to the PowerPC 9500 for processing and storage. Computer hardware comprises only half of the system's functionality, software being the main interface which dictates the equipment's intelligence and usability. Batch scanning of 5 × 7 prints was an option offered by Agfa Fotolook (Agfa-Gevaert, NV, Germany). Two or three images could be placed on the scanning bed at one time, each image scanned at the operator's preset specifications, saved in a choice of image formats, and placed into a designated folder. Unfortunately, the choice of formats was limited and an extra step was needed to save each image using an Adobe PhotoShop format in order to be able to use a layering function crucial to our process. The use of a text layer allowed us to annotate figures without permanantly embedding the labels into the background image.

PhotoShop was the software tool around which the imaging system was built. The intuitive interface and vast arsenal of image processing tools provided by this software gave us complete control over every aspect of the images. A "Dust and Scratches" filter would sweep each image automatically removing specks of a predetermined size. Seamless removal of old Letraset labelling and blemishes as well as manipulation of density and contrast are just a few more of its tangible assets. Many of the steps needed to process an image in PhotoShop such as format change, adding layers, and filter applications were repetitive and time consuming. A 'finicky' program called PhotoMatic (Daystar Digital, Flowery Branch, GA) alleviated some of the repetitive tasks. It uses a scripting language (AppleScript) in conjunction with PhotoShop to record specific functions and then perform them on any given number of images. This allowed the computer to work unsupervised on hundreds of images overnight leaving a folder of processed images waiting to be cropped and labeled in the morning. The conditions under which these scripts would run needed to be precise and therefore required extensive testing and consultation with the manufacturer to get it up and running. The important job of cataloging all the figures was given to a program called Aldus Fetch (Aldus Corporation, Seattle, WA). Fetch enabled us to view each of the figures in catalog form and print them four to a page along with its reference number and location.

Horror stories of data loss and system crashes are told and retold wherever computers are used; this production was not immune from these difficulties. Early in the process we would open 10 to 20 images at a time to collect opening and saving times into 5-minute breaks. The most significant and by far the most bizarre data loss came in the form of partial text disappearance. An image would be labeled, saved, and then brought into a catalog to be printed. There are four ways in which each of the images can be viewed: 1) as an icon in the finder; 2) as a 'thumbnail' in the catalog; 3) in PhotoShop; 4) on a printed page. The labels applied in the text layer or at least some of them, were not apparent on some of the images when opened in PhotoShop but were still visible in the other three viewing options. Even after consulting local experts and Adobe Systems, the problem remains unresolved but it has not reoccurred since a software patch was installed and the drives were defragmented.

Once the images have been digitized, labeled, cata-

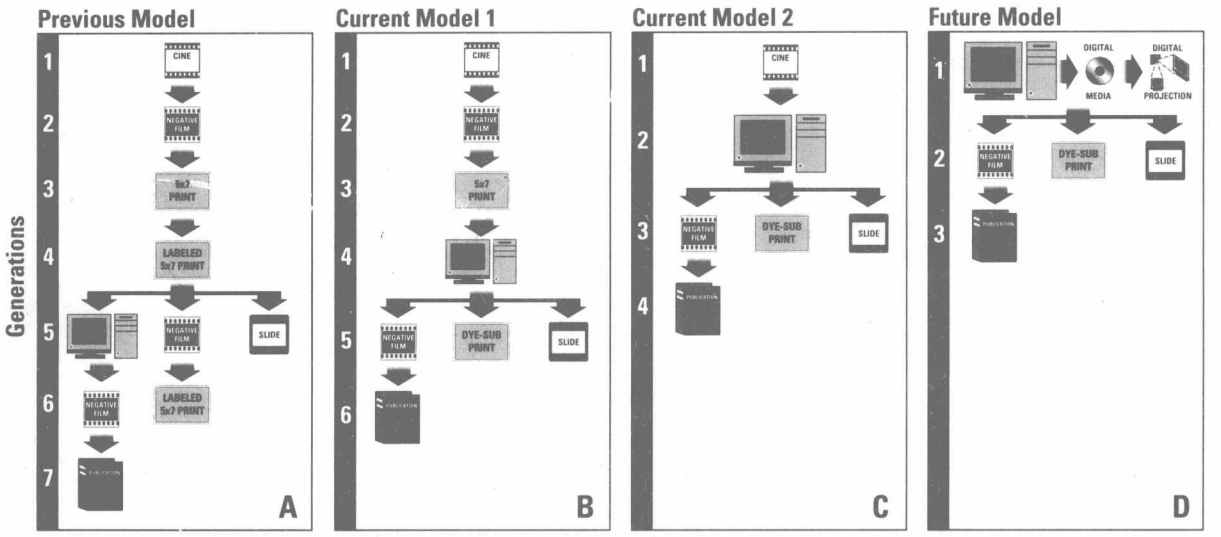

Fig. 1.
A: This flow sheet shows the earlier flow of a 35-mm cine film and its conversion to a 5 × 7 print, labeled with Letraset, rephotographed, and submitted to the publisher for incorporation into the text. At least seven generations were required before incorporation of the figure into the completed text. **B:** This flow sheet demonstrates the handling of cine film used in the production of *Congenital Heart Disease: Textbook of Angiocardiography* with digital labeling of all scanned images. The Letraset-step was obviated by this technique. Cine film still had to be processed to prints as in A. **C:** Some information could be scanned directly for digital labeling without first producing a 5 × 7 black and white print. These materials included chest radiographic, magnetic resonance images, and images acquired from digital subtraction techniques. **D:** This flow sheet indicates that future productions will not require any film processing, but rather all data will be directly acquired and processed digitally.

logued, and stored, they can be output as required. High-quality glossies were printed on a 300 dpi Kodak 8600 dye-sublimation printer (Eastman Kodak Company, Rochester, NY). All catalogs were printed on a 400 dpi Canon 800 laser printer with a Silicon Graphics Indy (Silicon Graphics, Inc, Mountain View, CA) server running Cyclone queue management software (Colorbus, Irvine, CA); this allowed for checking of images against legends and text as well as cross-referencing. A Lasergraphics Personal Plus high resolution film recorder (Lasergraphics, Irvine, CA) was also available for slide output.

These notes, we hope, will provide some understanding of how the authors and Graphic Centre staff worked together to produce *Congenital Heart Disease: Textbook of Angiocardiography.* These comments should not be interpreted as a "how-to" manual; rather, it is "how we did it". On reflection we now appreciate what we can do differently the next time to improve the quality of image collection, collation, and reproduction. Indeed, already we have the capability to digitize frames directly from the cine film, thus eliminating the need for a 5 × 7 print (Fig. 1C). Eventually, when digital catheter laboratories completely replace cine film, we hope to achieve a seamless transfer of digitally acquired data directly to a presentation format (Fig. 1D).

During the many hours the authors and I worked together, a sense of mutual understanding, respect, and affection developed. What better testimony to this work that consumed us all for more than a year, on days, nights, and weekends?

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