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Creating a database with cardioscopy and intra-operative imaging

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THE ABILITIES FOR BOTH COMPUTER TECHNOLOGY, and intra-operative video-imaging, are evolving rapidly. The merger of these two sciences can be very beneficial, both to congenital cardiac surgeons in general, and in facilitating the creation of a cardioscopic database in particular.

It is appreciation of the rapid development and growth of computer technology that leads to the realization that creating a comprehensive cardioscopic database for paediatric cardiac surgery has become a realistic and achievable goal. The co-founder and Chairman Emeritus of Intel, Gordon Moore, had already predicted in 1965 that the number of transistors in each integrated circuit would double with every year.[1,2] In 1975, he revised this prediction to doubling every 18 months.[3] In 1965, he had been director of research for the pioneering electronics company Fairchild Semiconductor. At that time, the most complex chip in the world, which existed in the laboratory at Fairchild, had 64 transistors.[4] In 1968, Moore co-founded Intel. One of their products, the Pentium 4, introduced in 2000, now contains 42 million transistors.[5] In the final analysis, Moore's Law implies that the speeds of the central processing unit in each computer will double every 1 to 2 years (Table 1). This reality has created a true opportunity to develop software not only to manage medical images and repositories such as the cardioscopic database, but also to allow this database eventually to become part of the electronic medical record.

Table 1. The number of transistors in computer chips has steadily increased over time.[5]

Processor	Year of introduction	Transistors
4004	1971	2,250
8008	1972	2,500
8080	1974	5,000
8086	1978	29,000
286	1982	120,000
Intel386™ processor	1985	275,000
Intel486™ processor	1989	1,180,000
Intel® Pentium® processor	1993	3,100,000
Intel® Pentium® II processor	1997	7,500,000
Intel® Pentium® III processor	1999	24,000,000
Intel® Pentium® 4 processor	2000	42,000,000
Intel® Itanium® processor	2002	220,000,000
Intel® Itanium® 2 processor	2003	410,000,000

The abilities to make intra-operative videos have also improved massively in the last decade. Video-assisted thoracoscopic surgery, together with cardioscopy, is increasingly used world-wide.[6–8] This increased use of technologies for video-imaging in the operating room of the paediatric cardiac surgeon is a recent development,[9,10] but the field has steadily

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evolved since 1993,[6] providing the facilities to treat both extracardiac and intracardiac lesions.[6]

Extracardiac lesions repaired using video-assisted thoracoscopic surgery now include ligation of the patent arterial duct,[11–17] repair of funnel chest,[18–23] division of vascular rings,[24,25] plication of the diaphragm,[26,27] creation of a pericardial window,[6] ligation of the thoracic duct[6] and collateral vessels,[6] insertion of epicardial pacemakers[6] and removal of endocardial pacemaker leads.[28] Encouraged by the success of these procedures, surgeons have now treated several intracardiac lesions using minimally invasive techniques. Operative cardioscopy is now increasingly used to facilitate surgical repairs, through both conventional and minimally invasive incisions.[9,10,29–31] Such cardioscopy enhances both the visualization and repair of remote intracardiac structures during the open-heart procedures. Cardioscopy also helps to document pathology, assists in the teaching and education of residents and cardiologists, and can facilitate minimally invasive and completely endoscopic open-heart surgical techniques. Intracardiac lesions now approached using these minimally invasive techniques include atrial septal defects,[32–40] left ventricular thrombus,[41] subaortic stenosis,[42,43] ventricular septal defect,[40,44–46] and tetralogy of Fallot.[44,46]

Methodology for creating the cardioscopic database

As the abilities for intra-operative video-imaging improve, and computer-based databases designed to record the outcome of cardiac surgery expand, it seems clear that a cardioscopic database represents the next step in this evolution. In this review, we discuss the challenges of creating such a digital database of operative images and videos. We then describe the potential benefits that emerge inexorably from the creation of such a database.

Our initial efforts to create a cardioscopic database began at Miami Children's Hospital in 1996.[29] The paediatric cardiac surgical team at Miami Children's Hospital had already acquired considerable experience with techniques for both intra-operative imaging and minimally invasive cardiac surgery,[6] dating back to the development by their chief surgeon (RPB) of video-assisted surgical techniques for ligation of the patent arterial duct at Boston Children's Hospital in 1993, initially in the animal laboratory, and later in the operating room. In 1995, the team at Miami Children's Hospital began taking analogue photographs of the cardiac anatomy encountered during the majority of their cases, recorded both on film and on paper. In 1996, an early version of the CardioAccess International Clinical Outcomes Database (CardioAccess Inc., St. Petersburg, Florida and Fort Lauderdale, Florida: http://www.cardioaccess.com) was installed at Miami Children's Hospital. Efforts were made to incorporate the operative photographs into this relational database, but significant obstacles were encountered. The analogue intra-operative photographs could not be recorded and stored digitally. Furthermore, even if such digital images were to exist, the initial database was unable to store them. Thus, in order to create the database, the problem needed to be approached in terms of first digitally capturing the images, and then in terms of how to store them.

These two challenges, improving the abilities for capture abilities, as well as those for storage, were approached simultaneously. Work has been done at The Congenital Heart Institute of Florida's All Children's Hospital campus, The Great Ormond Street Hospital for Children, and Miami Children's Hospital. In terms of capture, the challenge was to obtain digital images and videos of operative procedures. In the mid 1990s, the "state of the art" was non-digital, using images based on prints or film, along with video cassette-recorded analogue tape. The first step in the move to digital capture was simply to scan all printed photos to create digital copies, but this proved very time-consuming and labour intensive. Indeed, it was too labour intensive to facilitate consistent creation of digital files of operative photographs. The next step, therefore, was to achieve direct digital capture of the operative photographs. Combining their resources, Karl Storz and Sony created a video-assisted thoracoscopic surgical camera, along with a system of capture that allowed direct digital acquisition of the intra-operative images, but only in a proprietary language belonging to Sony. The breakthrough achieved was the ability to capture digital images directly, and to eliminate the need for the scanning, but the problem remained with the proprietary nature of the software. The data was stored on a proprietary Sony 0.5 inch 140 megabyte disc cartridge which could be opened by only a small minority of computers. This proprietary system proved to be unable to communicate easily with the software used in the database. So as to be manipulated within the cardioscopic database, the proprietary files, created in ".pmx" and ".pmp" format, needed to be converted to more standard and universally accepted ".bmp" or ".jpg" files. This conversion proved cumbersome, and required the discs to be shipped off-site. Furthermore, the quality of the images was harmed and degraded during the process, with the images becoming somewhat pixilated. The next advance, therefore, was to create a system which would capture the images directly as universally accepted ".bmp" or ".jpg" files. Only in the last several years has such technology become

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available. An example is the Advanced Image and Data Archive System developed by Karl Storz at Endoscopy-America, Inc., Culver City, California. This transition from capture of paper-based images to non-proprietary digital capture, nonetheless, although requiring several breakthroughs as discussed above, still represented but half the challenge in creating a true cardioscopic database.

As emphasized above, in addition to improving the abilities to capture images, we needed parallel advances in the capabilities to store them. The initial databases existing in the early 1990s were based on the data being entered onto paper. By the end of the decade, databases existed that allowed data to be entered directly into computers. Unfortunately, most of these computer-based systems did not allow for storage of digital operative photographs and videos. The first step in overcoming this problem was simply to store the digital operative photographs and videos on the same computer that contained the database. Even this step required considerable work. Initially, scanned files were placed on discs, manually transferred to the database computer, but then stored outside the database. Attempts to store the images, and especially videos, by embedding the files directly within the database, caused the size of the database files to expand exponentially. Our current solution, therefore, is to allow the images and videos to be stored in separate directories, which can then be mapped or linked to the database. In this way, digital files of operative images and videos can be viewed directly within a database such as CardioAccess.

The next logical step in this evolution is now well underway at Great Ormond Street. Digital tapes are now made of operative cases, and are stored both in their full versions, and in edited formats. The digitalized system involves the use of multiple cameras, including an overhead camera mounted directly above the table in the operating room, a camera mounted in the corner of the room on the ceiling, a headlight camera, a cardioscopic camera, and a camera mounted on a flexible arm attached to the sternal retractor. These cameras are all linked digitally to a master device for control and recording. The option even exists to record the signals directly onto digital video discs in real time. It is anticipated that the system will eventually permit every case to be filmed, with the digital video files of the operations linked directly to the outcomes database.

At Great Ormond Street, since 1996, one surgeon (MJE) has filmed the majority of his operations using a Storz headlight camera. Originally recording to tapes using the super VHS format, the Hospital has subsequently converted to using a digital videocam recorder. The entire operation is filmed, stored, and catalogued against a standard nomenclature, which is also used in the departmental database. The use of a standard nomenclature for filing is fundamental to the process, as it forms the basis of keyword and patient-based storage of the images and videos.

The videos obtained can be edited as required using proprietary software on either Apple Macintosh or IBM and Microsoft Windows Personal Computer systems. Transfer of edited material, with appropriate permission of the patients and their families, can then be made to VHS tape, compact disc, digital videodisc, or the World Wide Web. Quality can be controlled as part of the editing process, and depends on the degree and technique of compression. Appropriately compressed videos can fit into a conventional database as a file in their own right, but are more practically stored remotely via a "url" hyperlink. The videos can be stored as individual records for each patient, as batched files for teaching, such as files of repairs of ventricular septal defects of a similar type, and also as transferable files for giving to families, or to the surgical trainees as a record of the procedures they have undertaken. Great Ormond Street has also used these video images in medico-legal cases.

Thus, the current state of the art is digitally to capture the images and videos, and then subsequently manually link them to the database. The next step, and the long term goal, of this entire process, is to capture the digital image or video, and instantly and automatically to attach this file to the database for outcomes. This step requires both the direct linkage of the software and hardware used to capture the images with the software and hardware of the database, and the sharing of conventions between the systems. Efforts are currently underway to achieve this goal.

The rationale underscoring the creation of the cardioscopic database

Operative images are also created and stored during the majority of the surgical repairs of congenital cardiac malformations at All Children's Hospital in Saint Petersburg, and at Miami Children's Hospital. Based on this experience, we have noted numerous benefits that have emerged from the routine use of cardioscopy:[47,48]

- It enhances the visualization and repair of remote intracardiac structures.
- It minimizes the need for more extensive skin and cardiac incisions.
- It decreases potentially traumatic retraction of cardiac structures.
- It offers the potential for further development of completely endoscopic paediatric open-heart surgery.[49]
- It documents pathology.

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- It has facilitated, and will continue to facilitate, the development of nomenclature.
- It assists in teaching of residents and cardiologists.
- It increases options for education of the patients and their families.

Video assistance has facilitated advances in both extracardiac and intracardiac paediatric cardiothoracic procedures. Without it, we would have been unable to contemplate the creation of the cardioscopic database. On its own merits, video assistance remains a key piece in the evolution of the field of minimally invasive paediatric cardiac surgery, as evidenced by the initial five advances listed above. All advances in surgery, of course, must be subjected to rigorous scientific scrutiny. A database for recording outcomes that includes cardioscopic images and videos provides the framework for such scrutiny, permitting analysis of the risks and benefits of the further development of minimally invasive congenital heart surgery, and serving to validate the potential for completely endoscopic open-heart procedures in children. When combined with the outcomes database, the techniques of video imaging will almost certainly lead to further levels of advances, as suggested by the final four points listed above. These are of sufficient importance to warrant further discussion of each point.

The well-known Chinese proverb states that "a picture is worth a thousand words." Documentation of pathology in a cardioscopic database proves this proverb. Properly captured and stored still images and videos of cardiac pathology can provide a more accurate description than the word-based operative report. The additional data provided by storing digital intra-operative images and videos in the cardioscopic database will be especially useful when caring for patients with lesions prone to recurrence, such as recurrent subaortic obstruction after initial transaortic resection of subaortic fibrous shelf, or recurrent mitral regurgitation after mitral valvoplasty.

Cardioscopy has facilitated, and will continue to facilitate, the development of nomenclature. International efforts to standardize the worldwide nomenclature for congenital cardiac disease are ongoing.[50–54] In the future, databases could be developed that will allow for images of all lesions to be mapped in cyberspace to a universal system of nomenclature. In the short term, a paper and cyberspace virtual atlas can describe nomenclature and anatomy, and link a photograph of the anatomic specimen to an echocardiogram, an angiogram, and an intra-operative cardioscopic photograph.[55] Either way, the cardiac phenotype will be documented with a picture, and linked to its name. Proper application of the intra-operative images and videos will self-evidently permit the comparison of the surgical phenotype with the anatomical phenotype.[55] For example, this technique, by direct observation, will finally resolve whether the left atrioventricular valve in patients with common atrioventricular junction is a trifoliate structure, or is no more than a cleft in an otherwise normal mitral valve. Only by making direct comparisons between the anatomic specimens and the views obtained in the operating room will we resolve such ongoing problems of phenotypic analysis, since it is axiomatic that the naming of congenital cardiac malformations can best be resolved by agreeing on their phenotypic features.[55]

There can be no doubt that cardioscopy assists in teaching of residents and cardiologists. Surgical trainees benefit from such technology before, during, and after a procedure. Prior to an operation, our surgical residents are able to review videos of the anticipated repair as stored in video libraries. During the procedure, those surgical trainees not themselves involved in the procedure can visualize the intracardiac repair as seen in the cardioscopic image projected on a television monitor. After performing the procedure, the surgeon himself or herself can review the operation, critically evaluating his or her work as part of the programme of continuing professional development. Cardiologists can also benefit from cardioscopic correlation of their echocardiograms and angiograms.

It is now equally clear that cardioscopy increases the options for education of the patients and their families. Intra-operative images and videos are particularly useful for such educational purposes. After obtaining appropriate informed consent from the patients and their families, the images and videos can be placed on the Internet. There, they can be used to educate other patients and families. Patients and families can also be given copies of their own intra-operative images and videos for their personal records. Young children may even take the photographs to school for purposes of "show and tell", hopefully increasing their ability to cope psychosocially with their illness.

Moving images have additional advantages. They provide improved perspective, better conceptualization of the three-dimensional nature of cardiac anatomy and pathology, some indication of access, and a deeper understanding of scale. In the operating room, the images can be obtained via the conventional head camera, and of course, these images show exactly what is seen by the operating surgeon. By placing monitors sensibly around the operating theatre, everyone can see what is being done. At Great Ormond Street, one monitor is placed behind the surgeon to be seen by the assistants, one for the perfusionist to see, and one for all the other staff to see. Understanding and teaching

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are greatly facilitated. By storing the entire procedure against a known nomenclature, a superb library of videos can be obtained. Clever design of the database can allow retrieval of videoclips relating to a particular diagnosis, a particular procedure, a particular surgeon, or a particular patient.

In the final analysis, the video material forms a unique library in the form of an electronic text book of immense value to a busy teaching unit. As computer storage becomes more effective, and technology for retrieval becomes more sophisticated, such videos will form part of the electronic patient record in exactly the same way as the typed operation note does in the current era. We envisage a time in the not-too-distant future when recall of the operation will be a simple procedure, and the surgeon will indeed review the video of the previous operation, rather than have to discern what was done from the previously dictated note describing the operation.

Disclosure: Jeffrey P. Jacobs, MD is the non-salaried Medical Director of CardioAccess, Inc., Saint Petersburg, Florida and Fort Lauderdale, Florida. CardioAccess was founded by its current majority owners: Howard E. Jacobs (the brother of Jeffrey P. Jacobs, MD), Jeffrey P. Jacobs, MD, and Redmond P. Burke, MD.

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