美国超声心动图学会报告

数字超声心动图的指南和推荐

来自美国超声心动图学会数字超声心动图分会的一份报告

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概要

数码存储和回顾是目前超声心动图技术的发展现状，实践者渴望在他们的实验室里可以很快的过渡到一切都能靠数字化方法解决问题的状态。尽管对录像带的二次数字化作为过渡性方法可以被接受，但是数字实验室的最终优势只能通过来自当代超声心动图机器的数字结果的直接输出来实现。存储形式的标准化对促使实验室内部及实验室之间互操作性起到关键作用；所有应用程序均应遵守DICOM（Digital Imaging and Communications in Medicine，医学数字成像及通信）标准。为了完成可接受的小尺寸研究，我们必须进行临床压缩（如在选择视图存储1个或几个心动周期）和数字压缩（高效存储个别帧及循环）。无损压缩（行程长度编码）在DICOM中被采用，且对存储如频谱多普勒或M型多普勒中的停帧图像有很大作用。Motion-JPEG是唯一被DICOM委员会批准通过的一种有损耗失真压缩，文献支持及厂商使用表明压缩率高达20:1（具体参阅章节3.3.1部分对Packbits 和无失真/失真术语的讲解）。更多积极的压缩方案（如MPEG-1,MPEG-2和微波）正在进行DICOM评估，但至今仍然在DICOM格式转换上未被标准化，尽管这些方案可能在实时传输和数字网络回顾中有一定作用。数字实验室的硬件要求包括高速的网络（最低速度不能低于每秒100兆比特[100Mbps]是基本要求，即使是在中型超声心动图实验室内），行业标准服务器和存储方案。这些存储方案需要不仅能支持最近和返回病人信息的快速存取，同时还要支持长期数据的存取，包括至少7年内的已归档存储于数码磁带，DVD或者磁光媒介的数据。

有一些供应商可以独立提供所有的数字应对措施（包括硬件、网络和软件），而有的是在不同的厂家购买这些设施再重新整合。在过渡期，同时回顾数码影像和录影带十分有利，但对于长期来说，我们推荐只在网络故障的情况下使用录影带作为备份，以便能够对没有来得及捕捉到数字信息图像进行二次数字化。

对于录影带内容的保存，除非内容需要充分回顾并且内含诊断解释，我们推荐录影带在1周后便可循环使用而不必存档。一些幣端已被讨论，包括心电图信号干扰，它可以导致捕捉图像的心动周期不完整；还有房颤，需要捕捉多个心动周期的图像。

需要强调的是，随着未来与医院登记和诊断报告标准的预期整合，数字超声心动图目前还是一个进化发展中的领域。然而，该领域已经达到了一个如此成熟和稳定的状态，以至于在任

何一间现代超声心动图实验室都能得到关于全电子捕捉、存储和回顾的明确建议。

参考全文所讨论的细节，我们的总建议包含以下内容:

无论规模大小，推荐所有超声心动图实验室使用数码捕获、存储和回顾技术。

存储和数据转换应使用医学数字成像及通信（DICOM）的格式。

详细的临床编辑图像技术和电子压缩技术（医学数字成像及通信DICOM范围内）必须保持研究规模的可操作性。

大型实验室需要配备高速网络(100 Mbps)和一套数字转换架构体系。

短期和长期的备份存储是必要的，完全镜像异地存储更为理想。

同期录像带记录对于短期备份和缓解电子转换压力是很有用的；一旦电子转换完成，录影带文件不应被长期保存。

强烈推荐同电脑报告软件相结合。

简介

经过多年的发展、标准化及相对缓慢的实现过程，超声心动图世界现在应当全面着手全数字化存储及分析。对那些已经完成转化的实验室，在改进效率、质量并为相关医生提供临床服务方面，数字化超声心动图的优势十分明显。然而，尽管数字化超声心动图具有优势和可行性，一项近期美国超声心动图学会实验室数据项目（the Laboratory Data Project of the American Society of Echocardiography）的回顾显示，目前只有一小部分超声心动图实验室认为自己在数据处理时已经由数字化主导。对那些仍想转变的实验室，希望本文能为推动他们进入全数字化时代提供信息和动力。

本文由美国数字化超声心动图委员会官方出版。委员会于2001年首次会议，之后每3年举办一次，为那些寻求组建数字化超声心动图的实验室辨明问题、困难和可能的解决方案。这篇报告将概括一些数字化超声心动图的历史及技术背景，提出与医生和超声检查医师相关的执行方面问题，引入除了单纯数字图像存储之外的一些概念，比如结构化报告和医院数据库集成。

数字化超声心动图的优势

数字超声心动图比类拟的磁带存储有许多优势:

1)更有效的阅图, 因为超声检查医师可以将注意力集中在特定的图像，轻松地回顾数据并将检查相关的说明组合在一起。

2)更方便阅图，因为图像是存储在一个中央服务器，可以在世界任何地方，在由部门级网络或虚拟专用网络服务的任何计算机上，提取相关数据。

3)与先前的图像便捷对照，不需要翻找成堆的旧录像带来搜索一个特定的图像。

4)更容易量化，因为空间、时间和速率标定是直接建立在图像内的，从而在回顾流程中立即就能使用量化工具。

5)与相关医生沟通更方便，可以通过报告中图像的结论，也可以立即提取相关图像数据来回顾。

6)图像质量更高，因为图片如同仪器的最初记录时一样，在录像过程中没有任何退化。

7)图像质量更稳定，因为随着时间的推移，录像带会不断老化，而数字文件可以保持不变(只要它们存储的介质被保护好)。

8)在医院的电子医疗记录内可以将影像和报告结合起来。

9)更有力于科研，因为高质量的图像可用于具有内置的校准定量来测量。核心实验室能够从任何影像获取处立即获取数字文件，从而提供更好的质量保证和更及时的测量结果。

10)有利于临床质量控制程序便捷实施，即超声心动图可以被常规随机重新审查。

11)提高了准确性和再现性。

12更为医学教育提供了很大便利，因为在地方、国家和国际会议上，移动影像现在可以经常应用于使用计算机的演讲中。

成本效益 已经有少数几项相关研究调查了数字超声心动图的成本效益问题。最近的一项研究通过 101 例心脏瓣膜疾病，对比评估了数字超声心动图和模拟超声心动图在准确性、一致性和成本效益方面的差异。总体上，2 种方法给出了高度一致的结果，但数字化回顾所花时间比录像带回顾少了 38%，数字存储（平均每张 CD-ROM 有 60MB 容量）花费了 31 美分，而录像带则耗费了 62 美分(当代每项研究数字存储花费小于 5 美分，进一步扩大了数字化超声心动图的成本优势)。但一项儿科超声心动图的相似研究因其使用了非常昂贵的磁光盘作为介质，显示出了数字化存储的成本劣势。尽管数字超声心动图在减少花费成本方面尚有争议，但目前为止最受关注的焦点在于其对质量和效率的提高。

关于数字化超声心动图历史的完整描述可见附录A，供读者优先参考更多背景。此附录可在www.Digital-Zone.org.找到。

技术问题

术语介绍

录像数据数字存储的特点在于表现屏幕上离散点（像素）组成影像的方式，即用二进制数字（只由0和1表示）来表示特定的颜色和灰阶。一个二进制数称为一位,而一连串的8位是一个字节,可以代表文本的一个字母或一个0到255之间的数字。整体图像质量取决于屏幕分辨率(图像的行数和列数)和用来表示每个像素的位数。

对移动影像而言,有时间分辨率的问题,是指每秒存储的帧数。典型的超声心动图影像回放包含480行和640列,用24位来表示每个像素的颜色(8位[1个字节]用于分别表示256个水平的红色,绿色和蓝色,总共1680万种可能的颜色)。典型的帧速是30 Hz。把这些数字相乘(640*480*30*24)得到一个巨大的存储要求，即每秒221184000位(bps)，也就是一个典型的10分钟的超声影像需要超过16 GB的存储容量。

这么巨大的存储需求,随着超声心动图像质量的提高,自然会存储更高分辨率的影像,大约达到800*600的像素水平。同时存储影像也会有更加完整的帧速,当代超声心动图机器可以实现同步处理,频率高达200赫兹,从而增加了10倍的总存储需求。为了适应这些惊人的存储需求,“临床压缩” (选择视图存储1个或几个心动周期)和数字压缩(用更少的字节存储给定图像)的结合策略是必需的。

临床压缩可以减少很多存储需求,因为一个心动周期(反复)可以取代30-60秒的录像带图像。

数字压缩可以是无损或有损，这取决于影像是否因此而改变。无损压缩可以减少存储需求至3:1,而有损压缩通常压缩图像达到20:1或更多。这些技术细节将在下面讨论。

DICOM 图像格式标准

如上所述,早期的医疗应用数字存档系统使用专有、封闭的图像存储技术,因此某个制造商系统的研究记录不能在另一供应商的设备上查看。为了迎接即将到来的医学成像领域的“巴别塔”,美国放射学院(ACR)和美国国家电气制造商协会(NEMA)在80年代早期组织推动了数字图像转换的标准化。最初的版本发表于1985年和1988年，但对心脏病的影响不大,因为血管造影术和超声心动图(超出单帧灰度图像)还没有问世。

应用范围被限制在点对点的通信上，意在无需提供图像交换媒介（软盘、硬盘、磁盘），即可在遵从ACR/NEMA协议的仪器之间交换影像。而且这个协议是非常有限的，要求必须使用一种独特的50针接口，而这根本不符合计算机行业的新兴网络标准。

相比之下，ACR/ NEMA标准的3.0版本协议被指定用于医学数字成像及通信（DICOM），从而确定了其在一般医学成像领域及许多其他专业组织（包括美国心脏疾病协会、美国超声心动图学会和美国核心脏病学会）未来规划中的关键角色，并且解决了很多先前的局限性。

它目前已被指定用于更广泛的图像类型，包括超声、磁共振成像(MRI)、计算机断层扫描(CT)和x射线造影。尤其是彩色图像的记录现在被启用，作为在记录运动图像和生理数据。DICOM指定了图像网络交换和媒体交换，并且现在已成为一个行业标准。

DICOM 的总体结构 DICOM 只是一套如何在兼容设备之间转换图像及其他数据的规则。个人图像携带着病人信息、检查目的及方法、图像说明，当然还有像素数据本身，一并被保存起来。每种方式(超声心动图、CT、磁共振成像、核医学和血管造影)都指定了哪些数据元素是必需的,哪些在文件中是可选的以及像素存储的确切性质,包括任何可能的数字压缩。图像可以通过网络或磁盘转换。网络通信是一种设备之间的转让过程，确定了图像数据交换的最有效格式(作为最小公分母,所有必须能够发送和接收未压缩图像)。磁盘交换的格式必须事先达成一致(称为“应用规范”，适用于每种获取图像的方式)，这在 1994-1996 年间花费了 DICOM 大量的努力才得以实现。需要强调的是，DICOM 不是归档标准而是通信交流的标准。在规则内，能在任何介质上保存图像，才是最合适的。

超声心动图DICOM。在超声心动图中,图像交换的需求是多样化的。因此，统一标准支持了很多交换媒体。灰度、颜色和频谱多普勒图像可以通过网络存储或存储在1.44 mb的软盘、3.5英寸和5.25英寸的磁盘驱动、CD-R光盘。标度要素可能被存储为线性、时间和速率的度量和三维(3D)记录。图像可以用无损、有损压缩和非压缩方式进行存储。感兴趣的读者可以深入了解超声心动图的DICOM标准,但在大多数情况下,知道给定设备完全支持DICOM标准就已经足够了,而不用考虑实施细节。

数字压缩无损耗(如行程编码)。数字图像压缩分为 2 大类:无损压缩和有损压缩。顾名思义,无损算法允许恢复原始图像的每一个细节,消除了这种压缩可能影响临床图像内容的所有顾虑。对于无损编码，超声心动图的 DICOM 标准是使用一种称作缩算法（Packbits）的方案,其对同值像素重复块的编码非常有效(称为行程编码,或 RLE)。所有无损技术的缺点是相对较小的压缩比率,通常为 2:1 或 3:1。

JPEG。为了获得更高效的压缩(通常是 100:1 以上),必须使用有损压缩算法在微小程度(希望并不重要)上扭曲恢复的图像。超声心动图的DICOM标准允许使用超声心动图有损JPEG(联合图像专家组)算法,在其中 88 个像素块进行离散余弦变换,只有重要频率(主要是低频率)的内容被存储起来。定量图像分析表明超声心动图图像的小小退化使得压缩比高达 20:1,而存储在超级 VHS 录像带的图像的退化相当于 26:1 30:1 的压缩比。在一项盲比较中,绝大多数观察者选择了数字超声心动图，远远超过没有 20:1 JPEG 压缩的录像带。其他研究表明 20:1 JPEG 压缩对边缘检测算法没有不利影响,并允许在彩色多普勒图中精确提取速率。因此,20:1 JPEG 压缩应用于临床超声心动图看起来是可接受的。其他试验已经显示了有损压缩在电脑断层摄影术和核医学中应用的可能性。

MPEG。其他算法提供了更高的压缩度,虽然这些在 DICOM 中尚未被标准化。MPEG(动作图片专家组)方法利用帧间冗余扩展了 JPEG,在出色保真的条件下实现了 100:1 以上的压缩比。MPEG 是很有吸引力的,因为它正在成为多媒体计算和娱乐的标准。之前关于这种格式使得解码和编码更加困难并导致无法干脆停帧的顾虑，似乎已经缓解了。已经证明 MPEG 编码的特征内容相当于录像带,并且能够准确地定量测量,而通过使用 MPEG - 2 编码在高速数字网络(5 Mbps)下传输超声心动图可以得到更高的影像质量。MPEG 对于数字超声心动图的优点是有利于记录大量的连续视频(当临床压缩不佳时)。出于这个原因,MPEG 最初主要在为儿科超声心动图设计的系统里应用,其能够捕获时间更长的连续扫描影像。然而,缺少 DICOM 的支持仍然是 MPEG 的限制。

其他格式。其他压缩算法中我们也评估了微波压缩,它使用一个频率连续体来压缩图像，而未使用离散傅里叶变换的频率或在视频会议中广泛使用的 MPEG 多帧前端。微波压缩形成了新 jpeg - 2000 标准的基础,其正在被 DICOM 委员会考虑评估。微波也很容易扩展到多个维度，并且已被证明在无明显图像损失的条件下可压缩三维超声心动图数据达到 100:1。虽然这些新的压缩算法明显优于当前用于超声心动图的 JPEG 方法,然而在他们被 DICOM 委员会和供应商正式采纳之前，超声心动图领域都会被警告临床上不要使用这些格式,因为他们可能会限制系统和实验室之间的互通性。

数字超声心动图的组成

实验室图像采集:数字超声心动图机和图像数字化仪。当代心脏超声波仪器是获得真正数字超声心动图数据的最有效方式,通过使用一个标准的网络协议和 DICOM 格式，它能够直接输出数字图像和循环。幸运的是，在当今市场上所有主要制造商都能提供这样的数字输出的设备,虽然他们的实现细节可能不同。直接数字输出可保持最大保真，也使得标定要素直接与 DICOM 数据一同存储,便于在回顾工作站上量化。机器可以设置为存储单个或多个心脏的循环周期或固定时间(通常 1 到 3 秒)的循环。虽然一个默认值(也许 1 心动周期)可以预设,但可以轻松调整一个循环的持续时间，对于获得心律失常或复杂的结构异常方面的研究数据是很重要的。

超声心动图机的心电图(ECG)信号质量是获取完整超声心动图心脏周期的关键。常见的問題是因为 ECG 信号的干扰,节律障碍,或起搏器被识别为连续的 R 波而导致捕获的心动周期太短。建议超声心动图供应商实现识别心脏周期的算法,例如少于 400 毫秒的周期，这些周期最有可能被 ECG 干扰截断，自动默认一个更长的捕获时间从而获取数据时不会发生数据丢失。

旧的现有系统通过外部数字化模块应用于数字计算机，模块连接着超声心动图仪器视频端口。协议可以输出单帧,一个固定的时间间隔的数据,或完整的心脏周期,后者通过检测心电图 R 波的方式。这种方法的一个缺点是图像质量低于直接数字输出,虽然直接红绿蓝(RGB)信

号的数字化远好于录像带数字化。此外,校准数据和其他患者信息不随图像一并存储。然而,对于遗留系统,这是一个可以接受的方式将它们集成到一个数字实验室,尽管在常规设备升级周期中，推迟数字实验室的老化机器更新至更现代化仪器这一措施，更多的只是经济意义。为解决数字超声心动图的流视频(也称为“充分揭示”存储模型)问题，提出了视频捕捉的方案。图像通常被 MPEG 格式压缩存储,它能够以类似于数码录像机的方式捕获更长的片段。这可能在儿科和消化道研究中很有优势,因为其需要长时间的扫描。流媒体自然也允许采集的实时监控和指导。然而,缺乏内部校准和缺乏 DICOM 支持是这种方法的缺点。

图像传输:网络方面的考虑。网络传输是将超声心动图传到 DICOM 服务器的最有效的方法。可以在检查结束时传输全部图像,也可以更有效率地传输每个刚刚获得的图像,这意味着检查结束时刻和心脏科医生回顾图像的时刻之间没有延迟。如果整个医院没有网络用于床边检查,数据可以存储在内部硬盘并在之后转移到服务器。使用光碟将图像从超声心动图仪器转到阅图站并不是十分理想(既慢又更容易出现人为错误),但在无法直接网络连接时和远程实验室内，它是不可或缺的。

超声心动图检查通常存储在超声扫描仪器的一个硬盘上,直到硬盘容量用光。这种时候，最早的检查被自动删除并为新的检查腾出空间。这个程序允许设备运行多项检查并后续转移。它提供了一个短期裁减数据的方法。然而,实验室必须采用严格的途径来网络传输床边检查数据,以确保本地数据不会被覆盖删除。制造商必须在覆盖删除之前给用户相应的警告。

一个完整成人超声心动图检查可能由 50 到 100 MB 的压缩图像数据组成(1-2 GB 的未压缩的数据),其在检查第一次进行时和每次被查看时都必须通过网络传输。这个单一的检查可能会在某一天产生几百兆字节的网络流量,忙碌的实验室可能每天会达到数十 GB，这需要快速高效的网络。老医院网络 10 Mbps 的速度对于繁忙的数字超声心动图实验室而言太缓慢了。更多用的网络是 100 mbps, 而繁忙线路,如 DICOM 服务器和档案存储介质之间的连接,将受益于千兆(10^9bps)技术。

适当的体系结构甚至比网络的基本速度更重要。网络交换机好于路由器,因为它们在 2 台传输数据电脑之间建立一个单独的连接,从而限制了对其余网络的影响。大部分的超声心动图供应商在此过程中从 10 - mbps 的输出卡升级至 100 mbps 的输出卡,虽然增量传输将在很大程度上克服的慢速输出卡缺点。

设备与各种网络参数(速度:10 和 100 Mbps 和复式:一半和完整)的连接要求转变至自动感知设备的正确配置并建立可靠的连接。超声心动图的机器和网络交换机之间的自动协商机制有时并不完美,要求网络掉线被配置为固定的参数设置,从而限制了特定情况下一些机器的网络连接。制造商在这些自动协商机制方面应该努力提高灵活性。

无线遥测。通过从机器到服务器的超声心动图图像无线传输，可以使床边检查有更大的灵活性。可能的技术包括蓝牙,能够在 10 米内以 1 Mbps 速率传输数据，此速度对于数字超声心动图可能太慢。更有前景的是 802.11 b,这是超过 50 米达到 11 mbps 的传播方式,其规范很容易集成到一个标准的 “传输控制协议/网际协议”(TCP / IP)网络协议。DHCP 和 802.11 b 的结合将使超声心动图能够毫不费力地从医院任何有无线网的地方传输至存档地。最近批准的 802.11 g 标准使得更高的速度(54 Mbps)也成为可能。

图像存储:可移动媒体,短期存档,长期存档;灾难恢复备份。在大多数情况下,超声心动图数据应该最初本地存储在超声心动图实验室区域的高容量硬盘系统中，这样图像可以随时被查看。一个大型实验室可能希望建立一个拥有 tb 级或更多存储容量的 RAID 阵列,这将允许(每天 10 GB 的数据生成速率)超过 1 个月的数据存储在本地,同时保持足够的空间来从存档地点

查看旧的检查。RAID 阵列服务器在单独的硬盘内自动存储重复数据副本,为数据丢失提供额外保护。本地存储的大小可以定制成适合给定实验室的数据生成和特殊要求。存储容量,不仅包括目前检查还包括以前的检查数据(如定期超声心动图检查的门诊病人和所有住院病人)，在系列比较中令人满意。与医院信息通信服务相连的系统，可以从长期本地存储中提前搜索和检索所选检查(预取)。幸运的是,硬盘存储的成本已经下降显著,对于大型试验室甚至 tb 级或更多的本地存储的费用也并非难以接受。

除了本地存储,一份长期存档是至关重要的,旧的检查可以被永久保存,随后在需要时检索。DICOM 没有指定存档格式,只指定了将图像写入和读取的通信协议。根据实验室的规模和其他当地环境,存档可能采取的形式有光盘，CD-ROM 或 DVD。另外,数字线性磁带(DLT)或高级智能磁带(AIT)提供了一种非常具有成本效益的存储介质。通常整个机构将建立一个大型档案,允许存储超过 1 PB 的数据(1 PB 10^{15} 字节)。在连接建立后，对于一项给定的研究和大于 2 Mbps 的传输速率（理想中有千兆线路连接到服务器），存档应该是不到 2 分钟的时间。即使有这样的速度,在晚上通过网络将日常超声心动图数据归档的方式可能更好。因此,即使本地存储设备发生故障,只有小于 1 天的超声心动图会丢失(有可恢复的潜能,因为超声扫描仪本地硬盘可以保留超过 1 天的研究数据)。

系统庞大的程度决定了出现故障时其功能有多大。至少,存档的同时应该对每项检查做副本（备份）,保存在一个完全独立的位置,以防止档案本身的灾难性故障。在理想的情况下,会有 2 个或更多的完整冗余硬件-软件组合,允许瞬时和无缝切换到备份系统,尽管总冗余的系统费用高，但当数字查看功能偶尔的 (希望短暂)停机中断时其必要性显而易見。

归档软件。对于管理存储、转换、和数据存档，以及连接到医院信息系统管理日程计划、报告和费用等方面，软件和数字化采集的硬件同样重要。这个软件,一般来说,会在后台通过网络持续运行,与超声心动图的每个机器交互并查看工作站。它在网络超声心动图仪器、电脑磁盘和本地存储之间管理图像交换,然后将数据迁移到存档点。理想情况下,软件应该可以促进实验室工作流程,包括调度计划、数据预取、计费、报告和质量保证。

这个软件可以是集成硬件-软件网络解决方案的一部分或用在分开购买的第三方硬件上软件的一个独立部分,选择哪一种必须基于当地的实验室环境。集成解决方案的优点是显而易见的:一个供应商将负责维护整个系统集成的完整性,从而减轻终端用户管理单个组件的责任。然而,这种便利是要付出代价的,因为这样的解决方案通常比单独购买硬件和软件更加昂贵。如果有重要的本地专家可以来维护系统,特别是如果上述数字超声心动图实验室的主要组件已经到位,分别购买硬件和软件也许更有意义。选择要视具体情况而定,并没有明显的首选方法,只是不同的权衡而已。建议用户早期就咨询医院或具体的信息技术部门,以更好地了解当地情况的能力和限制。例如,可能已经有一个全系统级的档案(也许是强制性的)供使用;任何潜在的数字超声心动图实用解决方案必须使用这个档案。

图像审阅:工作站和监视器标准。建立监视性能标准是一个在数字超声心动图世界没有得到太多关注的主题。例如像素锐度,图像均质性,照片亮度等问题对于医生解释的准确性是十分重要的。放射协会已经采取了一些措施规范监控阅读普通 x 光的亮度,在空间分辨率、对比度和灰度深度提出要求。然而，在一般情况下,大多数当代监控器都足以充分显示相对较低像素的超声图像,特别是结合了由服务器软件内在控制的亮度和对比度。

远程医疗方面的考虑。数字超声心动图的巨大优势之一是促进有意义的远程医疗咨询。然而,远程医疗医院实验室的网络要求变得更加重要,因为连接通常要慢得多。例如，连接外围卫星设施和中心读取设备的远程医疗通常使用 T1 线路传输,最大 1.54 Mbps 的速度。因此,如

果 T1 线路的全部带宽可用,这情况很少发生,它需要大约 5 分钟来传输 50 mb 的超声心动图研究。通过使用超声心动图的增量传输机,这种问题大大改善了,但如果超声心动图研究需要被卫星设备从中心存档中查看,这样的延迟就变得无法忍受。表 1 说明了在不同的网度下传输 50 mb 的研究数据花费的代表时间。互联网速度提高,传输时间可以大幅减少,但永远不会比最慢的组件更快。

表 1 远程医疗 50-MB 研究数据需要的传输时间

28.8-kbps modem	3.9 hours
112-kbps ISDN line	1 hour
768-kbps DSL	8.6 minutes
768-kbps cable modem	8.6 minutes
1.54-Mbps T1 line	4.4 minutes
10-Mbps Ethernet	40 seconds
45-Mbps DS3	9 seconds
100-Mbps Ethernet	4 seconds
650-Mbps ATM	0.6 seconds

电缆调制解调器和 DSL 速度变化范围为 128 kbps 和 3 Mbps 之间。

电缆调制解调器带宽也同样受其他客户利用率的影响。

自动取款机,异步传输模式;DS3,数字信号 3 传输;DSL,数字订阅线路;ISDN,数字网络综合设备,KBPS,千字节每秒。

远程医疗需要通过拷贝图像來解决。大多数供应商提供能够将数字超声心动图检查直接刻录到光盘。查看软件复制到 CD 上，从而可以在任一个桌面个人电脑上回顾。如果 CD 刻录机不可用,则有必要纳入一个系统将数字系统连接到录像机。一些超声波系统有能力从磁盘中恢复检查数据，并将其记录在超声系统的录影带上。最终,通过互联网直接数字传输图像(类似于电子邮件但有适当的安全保证)将是促进外部查阅的最有效方法。

<u>**执行问题**</u>

用什么来数字化存储

单心动周期或多心动周期存储。如上所述, JPEG 算法提供的相对温和压缩的方法，要求超声心动图的临床压缩以捕获 1 个或多个心脏周期数据的形式而不是更多更长的记录。幸运的是, DICOM 允许灵活捕捉,无论是一段固定的时间(通常 1 到 3 秒),还是 R 波检测的方式都可以。捕捉单个或多个心动周期的方式通常是适用的,但当室壁运动异常时，要避免捕捉不完整的心动周期。几种情况下,较长时间的捕捉(10 秒或更多)可能更加合适:

1)生理盐水注射判断从左到右的分流时,其通过的时段对于分辨心脏和肺部的分流是非常重要的。

2)儿科检查时，用扫描來判断一种结构和另一结构的关系。然而最近的一份报告表明,反复单周期图像可以有效地整理复杂的解剖结构。

3)心房纤颤或频繁室性心律失常时，应捕捉多个连续几个心动周期来更好地识别心室功能。

4)食道超声和术中超声可能受益于较长时间的扫描，从而更好地描绘病理情况(尽管它通常可以从自动导向的图像中获得类似信息)。

心电图干扰。干扰的心电图和双腔起搏器都可能导致采集的心动周期不完整。在技术上应尽一切努力获得足够清晰的心电图记录，用前面的图来对比确认，如果发现问题就切换到定

时采集模式。支持制造商制作自动转换来检查异常短的 R-R 间隔，支持开发一个自动化方法识别双腔起搏器并调整采集时间。

录像带

记录什么,查看什么,保存多久。25 年以來，模拟录像存档已成为存储心脏超声检查的标准方法。数字采集和存储可以不再需要同时存储数字和视频(模拟)格式。尽管如此,实验室仍然觉得在以下几种情况下需要存储录像: 1) 在从模拟到数字的转变过程时; 2) 对数字转换媒介的可行性存在顾虑时; 3) 关于第一项问题的备份和灾难恢复,实验室从模拟到数字存储转型过程中，在数字采集和技术说明方面需要训练超声医师和主治医生。这个培训可以在在有限的时间内同时查看模拟和数字的检查数据,通常是 3 到 6 个月。关于问题 2 和 3, 当前数字技术提供了多种故障恢复办法,包括数据在超声仪器内保存几天的可用性,存储在通用格式(DICOM)，广泛用于计算机和娱乐领域(DVD、磁带或硬盘) 的标准硬件，多级冗余(离线镜像存储)。除了需要短期恢复临时网络故障或数字化检查不足的情况以外，模拟录像在这些方面的作用很小。然而一旦实验室用数字化存储系统取代旧系统，被公认会有成本和/或技术的约束，从而限制了图像从一个系统转移到另一个系统并限制了继续跟综原始存档。因此也就有理由长期存储磁带。请注意,长期存储录像在诉讼事件时是很有用的。

因此,我们在一般情况下,建议完成从模拟到数字存储过渡而无需长期录像存档，但需注意一些例外情况。在超声检查过程中继续录像是合理的,以防数字图像不合标准或错过了瞬间变化图像的采集。用于分析报告的任何视频序列都应该被二次数字化，从录像带转变至永久数字档案的 DICOM 存储格式。录像带可以在几天到一周内被重复使用。如果一个实验室选择使用录像存档,那么强烈建议完整查看回顾关系到超声心动图分析报告的录像带。

超声医师问题

培训、执行、转型和问题。超声心动图的一个重要方面：超声医师记录的典型超声心动图的能力在使用数字化格式时被放大了。超声医师必须记录单个代表性的数字剪辑，而不是不加区别地记录长的录像来捕捉一个视图。

当准备实现数字超声心动图实验室时,仔细评估当前记录的程序是至关重要的。标准化,书面记录程序,征求所有的超声医师和医生意见,将使得过渡更加简单,将目前每个模拟视图纳入数字图像程序内。表 2 是一个指导采集示例。按这个程序捕捉每一个视图的一个心动周期要产生 50 MB 的成像数据,但超声波检验师可以更自主地选择捕获多个周期的一个视图或一个心动周期多个视图，以确保病理被充分展现出来。附加的非标准视图也是必需的，用来充分展示特定的结构特征。

表 2 采集程序示例

PLAx*	Ap5Ch (AV zoom)*
PLAx (MV/AV zoom)*	Ap2Ch*
RV inflow*	ApLAx*
RV outflow*	ApLAx (MV/AV zoom)*
PSAx (AV)*	SCLAx*
PSAx (MV)*	SCSAx
PSAx (LV)	SSAoArch*
PSAx (Apex)	PW: MV, LVOT, TV
Ap4Ch*	RVOT, PV, HV
Ap4Ch (MV zoom)*	CW: MV, AV, TV, PV
Ap4Ch (TV zoom)*	M-Mode sweeps

共有 33 个循环图像(15:1 JPEG =1.5 MB)+10 个静止图像(RLE，200 kB);

50 mb /检查×180 检查/天=9 GB /天=2 tb /年。

AV,主动脉瓣;Ap2Ch 心尖 2 腔;Ap4Ch, 心尖 4 腔;Ap5Ch 心尖 5 腔;ApLAx, 心尖长轴;CW,连续波;HV,肝静脉,LV,左心室;LVOT,左心室流出道;MV,二尖瓣;PLAx 胸骨旁长轴;PSAx,胸骨旁短轴;PV,肺动脉瓣;PW,脉冲波,RV,右心室;RVOT,右心室流出道;SSAoArch,胸骨上凹口主动脉拱;SCLAx,肋下长轴;SCSAx,肋下短轴;TV,三尖瓣。* 2 D+颜色。

过渡到数字存储便于分阶段实施。最初,整个超声心动图应该被数字记录和录像记录,允许诊断医生来查看两者，并允许基于超声医师和医生的反馈来调整数字记录程序。如上所述，随着超声医师和诊断医生更加熟悉数字采集和回顾,录像带只应当作一个短期的备份来使用。永久的记录将是数字化数据。

因为超声医师在数据采集的前线,他们对上述问题必须保持警惕:

●干扰或起搏的心电图必须在采集时注意调整导联或切换为定时模式。

●房颤和其他心律失常需要采集多个连续心动周期或每个长达几秒的片段,以确保捕捉到一个代表性的视图。

●真正的瞬态事件可能无法被捕捉,除非超声心动图机器有能力获得刚刚发生的数据,而不是后续数据。鼓励供应商开发具备这样能力的设备。如果不可能,那么就需要从录像带二次捕捉来存储瞬态事件。

●多普勒音频信号: 在没有音频信号时候，记录单帧、静态图像的频谱多普勒数据是必要的。对于呈现并准确记录多普勒曲线，超声医师的专业技能是至关重要的。

超声医师的作为一个决策者的角色，总是要求具有高水平了解心脏解剖学、生理学、超声物理的能力。当记录数字图像时，超声医师的坏习惯或知识缺陷就会被放大。这种潜在的问题可以用来识别和改善超声医师的成像技术,因为当使用数字化记录格式时，更容易立即识别不良习惯和解决这些问题。

医生的问题

培训和过渡问题。医生过渡到数字实验室也需要一个循序渐进的教育和培训过程，如果在数字程序被普及到整个实验室之前，早期有 1 或 2 名医生解决掉所有技术和执行问题，那么这个过程就会更加简单。医生必须熟悉简单的故障排除,比如心电图干扰和网络电缆连接问题。

对于大多数“数字超声心动图实验室委员会”成员,转变为全数字回顾的过程简短得令人惊讶。在 1 到 4 周内，经验丰富的超声医师迅速接受了剪辑,大多数医生认同数字化回顾的优势,比如并排比较和离线测量，克服了任何限制，避免了常规录像带回顾。

在回顾时,不正确的医疗记录标签或名称拼写等登记错误必须被识别出来并立即改正以避免数据丢失。当登记直接取自医院信息系统时，大多数这样的错误是可以预防的。所有这些问题需要和超声医师们不断地进行密切沟通。定期的质量控制调查是很重要的，以检测和改正数字化错误。

超声心动图实验室认证委员会现在认可 DICOM 格式存储的数字化检查, 经验表明,数字实验室简化了认证流程。

安全问题

要求尽一切努力来为病人保密,以确保获取数字超声心动图图像的范围仅限于那些临床需要查詢数据的情况。至少,这需要由用户名和密码来控制访问服务器软件,如果能关闭全部文件来防止任何未经授权的访问则会更好。通过医院健康保险流通与责任法案，国会规定了严格的安全措施,其技术细节是由硬件和软件供应商处理。

DICOM 扩展

3 D 数据。最初的 DICOM 超声标准制定于 90 年代中期,只提供了图像交换存储在基于光栅的格式。三维数据得到了解决,但是只有一个初步方法,在 3D 的空间中引用了已登记的二维平面。目前, DICOM 工作组正积极改写标准，让真正的多维数据集的交换的标准。

极地的数据。原始 DICOM 标准的另一个限制是，超声心动图数据仅存储在直角坐标系，而不是超声扫描线采集的极性格式。这样的存储格式将是有益的，因为许多定量算法可以更精确地施加到扫描线数据而不是光栅数据。例如，来自组织速度数据应变率数据的计算是最准确地沿着扫描线施加。不幸的是，DICOM 委员会尚未制定极标准，但超声心动图社区鼓励这样的努力。

结构化报告

DICOM 工作列表。DICOM 工作列表允许图像采集仪器与医院中央调度及登记系统(通常 Health Level 7(HL7)标准编码)协作,从而使即将录入超声心动图仪的患者数据不需要重新打字输入,避免了打字错误的内在风险。强烈支持供应商实现这样一个自动登记系统。

标准化的测量交流。其他最近 DICOM 的工作集中在非成像相关数据元素（病人的人口统计，研究信息，图像/程序的调查结果）。 DICOM 补充 72 标准化术语为成人的超声心动图测量和计算,可以作为一个 DICOM 消息的一部分发送条款。它是由 DICOM 超声工作组（WG12）与美国超声心动图学会合作开发。 DICOM SR（补充 72）的实施，将减轻超声仪器和超声心动图实验室临床信息系统间操作的巨大障碍,并在完成之后敦促供应商采用此标准。

电脑报告。数码影像可以是电脑和超声心动图实验室工作流程再造的催化剂。医师和超声检查师与计算机（包括超声机器本身）交互获取，传输，分析和解释超声心动图。审阅影像同时完成最终报告，图像可以包含在最终的报告中。

美国超声心动图学会发表了报告指南,包括一个超声心动图结构化报告(SR)系统所含的基础数据要素 (“成人超声心动图标准化报告的建议”，可在美国超声心动图学会万维网站点上参阅)。计算机化报告在转录方面有很大的优势,包括报告生成和传播更为迅速,自动输入到数据库,自动计费,增强质量保证。

SR 系统应该支持超声医师和护士的数据输入，从而提高数据保真度并减少医生输入数据。报告本身应该包含一个临床总结和尽可能接近自然语言的详细结果。

医疗企业集成

医疗企业集成（IHE）是一个行业合作的临床整合整个医疗临床信息系统（HTTP：// www.rsna.org/IHE/index.shtml）。它的功能与使用标准，如 HL7 和 DICOM，为供应商的实践提供信息库。其目标是通过提供一个实施框架与现有标准开放连接，提高临床实践的效率和有效性，提高临床信息流动。IHE 始于 1999 年的放射学，通过在 2005 年美国心脏病学会会议计划了示范项目,现在已完全被美国心脏内科协会所接受,并得到美国超声心动图学会的支持。

结论

希望本文将展示出向全数字超声心动图实验室转变的优点和技术。实现数字检查的实验室可以迅速获得优势,随着数字化检查和结构化报告在这一领域普及，全面影响及稳步增长，促进了实验室之间的优化互通性，让患者从中获益。

Guidelines and Recommendations for Digital Echocardiography

A Report from the Digital Echocardiography Committee of the American Society of Echocardiography

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EXECUTIVE SUMMARY

Digital storage and review is now the state of the art in echocardiography, and practitioners are urged to move quickly to an all-digital solution in their laboratories. Although secondary digitization from videotape may be an acceptable transitional solution, the ultimate benefits of the digital laboratory can only be achieved with direct digital output from a contemporary echocardiography machine. Standardization of storage format is critical to enable interoperability within and between laboratories; adherence to the DICOM (Digital Imaging and Communications in Medicine) standard should be ensured in all applications. To achieve studies of acceptably small size, one must use both clinical compression (ie, storage of 1 or several cardiac cycles from selected views) and digital compression (more efficient storage of individual frames and loops). Lossless compression (Packbits run-length encoding) is used by DICOM and is useful for storing still frames such as spectral Doppler or M-mode. Motion-JPEG is the only lossy compression approved by the DICOM committee, and compression ratios as high as 20:1 are supported by the literature and used by manufacturers (see Section 3.3.1 for an explanation of Packbits and lossless/lossy terminology). More aggressive compression schemes (eg, MPEG-1, MPEG-2, and wavelets) are under evaluation by DICOM but for now remain nonstandard for DICOM exchange, although they may be useful for real-time transmission and review over digital networks and the Internet. Hardware requirements for the digital laboratory include high-speed networking (100 megabits per second [Mbps] being the minimum speed in even a medium-sized echocardiography laboratory), industry-standard servers, and storage schemes that support both rapid access for recent and returning patients (RAID [redundant array of inexpensive hard disks] hard-disk array with several weeks to months of storage) and long-term archiving on digital tape, DVD, or magneto-optical media for at least 7 years. All-inclusive digital solutions (hardware, networking, and software) are available from several vendors, or one may prefer to integrate these 3 components individually. During the transition period, parallel review of digital clips and videotape is quite helpful, but in the long run, it is recommended that videotape be used only as a backup in case of network failure and to allow secondary digitization of transient events that may not have been captured digitally. Unless the videotapes are fully reviewed and their content included in the diagnostic interpretation, it is recommended that videotape not be archived but be recycled, perhaps in 1 week's time. A number of pitfalls are discussed, including noisy ECG signals, which can lead to capture of truncated cardiac cycles, and atrial fibrillation, which requires multibeat capture. It is emphasized that digital echocardiography is an evolving field, with future integration anticipated with hospital registration and results-reporting standards. Nevertheless, the field has reached such a state of maturity and stability that an unequivocal recommendation can be made for all-digital capture, storage, and review

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in any contemporary echocardiography laboratory.

Subject to the many nuances discussed in the entire document, our overall recommendations include the following:

Digital capture, storage, and review are recommended for all echocardiography laboratories, regardless of size.

The DICOM format should be used for storage and data exchange.

Both careful clinical editing and digital compression (within DICOM) are required to keep study size manageable.

High-speed ($\geq$ 100 Mbps) networking and a switched architecture are needed for large laboratories.

Redundant short- and long-term storage is necessary, ideally with full mirroring offsite.

Parallel videotape recording is useful for short-term redundancy and to ease the digital transformation; once transformation is complete, videotape should not be archived in the long term.

Integration with computerized reporting software is strongly encouraged.

INTRODUCTION

After years of development, standardization, and relatively slow implementation, the echocardiography world should now fully embrace all-digital storage and analysis. For those laboratories that have made the transition, the advantages of digital echocardiography are all too obvious, with improved efficiency, quality, and clinical service provided to their referring physicians. However, despite the feasibility and advantage of digital echocardiography,[1-4] a recent review of the Laboratory Data Project of the American Society of Echocardiography revealed that only a small minority of echocardiography laboratories currently consider themselves predominately digital in their data handling. For those laboratories still waiting to convert, we hope that this document will provide both the information and the impetus to move them into the all-digital era.

This document represents the official publication from the Digital Echocardiography Committee of the American Society of Echocardiography. The committee began meeting in 2001 and has met triannually since then to identify the issues, pitfalls, and potential solutions for those who seek to adopt a digital echocardiography laboratory. This report will outline some of the historical and technical background of digital echocardiography, address implementation issues for both physicians and sonographers, and introduce concepts beyond mere digital-image storage, such as structured reporting and integration with hospital databases.

Advantages of Digital Echocardiography

Digital echocardiography offers many advantages over analog tape storage:

1) More efficient reading, because the echocardiographer can direct his or her attention to specific clips and review data easily to put together a coherent interpretation of the study.
2) More convenient reading, because the studies are stored on a central server and are available to be pulled up on any computer served by that department's network or, via virtual private networks, anywhere in the world.
3) Easy comparison with previous studies, which eliminates the need to rummage through racks of old videotapes and search for a specific study.
4) Easier quantification, because spatial, temporal, and velocity calibration is built directly into the image, and quantification tools can generally be accessed instantaneously within the reviewing program.
5) More convenient communication with the referring physician, whether by the inclusion of images within a report or by virtue of being able to pull up studies instantly to review the pertinent findings of the examination.
6) Higher image quality, because the images appear exactly as they were originally recorded from the machine, without any degradation from the videotaping process.
7) More stable image quality, because over time, videotape degrades continuously, whereas digital files remain intact (as long as the medium on which they are stored is preserved).
8) Integration of the images and reports within the hospital's electronic medical record.
9) More robust research, because the highest-quality images are available for quantitative measurement with built-in calibration. Digital files may also be forwarded instantaneously from acquisition site to a core laboratory, permitting both better quality assurance and more timely measurements.
10) Easy implementation of a clinical quality-assurance program, whereby echocardiograms can be re-reviewed randomly on a regular basis.
11) Improved accuracy and reproducibility overall.
12) Greater facilitation of medical education, because moving images can now routinely be included in computer-projected presentations at local, national, and international meetings.

Cost-effectiveness. There have been relatively few formal studies to examine the cost-effectiveness of digital echocardiography. One recent study evaluated the accuracy, concordance, and cost-effectiveness of digital versus analog echocardiography for 101 patients with valvular heart disease.[5] Overall, the 2 methodologies gave highly concordant results, but the digital review took 38% less time than videotape review, whereas digital storage (an average of 60 megabytes [MB] on a CD-ROM) costs 31¢ vs 62¢ for Super VHS videotape [NB: contemporary storage on digital tape would cost less than 5¢ per study, further magnifying the cost advantage of digital echocardiography]. A similar study in pediatric echocardiography showed a cost disadvantage for digital storage but used very expensive magneto-optical disks as the medium.[6] Although arguments can be made for digital echocardiography on the basis of a decrease in cost, by far the most compelling argument is on the basis of increased quality and effectiveness.

Historical Development

A full description of the history of digital echocardiography is found in Appendix A, with the reader referred to prior references for further background.[7,8] This Appendix may be found at *www.Digital-Zone.org*.

TECHNICAL ISSUES

Introduction to the Terminology

The hallmark of digital storage of video data is the representation of the image at discrete points on the screen (pixels), with binary numbers (numbers represented only by 0 and 1) used to specify a certain color or gray level. A single binary number is termed a bit, whereas a string of 8 of these is a byte, capable of either representing a letter of text or a number between 0 and 255. The overall image quality is given by the screen resolution (the number of rows and columns in the image) and the number of bits used to represent each pixel. For moving images, there is the additional issue of temporal resolution, which refers to the number of frames per second that are stored. Typical echocardiographic cine loops consist of 480 rows and 640 columns, with 24 bits used to represent the color of each pixel (8 bits [1 byte] used to represent 256 levels each of red, green, and blue, for a total of 16.8 million possible colors). The typical frame rate is 30 Hz. Multiplying these numbers together ($640 \times 480 \times 30 \times 24$) yields an enormous storage requirement of 221,184,000 bits per second (bps), or more than 16 gigabytes (GB) of storage for a typical 10-minute study. As enormous as this storage requirement is, with improvements in echocardiographic quality, it may become reasonable to store images at even higher resolution, perhaps 800×600 pixels, and at the full frame rate that contemporary echocardiography machines can achieve with parallel processing, as high as 200 Hz, thereby increasing by 10-fold the total storage requirement. To accommodate these prodigious storage requirements, a combined strategy of "clinical compression" (the storage of only 1 or a few cardiac cycles for a given view) and digital compression (storage of a given image in fewer bytes) is required. Clinical compression can reduce storage needs many-fold, because a single cardiac cycle (played over and over) may replace 30 to 60 seconds of imaging on videotape. Digital compression can be either lossless or lossy, depending on whether the image is altered in any way or not. Lossless compression can reduce storage needs by up to 3:1, whereas lossy compression routinely compresses the image 20:1 or more. Specifics of these techniques will be discussed below.

DICOM Image Formatting Standard

As noted above, early digital archiving systems for medical applications used proprietary, closed technology for image storage, so a study recorded with the use of one manufacturer's system could not be viewed on another vendor's equipment. To head off this coming "tower of Babel" in medical imaging, the American College of Radiology (ACR) and the National Electrical Manufacturers' Association (NEMA) organized in the early 1980s to standardize the exchange of digital images. Initial versions were published in 1985 and 1988 but had little impact in cardiology because angiography and echocardiography (beyond single-frame gray-scale images) were not addressed. The scope was further limited to point-to-point communications, meant to allow ACR/NEMA–compliant radiographic machines to exchange images, with no provision for storage of these images on exchange media, whether floppy disk, hard disk, or magnetic tape. Furthermore, the protocol was extremely limited, requiring the use of a unique 50-pin connector, which did not conform to any emerging networking standards in the computer industry. By contrast, version 3 of the ACR/NEMA standard, now specified as DICOM to emphasize its role in the general field of medical imaging and the inclusion of many other professional organizations (including the American College of Cardiology, the American Society of Echocardiography, and the American Society for Nuclear Cardiology) in its formulation, has addressed many of the prior limitations. It now specifies a much wider range of image types, including ultrasound, magnetic resonance imaging (MRI), computed tomography (CT), and x-ray angiography. In particular, recording of color images is now enabled, as is recording of moving images and physiological data. DICOM specifies both network exchange of images and media exchange and is now an industry standard.

Overall structure of DICOM. DICOM is simply a set of rules to specify how images and other data should be exchanged between compliant pieces of equipment. Individual image files are stored with information on the patient, the purpose and technique of the examination, interpretation of the image, and of course, the pixel data themselves. Each modality (echocardiography, CT, MRI, nuclear medicine, and angiography) has specified which data elements are required and which are optional in the file and the exact nature of the pixel storage, including any possible digital compression. Images may be exchanged either by network or by disk. For network communications, a process of negotiation ensues between equipment to determine the most efficient format for the image data to be exchanged (as a lowest common denominator, all must be able send and receive uncompressed images). For disk exchange, the format must be agreed to in advance (termed "application profiles," specific to each modality); this composed the bulk of the DICOM efforts from 1994 to 1996. It should be emphasized that DICOM is not an archival standard but rather a communication and exchange standard. Within an institution, images may be stored on whatever media are most appropriate.

DICOM for echocardiography. In echocardiography, the needs for image interchange are diverse. Accordingly, several interchange media are supported by the standard. Gray-scale, color, and spectral Doppler images can be exchanged over a network or stored on 1.44-MB floppy disks, 3.5- and 5.25-inch magneto-optical drives, and CD-R disks. Calibration factors may be stored for linear, temporal, and velocity measurements and 3-dimensional (3D) registration. Images may be stored either uncompressed or with lossless or lossy compression. An in-depth review of the DICOM standard for echocardiography is available for the interested reader,[9] but for most purposes, it is sufficient to know that a given piece of equipment fully supports the DICOM standard, without worrying about details of the implementation.

Digital Compression

Lossless (eg, Run-length Encoding). Digital compression of images falls into 2 broad categories: lossless and lossy. As the name implies, lossless algorithms allow the original image to be recovered in every detail, removing all concern that such compression might affect the clinical content of the image. For lossless encoding, the echocardiographic DICOM standard uses a scheme called Packbits, wherein repetitive blocks of same-valued pixels are coded very efficiently (termed run-length encoding, or RLE). A disadvantage of all lossless techniques is relatively poor compression ratios, typically 2:1 or 3:1.

JPEG. To gain more efficient compression (often beyond 100:1), lossy algorithms must be used that distort the recovered image in a slight (and, it is hoped, unimportant) fashion. The DICOM echocardiography standard allows the use of the lossy JPEG (Joint Pictures Expert Group) algorithm, in which 8×8 pixel blocks undergo a discrete cosine transform, and only the significant (mostly low) frequency components are stored. Quantitative image analysis has shown little degradation of echocardiographic images at compression ratios as high as 20:1, whereas images stored on Super VHS videotape show degradation equivalent to 26:1 to 30:1 compression.[10] In a blind comparison, a large group of observers overwhelmingly selected digital echocardiograms over videotape equivalents, with no impact of 20:1 JPEG compression.[11] Other studies have shown that 20:1 JPEG compression has no adverse impact on edge-detection algorithms and allows accurate extraction of velocity from color Doppler maps.[12] Thus, 20:1 JPEG compression appears acceptable in clinical echocardiography. Other trials have shown the acceptability of lossy compression for computed tomography and nuclear medicine.

MPEG. Higher degrees of compression are available from other algorithms, although these have not yet been standardized within DICOM. The MPEG (Motion Pictures Expert Group) approach extends JPEG by exploiting redundancies between frames, achieving compression ratios beyond 100:1 with excellent fidelity. MPEG is attractive because it is emerging as the standard for multimedia computing and entertainment, and prior concerns that it was more difficult to encode than decode and did not allow crisp stop frames appear to have been alleviated. It has been demonstrated that MPEG encoding has diagnostic content equivalent to videotape,[13] with accurate quantitative measurements possible,[14] whereas even higher quality can be obtained by transmitting echocardiograms over high-speed digital networks (5 Mbps) using MPEG-2 encoding.[15] The advantages of MPEG for digital echocardiography are most pronounced when it is advantageous to record a significant amount of continuous video (i.e., when clinical compression is suboptimal). For this reason, MPEG had been implemented primarily in systems designed for pediatric echocardiography, to enable capture of longer continuous video sweeps. However, lack of adoption in DICOM remains a limitation of MPEG.

Others. Among other algorithms being evaluated are wavelet compression, which uses a continuum of frequencies to compress the image rather than the discrete frequencies of the Fourier transform,[16,17] and H.261, a multiframe precursor of MPEG widely used in video conferencing. Wavelet compression forms the basis for the new JPEG-2000 standard, which is being considered by the DICOM committee. Wavelets also can be readily expanded to multiple dimensions and have been shown to compress 3D echocardiographic data by as much as

100:1 without significant loss of image content.[18] Although these new compression algorithms clearly have advantages over the current JPEG method used in echocardiography, until they are formally adopted by the DICOM committee and universally implemented by vendors, the echocardiography community is cautioned against their use clinically, because they may limit interoperability between systems and laboratories.

Components of the Digital Echocardiography Laboratory

Image acquisition: Digital echocardiography machine vs. image digitizer. The most efficient way to obtain true digital echocardiographic data is with a contemporary cardiac ultrasound machine that enables direct output of digital images and loops using a standard network protocol and the DICOM format. Fortunately, all of the major manufacturers have instruments on the market today that provide just such digital output, although their implementation details may differ. With direct digital output, maximal fidelity is maintained, and calibration elements are stored directly with the DICOM data, facilitating quantitation on the review workstation. The machines can be configured to store loops containing single or multiple cardiac cycles, as well as loops of fixed duration (typically 1 to 3 seconds). Although a default value (perhaps 1 cardiac cycle) can be preset, the ability to easily adjust the duration of a loop is important to obtain data in studies with arrhythmias or complex anatomic abnormalities. The quality of the electrocardiographic (ECG) signal on the echocardiography machine is critical to proper acquisition of complete cardiac cycles of echocardiography data. A common pitfall is a loop that is too short because the spikes of a noisy ECG signal, dysrhythmia, or pacemaker are interpreted as successive R waves. It is suggested that echocardiography vendors implement algorithms to recognize cardiac cycles of, for example, less than 400 milliseconds as those most likely to be truncated by noise in the ECG and automatically default to a longer capture so the data are not lost at the time of acquisition.

Older existing systems may be adapted for digital use by external digitizing modules that connect to the video port of the echocardiography machine. Protocols can export either single frames, a fixed time interval of data, or full cardiac cycles, the latter by detecting R waves from the screen ECG. A disadvantage of this approach is lower image quality than with direct digital output, although digitization of the direct red-green-blue (RGB) signal is much preferable to videotape digitization. Also, calibration data and other patient information are not stored with the images. Nevertheless, for legacy systems, this is an acceptable way of integrating them into a digital laboratory, although it may make more financial sense to defer including these aging machines in the digital laboratory until they are replaced by more contemporary machines during the regular equipment upgrade cycle. Video capture has also been proposed for streaming-video solutions to digital echocardiography (also called "full-disclosure" storage models). Images are usually stored with MPEG compression, which allows longer clips to be captured in a manner that resembles a digital VCR. This may have advantages in pediatric and transesophageal studies, in which long sweeps are desirable. The streaming nature also allows real-time monitoring and guidance of acquisition. However, the lack of calibration and lack of support within DICOM are disadvantages of this approach.

Image transmission: network considerations. Network transfer is the most efficient method to deliver echocardiographic studies to a DICOM server. Echo loops can be sent either at the conclusion of the study or, more efficiently, incrementally as each view is obtained, which means there is no delay between the end of the study and the availability of the images for review by the cardiologist. If network access is not available for bedside studies throughout the hospital, data can be stored on the internal hard disk and transferred later to the server. It is less desirable to use optical disks for transferring images from the echocardiography machine to the review workstation (which is slower and more prone to human error), but it may be necessary in cases in which direct networking is not possible or in remote laboratories or clinics.

Echocardiographic studies are generally stored on a hard drive within the echocardiograph and retained until the drive is full, at which point the oldest study is automatically deleted to make space for the current examination. This procedure allows multiple studies to be held on the device for subsequent transfer, and it provides a mechanism for short-term redundancy of the data. However, the laboratory must adopt a disciplined approach to network transfers of portable studies, to ensure that local data are not overwritten. Manufacturers must give users appropriate warning of such overwrites before they occur.

A complete adult echocardiography study may consist of 50 to 100 MB of compressed imaging data (1 to 2 GB of uncompressed data), which must be moved across the network when the examination is first conducted and every time it is reviewed. This single examination may generate several hundred megabytes of network traffic in a given day, totalling tens of gigabytes daily for a busy laboratory and requiring a fast efficient network. Older hospital networks have a speed of 10 Mbps, far too slow for a busy digital echocardiography laboratory. Much more usable are 100-Mbps networks, and heavily trafficked lines, such as the connection between the DICOM server and the archive, would benefit from gigabit (10^9 bps) technology.

Even more important than the basic speed of the network is having the proper architecture. Network switches are preferable to routers because they establish an isolated connection between the 2 computers that are transferring data at a given time, thus limiting impact on the remainder of the network. Most of the echocardiography vendors are in the process of migrating from 10- to 100-Mbps output cards, although incremental transfer of clips will largely overcome the disadvantage of the slower cards.

The ability to connect devices with various networking parameters (speed: 10 vs. 100 Mbps and duplex: half vs. full) requires the switch to automatically sense the proper configuration of a device and establish a reliable connection. Autonegotiation between echocardiography machines and the network switch is sometimes imperfect, requiring network drops to be configured with fixed parameter settings, thereby restricting network connections for some machines to specific locations. Manufacturers should work toward improving flexibility in these autonegotiations.

Another possible difficulty in some environments may be the inability for some echocardiographs to dynamically obtain a network address. Dynamic Host Configuration Protocol (DHCP) services are often used to allow connections in various locations and maintain an order to the control and uniqueness of network addresses. Unfortunately, current DICOM configurations on some machines require fixed network addresses, in part to enforce security. However, the need for portable echocardiographic services should encourage manufacturers to provide DHCP services to make networking as convenient as possible.

Wireless telemetry. Even greater flexibility in portable studies can be obtained by wireless transmission of echocardiographic images from the machine to the server. Possible technologies include Bluetooth, which is capable of transmitting data at 1 Mbps over a range of approximately 10 meters, a data rate that may be too slow for digital echocardiography. More promising is 802.11b, which is capable of 11-Mbps transmission over 50 meters, with a specification that is easily integrated into a standard Transmission Control Protocol/Internet Protocol (TCP/IP) network protocol. The combination of DHCP with 802.11b would enable echocardiograms to be moved to the archive effortlessly from anywhere within the hospital that the wireless "cloud" exists. Even higher speeds (up to 54 Mbps) are possible with the recently approved 802.11g standard.

Image storage: removable media, short-term archive, long-term archive; disaster recovery backup. In most circumstances, echocardiography data should initially be stored locally in the echocardiography laboratory area on a high-capacity hard-disk array so that the images are readily available for review that day. A large laboratory may wish to establish an RAID array with a terabyte or more of storage capacity, which would allow (at a data generation rate of 10 GB per day) more than 1 month's worth of data to be stored locally while maintaining sufficient space to review old studies from the archive. RAID array servers automatically store duplicate data copies in separate hard drives, which provide extra protection from data loss. The size of the local storage can be tailored to fit the data generation and particular requirements of a given laboratory. Storage capacity that includes not only current studies but also older studies performed in active patients (e.g., outpatients with scheduled echocardiography examinations and all inpatients) is desirable for serial comparison. A system that communicates with the hospital information service may search and retrieve selected studies ahead of time (prefetch) from long-term to local storage. Fortunately, the cost of hard-disk storage has fallen so dramatically that even a terabyte or more of local storage is not an unreasonable expense for a large laboratory.

In addition to local storage, a long-term archive is essential, in which old studies can be stored permanently and subsequently retrieved as needed. DICOM does not specify the form or format of the archive, only the communications protocol to move images to and from it. Depending on the size of the laboratory and other local circumstances, an archive may take the form of a jukebox of optical disks, CD-ROMs, or DVDs. Alternatively, digital linear tape (DLT) or advanced intelligent tape (AIT) provides a very cost-efficient storage medium. Often a large archive will be established for the entire institution, allowing storage of more than 1 pedabyte (PB) of data (1 PB = 10^{15} bytes). An archive should have an access time of less than 2 minutes for a given study and a transfer rate greater than 2 Mbps after the connection is established, ideally with a gigabit line connecting it to the server. Even with this speed, it may be preferable to have the daily echocardiography data archived over the network at night. Thus, even if the local storage device were to fail, less than 1 day's worth of echocardiograms would be lost (and potentially recoverable, because the local hard drives of the echocardiographs may retain a study for longer than 1 day).

The degree of system redundancy dictates how smoothly it can function in the event of a failure. At the least, the archive should simultaneously generate a second copy of each study (backup) that would be stored in an entirely separate location to guard against catastrophic failure of the archive itself. Ideally, there would be 2 or more completely redundant hardware-software combinations, allowing instantaneous and seamless switching over to the backup system, although the expense of total redundancy may make it necessary to accept the occasional (hopefully brief) outage of digital review capabilities.

Archiving software. Equally important as the hardware for digital acquisition is the software to manage the storage, transfer, and archival of data, as well as the connectivity to hospital information systems for scheduling, reporting, and billing. This software, in general, runs continuously in the background over the network, interacting with each of the echocardiography machines and viewing stations. It manages image transfers from the network echocardiography machines or computer disk to local storage and then migrates that data onto the archive. Ideally, software should be available to facilitate laboratory workflow, including scheduling, prefetching, billing, reporting, and quality assurance.

This software may be part of an integrated hardware-software network solution or a stand-alone piece of software to be used on third-party hardware purchased separately, the choice of which must be based on local laboratory circumstances. The advantages of the integrated solution are clear: a single vendor will be responsible for maintaining the integrity of the entire system, thus relieving the end user of the responsibility of managing the individual components. Such convenience comes at a price, however, because such solutions generally are more expensive than purchasing the hardware and software separately. If significant local expertise is available for maintaining the system, and particularly if major components of the digital echocardiography laboratory mentioned above are already in place, it may make more sense to purchase hardware and software separately. Again, the choice is strictly a local one, and there is no obviously preferred way, just different tradeoffs. The user is advised to consult with the hospital's or practice's information technology department early in the process to better understand the capabilities and constraints of the local situation. For example, there may already be a systemwide archive available (and perhaps mandatory) for use; any potential digital echocardiography solution must use that archive to be practical.

Image review: standards for workstations and monitors. A topic that has not received much attention in the digital echocardiography world is the establishment of standards for monitor performance. Such issues as pixel sharpness, image isotropy, and picture brightness are obviously important to the ease and accuracy of physician interpretation. The radiological community has made some efforts to standardize monitor brightness for the reading of plain x-rays, which are very demanding in terms of spatial resolution, contrast, and gray-scale depth.[19] In general, however, most contemporary monitors are of sufficient quality to provide adequate display of the relatively lower-resolution ultrasound images, particularly in combination with brightness and contrast controls intrinsic to the server software.

Table 1 Transmission time requirements in telemedicine for 50-MB study

28.8-kbps modem	3.9 hours
112-kbps ISDN line	1 hour
768-kbps DSL	8.6 minutes
768-kbps cable modem	8.6 minutes
1.54-Mbps T1 line	4.4 minutes
10-Mbps Ethernet	40 seconds
45-Mbps DS3	9 seconds
100-Mbps Ethernet	4 seconds
650-Mbps ATM	0.6 seconds

Cable modem and DSL speed may vary between 128 kbps and 3 Mbps. Cable modem bandwidth is also impacted by simultaneous utilization by other customers.
ATM, Asynchronous transmission mode; DS3, digital signal 3; DSL, digital subscriber line; ISDN, integrated services digital network; and KBPS, kilobytes per second.

Telemedicine considerations. One of the great advantages of digital echocardiography is the facilitation of meaningful telemedicine consultation. However, the networking requirements of the hospital-based laboratory become even more important in telemedicine, because the connections are generally much slower. For example, telemedicine links between outlying satellite facilities and a central reading facility typically use a T1 line for transfer, which has a maximal speed of 1.54 Mbps. Thus, if the full bandwidth of the T1 line is available, which rarely occurs, it would take approximately 5 minutes to transfer a 50-MB echocardiography study. With incremental transfer from the echocardiography machine, this is significantly ameliorated, but if echocardiography studies need to be reviewed at the satellite facility from the central archive, such a delay can become intolerable. Table 1 illustrates representative times to transmit a 50-MB study over lines of varying speeds. As Internet speeds improve, transfer times can be reduced considerably, but will never be faster than the slowest component.

Related to telemedicine are requests from outside the laboratory for duplicate recordings of studies. Most vendors offer the ability to burn digital echocardiography studies directly onto a CD. The review software is copied onto the CD for review on any desktop personal computer. If a CD burner is not available, it will be necessary to incorporate a system to connect the digital system to a video recorder. Some ultrasound systems have the ability to retrieve a study from a disk and record it onto videotape at the ultrasound system. Ultimately, direct digital transfer of a study over the Internet (similar to e-mail but with appropriate security assurances) will be the most efficient method for facilitating outside review.

IMPLEMENTATION ISSUES

What to Store Digitally

Single- or multiple-cycle storage. As noted above, the relatively modest compression afforded by the JPEG algorithm requires clinical compression of echocardiograms in the form of capturing only 1 or several cardiac cycles of data rather than more extended recordings. Fortunately, DICOM allows flexible capture, either a fixed period of time (usually 1 to 3 seconds) or, with R-wave detection, capture of single or multiple cardiac cycles, which generally is preferable, because wall-motion abnormalities are better appreciated from discrete cardiac cycles with no partial beats being shown. There are several situations in which longer captures (10 seconds or more) might be preferable:

1) Saline contrast injection to assess left-to-right shunt flow, in which the timing of the passage is important in differentiating cardiac from pulmonary shunts.
2) Pediatric studies, in which sweeps are used to relate 1 structure to another[20,21]; however, a recent report suggests that multiple single-cycle clips can be effective in sorting out complex anatomy.[22]
3) Atrial fibrillation or frequent ventricular ectopy, for which multiple consecutive beats should be examined to better appreciate ventricular function.
4) Transesophageal and intraoperative echoes that may benefit from longer sweeps to better delineate the pathology (although it is usually possible to obtain comparable information from a series of anatomically oriented loops).

Noisy ECGs. Noisy ECGs and dual-chamber pacemakers may lead to truncated cardiac cycle capture. Every effort should be made to obtain a technically adequate ECG recording, confirmed by checking the quality of the captured loops early in the study and, if problems are identified, switching to a timed acquisition mode. Manufacturers are encouraged to make this switch automatically anytime an unusually short R-R interval is sensed and to develop an automated method to recognize dual-chamber pacemakers and adjust the capture for them.

Videotape

What to record, what to review, and how long to keep it. Analog videotape archiving has been the standard method of storing cardiac ultrasound studies for more than 25 years. Digital acquisition and storage obviates the need for parallel storage in both digital and video (analog) formats. Nonetheless, laboratories may perceive the need to store videotape for some of the following reasons: 1) during the transition from analog to digital acquisition; 2) concern for viability of the digital media; and 3) for backup and disaster recovery With regard to the first issue, laboratories making the transition from analog to digital storage will need to train sonographers and attending physicians in digital acquisition and interpretive techniques. This training can be facilitated by parallel review of analog and digital studies for a finite period, usually 3 to 6 months. With regard to issues 2 and 3, current digital technology provides for multiple fault recovery, including data availability for several days on the ultrasound carts, storage in a universal format (DICOM), use of standard hardware widely supported by the computer and entertainment fields (DVD, tape, or hard disks), and multiple levels of redundancy (offsite mirrored storage). Analog videotape adds little to this, except for short-term recovery in the case of temporary network failure or an inadequately digitized study. However it is recognized that should a lab replace one digital archival system with another, there may be cost and/or technical constraints that limit both migration of images from one system to another and continued access to the original archive. Thus there may be a rationale for longterm tape storage.Please note that videotape in long term storage is discoverable in the event of litigation.

Therefore, we, in general, recommend complete transition from analog to digital storage, without long-term videotape archival recognizing special circumstances that justify exceptions to this policy exist. It is reasonable to continue video recording at the time of the study in case the digital images are inadequate or a transient event is missed in capture. Any video sequence thus used in the interpretation should be secondarily digitized from the videotape and stored in the DICOM format in the permanent digital archive. Videotapes may then be recycled with a lifespan of several days to a week. If a laboratory chooses to archive the videotape, it is strongly suggested that it be reviewed fully as part of the echocardiography interpretation.

Sonographer Issues

Training, implementation, making the transition, and pitfalls. A critical aspect of echocardiography—the sonographer's ability to record a representative echocardiogram—is magnified when the digital format is used. Instead of indiscriminately recording

Table 2 Sample acquisition protocol

PLAx*	Ap5Ch (AV zoom)*
PLAx (MV/AV zoom)*	Ap2Ch*
RV inflow*	ApLAx*
RV outflow*	ApLAx (MV/AV zoom)*
PSAx (AV)*	SCLAx*
PSAx (MV)*	SCSAx
PSAx (LV)	SSAoArch*
PSAx (Apex)	PW: MV, LVOT, TV
Ap4Ch*	RVOT, PV, HV
Ap4Ch (MV zoom)*	CW: MV, AV, TV, PV
Ap4Ch (TV zoom)*	M-Mode sweeps

A total of 33 loops (15:1 JPEG ≈1.5 MB) + 10 stills (RLE, 200 kB); 50-MB/study × 180 studies/day = 9 GB/day = 2 terabytes/year.
AV, Aortic valve; Ap2Ch, apical 2-chamber; Ap4Ch, apical 4-chamber; Ap5Ch, apical 5-chamber; ApLAx, apical long axis; CW, continuous-wave; HV, hepatic veins; LV, left ventricle; LVOT, left ventricular outflow tract; MV, mitral valve; PLAx indicates parasternal long axis; PSAx, parasternal short axis; PV, pulmonic valve; PW, pulsed-wave; RV, right ventricle; RVOT, right ventricular outflow tract; SSAoArch, suprasternal notch aortic arch; SCLAx, subcostal long axis; SCSAx, subcostal short axis; and TV, tricuspid valve.
*2D + color.

long lengths of videotape to capture a view, the sonographer must record a single representative digital clip.

When preparing for implementation of the digital echocardiography laboratory, careful evaluation of the current recording routine is crucial. A standardized, written recording protocol, soliciting input from all sonographers and physicians, will make the transition easier, incorporating each current analog view in the digital acquisition protocol. Table 2 is a sample protocol to guide acquisition. Capturing a single cardiac cycle per view in this protocol yields ≈50 MB of imaging data, but sonographers may be more comfortable capturing either multiple cycles in a clip or multiple clips in a view to ensure that the pathology is adequately demonstrated. Additional nonstandard views are necessary to fully show specific anatomic features.

The transition to digital storage may well be implemented in stages. Initially, the entire echocardiogram should be recorded digitally and on videotape, allowing the interpreting physicians to review both and permitting adjustments to the digital protocol based on sonographer and physician feedback. As the sonographers and interpreting physicians become comfortable with digital acquisition and review, the videotape should be used only as a short-term backup, as described above. The permanent record will be the digital data.

Because the sonographers are on the front lines of acquisition, they must be vigilant for many of the pitfalls mentioned above:

- Noisy or paced ECGs must be recognized at the time of acquisition and the leads modified or acquisition switched to a timed mode.
- Atrial fibrillation and other dysrhythmias require acquisition of multiple consecutive beats or several seconds per clip to ensure a representative view is captured.
- Truly transient events may be impossible to capture unless the echocardiography machine has the ability to acquire data that have just been viewed rather than subsequent data. Vendors are encouraged to develop equipment with such a capacity. If this is impossible, secondary capture from videotape will be required to store the transient event.
- Doppler audio signal: it may be necessary to record single-frame, still-image recordings of spectral Doppler without the audio signal. Sonographer expertise is crucial to representing an accurate recording of the Doppler tracing.

The sonographer's role as a decision maker always demands a high-level understanding of cardiac anatomy, physiology, and ultrasound physics, and bad habits or study flaws are magnified when digital loops are being recorded. This potential pitfall can be used to identify and improve the sonographer's imaging technique, because the ability to immediately identify poor habits and address them is far easier when the digital recording format is used.

Physician Issues

Training and transition issues. Physician transition to the digital laboratory also requires a gradual process of education and training and may occur more smoothly if started with 1 or 2 physicians to work out any technical and implementation issues before the digital protocol is generalized to the rest of the laboratory. Physicians must become comfortable with simple troubleshooting, such as noisy ECGs and network cable connections.

For most members of the Digital Echocardiography Laboratory Committee, the process of converting to full digital review was surprisingly short. Experienced sonographers quickly embraced clipping, and within 1 to 4 weeks, most physicians believed that the advantages of digital review, such as side-by-side comparison and offline measurements, overcame any limitations, allowing routine videotape review to be avoided.

Registration errors such as incorrect medical record labeling or name spelling must be recognized at the time of review and corrected immediately to avoid data loss. Most such errors can be prevented when registration is taken directly from the hospital information system. All of these issues require constant and close communication between echocardiographers and the sonographer performing the studies. It is important to conduct quality-assurance surveys regularly to detect and correct digital errors.

The Intersocietal Commission for the Accreditation of Echocardiography Laboratories can now accept digital examinations stored in the DICOM format, and experience has shown that the presence of a digital laboratory eases the accreditation process.

Security Issues

Patient confidentiality requires that every effort be made to ensure that access to digital echocardiographic images be limited to those with a clinical need to access the data. At the least, this requires that access to the server software be controlled by user name and password, preferably with logging of all activity to ascertain any unauthorized access.

Congress has mandated strict security measures through the Hospital Insurance Portability and Accountability Act, the technical details of which are handled by the hardware and software vendors.

BEYOND IMAGES

DICOM extensions

3D Data. The original DICOM standard for ultrasound, adopted in the mid 1990s, provided only for exchange of images stored in a raster-based format. 3D data were addressed, but only in a rudimentary way, referencing the location of registered 2-dimensional slices in 3D space. Currently, a DICOM Working Group is actively rewriting the standard to allow exchange of true multidimensional data sets.

Polar data. Another limitation of the original DICOM standard was that echocardiography data were stored only in cartesian coordinates, rather than the polar format of the ultrasound scan-line acquisition. Such a storage format would be helpful, because many quantitative algorithms can more accurately be applied to scan-line data than to raster data. For example, calculation of strain-rate data from tissue-velocity data is most accurately applied along a scan line. Unfortunately, the DICOM committee has not developed a polar standard, but the echocardiography community encourages such an effort.

Structured Reporting

DICOM work lists. DICOM work lists allow the image-acquisition machine to interact with the hospital centralized scheduling and registration system (generally encoded in the Health Level 7 (HL7) standard) to enable patient data to be entered into the echocardiography machine without the need to retype it, with the inherent risk of typing error. Vendors are strongly encouraged to implement such an automated registration system.

Standardized measurement exchange. Other recent work in DICOM has focused on nonimaging data elements (patient demographics, study information, image/procedural findings) that can be associated with an image or image set. DICOM supplement 72 standardizes terms for adult echocardiographic measurements and calculations that can be transmitted as part of a DICOM message. It was developed by the DICOM Ultrasound Working Group (WG12) in collaboration with the American Society of Echocardiography. Implementation of DICOM SR (supplement 72) will alleviate a significant barrier to interoperation of ultrasound machines with echocardiography laboratory clinical information systems, and vendors are urged to adopt the standard when it has been finalized.

Computerized reporting. Digital imaging can be a catalyst for computerization and reengineering of echocardiography laboratory workflow. Physicians and sonographers interact with computers (including the ultrasound machine itself) to acquire, transmit, analyze, and interpret echocardiography studies. Final reports can be generated at the same time as study review, and images can be included in the final report.

The American Society of Echocardiography has published reporting guidelines that include base data elements that should be included in an structured report (SR) system for echocardiography ("Recommendations for a Standardized Report for Adult Transthoracic Echocardiography," available on the American Society of Echocardiography's World Wide Web site). Computerized reporting has considerable advantages over transcription, including more rapid report generation and dissemination, automated input into a database, automated billing, and enhanced quality assurance.

An SR system should support data input by sonographers and nurses to improve data fidelity and reduce data entry by physicians. The report itself should contain a clinical summary and detailed findings in as close to natural language as possible.

Integrating the Healthcare Enterprise

Integrating the Healthcare Enterprise (IHE) is an industry-clinical partnership to integrate clinical information systems throughout health care (*http://www.rsna.org/IHE/index.shtml*). It functions as an implementation guide using standards such as HL7 and DICOM to provide dictionaries for vendor implementation. The goal is to improve the efficiency and effectiveness of clinical practice by providing an implementation framework for open connectivity with existing standards and to improve clinical information flow. IHE began in radiology in 1999 and is now fully embraced by the American College of Cardiology, with a demonstration project planned for the 2005 American College of Cardiology meeting, with endorsement from the American Society of Echocardiography.

CONCLUSIONS

It is hoped that this document will demonstrate both the advantages and mechanics of migration to an all-digital echocardiography laboratory. Although benefits will accrue immediately to any laboratory that implements digital review, the full impact will grow steadily as digital review and structured reporting are generalized within the community, allowing optimal interoperability between laboratories, to the benefit of our patients.

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