Data management practices of cone beam computed tomography volumes: An exploratory user survey

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Objective. The aim of this study was to query cone beam computed tomography (CBCT) users about their storage and transfer practices to identify trends in the handling of CBCT data in dentistry.

Study Design. A computer-based survey was distributed to 2 CBCT user groups. The survey consisted of 18 questions on settings for data capture, data storage, archiving strategies, bit depth/compression, monitoring user access to patient information, and dissemination to end users. All information was anonymously collected. Descriptive data and frequency patterns were collected and discussed.

Results. A total of 68 surveys were returned, with 56 fully completed. Results reflected a low consensus about usage and management of radiographic data sets. Some preferential usage patterns, however, were noted along with the following trends:

(1) 53% of respondents utilized Digital Imaging and Communications in Medicine volumetric data sets for initial storage.

(2) 46% of respondents saved data in raw or native file formats.

(3) 60% of storage sites were in onsite servers.

(4) 35% of volumes saved were in a "Zip" compression format.

(5) 37% of respondents used a picture archiving and communication system for storage.

Conclusions. The absence of consensus on postcapture management of volumetric data sets indicates that a dentistry-wide data management standard would benefit patient care while mitigating information technology storage issues. (Oral Surg Oral Med Oral Pathol Oral Radiol 2019;128:e100−e107)

Over the past 2 decades, an increasing number of patient-centered cone beam computed tomography (CBCT) applications has triggered a proliferation of CBCT imaging systems in the dental marketplace. This proliferation has engendered significant information technology (IT) challenges—in particular, data storage and transfer. A wide variety of imaging platforms and equally diverse vendor software have a potentially adverse impact on patient care. This issue has been particularly notable during volume retrieval, when multiple providers are involved in a single patient's health care. In brief, standardized protocols do not exist when managing data-rich CBCT studies, especially when data are acquired across multiple platforms.

Digital Imaging and Communications in Medicine (DICOM) is a currently mandated standard of managing patient digital records. With respect to imaging, the DICOM standard is designed to address interoperability between multiple manufacturers' imaging devices when processing viewing, storing, printing, and transmitting medical imaging data. In the simplest applications, the DICOM standard includes file format definition and a protocol for network communications.[1] DICOM is now an International Organization for Standardization standard and shows promise for handling CBCT data sets when clinicians prefer to use third-party DICOM-compliant software for viewing data sets. However, there are drawbacks (e.g., cost and user flexibility) because CBCT imaging vendors prefer to recommend saving their data sets in a proprietary format, which, in turn, discourages third-party use of viewing software and thus DICOM's universally accepted format in dentistry.[2-4]

Statement of Clinical Relevance

We surveyed users regarding management practices of cone beam computed tomography volumes. Results showed multiple management strategies for scan volumes. We recommend the use of a standardized Digital Imaging and Communications in Medicine format for volumes and various information technology management protocols to achieve more efficient patient care.

This research was originally presented in oral format as: Saving, transferring and long-term storage of CBCT volumes: a user survey. American Academy of Oral and Maxillofacial Radiology 67th Annual Session. Scottsdale, AZ, USA. Oral Presentation (September, 2016).

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We created and distributed a web-accessible survey to begin to obtain a clearer perspective of storage issues while also collecting a cross-sectional assessment of how dental health care facilities provide CBCT services and manage patient CBCT data sets. Survey questions were designed to assess respondents' protocols of data management, with emphasis on collection and archiving. Question sets were posted on 2 major CBCT user e-mail message boards. This article presents a summative descriptive analysis of user responses and a discussion of the findings.

The objectives of this study were to query CBCT users about their storage and transfer practices and to identify trends in the handling of CBCT data in dentistry.

MATERIALS AND METHODS

Questionnaires were posted with Qualtrix Survey Solutions online survey software (Qualtrix, Provo, UT). The survey was posted in winter 2015, and responses were collected by April 2016. The survey was conducted among 2 CBCT user groups—(1) ORADLIST, an online discussion group hosted by information technologists at the University of California at Los Angeles; which includes oral and maxillofacial radiologists, other dental specialists, generalist dentists, and other clinicians and related professionals; and (2) the American Association of Dental Maxillofacial Radiographic Technicians (AADMRT). Both groups include oral and maxillofacial radiologists, other dental specialists, generalist dentists, and other clinicians and related professionals with an interest in oral and maxillofacial radiology. Surveys were emailed to all AADMRT members by the AADMRT administrative team via direct electronic mailing. All ORADLIST members received an email via the group's discussion board, linking them to the survey.

Questionnaires consisted of 18 questions related to CBCT scan data storage, retrieval, and archival methods. The following study introduction and scope was posted on the first survey window: "We are interested in the trends and patterns of CBCT users when it comes to saving, transferring and storing CBCT volumes. We use axiUm and MiPACS at our institution. Depending on the CBCT manufacturer and particular unit, the level of management for the different types of files may vary. This brief survey will provide information on the trends of CBCT users in our oral- and maxillofacial-imaging community. Thank you for your contribution to this effort."

Respondents anonymously answered questions on topics including data capture settings, where and how data are stored and backed up, bit depth compression, user access, patient information protection, and the dissemination of scan volumes to end users. All survey questions and results are listed below. Observed trends and descriptive statistics in data management are described where possible.

RESULTS

A total of 68 surveys were returned, with 56 fully completed. Respondents were not restricted to single answers. Where multiple management strategies applied to a given question, respondents were encouraged to answer appropriately. As a result, the number of responses often exceeded the number of respondents.

Survey questions: management practices of CBCT data volumes

As shown in Table I, 53.1% of respondents were from academic teaching clinics and 37.0% from imaging centers. The remainder were from smaller centers: primarily dental clinics, data storage providers (1.2%), dental hospitals (1%), and a specialty dental clinic (1%). Some facilities functioned in multiple capacities. For example, an academic institution may also serve as an imaging center for the local professional community.

As summarized in Table II, more than half the respondents (53.8%) did not use a PACS, but stored data on the scanner's capture central processing unit (CPU) or auxiliary CPU. 21.2% used MiPACS, a third-party PACS product that is marketed to the dental profession. Proprietary storage systems of CBCT manufacturers (e.g., Schick, Accuitomo, etc.) were used by 7.4% of respondents. The remaining 17.6% included a variety of other third-party systems, which were mainly a PACS, such as Infinitt, OnDemand 3-D, and Dolphin Imaging. Some of the other systems identified in the survey may not be considered true PACS technologies because a true PACS is typically able to store DICOM files and index them in a database and support the DICOM communication protocol. Other systems may upload and share storage media, but they do not necessarily store files in a DICOM format or support the DICOM communication protocol.

Table III demonstrates that approximately half the respondents did not index the scans to patients' health records, and when it was done, axiUm via MiPACS was used by most. Other electronic health records (EHRs)

Table I. Question 1 results

Q1 - How would you classify your situation with respect to cone beam computed tomography (CBCT) imaging? (Select all that apply)

Answer	*%*	*Count*
Academic institution	53.1%	43
Imaging center	37.0%	30
Data storage provider	1.2%	1
Referring end user	6.2%	5
Other, please specify*	2.5%	2
Total		**81**

*Other systems included Box.com, GE, Planmeca, and Syngo.

Table II. Question 2 results
Q2 - What picture archiving and communication system (PACS) is used for storing cone beam computed tomography (CBCT) image data? (Select all that apply)

Answer	*%*	*Count*
No PACS, stored on capture central processing unit (CPU) or auxiliary CPU (server)	53.8%	43
In-house PACS, please specify	7.4%	6
Commercial PACs—MiPACS	21.2%	17
Commercial PACS—Dolphin	3.8%	3
Commercial PACS—other, please specify	13.8%	11
Total		**80**

Table III. Question 3 results
Q3 - Are the picture archiving and communication system (PACS) files indexed to patient files in an electronic health record (EHR)? (Select all that apply)

Answer	*%*	*Count*
No	49.3%	36
Yes—axiUm	30.2%	22
Yes—other, please specify which software	20.5%	15
Total		**73**

used included Titanium, Salud, Dolphin, Dentrix, Opus, and Courier.

As shown in Table IV, 43.2% of volumes were stored in a standard DICOM file format. Raw data files (21.0%) and native reconstructions (25.3%) were the next most common formats, although one respondent saved data in both native and DICOM formats. Of note, 9.5% of users stored data with directories of DICOM, bringing total DICOM storage to 52.7%.

Table V shows that there was a strong preference to retain scan data in the main PACS, or primary storage area, for more than 2 years before archiving (66.7%). This trend suggests that users continue to expand the PACS or primary storage before archival. Potential explanations include cost-saving strategies, growth-phase mentality, or being unaware of the advantages/disadvantages of long-term archiving.

Table IV. Question 4 results
Q4 - For initial storage, cone beam computed tomography (CBCT) volumes are stored as: (Select all that apply)

Answer	*%*	*Count*
Capture raw data files	21.0%	20
Native (proprietary) reconstructed data files	25.3%	24
DICOM (Digital Imaging and Communications in Medicine) data files	43.2%	41
Directories of DICOM data files	9.5%	9
Other, please specify	1.0%	1
Total		**95**

Table V. Question 5 results
Q5 - How long are cone beam computed tomography (CBCT) volumes stored in the picture archiving and communication system (PACS) before being archived in other storage media?

Time Period	*%*	*Count*
Up to 6 months	16.7%	7
6–12 months	9.5%	4
12–18 months	7.1%	3
18–24 months	0%	0
>24 months	66.7%	28
Total		**42**

Table VI. Question 6 results
Q6 - How are the volumes saved when being sent to long-term storage? (Select all that apply)

Answer	*%*	*Count*
Raw data files	15.9%	13
Proprietary constructed data files	26.8%	22
DICOM (Digital Imaging and Communications in Medicine) data files	46.3%	38
Directories of DICOM Data Files	6.1%	5
Other, please specify*	4.9%	4
Total		**82**

*Other, please specify (Responses recieved for "Other")
Hard disk installed in cone beam computed tomography (CBCT) computerIn any software in which the images were processed (e.g., SimPlant, Anatomage)
Not applicable

As summarized in Table VI, the trend for long-term data storage was similar to that for intermediate and short-term storage, with DICOM storage formats being preferred by

Table VII. Question 7 results
Q7 - When archiving cone beam computed tomography (CBCT) volumes, what type of storage medium is being used? (Choose all that apply)

Answer	*%*	*Count*
Cloud	3.9%	3
Storage disks	23.7%	18
Dedicated server	40.8%	31
Picture archiving and communication system (PACS) server	25.0%	19
Other, please specify*	6.6%	5
Total		**76**

*Other, please specify (Responses recieved for "Other")
External hard drive (HD)
Some not saved other than on capture

Table VIII. Question 8 results
Q8 - When archiving cone beam computed tomography (CBCT) volumes, what level of redundancy/backup is used?

Answer	*%*	*Count*
Single server location	44.8%	26
Two server locations	36.3%	21
>2 server locations	18.9%	11
Total		**58**

Table IX. Question 9 results
Q9 - When archiving cone beam computed tomography (CBCT) volumes, where is/are the storage media locations? (Choose all that apply)

Answer	*%*	*Count*
Cloud	4.1%	3
On site	60.4%	44
Remote site, <25 miles away	26%	19
Remote site, 25−50 miles away	2.7%	2
Remote site, >50 miles away	6.8%	5
Total		**73**

most. Alternatively, others stored workup files in third-party software (e.g., SimPlant and InVivoDental).

Table VII demonstrates that most respondents employed long-term storage on a variety of servers: PACS (25.0%), dedicated servers (40.8%), and Cloud (3.9%). 23.7% of respondents stored data on removable media.

As shown in Table VIII, a slight preference for data storage on more than one archival medium (55.2%) was evident, although nearly half the respondents continued backing up data on 1 server.

Table IX reveals that the majority of respondents (60.4%) stored imaging data on site. To ensure the security and integrity of data sets, medical data are routinely stored at remote sites.[5] This practice was not routine with regard to dental CBCT data.

Table X. Question 10 results
Q10 - When archiving cone beam computed tomography (CBCT) volumes, what is the retrievable index label being used for the search? (Choose all that apply)

Answer	*%*	*Count*
Patient's legal surname	39.0%	41
Electronic health record (EHR) patient (chart) number	36.3%	38
Date of Imaging	21.9%	23
Other, please specify*	2.8%	3
Total		**105**

*Other, please specify (Responses recieved for "Other")
No archiving for the moment
Do not archive
Patient number

Table XI. Question 11 results
Q11 - What is the routine bit depth at which the cone beam computed tomography (CBCT) volumes are being stored?

Answer	*%*	*Count*
<12 bit depth	6.9%	4
12 bit depth	36.2%	21
14 bit depth	36.2%	21
16 bit depth	17.3%	10
>16 bit depth	3.4%	2
Total		**58**

As summarized in Table X, data retrieval practices vary. The patient's legal surname and EHR numbers were the most common retrieval indices. Although the date of imaging could be referenced, it was not indexed as a specific search item, thereby requiring multiple query entries in a search-response queue.

Table XI demonstrates that depth storage may reflect bit depth capture by CBCT scanners because data were stored at the bit depth of the capture potential. Although greater bit depth requires more storage space, the issue of server capacity did not appear to influence the decision-making process.

As shown in Table XII, files were zipped by some respondents to reduce storage space,[6] yet only 34.5% of respondents utilized this function. Image degradation can result from compression, and the extent of degradation often varies dramatically, depending on the compression process used.[7-9] This may explain why "zipped" files are not widely utilized.

In relation to Table XIII, there is debate on how many of the patient volumes should be saved in patients' PACS records (i.e., original scan volume, implant planning volume, guided surgery stent volume, orthognathic planning volume, etc.) With digital milling and other digital workflow data being created, the question is which, if not all, of these should be part of

Table XII. Question 12 results
Q12 - What percentage of cone beam computed tomography (CBCT) volumes are stored in zip files with other patient data or viewer software?

Percentage of zipped files	*%*	*Count*
100%	10.3%	6
51%−99%	5.2%	3
25%−50%	6.9%	4
1%−24%	12.1%	7
0%	65.5%	38
Total		**58**

Table XIII. Question 13 results
Q13 - Are adjunctive patient volumetric assessments, such as implant placement workup files, surgical guide planning workups, and similar types of workup file folders, saved in the patient picture archiving and communication system (PACS) record? (Choose all that apply)

Answer	*%*	*Count*
Yes, although saved as other scan volumes	21.7%	15
Yes, although saved for only a short period	2.9%	2
Yes, although discarded after a set period	2.9%	2
Saved on a central server, but not in the PACS record	10.1%	7
Saved on individual PCs where the workup files are created	21.8%	15
Not saved in the PACS record	40.6%	28
Total		**69**

the patient's record? In our survey, most of the users were not saving these data in the PACS. As software companies continue to develop patient care applications, there will be a greater need for more centralized data storage in one common area. The need is likely to increase as the number of providers per patient and the need to share information continue to grow.[10]

Table XIV addresses the idea that as network communications improve and grow in use, more electronic data transmission is expected.[11] Increased demand for electronic patient data transmission is anticipated with the introduction of more HIPAA (Health Insurance Portability and Accountability Act of 1996)–compliant transmission platforms (DropBox, OneDrive, Google Drive, etc.).[12] As previously noted, nearly 50% of the respondents reported transferring patient data to a hard copy medium for physical storage; this reflects the need for standards in the storage and communication of patient information in dentistry.

Table XIV. Question 14 results
Q14 - How are patient cone beam computed tomography (CBCT) volumes transferred for use off site to consultants, patients and/or referral sources? (Choose all that apply)

Answer	*%*	*Count*
Transfer of a hard copy by courier	47.9%	35
Transfer via HIPAA (Health Insurance Portability and Accountability Act of 1996)–compliant intranet service	6.8%	5
Transfer via HIPAA-compliant internet service	19.3%	14
Transfer via HIPAA-compliant secure email	9.6%	7
Transfer via Direct Secure Message through a health information system program (HISP)	4.1%	3
Direct access to electronic health record (EHR) and picture archiving and communication system (PACS)	12.3%	9
Total		**73**

Table XV. Question 15 results
Q15 - Which of the following geographic regions best represents your location?

Answer	*%*	*Count*
North America	69.5%	39
Central America	1.8%	1
South America	3.6%	2
Europe	14.3%	8
Africa	1.8%	1
Middle East	3.6%	2
Asia	3.6%	2
Australia, New Zealand, Pacific Islands (Oceania)	1.8%	1
Total		**56**

Table XV shows that most respondents were based in North America. However, 30.5% were from other continents, with those from Europe representing the next highest number of responders. We could not determine if there were differences in international trends because the sample was small.

The most effective and time-efficient strategy for HIPPA compliance for control of access to protected health information would be via a PACS; yet, in our survey, as illustrated in Table XVI, only 26.5% of the respondents used a PACS to control access to patient

Table XVI. Question 16 results
Q16 - How do you control access to cone beam computed tomography (CBCT) images? (Choose all that apply)

Answer	*%*	*Count*
Access not controlled	7.8%	5
Access is only available in one department	17.2%	11
Access is controlled by the picture archiving and communication system (PACS) interface	26.5%	17
Access is controlled by one or more individuals	39.1%	25
Access is controlled by a paper process	0%	0
Other, please specify*	9.4%	6
Total		**64**

*Other, please specify (Responses recieved for "Other")
Password protection
Passwords
Internally only—local drive
Anyone with institutional intranet log in credentials could access CBCT images
Computer password
All users must sign on to AxiUm, and a trail of who looked where is recorded. HIPAA (Health Insurance Portability and Accountability Act of 1996) is strictly enforced, and unauthorized use will result in termination of that individual.

Table XVII. Question 17 results
Q17 - How do you control access to workup files? (Choose all that apply)

Answer	*%*	*Count*
Access not controlled	13.1%	8
Access is only available in one department	16.4%	10
Access is controlled by the picture archiving and communication system (PACS) interface	22.9%	14
Access is controlled by one or more individuals	39.4%	24
Access is controlled by a paper process	0%	0
Other, please specify*	8.2%	5
Total		**61**

*Other, please specify (Responses recieved for "Other")
No workup files
Passwords
Access is controlled by individual specialty clinics
Workup files not stored

data. The multiple responses to this question reflect a delay in the automation and efficiency of dental health care data management.

As shown in Table XVII, access to workup files followed a pattern similar for that of access to image files. Only 22.9% of the respondents reported using a PACS to control access to workup data.

DISCUSSION

CBCT has become a common imaging modality for dental diagnostics and treatment planning. In medicine, computed tomography has been used for decades.[13] Early in the use of digital medical images, DICOM was mandated as the standard for medical data management. This decision facilitated computed tomography interoperability for the storage, retrieval, and viewing of medical imaging data.

The data from this survey showed that most dental facilities prefer to use their platform manufacturer's software, thus potentially increasing the number of protocols for data storage and transfer.[3] This complicates patient care when health care providers need to utilize these data but do not share compatible imaging software. The best solution to the problem(s) of lack of interoperability at each level of data management is to more fully implement the DICOM standard for CBCT dental imaging.[1,2] Although current manufacturers may comply with the requirements of a DICOM-enabled export, questions remain as to the *quality*,[14-16] or *reliability* of their DICOM export function.[17]

The data storage/transfer challenge is further complicated by facilities that operate multiple units from different vendors and/or when attempting to share information with other providers that operate different management and viewing systems.[18] Lack of conformance appears to be a persisting issue for CBCT platforms.

DICOM is not a singular solution to dental data management. If an imaging facility with a PACS already in place is adding new CBCT units, it is crucial to review each manufacturer's conformance statement to determine PACS compatibility. This will simplify storage, retrieval, and transmission of all volumes within a given practice as well as with other users and clinicians who follow the DICOM standard protocols. All imaging facilities should undertake a conformance review to ensure a standardized file format.

In our experience, the process of routinely converting and transferring proprietary image files to the DICOM file format for a PACS server is labor intensive.[17] This problem is compounded when attempting to locate proprietary image volumes stored on multiple servers and archived in different formats. Moreover, a sought-for volume may be compressed[19-22] or stored in a lower bit depth and file type.[23-25]

Another notable challenge is the lack of indexing of CBCT imaging files with patients' EHR files. axiUm was the most popular EHR in this survey, possibly because most respondents were dental care providers at larger health care facilities (educational, military, penal, etc.). If the scans are *not indexed* to a corresponding health record (approximately 50% in our survey), scan data lack a consistent home-site for ready access. This practice runs counter to the trend in health care—that is, to have universal patient record accounts, where patient's data can be permanently archived and universally retrieved.[10,26,27]

Perhaps most importantly, this survey demonstrated that respondents follow availability options provided by vendors of CBCT equipment. The main storage option provided is the continuance of their proprietary data storage formats. This practice makes it more difficult to adopt a single DICOM protocol as instituted in medicine. This unfortunate trend and the lack of disclosure to new CBCT users of the added IT burden when purchasing CBCT technology are both hindrances to achieving interoperability of CBCT platforms—an important outcome in the continuum of data management.

To further comprehend the shortcomings of contemporary data management trends and to overcome the shortcomings identified, a follow-up quantitative survey investigation of contemporary users is advised. Additional cumulative information can now be obtained as a result of changes in the CBCT consumer profile. The CBCT imaging industry has a broader range of users, both medical and dental, and there are more options for CBCT units in the industry's marketplace. It is recommended that further investigation stratify the users, particularly within both the medical and dental professions.

CBCT is now popular in large otolaryngology and orthopedic practices. These practices may have different

data management styles from those used in the dental profession. It would be helpful to determine how their PACS and EHRs are indexed to the patient. Furthermore, it would be helpful to know how this combination affects digital workflow management and where the data are stored to remain in compliance with current HIPAA standards and their archiving strategies.

Within the dental profession, the user stratification should consider the differences among imaging centers and large institutions in comparison with CBCT users in specialty and general practices. Because the field of view varies among user types, it would be helpful to identify user trends in these different groups, with the goal of establishing guidelines to facilitate practice management within and among practices that have patients common to multiple practices. The data from such a follow-up quantitative survey investigation would then provide a broader analysis of variance with respect to practice type and machine type for the industry at large. These findings would be helpful to determine if there are useful trends that are different and those that are common among the various user types.

Alternatively, or concurrently, a qualitative approach to particular user experience could be employed. For a more focused view of a behavioral approach, usability laboratory or benchmarking are options. Attitudinal research methods using participatory design, focus groups, and/or interviews would provide deeper insight into why data storage patterns demonstrated, for example, a preference for particular vendor recommendations.

Combining an expanded, larger sampling of quantitative use patterns with qualitative methodology for understanding the "whys" could inform both the user and the developer alike. Ultimately, standardization leading to best practices will benefit all involved.

CONCLUSIONS

This survey revealed a lack of consensus on data management in a relatively small, although representative, sample of high-volume CBCT users. Although the survey may not represent all of dentistry, it provides insight into the trends and challenges faced by those tasked with managing advanced imaging data in the dental field.

More research is needed on CBCT data management. Information in the current literature is sparse, and parallels in imaging data from other fields may not adequately address CBCT issues. Ultimately, data retrieval, transfer, and communication among providers will benefit patients. This survey revealed that there is a need to study, develop, and implement guidelines in CBCT data management, software development, and specialized IT support for this reason alone.

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