# A proposal of a digital cephalogram standard using DICOM


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## Abstract

*An important aspect of distributed data management is the structure of the managed information, which is the basis for a semantic approach of information and ensures extensibility, interoperability and adaptability in collaborative environments. This document describes how to use DICOM to store and transfer digital cephalograms in collaborative orthodontics systems.Digital cephalograms are more than just plain medical radiographs of the skull. They are used to make exact measurements for craniofacial growth studies, as well as for the planning of orthodontic cases. For these applications, it is important that cephalograms be stored in a format that can hold information necessary to guarantee their accuracy. This document specifies how to use DICOM to store such information along with the cephalograms themselves.*


This document describes how to use DICOM to store and transfer digital cephalograms. It is divided in six parts:

1. In the introduction the reader is presented with a brief history of the issues concerning the development of a standard for the electronic orthodontic patient record.

2. A discussion of the requirements for digital cephalograms, and how current DICOM resources could handle them.

3. The gap analysis to produce a list for what needs to be addressed.

4. Conclusion and discussion of further work.

## 1. Introduction

It was only in 1991, during the annual meeting of the American Association of Orthodontics (AAO), that the belief of the new information age reaching into the orthodontic world was accepted. Unfortunately, the introduction of computer technology into the orthodontic office occurred before the analytic requirements of a computerized orthodontic record keeping system could be determined. To continue to communicate effectively in the information age, a standard way of storing and retrieving computerized orthodontic records needs to be established.

Currently, the profession is being challenged to provide more information on the efficacy of various treatment methods. In addition, valuable cephalogram film series belonging to studies performed during the first half of the 20th century, are now starting to decay. Various growth studies have been done in the past century, where patients where voluntarily x-rayed periodically (sometimes even with implanted artificial landmarks) in order to research cranial growth and development. Today, such studies would be impossible to perform, which makes the preservation of these films a high priority project for many institutions. These challenges has increased the need for a standardized cephalogram database of treated and untreated orthodontic cases. The personal computer may provide a solution to this problem because it is easy to make and access copies of computerized information and because digital copies don't suffer from deterioration. However, for the copies to be useful, they must be compatible among various computers and computer software programs.

To date, no standards have been proposed or adopted by the orthodontic profession for storage and exchange of computerized cephalograms and other patient information. During a 1991 meeting of Orthodontic Educators, three issues were identified that need to be addressed before standards can be established:

1. Lexicon issues: what terms will be used to describe orthodontic conditions.
2. Resolution issues: what is the resolution (spatial and grey-scale) necessary for orthodontists to use digital representations of x-ray and models instead of the originals.
3. Registration issues: how should digitized records be registered and scaled.

Two years after the 1991 educators meeting, Hans organized a workshop sponsored by the American Association of Orthodontics Foundation (AAOF) which was held at the Bolton-Brush Growth Study Center (Case Western Reserve University, Cleveland, OH, USA) in March 1993. It was entitled *Standards for Digital Storage, Retrieval and Analysis of Orthodontic Records* [2] and was the first attempt to discuss the technical details of creating a standard for digital orthodontic data. The workshop only focused on digital x-rays and delivered a rather broad set of minimum requirements necessary for digital cephalograms to be of orthodontic use. After the workshop, interest in the project faded. It was only ten years later that Hans et al. proved the conclusions held at the workshop to be true [3]. Two years later, Magni recovered the effort and produced a poster-board [7], an article [6], and a Master's Thesis[5]. The work provided a method for the development of a standard for the electronic orthodontic patient record, as well as a draft for a digital cephalogram standard, and a small implementation of it in JAVA (More information can be found on the Project PANIO homepage [4]).

Cephalograms are more than a simple radiograph of the skull. They are used for craniofacial growth studies as well as for orthodontic treatment planning. It is therefore important to store, along with the radiograph itself, further information, which can guarantee the accuracy of the image itself. For this purpose, the DICOM standard is highly developed and contains enough definitions to unambiguously store all metadata that should accompany all cephalograms. The intention of this document is to apply the image resolution issues presented in [3] and the registration issues discussed in [2] into a DICOM extension for cephalograms. Lexicon issues are not addressed, as they are believed not to be necessary for the storage and retrieval of digital cephalograms.

As of today, there are two major projects that could directly profit from a standard for digital cephalograms:

1. Working Group 11.6 at the American Dental Association's Standards Committee for Dental Informatics is working on the development of a standard for the electronic orthodontic patient record [6], which is based on digital cephalograms.
2. There are certain orthodontic records that should be preserved for orthodontic educational purposes as well as controls for research and growth studies. These materials include legacy materials which are untreated longitudinal records stored in various locations that are deteriorating with time, and because of their nature may never be collected again. Preserving these orthodontic records is a priority for the American Association of Orthodontics Foundation second only to the support of junior faculty.

DICOM (Digital Imaging and Communications in Medicine) is a well established standard maintained by the National Electric Manufacturing Association (NEMA). It defines how to store and transfer images related to the medical field. Currently, most medical equipment which deal with images, can interpret the DICOM format. DICOM was chosen as the framework to implement the standard because of its popularity and its advanced stage of development. In fact, the widespread use of DICOM in the medical field will greatly facilitate the integration of the cephalometric images with existing software. Integration and implementation are a keystone of standards development, since a well developed standard that remains unimplemented is of little use.

## 2. Digital cephalograms and DICOM

The need for the development of a standard for digital cephalograms has existed for about fifteen years. While DICOM can handle all necessities required by digital cephalograms (in some cases in more than one way), cephalograms are nowhere explicitly mentioned in the normative DICOM documentation.

This section contains a description of the requirements to correctly make use of a digital cephalogram for clinical and research applications. It also briefly discusses how DICOM can accommodate for these necessities. It does not dive into the depths of DICOM attributes and objects: this paper shall only provide the basis for the development of a novel standard for storage and transfer of digital cephalograms.

The following list represents the six basic issues that need to be addressed in order to represent cephalograms in a digital format:

1. Cephalogram pair
2. Patient demographics
3. Radiographic magnification
4. Head orientation
5. Image distortion
6. Resolution

### 2.1. Cephalogram pairs

A cephalogram pair is considered to be a set of a lateral and PA cephalogram which are part of the same study. In such situation, the lateral cephalogram is related to the PA by making use of the *Referenced Image Sequence* (0008,1140), which is part of the *Image SOP Instance Reference Macro*.

*Image Type* (0008,0008) is an attribute which could very well be suited to define a cephalogram pair. Yet, it is part of the *X-Ray Image Module* (C.8.7.1), which is not included in the DX Image IOD.

### 2.2. Patient Demographics

The cephalogram is part of the patient record, and should therefore contain information for its proper identification. Such information should be patient name, ID, gender, date of birth, date/time when exposure was taken.

Information on the patient should be stored in the patient information entity modules as defined by DICOM. Refer to C.7.1.1, C.7.1.2 and C.7.1.3 [8, PS 3.3].

### 2.3. Radiographic magnification

Radiographic magnification is an essential element that allows the correct interpretation of the distances within a cephalogram. It is defined as the magnification that occurs on the film due to the point-like nature of the x-ray source, and depends therefore on the distances between detector, patient and source.

Radiographic magnification can be stored in various forms: distance between mid-sagittal plane and film associated with the distance between source and film; ratio between these two distances; ratio between 1 mm on cephalogram and 1 mm on the subject (as in, for example, the scale of a geographical map); percentage; inclusion of a 10 cm x-ray visible scale in each and every exposure. Of all the above, percentage is the preferred unit for magnification, as it directly represents the desired information. The percentage of magnification allows the conversion between the two coordinate systems (real world to cephalogram) through a simple relationship:

$$d\left(1+\frac{p}{100}\right)=d' \qquad (1)$$

where $d$ is a distance on the subject (a real world distance), $d'$ the distance as measured on the cephalogram and $p$ magnification of the cephalogram in percentage.

DICOM accounts for two ways to store the geometric magnification along with the x-ray image. The first method stores the ratio between the source to patient and the patient to film distances; the second stores the distance between two pixel centers in the real world.

**Using SID/SOD** Radiographic magnification can be encoded within a DICOM DX IOD making use of the *DX Positioning Module* [8, PS 3.3 - Page 631]. The module contains three useful attributes: *Estimated Radiographic Magnification Factor* (0018,1114) which is defined to be the "Ratio of Source Image Receptor Distance (SID) over Source Object Distance (SOD)."; *Distance Source* *to Patient* (0018,1111) and *Distance Source to Detector* (0018,1110). By making use of either the first, or a combination of the last two attributes, magnification information can be accurately preserved along with the image.

In most cases, the SOD and SID distances are kept constant for all cephalograms. Utilizing these attributes is therefore relatively practical and suggested.

**Using pixel spacing** Alternatively, radiographic magnification can be encoded within a DICOM DX IOD making use of the *DX Detector Module:* the module contains the *Basic Pixel Spacing Calibration Macro* where the *Pixel Spacing* (0028,0030) attribute can be used to store what one pixel to the left and/or one pixel down corresponds to on the patient. From the DICOM documentation [8, PS 3.3 - Page 80], the official definition is:

> "The Pixel Spacing (0028,0030) attribute specifies the physical distance in the patient between the center of each pixel."

The macro even allows for specifying how the calibration was performed, if through the use of fiducials, or if it was just known. This can be specified through the optional attribute *Pixel Spacing Calibration Type* (0028,0402):

> "The type of correction for the effect of geometric magnification or calibration against an object of known size, if any. Enumerated Values:
>
> GEOMETRY: the Pixel Spacing (0028,0030) values account for assumed or known geometric magnification effects and correspond to some unspecified depth within in the patient; the Pixel Spacing (0028,0030) values may thus be used for measurements of objects located close to the central ray and at the same depth.
>
> FIDUCIAL: the Pixel Spacing (0028,0030) values have been calibrated by the operator or image processing software by measurement of an object (fiducial) that is visible in the pixel data and is of known size and is located close to the central ray; the Pixel Spacing (0028,0030) values may thus be used for measurements of objects located close to the central ray and located at the same depth within the patient as the fiducial." [8, PS 3.3 - Page 81]

Similarly, the attribute *Object Pixel Spacing in Center of Beam* (0018,9404) could be used: it defines the pixel spacing at the center of the beam.

Although this method would also solve the problem of knowing what the distance of the digital image corresponds to in real life, it is less practical, because it needs to be calculated from the resolution, the *Imager Pixel Spacing* (0018,1164) and the actual SID/SOD ratio.

The radiographic magnification factor is to be stored within the DX Positioning Module (C.8.11.5) making use of the *Distance Source to Patient* (0018,1111) the *Distance Source to Detector* (0018,1110) and the *Estimated Radiographic Magnification Factor* (0018,1114) attributes.

These three attributes present the user with a choice: either make use of the first two, or of the third, which, according to DICOM, is simply the ratio of the first two attributes.

## 2.4. Head orientation

The orientation of the head with respect to the x-ray beam must be known in order to be able to accurately relate the x-ray distances with the subjects measurements. Normally this is done with the cephalostat by keeping the subject in a locked position, and by orienting the central x-ray beam exactly through the transmeatal axis. The cephalostat, which secures the subject by the ears, only allows movement about the transmeatal axis. In lateral cephalograms, this kind of rotation is of little importance, since it can be easily corrected by physically rotating the x-ray film after it has been developed (no distortion inserted). Yet for PA (posteroanterior) cephalograms such rotation causes a distorted projection of the skull. Correlation between cephalogram and patient measurements is not possible if the angle of rotation is unknown.

For this reason it has been decided to define, within the PA cephalogram, the angle about the transmeatal axis with respect to the Frankfort plane[1] as a mandatory field. This has two advantages: (1) The distances on the cephalogram can be accurately related to measurements on the subject and (2) the technician is forced to pay particular attention to the orientation of the head.

Assuming the distortion caused by radiographic magnification to be negligible, distortion in

[1] The Frankfort plane is defined by the left orbitale (the lowest point on the lower edge of the orbit) and the right and left tragions (upper edge of the tragus). This plane is usually held horizontal, i.e. parallel to the ground.

the PA caused by rotation about the transmeatal axis can be corrected with the following relation:

$$d' = \frac{d''}{\cos\alpha} \quad (2)$$

where $d''$ is an anatomical measurement performed on the cephalogram, $\alpha$ the angle of rotation with respect to the Frankfort plane and $d'$ what the anatomical measurement would be, were there no rotation (no transmeatal distortion). Eq. 2 can complement Eq. 1 by forming the following more complete magnification correction relation:

$$d = \frac{d''}{\cos\alpha\left(1+\frac{p}{100}\right)} \quad (3)$$

Eq. 3 can substitute Eq. 1 in any situations: the cosine term disappears when the angle is zero degrees, reducing to Eq. 1.

DICOM provides a way to store the angles at which the patient is oriented with respect to the detector and beam in the *DX Positioning Module* (C.8.11.5) defined in [8, PS 3.3, C.8.11.5]. This field already defines which side the beam hits the patient first. For example postero-anterior specifies the beam direction: from posterior to anterior. In addition, this field also allows oblique sequences.

However, this attribute does not account for non-standard angles. Such angles can easily be stored using the *Positioner Primary Angle* (0018,1510) and *Positioner Secondary Angle* (0018,1511) attributes. The *Positioner Primary Angle* definition is like longitude (in the equatorial plan). This is the angle that defines whether the accompanying image is a lateral or PA cephalogram. The *Positioner Secondary Angle* definition is like latitude (in the sagittal plane). This is the angle that defines the rotation about the transmeatal axis. For example, a patient facing the x-ray source for an antero-posterior image would be encoded with Primary Angle 0 degrees and Secondary Angle 0 degrees, whereas a patient oriented for a lateral Cephalogram, with the beam coming from the right side of the face, with Primary Angle -90 and Secondary Angle 0.

## 2.5. Image distortion

Analog cephalograms usually don't contain any additional error introduced by the imaging equipment. Yet Schnepper [10] has shown that the digitization process could introduce error if scanners are not properly tested and calibrated. A slight difference in vertical and horizontal pixel sizes, could render the image of no clinical value. It would be very convenient to have a method for verifying the accuracy of the manufacturers calibration.

At the Bolton-Brush Growth Study Center four pinholes, called SB fiducials, are punched at the corners of the cephalogram making use of a template. The distance between these points is well known and should be persevered throughout the digitization process. This can be accomplished either by storing each fiducial as a point (in x,y coordinates) or by storing the distances of the four fiducials from each other. The latter method provides two advantages: (1) there are only 6 numbers to store, instead of 8 (each point is composed of an x and a y coordinate value) and (2) there is no need to account for possible coordinate shifts introduced by the scanning or the pinhole-punching process. We therefore decided that SB Fiducials should be stored with the cephalogram making use of six fields representing the six distances of the points with each other. Only if all six distances are known, can the relation between all points be guaranteed.

A cephalogram must contain all six distances if it is digitized from film. In the case when a cephalogram originates directly from a digital x-ray sensor, making use of alternate fiducials is still suggested. By placing four or more fiducials at known distances close to the patient inside the field of view of the imaging device, this distortion can easily be detected.

It is not within DICOM's scope to directly address the distortion caused by digitization. Yet it does allow for associating fiducials to an image, which, in turn, can be used to verify image distortion. Such fiducials can be represented with an IOD called *Spatial Fiducials*[2]. Although it is not possible to store the distance between each fiducial, the IOD has attributes for the coordinates of each SB corner fiducial. With a little math, it is possible to convert from distances to coordinates, and vice versa.

## 2.6. Resolution

The main purpose of cephalograms is to measure angles and distances between anatomical landmarks. It is therefore essential to be able to accurately identify anatomical landmarks. Based on a research held at Case Western Reserve University [3], the minimum resolution needed for a cephalo-

[2]This IOD is primarily intended to be used to correctly reference and overlap two separate images.

gram to be useful for orthodontic treatment or research is of 4096 shades of grey and 1536x1024 pixels on an 8"x12" film, which translates into a resolution of 128dpi x 12 bits of grey. This means that a pixel must have a vertical or a horizontal size of 0.19mm (1/128th of an inch) or less.

The standard should therefore require the pixel size to be smaller than 0.19mm both horizontally and vertically and have a depth of 12 bits.

Information on resolution can be correctly stored using the *Image Pixel Module* (C.7.6.3). Minimum resolution requirements should be mandatory for cephalograms to be used for clinical purposes, yet should not be necessary for presentation purposes. This distinction can be made by making use of two different levels of conformance, as specified in the next section.

### 2.7. Conformance specifications

Digital cephalogram can conform to the specifications in two ways: the first simply guarantees that the image is properly formatted (this, taking advantage of DICOM's existing resources, would be names "FOR PRESENTATION"), while the second adds the resolution requirements discussed in 2.6, which makes the image clinically useful (named "FOR PROCESSING").

The actual cephalogram standard proposal [5] provides the details on how to encode and relate a single cephalogram or a cephalogram pair with a set of fiducials using DICOM objects.

## 3. Gap analysis

This section highlights the gap between what is required for cephalograms and what DICOM can provide. It serves as background for the formulation of the standard presented in the next section.

As presented above, DICOM provides all necessary resources to be able to correctly encode cephalograms. Nonetheless, its documentation does not directly address cephalograms (neither as normative, nor as informative). Some minor refinements need to be made, most of which could be part of a separate implementation manual. Ideally they could be included within the official DICOM documentation.

The gap analysis can be resumed in three basic points:

1. DICOM does not specify minimum requirements for resolution. The specific resolution requirements for cephalograms need to be specified.
2. The DICOM normative documentation considers some fields as *Optional Data Elements*, while, for cephalograms, they should be mandatory.
3. DICOM does not specify a way for verifying the accuracy of the digitalization process (discussed in SB Corner Fiducials on the preceding page).

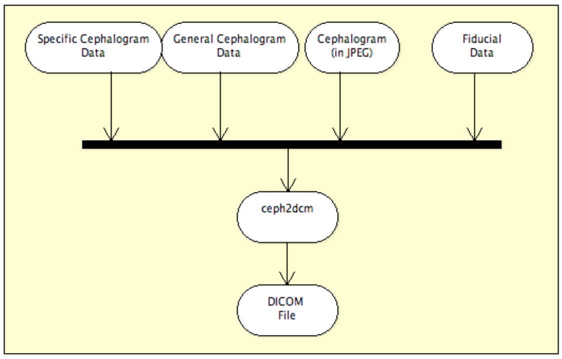


**Figure 1. Activity diagram of the `ceph2dcm` utility.**

## 4. Providing results with `dcm4ceph`

This section presents an open source software package that was developed to produce digital cephalograms stored in DICOM according to the suggestions presented in this paper. It is based on the `dcm4che` 2.0.7 [1] open source project. `dcm4che` is a collection of open source applications and utilities for the healthcare enterprise. These applications have been developed in the Java programming language for performance and portability. At the core of the dcm4che project is a robust implementation of the DICOM standard. Versions 1.x of the DICOM toolkit is used in many production applications across the world, while the current (2.x) version has been re-architected for high performance and flexibility.

`dcm4ceph` is composed of a core package and a utility package. The core package consists of two fundamental classes: Cephalogram and FiducialPoint. The Cephalogram class provides a set of methods that are able to deal with all general requirements of digital cephalograms. It is a wrapper for various `dcm4che` classes and methods to represent the appropriate DICOM objects and attributes. The FiducialPoint represents one single fiducial which, when part of a set, can be used to verify the calibration of the imaging device.

The core distribution package also contains another JAVA package, called "cwru", which in turn is made out of two more specific classes: The BBCephalogramSet and the SBFiducialSet. These classes contain methods which are specific to the Bolton-Brush cephalogram collection at Case Western Reserve University (CWRU).

In addition, the software comes with a utility program, called `dcm2ceph`, which is a convenience command line utility that reads a cephalogram in JPEG format, a file that contains the cephalogram data, and a configuration file (and an optional fiducial file) and outputs a DICOM cephalogram object (see 1).

## 5. Conclusions

In order to successfully address distributed data management and interoperability between orthodontic software, the full electronic orthodontic patient record must be standardized such that software vendors will be able to, by simply implementing such standard, easily import and export patient record. Digital cephalograms are an important part of the patient record, yet no standards exists for their storage. This paper discusses the necessities of digital cephalograms, and how they could be satisfied by making use of DICOM.

Imminent further work should be focused on the development of a more technical document, which should be published either by the American Dental Association's Standard Committee for Dental Informatics, or become an official DICOM Supplement to directly address the issue of digital cephalograms.

In addition, this paper can directly support the present ongoing effort of the American Association of Orthodontics Foundation of preserving untreated longitudinal cephalogram records stored in various locations that are deteriorating with time, and because of their nature may never be collected again.

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