# Evaluation of DICOM Viewer Software for Workflow Integration in Clinical Trials

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## ABSTRACT

The digital imaging and communications in medicine (DICOM) protocol is nowadays the leading standard for capture, exchange and storage of image data in medical applications. A broad range of commercial, free, and open source software tools supporting a variety of DICOM functionality exists. However, different from patient's care in hospital, DICOM has not yet arrived in electronic data capture systems (EDCS) for clinical trials. Due to missing integration, even just the visualization of patient's image data in electronic case report forms (eCRFs) is impossible. Four increasing levels for integration of DICOM components into EDCS are conceivable, raising functionality but also demands on interfaces with each level. Hence, in this paper, a comprehensive evaluation of 27 DICOM viewer software projects is performed, investigating viewing functionality as well as interfaces for integration. Concerning general, integration, and viewing requirements the survey involves the criteria (i) license, (ii) support, (iii) platform, (iv) interfaces, (v) two-dimensional (2D) and (vi) three-dimensional (3D) image viewing functionality. Optimal viewers are suggested for applications in clinical trials for 3D imaging, hospital communication, and workflow. Focusing on open source solutions, the viewers ImageJ and MicroView are superior for 3D visualization, whereas GingkoCADx is advantageous for hospital integration. Concerning workflow optimization in multi-centered clinical trials, we suggest the open source viewer Weasis. Covering most use cases, an EDCS and PACS interconnection with Weasis is suggested.

**Keywords:** DICOM, EDCS, eCRF, Data Capture, Integration, Interfaces, Display

## 1. INTRODUCTION

Nowadays, the digital imaging and communications in medicine (DICOM) protocol of the National Electrical Manufacturers Association (NEMA) and the American College of Radiology (ACR) has been established as the leading standard for image data management in medical applications [1]. Since its release in 1993, DICOM is applied to capture, exchange and store image data via DICOM workstations and picture archiving and communication systems (PACS). Due to DICOM's popularity, a broad range of commercial as well as free or open source software tools have been developed up to today. Almost 350 free software projects are currently listed in the database of the I Do Imaging web site (http://www.idoimaging.com/).

Furthermore, medical imaging is looming large today in clinical trials. Image-based surrogate endpoints offer qualitative and quantitative disease findings improving eligibility, efficacy, and security evaluation in studies [2]. Here, patient's data is captured using electronic data capture systems (EDCS), which provide electronic case report forms (eCRFs) instead of the traditional paper-based CRFs. ECRFs allow data evaluation by automatic range checks and can be accessed via web. This improves data quality and simplifies access in multi-centered trials [3,4]. However, EDCS lack in support of DICOM. Neither a structured way to integrate DICOM data into EDCS, nor interfaces for communication with PACS exist. Up to now, visualization of DICOM objects in eCRFs is impossible. Appropriate DICOM viewers are not yet integrated.

Four increasing levels of integration for connecting a DICOM viewer, a PACS and an EDCS have been discussed in previous work [5]. According to improve functionality and optimize the workflow, the requirements to interfaces of the software components increase with each of the levels. Components of an integrative system are not only required to offer rich functionality for fulfilling their designated purpose (e.g. visualization features for a viewer), but also have to include a wide range of interfaces.

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Finding optimal software in the large pool of DICOM tools is challenging. Focusing on open source DICOM tools, Nagy published a list of suitable software including server, viewer, image processing, teaching file tools, web-based PACS, and general toolkits, which include conversion and code libraries [6]. In 2003, Horii has presented a survey of free and commercial DICOM viewers [7]. In his work, he investigated image viewing functionality such as supported DICOM information object types, included image processing methods and ability to export images in other formats. As result, he stated that tools, which are easy to use and include rich functionality, can also be found in the open source field. However, Nagy and Horii's publications rather focused on presenting a collection of tools, than a comprehensive and systematic comparison.

In 2007, Liao et al. have published an evaluation of 21 free non-diagnostic DICOM viewers [8]. The survey has been focused on free and standalone DICOM viewers, which provide a graphical user interface (GUI). In the evaluation, the viewers have been investigated based on a set of 28 various DICOM data sets. During this, all viewers have been analyzed regarding the criteria (i) data import and (ii) export; (iii) header viewing; (iv) two-dimensional (2D) and (v) three-dimensional (3D) image viewing, (vi) support, (vii) portability, (viii) workability, and (ix) usability. All criteria have been defined as "yes"/"no" categories except workability and usability, which have been assessed rather qualitatively (e.g. by subjective percent values). Optimal DICOM viewers have been suggested for the application profiles inexperience users, data conversion, and volume rendering.

However, all these publications are out of date and completely disregard any interfacing functionality. In this paper, a comprehensive evaluation of open source, free and commercial DICOM viewer software is performed. Beside concerning general and viewing functionality of the tools, the focus lays on aspects of integration into system environments. We focus in particular on controlled clinical trials with respect to extensive 3D imaging, interconnection to hospital's data, and optimal workflow.

## 2. MATERIAL AND METHODS

### 2.1 Catalog of Criteria

A catalog of 29 criteria in 6 groups defining requirements for general (G), integration (I) and viewing (V) functionality has been built up, concerning (i) license and (ii) support; (iii) platform and (iv) interfaces; as well as (v) 2D and (vi) 3D image viewing, respectively. Interface criteria are based on functionality which has been found during the survey and valued as advantageous. The viewing criteria have been mainly adopted by the work of Liao et al. Facing on integration of systems, criteria such as data import and export have been discharged. To avoid subjectivity, all criteria are designed as simple "yes" (+) or "no" (-) categories.

#### 2.1.1 License

The first group of criteria focusses on the licensing policies of the software and maps the viewers to open source, free or commercial products.

**G1 – Open Source:** Open source software is free to use and its source code is public available. In addition, users are typically allowed to modify the software and adopt its functionality to their needs. However, a wide range of open sources licenses with specific characteristics exists (e.g. GNU General Public License (GPL), Berkeley Software Distribution (BSD) license).

**G2 – Free:** Free software is costless, too, but its source code is not public available and cannot be modified.

**G3 – Commercial:** A commercial software product is marketed by a company and the software underlies a fee-based licensing model.

#### 2.1.2 Support

Support requirements identify in which way helpful information for the software is provided.

**G4 – Documentation:** Written documentation for the software including manuals is available.

**G5 – Mail:** A mailing list is offered to get support via mail communication.

**G6 – Forum:** A web-based forum is provided in case support is needed.

**G7 – Wiki:** A wiki web page is available for users.

### 2.1.3 Platform

The platform criteria concerns the viewer's system environment and is structured in standalone, web, platform-independent, and mobile device applications.

**I1 – Standalone:** Standalone applications are designed to be only runnable on a specific operating systems (e.g. Windows, Linux or Mac OS). Usually specific software versions for various platforms exists.

**I2 – Web:** Web applications are running on a web server usually based on a Linux or Windows operating system and can be accessed by client systems via modern browsers.

**I3 – Platform Independent:** A few programming languages (e.g. Java) are platform-independent and can be executed on standalone systems (e.g. using Java runtime environment (JRE)) or transferred by the web server to a client system (e.g. using Java Web Start).

**I4 – Mobile Devices:** In case the DICOM viewer provides a suitable GUI, the software can be used and medical images viewed on smartphones and tablets.

### 2.1.4 Interfaces

Aiming at integration, interfaces are needed for communication of the viewer with other systems:

**I5 – DICOM C-STORE SCP:** C-STORE is a DICOM operation [1,9], which allows transfer and storage of DICOM objects into a connected system. In case of the role as C-STORE service class provider (SCP), the viewer passively receives data from other DICOM nodes (e.g. PACS).

**I6 – DICOM C-STORE SCU:** In case of the role as C-STORE service class user (SCU), the viewer actively stores data into other DICOM nodes.

**I7 – DICOM Q/R:** DICOM query and retrieve (Q/R) allows a system to actively request and gather data from other DICOM nodes.

**I8 – WADO:** Web access to DICOM objects service (WADO) allows a system to offer other systems access to DICOM objects via web protocols [10].

**I9 – Parameter Transfer:** Parameter calls are provided to transfer information (e.g. settings) directly on invocation of a software application. For instance, parameter calls may be used to forward DICOM objects or references.

### 2.1.5 2D Viewing

Focusing on viewing functionality, some viewer features are in special useful viewing 2D images.

**V1 - Scrolling:** During viewing of images in a DICOM series, the possibility to move to the next or previous image by simply scrolling with the mouse wheel or using up and down keys on the keyboard, reduces mouse interaction and improves usability.

**V2 – Metadata:** Header viewing functionality includes parsing and displaying of DICOM object's metadata. This functionality should include all DICOM tags such as image (e.g. resolution), study (e.g. patient's identifier) and vendor specific properties (e.g. special settings of recording device).

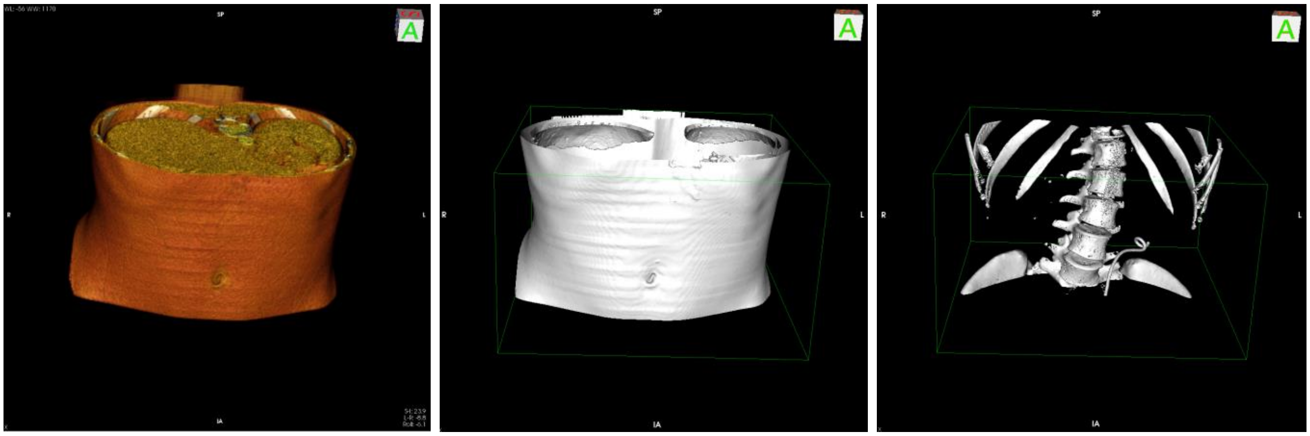
**V3 – Information Overlay:** Important information should be directly visualized in the display window as an overlay (e.g. current position in the DICOM series or patient's pseudonym).

**V4 – Windowing:** Windowing controls brightness and contrast of the displayed image, which can be adjusted in case structures of the image are not optimally visualized using default settings.

**V5 – Pseudo Coloring:** Pseudo-Color look up tables (LUT) map grey values of images to pseudo-colors to improve the visual effect of images.

**V6 – Histogram:** Histograms visualize the occurrences and distribution of color values in the images and describes meaningful image characteristics.

**Figure 1: DICOM Library data set visualized by (i) volume rendering, (ii) transfer and (iii) surface generation functionality in OsiriX Lite.**



**V7 – Measurements:** Measurements allow drawing (e.g. lines) and analysis (e.g. distances, angles) of geometric figures in the image. Since DICOM header often contain calibration information (e.g. pixel to centimeters relation) representative results can be determined using measurement tools.

**V8 – Annotations:** Results of image viewing (e.g. by measurements, text annotations) should be storable in the image bitmap or in the metadata header for later purposes.

### 2.1.6 3D Viewing

In contrast to 2D images, other features are needed in case 3D volume data is viewed.

**V9 – Secondary Reconstruction:** Usually, medical volume data is acquired along one body axis (e.g. transversal). In some cases, it is important to view the data in other directions (e.g. sagittal or coronal) to improve visualization of certain structures. For this, functionality for constructing a secondary axis based on the primary direction has to be provided.

**V10 – Slice Cube:** Volume slices typically can be better displayed at a particular position. Slice cube functionality allows to independently adjust the position of the various slice axis (e.g. transversal, sagittal or coronal) in the volume model, while the slices are shown themselves in a separate window.

**V11 – Volume Rendering:** By volume rendering, 3D image data is directly visualized as volume and the user can interact with the volume by rotating, translating or scaling (Fig. 1).

**V12 – Transfer Function:** Transfer functionality is used to map grey values of image voxels to opacity values of specific tissue types (e.g. bones). By this, the structures in the image matching the specified grey values are highlighted and are more clearly visible, while not mapped grey values are shown transparent.

**V13 – Surface Generation:** Various algorithms (e.g. marching cubes) can be applied to a 3D image to calculate surfaces of voxels with the same grey values. Surface representations can also be applied to improve the visualization of certain image structures.

## 2.2 Selection of Tools

The software tools included in our survey have been collected by a non-systematic internet survey using Google and the I Do Imaging database. The survey has been primarily focused on open source licensed projects. In addition, 16 of 21 projects of Liao et al.'s work have been incorporated. The projects Julius, syngo FastView and UniView are not available anymore. The viewer Amide and FPImage seems to be no longer maintained, since no version running on our 64-Bit Windows system was available.

### 2.3 Evaluation

General and integration requirements have been evaluated on public available information provided by the developers or vendors. In contrast, viewing functionality has been investigated by the authors themselves. For this, standalone and platform independent tools have been installed on a local system (Windows 7 Enterprise Service Pack 1, 64-Bit Genuine Intel CPU 1.60 GHz, 3GB RAM). Aiming at reproducibility, the criteria have been verified using public available datasets. The "DICOM Samples CT" dataset is offered by DICOM library (http://www.dicomlibrary.com/) and contains a series of 361 computer tomography (CT) images using JPEG 2000 transfer syntax. However, since this transfer syntax caused issues in some viewers, another similar dataset has been included. The "CT0001" DICOM dataset is provided by the NEMA (ftp://medical.nema.org/) and includes a series with 153 CT images and uses explicit little endian as transfer syntax, which seems to be more broadly supported by the viewers. The evaluation of web applications is based on demo

| Name | Version | Reference | Dataset |
|---|---|---|---|
| 3D Slicer | 4.3.1 | http://www.slicer.org/ | DICOM Library |
| BioImageSuite | 3.0.1 | http://bioimagesuite.yale.edu/ | DICOM Library |
| Cornerstone | 2014-05-01[2] | https://github.com/chafey/cornerstone/ | MISTER^MR |
| DWV | 0.8.0 | https://github.com/ivmartel/dwv/ | Baby MRI |
| DicomWorks | 1.3.5b | http://www.dicomworks.com/ | NEMA |
| Eviewbox | 2013-04-21[2] | http://eviewbox.sourceforge.net/ | NEMA |
| ezDICOM | 2004-12-02[2] | http://www.mccauslandcenter.sc.edu/mricro/ezdicom/ | NEMA |
| Gingko CADx | 3.7.0 | http://ginkgo-cadx.com/en/ | DICOM Library |
| Image J | 1.48 | http://imagej.nih.gov/ij/ | NEMA |
| iOviyam | 2.0 Beta | http://oviyam.raster.in/ | CT^HEAD |
| JiveX Dicom Viewer | 4.6.2 RC05 | http://www.visus.com/ | DICOM Library |
| JiveX Mobile | 4.6.3 RC03 | http://www.visus.com/ | Anonymized |
| MedDream | 2.0.8 | http://www.softneta.com/ | DICOM Library |
| MediINRIA | 1.9.4 | http://med.inria.fr/ | DICOM Library |
| MedImaView | 1.8 | http://www.dicom-solutions.com/ | NEMA |
| MicroView | 2.1.2 | http://microview.sourceforge.net/ | DICOM Library |
| MIPAV | 7.1.1 | http://mipav.cit.nih.gov/ | DICOM Library |
| MRIcro | 1.40 | http://www.mricro.com/ | DICOM Library |
| OpenDicomViewer | 0.9.0 | http://sourceforge.net/projects/opendicomviewer/ | NEMA |
| OsiriX Lite | 6.0.2 | http://www.osirix-viewer.com/ | DICOM Library |
| Oviyam | 2.0 | http://oviyam.raster.in/ | DICOM Library |
| RadiAnt | 1.9.16 | http://www.radiantviewer.com/ | DICOM Library |
| Phillips DICOM Viewer | 3.0 SP3 | http://www.healthcare.philips.com/main/about/connectivity/ | NEMA |
| Slice::Drop | 2014-12-05[2] | http://slicedrop.com/ | DICOM Library |
| Tomovision | 2.1-rev5 | http://www.tomovision.com/ | NEMA |
| Weasis | 2.0.1 | http://www.dcm4che.org/confluence/display/WEA/Home | DICOM Library |
| XMedCon | 0.13.0 | http://xmedcon.sourceforge.net/ | NEMA |

**Table 1: Included DICOM viewer projects with version, reference and used data set.**

[2]No version number found, identified by revision date.

systems provided by the I Do Imaging website or the software developers. Since the demo applications usually do not allow import of data sets, the criteria have been investigated using already available data sets. In general, we always remark, which dataset has been used (Tab. 1).

### 2.4 Use Cases

Depending on study characteristics (e.g. imaging modality, goal of the study, number of centers), various use cases for viewing of patient's DICOM data in clinical trials are conceivable. Each of these use cases has its own focus and appreciates certain functionality of DICOM viewer candidates. On a certain level of abstraction, we determine the use cases 3D imaging, hospital communication and workflow optimization in clinical trials.

In case of 3D imaging, the focus of a system lays on an excellent visualization of 3D volumes and a powerful support by rich image processing and rendering functionality in the viewer. Aiming at extensive 3D visualization, powerful system resources are primarily needed and a close system integration plays a negligible role. In case integration is impossible, patient's DICOM is rather manually transferred to another system than 3D functionality relinquished.

In contrast, in the hospital communication use case, an extensive visualization of 3D volume data only plays a minor role. Stable 2D viewing functionality is rather needed than sophisticated 3D rendering. However, the highest priority is set to a broad availability of interfaces for communication with the hospital infrastructure. In hospitals, this requirement primarily demands availability of DICOM interfaces.

In the third use case for workflow optimization, 2D viewing functionality is rather required than sophisticated rendering of 3D volume data, as well. However, a close integration of the DICOM viewer into the EDCS has the highest priority. This provides an optimal workflow in data acquisition, which particularly plays an important role in multi-centered trials. Here, resources have to be shared between involved centers and long distances have to be covered for transfer of patient's image data.

## 3. RESULTS

We included 15 open source, 9 free and 3 commercial DICOM viewer tools in our survey (Tab. 2). Regarding integration aspects, 15 viewers are designed as standalone, 7 as web-based and 5 as platform independent. In addition, 6 tools also provide GUIs for support of mobile devices. In each case, interfaces for DICOM C-STORE as SCP, as SCU, and Q/R, are supported by 4 tools, respectively. WADO and parameter transfer is provided by 7 and 5 viewers, respectively. However, C-STORE SCP, SCU and Q/R interfaces are exclusively offered by standalone tools. In contrast, excluding OsiriX and GingkoCADx, WADO is only supported by web applications. In total, GingkoCADx and OsiriX supply the most interfacing possibilities, only parameter transfer seems to be not possible with both viewers.

A total of 13 image viewing criteria including 8 requirements for 2D and 5 requirements for 3D have been investigated. Including all viewers, 4,48 2D and 1,37 3D viewing criteria are fulfilled on average, summed up in a mean of 5,85 criteria for image viewing at all. Concerning only standalone viewers, a mean of 4,60 and 1,67 criteria are met for 2D and 3D viewing, respectively. On the other hand, for web-based viewers 3,43 2D and 0,29 3D viewing criteria are met on average. However, with 5,60 2D and 2,00 fulfilled 3D image viewing criteria, platform independent tools achieved the highest values here.

The most 2D requirements of standalone, web-based and platform-independent viewers are met by GingkoCADx, OsiriX and Phillips DICOM viewer (all 7 criteria), Oviyam and DVW (both 5 criteria), and MIPAV (8 criteria), respectively. Regarding 3D viewing, OsiriX Lite and MicroView fulfill the most criteria of standalone (both 5 criteria), Slice::Drop (2 criteria) of web-based, and ImageJ as well as MIPAV (both 5 criteria) of platform-independent viewers.

## 4. DISCUSSION

Focusing on software for clinical trials, flexible low-budget solutions are advantageous, in special regarding investigator initiated trials (IIT). Hence, open source viewers are more recommendable than free or commercial product. However, as our survey shows, open source tools are at least on par with commercial software, and in fact reached better scores in our survey.

As we have expected, a general solution covering all requirements does not exist. Each application has its own focus, strength, and weaknesses. Hence, it is not useful to compare all DICOM viewers at once. More significance is achieved by comparing the viewer regarding our defined 3D imaging, hospital communication and workflow optimization use cases.

As we defined in the 3D imaging use case, it is advantageous to already have extensive 3D volume functionality included in the viewer. Since – at least up to today – the 3D performance of web browsers is still restricted, web applications are not really suitable for 3D rendering, and standalone or platform independent viewers preferable. Analyzing our results, the highest score regarding 3D imaging is reached by ImageJ, MicroView, MIPAV, and OsiriX Lite, each fulfilling all 3D viewing criteria. Furthermore, MIPAV satisfies all 2D viewing criteria as well, which may be helpful for 2D visualization of single slices of the volume. However, we recommended ImageJ and MicroView, since these projects are open source.

In the hospital communication use case, it is particular important to gather patient's routine data from hospital's infrastructure and to visualize it in the viewer. This can be done by directly sending patient's data to the viewer or by retrieving the images from the hospital's PACS. In both cases, DICOM interfaces are necessary. Since data is immediately gathered from hospital's routine, high security regulations have to be satisfied. Rendering a tight system integration and allowing access to a large pool of valuable data is impossible. Focusing on DICOM interfaces, the viewer GingkoCADx, MIPAV and OsiriX Lite support DICOM C-STORE as SCP and SCU, and Q/R. MIPAV fulfills the most 2D criteria in this collection as well, but we suggest GingkoCADx, since its open source and only the histogram visualization criteria is not satisfied regarding 2D viewing.

In clinical trials with multi-centered data capturing, the viewer can be directly embedded and image data can be viewed within in the eCRF. Since, EDCS are today designed as web-applications, only web- or platform-independent viewers can be integrated. Data and context integration is necessary, which can be provided by WADO and parameter transfer, respectively. Oviyam and Weasis are the only web-based and platform-independent candidates, and utilized with WADO as well as parameter transfer interfaces. Both projects are open source. However, Weasis slightly beats Oviyam regarding 2D image viewing by two criteria, but Oviyam could be extended by iOviyam for support of mobile devices. However, we recommended Weasis as optimal viewer for this use case, since we rank pseudo-coloring and annotations as more important.

In general, we guess that in most clinical trials an optimal data capture workflow is more important and useful than 3D imaging functionality and direct access to patient's hospital data. As we already showed in previous work, tight system interconnections reduces errors, time and costs [11]. Apart from this, our survey offers a collection of available DICOM viewers for identification of an optimal component in various applications. According to the four levels of system integration, a PACS can be interconnected between EDCS and DICOM viewer, which provides necessary DICOM interfaces combining the hospital access and workflow optimization use cases. Since the developers of Weasis state, that Weasis "can be easily connect to any PACS"[3], this viewer seems to be also the optimal choice in this case.

[3]http://www.dcm4che.org/confluence/display/WEA/Home

| | General | | | | | | | Integration | | | | | | | | | Viewing | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Open Source | Free | Commercial | Documentation | Mail | Forum | Wiki | Standlone | Web | Independent | Mobile | C-STORE SCP | C-STORE SCU | DICOM Q/R | WADO | Parameter | Scrolling | Header | Overlay | Windowing | Pseudo-Coloring | Histogram | Measurements | Anotations | Secondary | Slice Cube | Volume | Transfer | Surface |
| Name | G1 | G2 | G3 | G4 | G5 | G6 | G7 | I1 | I2 | I3 | I4 | I5 | I6 | I7 | I8 | I9 | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 | V9 | V10 | V11 | V12 | V13 |
| 3D Slicer | + | - | - | + | + | + | + | + | - | - | - | + | - | + | - | - | + | - | - | + | + | + | - | - | + | - | + | + | + |
| BioImageSuite | + | - | - | + | + | + | - | + | - | - | - | - | - | - | - | - | + | - | - | - | - | + | - | - | + | + | + | - | - |
| Cornerstone | + | - | - | - | - | + | - | - | + | - | + | - | - | - | +[4] | - | + | - | - | + | - | - | + | - | - | - | - | - | - |
| DWV | + | - | - | +[5] | + | - | + | - | + | - | + | - | - | - | +[6] | - | - | + | - | + | + | + | + | - | - | - | - | - | - |
| DicomWorks | - | + | - | - | - | - | - | +[7] | - | - | - | - | - | - | - | - | + | + | + | + | - | - | + | - | - | - | - | - | - |
| Eviewbox | + | - | - | - | + | -[8] | - | - | - | + | - | - | - | - | - | - | - | + | - | + | - | - | - | - | - | - | - | - | - |
| ezDICOM | + | - | - | - | - | + | - | + | - | - | - | - | - | - | - | - | | +[9] | - | +[9] | - | - | - | - | - | - | - | - | - |
| Gingko CADx | + | - | - | - | - | + | + | + | - | - | - | + | + | + | + | - | + | + | + | + | + | - | + | + | - | - | - | - | - |
| Image J | + | - | - | + | - | - | - | - | - | + | - | - | - | - | - | +[10] | + | + | - | + | + | + | + | +[11] | + | + | + | + | + |
| iOviyam | + | - | - | + | - | + | - | - | +[12] | - | + | - | - | - | + | - | + | - | + | + | - | - | -[13] | - | - | - | - | - | - |
| JiveX Dicom Viewer | - | + | - | + | - | - | - | + | - | - | - | - | - | - | - | + | + | - | + | + | + | - | + | +[11] | - | - | - | - | - |
| JiveX Mobile | - | - | + | - | - | - | - | - | +[14] | - | + | - | - | - | - | - | + | - | - | + | - | - | + | - | - | - | - | - | - |
| MedDream | - | - | + | + | - | - | - | - | +[15] | - | - | - | - | - | - | + | + | - | + | + | - | - | + | - | - | - | - | - | - |
| MediINRIA | - | + | - | + | + | + | - | + | - | - | - | - | - | - | - | - | + | -[16] | + | +[17] | + | - | - | - | + | + | + | - | + |
| MedImaView | - | + | - | -[18] | + | - | - | + | - | - | - | - | - | - | - | - | + | + | - | + | + | -[19] | - | - | - | - | - | - | - |
| MicroView | + | - | - | + | + | + | - | + | - | - | - | - | + | - | - | - | + | + | - | + | + | - | - | - | + | + | + | + | + |
| MIPAV | - | + | - | + | + | - | + | - | - | + | - | + | + | + | - | - | + | + | + | + | + | + | + | +[20] | + | + | + | + | + |
| MRIcro | - | + | - | + | - | - | - | + | - | - | - | - | - | - | - | - | +[21] | +[21] | - | +[21] | +[21,22] | -[19] | - | +[11,21] | +[21] | - | +[21] | - | - |
| OpenDicomViewer | + | - | - | - | - | + | - | - | - | + | - | - | - | - | - | - | + | + | + | + | - | - | - | - | - | - | - | - | - |
| OsiriX Lite | - | + | - | + | + | - | + | + | - | - | + | + | + | + | + | - | + | + | + | + | + | - | + | + | + | + | + | + | + |
| Oviyam | + | - | - | + | - | + | - | - | +[23,24] | - | - | - | - | - | + | + | + | + | + | + | - | - | + | - | - | - | - | - | - |
| RadiAnt | - | - | + | + | + | + | - | + | - | - | - | - | - | - | - | - | + | + | + | + | - | - | + | + | + | - | - | - | - |
| Phillips DICOM Viewer | - | + | - | - | - | - | - | + | - | - | - | - | - | - | - | - | +[25] | +[25] | +[25] | +[25] | +[25] | - | +[25] | +[25] | - | - | - | - | - |
| Slice::Drop | + | - | - | - | + | - | - | - | + | - | + | - | - | - | - | - | - | - | - | + | - | - | - | - | +[26] | +[26] | - | - | - |
| Tomovision | - | + | - | - | + | - | - | + | - | - | - | - | - | - | - | - | +[27] | + | + | + | - | - | - | - | - | - | - | - | - |
| Weasis | + | - | - | + | - | + | - | + | - | + | - | - | - | - | +[28] | + | + | + | + | + | + | - | + | +[29] | - | - | - | - | - |
| XMedCon | + | - | - | + | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | +[30] | +[30] | - | - | - | +[30] | - | - | - | - |

**Table 2: Results of the DICOM viewer survey.**

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[4]Via additional CornerstoneWADOImageLoader plugin, [5]comprehensive documentation in Wiki, [6]Conquest, DCM4CHEE or Orthanc PACS for WADO required, [7]only executable on Windows with administrator rights, [8]forum offline, [9]displays only first slice of test data, [10]using startup macro feature, [11]saves annotations in other formats, but not DICOM, [12]requires Oviyam, [13]designated, but not working, [14]requires JiveX communication server or PACS, [15]requires PACS (supports Conquest, PacsOne, ClearCanvas or DCM4CHEE), [16]only technical information, no patient/study related information, [17]bad resolution and grayscale, [18]only commercial, [19]shows initial histogram only, [20]annotated objects could not be reopened, [21]does not open DICOM, but files can be converted to NIFTI, [22]pseudo coloring did not affect visualization of test data, [23]requires DCM4CHEE PACS, [24]runs only with Google Chrome, [25]compression artefacts, [26]does not recognize dataset as volume, [27]only on single multi-frame DICOM files, [28]DCM4CHEE PACS Connector plugin needed, [29]only via screenshot, [30]shows every slice of a multi-frame DICOM file separately.