
**ANALYSIS OF SOFTWARE SOLUTIONS FOR THE MANIPULATION AND
PROCESSING OF IMAGING NEUROLOGICAL NUCLEAR MEDICINE STUDIES**

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Abstract: Nowadays nuclear medicine studies take an important place in diagnostic evaluation of patients with neurological diseases. Unlike radiological methods, that give us insight in morphology, nuclear medicine studies can be used for functional examination of nervous system. Using nuclear medicine methods we can test efficiency, transport, binding to receptors or effectiveness of new experimental neurological medications.

Methods: Program IBM SPSS Statistics 22.0v for MacOS was used for statistical analyses. Variables were divided into six groups. First group contains of DICOM readers, general imaging, DICOM applications, nuclear medicine software, PACS work stations and radiation protection programs. According to data, parametric and nonparametric tests, as methods of descriptive statistics, were used for statistical analysis.

Results: The study included 88 programs: 33 DICOM readers (31,4%), 5 general imaging (4,8%), 9 DICOM applications (8,6%), 30 nuclear medicine studies (28,6%), 9 PACS work stations (8,6%) and 2 radiation protection programs (1,9%). From all analysed programs 36 (34,3%) were for Windows, 1 (1%) for Linux, 6 (5,7%) for MacOS, 5 (4,8) were based on multiplatform integration for Windows and Linux, and 32 (30,5%) for Windows, Linux and Mac OS integrated multiplatforms. From all software solutions that were analysed, PACS integration had 29 (27,6%) programs and 53 (50,5%) did not have PACS integration. DICOM integration had 77 (73,3%) programs and 5 (4,8%) programs did not have DICOM integration. HL7 integration had 37 (35,2%) programs and 45 (42,9%) did not have HL7 integration. 52 (49,5%) programs did not have a special purpose, while 30 (28,6%) had a special purpose. Reconstructions performed during image reconstruction are filtered back projection (FBP) 1 (16,7%), OSEM3D 1 (16,7%) and Flash3D 1 (16,7%). The filters that were used during the reconstruction were the following and Hanning filter 1 (16,7%), Gauss filter 3 (50,0%), unknown was 1 (16,7%), Chang and Butterworth 1 (16,7%). 76 (72,4%) programs had formats for selecting different export from the system, while 6 (5,7%) did not have this possibility. 42 (40%) programs had film export formats, while 35 (33,3%) programs did not, 4 (3,8%) programs were unknown. 34 (32,4%) programs had support for multiple monitors, while 45 (42,9%) programs did not, while

3 (2.9%) programs did not have support. 74 (70.5%) programs had a cine function, while 8 (7.6%) did not have a cine function. 69 (65.7%) had a reference line, while 13 (12.4%) did not have a reference line. Of the total number of programs, 81 (100%) are free, 53 (50.5%) programs are free, while 25 (23.8%) programs are shareware, and the status of 1 (1.0%) program is unknown.

Conclusion : Iterative reconstruction is one of the most frequently used reconstructions in nuclear medicine for neurological diagnostic. It is combined with Gaussian, Hanning or Butterworth algorithms for study processing. In the future , nuclear medicine studies will probably be integrated into the Cloud environment , where only the hardware components of processing workstations can be a limiting factor in neurological nuclear medicine reconstructions.

Keywords : nuclear medicine, neurology, reconstruction, filters, diagnostic methods.

1. INTRODUCTION

Nowadays nuclear medicine studies take an important place in diagnostic evaluation of patients with neurological diseases. Unlike radiological methods, that give us insight in morphology, nuclear medicine studies can be used for functional examination of nervous system. Using nuclear medicine methods we can test efficiency, transport, binding to receptors or effectiveness of new experimental neurological medications.(Akdemir & Atay Kapucu, 2016)

Today, all searches are archived in "picture archiving and communication systems" (PACS), and their connection, analysis and processing are also done via workstations. (Grosser et al., 2015)

Medical image, that represents structure and function of specific anatomical region, is build from basic elements called pixels or voxels. Role of this basic elements is to represent a numerical value in a certain space. The number of pixels used to display the field of a certain image modality represents an impression of an anatomical function. The number of pixels is important for the acquisition protocol, reconstruction and eventual post-processing.

Medical image formats can be divided into two categories. The first category represents a format that can be generally used in displaying a radiological image, such as e.g. DICOM. Other formats are made for post-processing of medical images, such as e.g. Analyze, Nifty and Mint. Medical formats are typically stored using one of these two configurations.

Two formats that are most often used in nuclear medicine are Interfile and DICOM . Interfile was developed as part of the European program for the exchange of phantom quality images and is one of the most widely distributed formats used by all major manufacturers of nuclear medical devices./ In addition to being an image format, the Dicom format also functions as an Internet TCP/IP protocol in medical image communication. Due to its multifunctionality, DICOM has become a standard not only in radiology and nuclear medicine, but also in other branches of medical imaging.

The problem of displaying dynamic studies, flow phases, as well as multi-energy acquisition, imaging in multiple layers, which are less commonly used in conventional radiological imaging, while they are standardly used in neurological studies. For this reason, PACS systems do not correctly display nuclear medicine studies due to non - implementation in an appropriate manner .

2. OBJECTIVES

Some manufacturers also put their private lens elements in the DICOM file in order to achieve maximum compatibility with their image processing software. Nuclear medicine uses the Nuclear Medicine Information Documentation Definition (NM IOD) which is part of the DICOM standard. PET uses a different PET IOD section of the DICOM standard. Manufacturers of PACS systems (vendors) who have not specified or determined and implemented part of the standard have problems with storing and displaying part of the studies.

The aim of the paper is to present all the current software solutions that are on the market at the time of writing the paper and their compatibility in the manipulation of neurological nuclear medicine studies.

3. METHODS

Study was conducted from 1.1.2020. until 1.1.2022. Referenced databases as PubMed, Excerpta Medica Database (EMBASE), Cochrane Library, PubMed Central (PMC), UpToDate and official websites on information related to software solutions intended for the analysis of imaging nuclear medicine studies in neurology were included in the study.

A database was created in MySQL, in which all data downloaded from the Internet were entered. The following variables were analyzed : the name of the program, the version of the last upgrade, the operating system for which they are intended, the development environment in which they were written , whether the interface is web-based, whether the application has a website, whether it has support house for PACS and DICOM format, as well as the HL7 standard, special purpose software, documentation, image export formats, film export formats, ease of use of

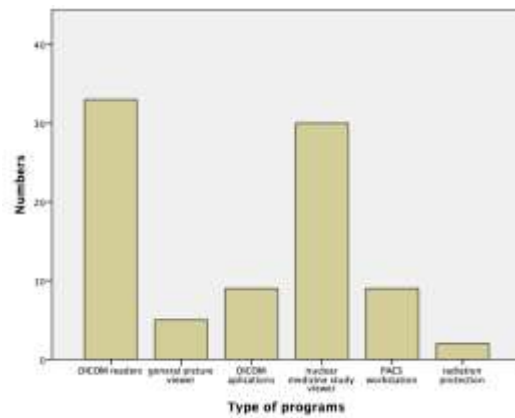
the program, special features of the program, support for multiple monitors , cine functions, having a reference line, whether it has a browser, a browser with a processing or analyzing processor , the type of reconstruction and the price of the software.

Statistical analysis was performed in the program IBM SPSS Statistics 22.0v for MacOS. The variables are divided into 6 groups. The first group is DICOM readers , general imaging , DICOM applications, nuclear medicine software, PACS workstations and programs for radiation protection. The analysis was carried out using the methods of descriptive statistics, during which the statistical methods of parametric or non-parametric tests were applied , depending on the type of data.

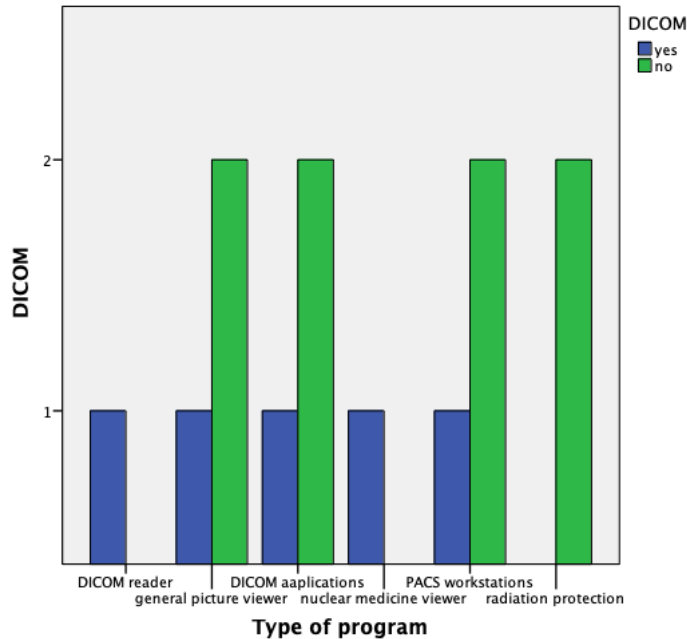
4.RESULTS

A total of 88 programs were analyzed. DICOM readers were 33 (31.4 %), general image display 5 (4.8%), DICOM applications 9 (8.6%), display of nuclear medicine studies 30 (28.6%). PACS workstations 9 (8.6%) and radiation shielding programs 2 (1.9%) of the tested programs.

Chart 1: Type of program



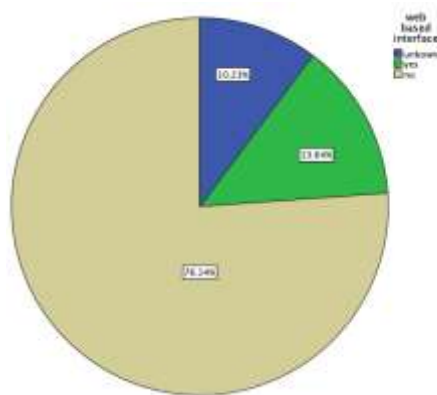
Graph 2: Representation of programs compatible with the DICOM format



Of the total number of analyzed programs based on the Windows environment , there were 36 (34.3%), for Linux 1 (1.0%), MacOS 6 (5.7%), multiplatform integration for Windows and Linux 5 (4.8%), while multiplatform integration for Windows, Linux and MacOS amounted to 32 (30.5%) programs. There is a statistically significant

difference in the frequency of program type and DICOM compatibility for study processing between the observed groups [$\chi^2(88)=37,222, P<0.05$]. The results of research on the representation of the development environment in which the software package was developed gave the following data : 50 (47.6%) programs were unknown, Java 16 (15.2%), Python 2 (1.9%), C++ 3 (2.9%), ActiveX1 (1.0%), C 2 (1.9%), C 2 (1.9%), GTX+ 1 (1.0%), Delphi 1 (1.0%), Cocoa 1 (1.0%), OpenGL 1 (1.0%), XCode 1 (1.0%), Perl 1 (1.0%), a combination of Java, Python, C++, C#, R, Ruby, Tel was 2 (1.9%), Java, Python, C++ 2 (1.9%) , C++, C, Fortran, Ruby, Java, Tel, ActiveX amounted to 1 (1.0%) of the total number of programs. There is no statistically significant difference in the correlation between the development environment and PACS capabilities between the observed groups [$\chi^2(88)=20.972, P>0.05$]. The total number of software packages that had a web-based interface is shown in the following data : 9 (8.6%) were unknown, 12 (11.4%) had, while 67 (63.8%) did not have a web -based interface. There is a statistically significant difference in the correlation between the operating system and the web-based interface between the observed groups [$\chi^2(88)=43,232, P<0.05$].

Chart 2: Web- based frontends



80 (76.2%) programs had an active manufacturer's website , while 8 (7.6%) did not have a manufacturer 's website . There is no statistically significant difference in the correlation between the price of the software solution and website maintenance between the observed groups [$\chi^2(88)=1.448, P>0.05$].

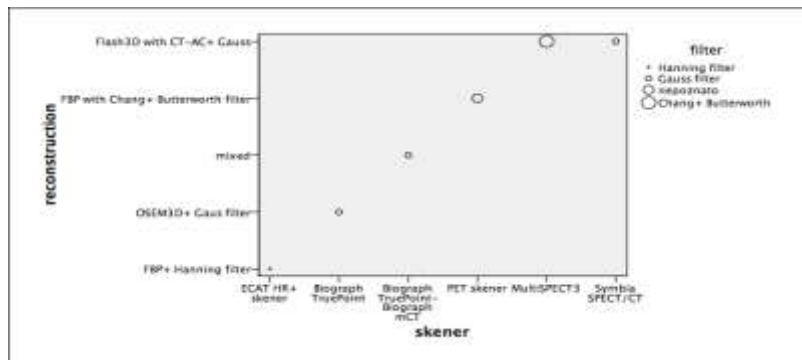
Of the total number of software solutions , 29 (27.6%) programs had PACS integration, while 53 (50.5%) did not have PACS integration. There is no statistically significant difference in the correlation between the type of program and PACS implementation between the observed groups [$\chi^2(88)=24.686, P>0.05$].

77 (73.3%) programs had DICOM integration, while 5 (4.8%) did not have DICOM integration. There is a statistically significant difference in the correlation between the type of program and the DICOM interface between the observed groups [$\chi^2(88)=37.222, P<0.05$].

37 (35.2%) programs had HL7 integration, while 45 (42.9%) did not have HL7 integration. There is no statistically significant difference in the correlation between the type of program and the HL7 standard between the observed groups [$\chi^2(88)=11.045, P>0.05$].

52 (49.5%) programs did not have a special purpose, while 30 (28.6%) had a special purpose. There is no statistically significant difference in the correlation between the type of program and the special purpose between the observed groups [$\chi^2(88)=9.861, P>0.05$].

Figure 3: Software display and reconstruction filter integration



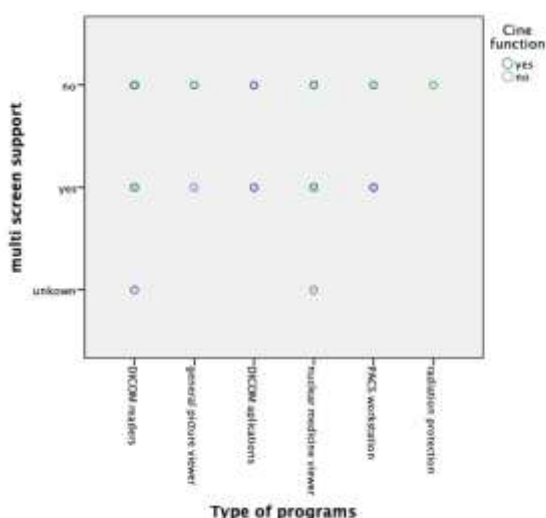
Of the total number of programs that were researched , 6 of them (100%) have information about the image reconstruction software solution and the filters they use. Biograph TruePoint 1 (16.7%), ECAT HR 1 (16.7%), ECD SPECT 1 (16.7%), Florbetapir PET 1 (16.7%), HMPAO SPECT 1 (16.7%) and mCT 1 (16.7%) were investigated. . There is no statistically significant difference in the correlation between the scanner used for recording and the filters used in the reconstruction between the observed groups [$\chi^2(88)=18,000, P>0.05$].

ECAT HR+ 1 (16.7%), Biograph TruePoint 1 (16.7%), Biograph mCT 1 (16.7%), PET scanner 1 (16.7%), MultiSpect 1 (16.7%), Symbia 1 (16.7%) were used.

Reconstructions performed during image reconstruction are filtered back projection (FBP) 1 (16.7%), OSEM3D 1 (16.7%) and Flash3D 1 (16.7%). The filters that were used during the reconstruction were the following and Hanning filter 1 (16.7%), Gauss filter 3 (50.0%), unknown was 1 (16.7%), Chang and Butterworth 1 (16.7%). There is no statistically significant difference in the correlation between the scanner used for recording and the reconstruction algorithm between the observed groups [$\chi^2(88)=24,000, P>0.05$].

76 (72.4%) programs had formats for selecting different export from the system, while 6 (5.7%) did not have this option . 42 (40%) programs had film export formats, while 35 (33.3%) programs did not, 4 (3.8%) programs were unknown.

Chart 4: Program type and support for multiple monitors when interpreting



40 programs had support for multiple monitors , while 45 (42.9%) programs did not, while 3 (2.9%) programs did not have support. There is no statistically significant difference in the correlation between the type of program and support for multiple monitors between the observed groups [$\chi^2(85)=8.625, P>0.05$].

74 (70.5%) programs had a cine function, while 8 (7.6%) did not have a cine function. 69 (65.7%) had a reference line, while 13 (12.4%) did not have a reference line. There is a statistically significant difference in the correlation between the type of program and the Cine function between the observed groups [$\chi^2(88)=20.522, P<0.05$] . There is no statistically significant difference in the correlation between the type of program and the reference line of the observed groups [$\chi^2(85)=12.566, P>0.05$].

77 (73.3%) programs had the browser implemented, while 5 (4.8%) had no implementation. There is a statistically significant difference in the correlation between the type of program and browser between the observed groups [$\chi^2(88)=34.353, P<0.05$] . The browser with a radiological processor had 23 (21.9%) programs. while 57 (54.3%) did not have this function. There is no statistically significant difference in the correlation between the type of program and the browser with the radiological processor between the observed groups [$\chi^2(85)=5.056, P>0.05$] browser with an editing processor , while (53.3%) did not have this function. There is no statistically significant difference in the correlation between the type of program and browser with editing processor between the observed groups [$\chi^2(85)=9.596, P>0.05$].

Out of the total number of programs, 81 (100%) are free, 53 (50.5%) programs are free, while 25 (23.8%) programs are shareware, the status of 1 (1.0%) program is unknown.

5. DISCUSSION

The methods of nuclear medicine began to use in neurology with the development of new radiotracers applicable in brain visualization. Currently, more than 200 radiopharmaceuticals have been synthesized, and using them it is possible to obtain unique information about glucose metabolism, various amino acids, fatty acids, DNA synthesis, perfusion, cell proliferation, the degree of their hypoxia, accumulation of β -amyloid, tau protein, dopamine metabolism, acetylcholine and other neurotransmitters. (Granov, Tyutin, & Stanzhevskii, 2012)

Displaying and analyzing such studies requires a specific workstation. Nuclear medicine workstations are not sufficiently represented in the world due to the small number of institutions that can do research. Brain research and neurophysiological tests are performed by a small number of institutions. Vendors/producers who produce the devices provide, along with the gamma camera itself, one or more workstations that work with the device in the form of a viewer or complete studio processing. Their cost of \$ 25,000 for a partial study processing software solution or \$50,000 for a full software solution is a large expense for nuclear medicine centers. Most of the users prefer the solutions they received with the purchased device. (Barbaras, Tal, Palmer, Parker, & Kolodny, 2007)

Image fusion in SPECT/CT and PET/CT studies are important in neurological studies, as they show the molecular structure of the brain in addition to anatomical structures. Brain research today cannot be imagined without PET/CT and SPECT/CT hybrid machines. Image fusion depends on the vendor that supplied the machine, so the interpretation of the study depends on the used algorithm. (Harmon et al., 2020)

Our research showed that out of the total number of 81 (100%) programs, 53 (50.5%) programs are free, while 25 (23.8%) programs are shareware, and the status of 1 (1.0%) program is unknown. This information is matched with the relevant databases on the pricing and payment model of software solutions.

The results of the research show that a complete software solution has a high price for the entire software package, and that a partial software solution does not meet all the needs of the user. Free software packages are closely related to research centers and their programming teams in case of software and integration problems. Most programs offer (Barbaras et al., 2007; Escott & Rubinstein, 2003)

Of the total number of software solutions, 29 (27.6%) programs had PACS integration, while 53 (50.5%) did not have PACS integration. 77 (73.3%) programs had DICOM integration, while 5 (4.8%) did not have DICOM integration. 37 (35.2%) programs had HL7 integration, while 45 (42.9%) did not have HL7 integration. 52 (49.5%) programs did not have a special purpose, while 30 (28.6%) had a special purpose. This data coincides with statistical data from world databases.

Our research has shown that the practice of vendors/manufacturers is to integrate their functions into software packages and in this way enable full compatibility on their devices. (Park, 2022) All manufacturers of software solutions that do not have hardware components provide some study storage function in the form of a PACS system. (Escott & Rubinstein, 2003; Grosser et al., 2015; Larobina & Murino, 2014)

Of the total number of analyzed programs based on the Windows environment, there were 36 (34.3%), for Linux 1 (1.0%), MacOS 6 (5.7%), multiplatform integration for Windows and Linux 5 (4.8%), while multiplatform integration for Windows, Linux and MacOS amounted to 32 (30.5%) programs.

Most of the software solutions are based on the Windows environment, because it is the most represented in the world. However, the question arises as to whether it is a high-quality solution due to its spread and the shortcomings it contains, such as viruses or system upgrades that are more common on this platform. (Langer, Charboneau, & French, 2010; Lo Presti et al., 2015)

The results of research on the representation of the development environment in which the software package was developed gave the following data: 50 (47.6%) programs were unknown, Java 16 (15.2%), Python 2 (1.9%), C++ 3 (2.9%), ActiveX1 (1.0%), C 2 (1.9%), C 2 (1.9%), GTX+ 1 (1.0%), Delphi 1 (1.0%), Cocoa 1 (1.0%), OpenGL 1 (1.0%), XCode 1 (1.0%), Perl 1 (1.0%), the combination of Java, Python, C++, C#, R, Ruby, Tel was 2 (1.9%), Java, Python, C++ 2 (1.9%), C++, C, Fortran, Ruby, Java, Tel, ActiveX amounted to 1 (1.0%) of the total number of programs.

Recently, most software solutions are written with universal code, so that it is portable for several different platforms. Research has shown that in this way the manufacturer saves money and enables "cleaner" program code as well as a cross-platform option of using their software. (Barra, Barra, & Sobrinho, 2010; Lo Presti et al., 2015)

The total number of software packages that had a web-based interface is shown in the following data: 9 (8.6%) were unknown, 12 (11.4%) had, while 67 (63.8%) did not have a web-based interface.

Research has shown that web-based user interfaces are modern these days, as well as Cloud-based applications that can be used by research teams independently of each other. (Luo, Jiang, & Zhuang, 2009)

Neurological nuclear medicine research and conventional tests are mostly related to software solutions that are needed for complete interpretation of the studies. Our research obtained the following information: out of the total number of programs that were researched, 6 of them (100%) have information about the image reconstruction

software solution and the filters they use. Biograph TruePoint 1 (16.7%), ECAT HR 1 (16.7%), ECD SPECT 1 (16.7%), Florbetapir PET 1 (16.7%), HMPAO SPECT 1 (16.7%) and mCT 1 (16.7%) were investigated. .

Scanner who was used were ECAT HR+ 1 (16.7%), Biograph TruePoint 1 (16.7%), Biograph mCT 1 (16.7%), PET scanner 1 (16.7%), MultiSpect 1 (16.7%), Symbia 1 (16.7%).

Research has shown that nuclear medicine plays a major role in proving brain death, epilepsy , Parkinson's disease, as well as researching the effects of new medications. Segmental reconstruction is important when researching medications, because based on reconstruction methods, for example, the binding of the medication at the receptor can be monitored.(Zaharchuk & Davidzon, 2021)

Dementia and Parkinsonism studies are the most frequently used nuclear medicine methods in neurology. Both diseases represent an important social and medical issue due to the increasing prevalence of the disease in the world. In addition to the metabolic state, anatomical localization is also important for research. (Granov et al., 2012; Seifert, Weber, Kocakavuk, Rischpler, & Kersting, 2021)

Segmental reconstruction is important for the appropriate display of anatomical structures during interpretation. (Costa, Pilowsky, & Ell, 1999), (Bruyant, 2002; Frey, Humm, & Ljungberg)So the software solutions use the following filters and reconstructions: filtered back projection (FBP) 1 (16.7%), OSEM3D 1 (16.7%) and Flash3D 1 (16.7%). The filters that were used during the reconstruction were the following and Hanning filter 1 (16.7%), Gauss filter 3 (50.0%), unknown was 1 (16.7%), Chang and Butterworth 1 (16.7%).

76 (72.4%) programs had formats for selecting different export from the system, while 6 (5.7%) did not have this option . 42 (40%) programs had film export formats, while 35 (33.3%) programs did not, 4 (3.8%) programs were unknown. 74 (70.5%) programs had a cine function, while 8 (7.6%) did not have a cine function. 69 (65.7%) had a reference line, while 13 (12.4%) did not have a reference line.

When we talk about image viewers , it is important to mention the CINE function and the reference line, which is important when interpreting the image fusion of SPECT /PET images with MRI or CT. (Akdemir & Atay Kapucu, 2016; Fatima & Zaman, 2017; Langer et al., 2010)

It should be noted that hypometabolism in the parietal and temporal regions of the associative cortex is not typical of dementia. Comparison of anatomical structures with functional metabolic ones is very important. (Granov et al., 2012)The integration of these two functions is very important when interpreting the findings. 77 (73.3%) programs had the browser implemented, while 5 (4.8%) had no implementation. The browser with a radiological processor had 23 (21.9%) programs, while 57 (54.3%) did not have this function. 26 (24.8%) programs had a browser with an editing processor , while (53.3%) did not have this function.

6. CONCLUSION

Nuclear medicine is represented for functional tests in neurological studies. Research into epilepsy, Parkinson's disease or dementia cannot be done without iterative reconstruction. It is combined with Gaussian, Hanning or Butterworth algorithms for study processing. Image fusion with CT or MRI scans provides insight not only at the molecular level, but also into anatomical changes in the brain structure.

In a future, nuclear medicine studies will probably be integrated into the Cloud environment, where only the hardware components of processing workstations can be a limiting factor in neurological nuclear medicine reconstructions.

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