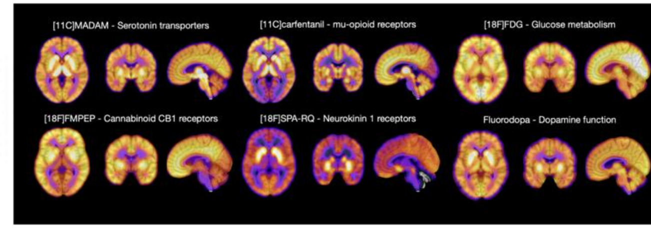
NUMMENMAA LAB
Human Emotion Systems Laboratory

Carimas



Using Carimas software for image analysis

Chunlei Han MD, Ph.D

Mathematical modeller in Turku PET Centre &

adjunct professor at the department of clinical physiology in Turku University Hospital

Turku PET Centre and Turku University Hospital

TURKU PET CENTRE NEUROIMAGING COURSE 2025

14:45-15:30, August. 31, 2026 Turku Finland

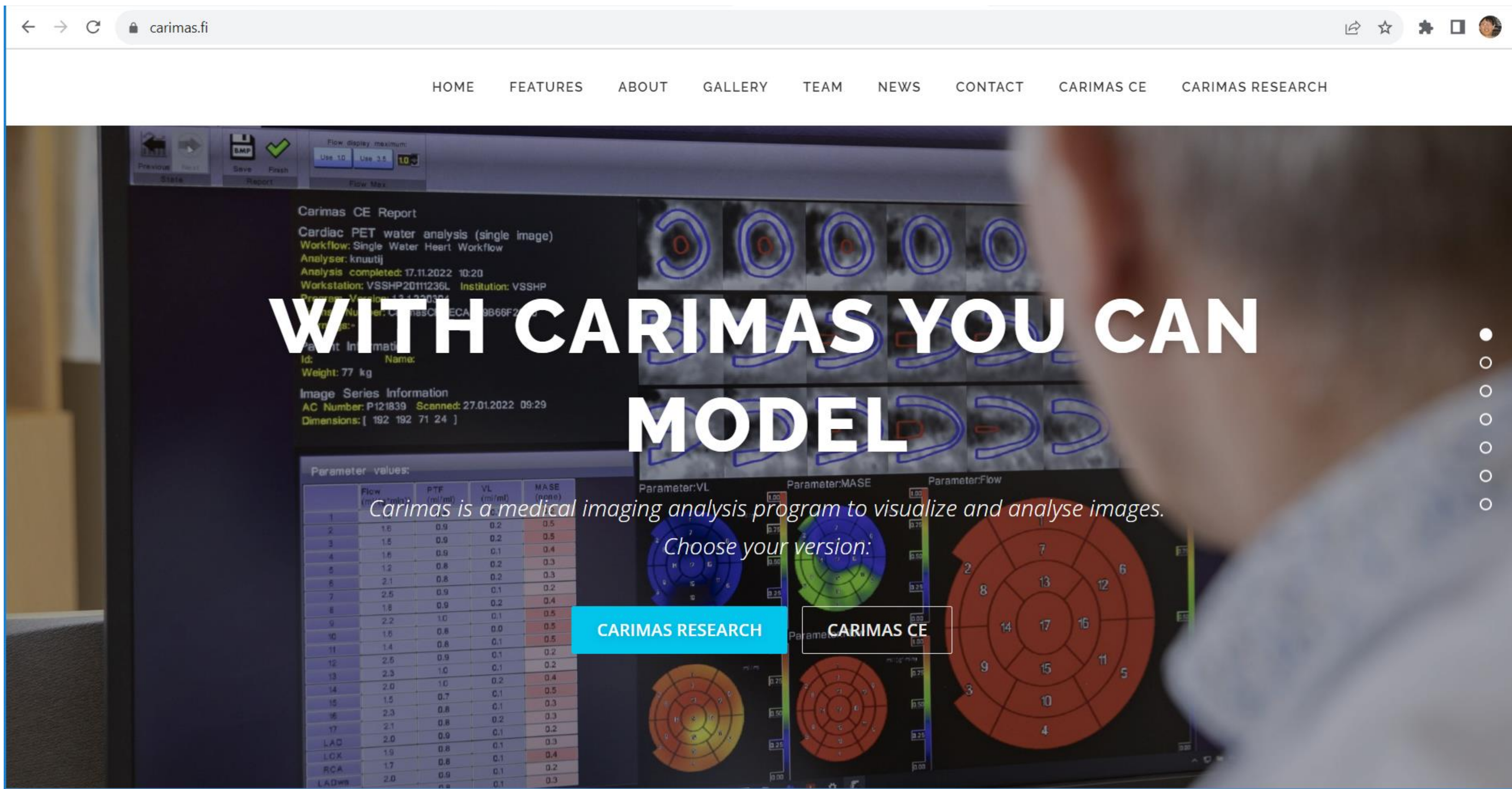
ÅBO AKADEMI

Contents

- ***Brief on Carimas***
- Features and program structure
- Demonstration

Key points of Carimas

- *Visualising, analysing, modelling and reporting PET and other medical imaging data*
- *Widely used as a medical imaging processing tool all the world over 15 years*
- *Over 500 scientific research papers published based on analysis of Carimas*
- *Two versions: Carimas Research and CarimasCE*



Short history of Carimas

- Carimas 1: ~2007-2015. Coded by IDL. Only for ^{15}O-radio water myocardial perfusion data.
- Carimas 2: ~2010-present: A general tool for PET and other imaging data. Coded by C#
- CarimasCE:~ 2020-present. Coded by C#

CE 0537

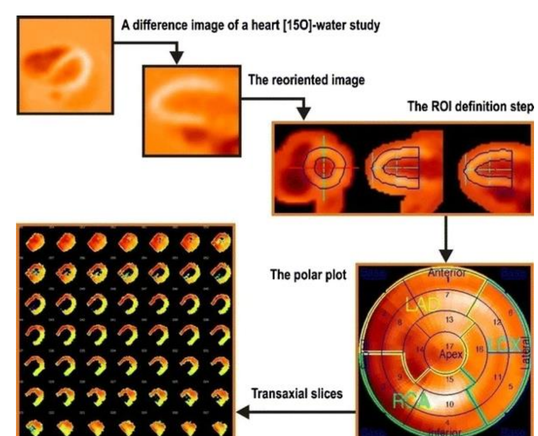
CERTIFIED MANAGEMENT SYSTEM eurofins ISO 13485

<u>First publication of Carimas on 2009 on Eur J Nucl Med Mol Imaging</u>

> Eur J Nucl Med Mol Imaging. 2009 Oct;36(10):1594-602. doi: 10.1007/s00259-009-1143-8. Epub 2009 Apr 30.

Myocardial perfusion quantitation with 15O-labelled water PET: high reproducibility of the new cardiac analysis software (Carimas)

Sergey V Nesterov [1], Chunlei Han, Maija Mäki, Sami Kajander, Alexandru G Naum, Hans Helenius, Irina Lisinen, Heikki Ukkonen, Mikko Pietilä, Esa Joutsiniemi, Juhani Knuuti



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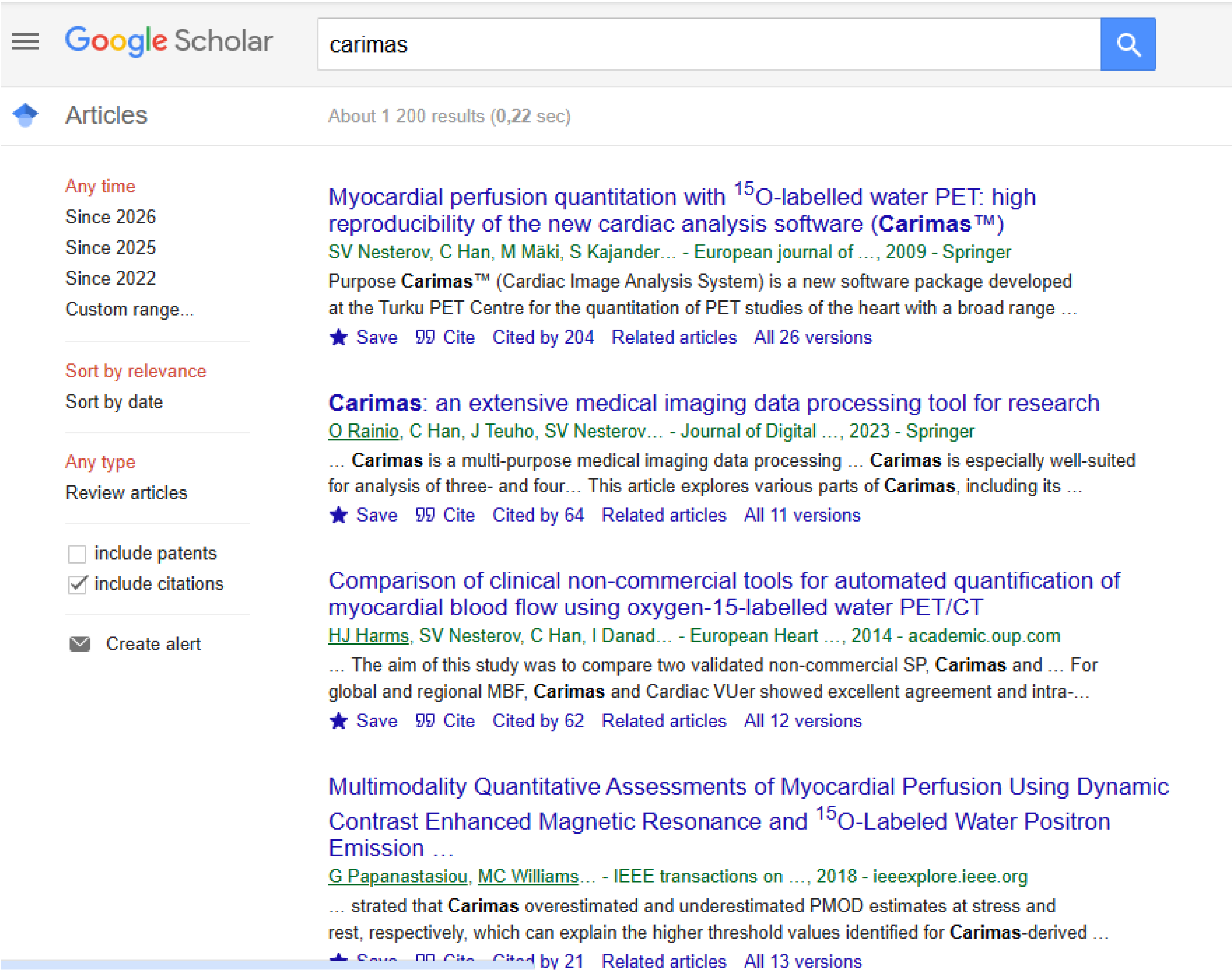

Google Scholar carimas

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Myocardial perfusion quantitation with ^{15}O-labelled water PET: high reproducibility of the new cardiac analysis software (**Carimas**™)
SV Nesterov, C Han, M Mäki, S Kajander… - European journal of …, 2009 - Springer
Purpose **Carimas**™ (Cardiac Image Analysis System) is a new software package developed at the Turku PET Centre for the quantitation of PET studies of the heart with a broad range …
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Carimas: an extensive medical imaging data processing tool for research
O Rainio, C Han, J Teuho, SV Nesterov… - Journal of Digital …, 2023 - Springer
… **Carimas** is a multi-purpose medical imaging data processing … **Carimas** is especially well-suited for analysis of three- and four… This article explores various parts of **Carimas**, including its …
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Comparison of clinical non-commercial tools for automated quantification of myocardial blood flow using oxygen-15-labelled water PET/CT
HJ Harms, SV Nesterov, C Han, I Danad… - European Heart …, 2014 - academic.oup.com
… The aim of this study was to compare two validated non-commercial SP, **Carimas** and … For global and regional MBF, **Carimas** and Cardiac VUer showed excellent agreement and intra-…
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Multimodality Quantitative Assessments of Myocardial Perfusion Using Dynamic Contrast Enhanced Magnetic Resonance and ^{15}O-Labeled Water Positron Emission …
G Papanastasiou, MC Williams… - IEEE transactions on …, 2018 - ieeexplore.ieee.org
… strated that **Carimas** overestimated and underestimated PMOD estimates at stress and rest, respectively, which can explain the higher threshold values identified for **Carimas**-derived …
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Google scholar: Carimas 1 200 found, Aug 31, 2026

EJNMMI Research

https://doi.org/10.1186/s13550-026-01460-6

Article in Press

The test-retest reproducibility of [^{11}C]PK11195 positron emission tomography using Biograph Vision Quadra scanner

Received: 29 December 2025

Accepted: 20 May 2026

Published online: 02 June 2026

Cite this article as: Sjöros T., Matilainen M., Saunavaara V. *et al.* The test-retest reproducibility of [^{11}C] PK11195 positron emission tomography using Biograph Vision Quadra scanner. *EJNMMI Res* (2026). https://doi.org/10.1186/s13550-026-01460-6

Tanja Sjöros, Markus Matilainen, Virva Saunavaara, Saara Wahlroos, Johan Rajander, Mikko Koivumäki, Eveliina Honkonen, Amelie Luoma & Laura Airas

Google scholar: Carimas 1 200 found, Aug 31, 2026

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Image-derived Input Functions for Cerebral Blood Flow Quantification from Dynamic 15O-water PET Images of Humans

Original Article | Open access | Published: 26 August 2026

(2026) Cite this article

You have full access to this open access article

Download PDF Save article

Oona Rainio, Henri Kärpijoki, Sergey V. Nesterov, Riku Klén & Juhani Knuuti

Abstract

Purpose

Cerebral blood flow (CBF) quantification from dynamic ^{15}O-water positron emission tomography (PET) images via compartmental modeling requires measuring the tracer

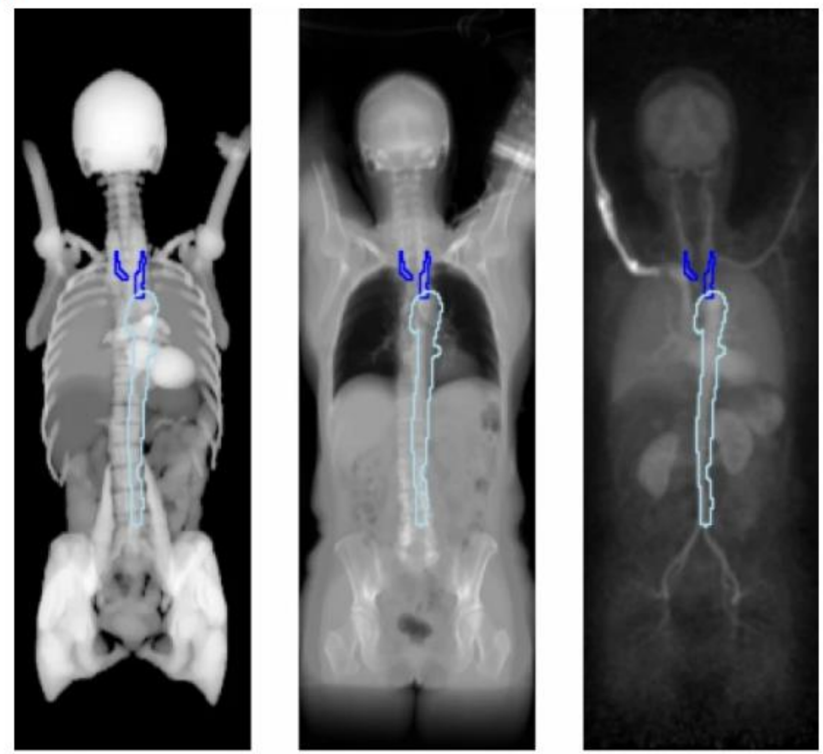
026-01050-w#data-availability arterial blood with respect to time. The existing methods for this

2 Materials and Methods

2.1 Software

We used Carimas (version: 2.10) [19] for image visualization, TotalSegmentator (version: 2.0) [18] for automatic VOI definition, Python (version: 3.12.8) [20] for image processing and TAC extraction, and R (version: 4.4.2) [21] for model fitting and statistical testing.

Fig. 1



(a) (b) (c)

Full size image

The location of the initial TotalSegmentator VOIs of the aorta (in lightblue) and the left and the

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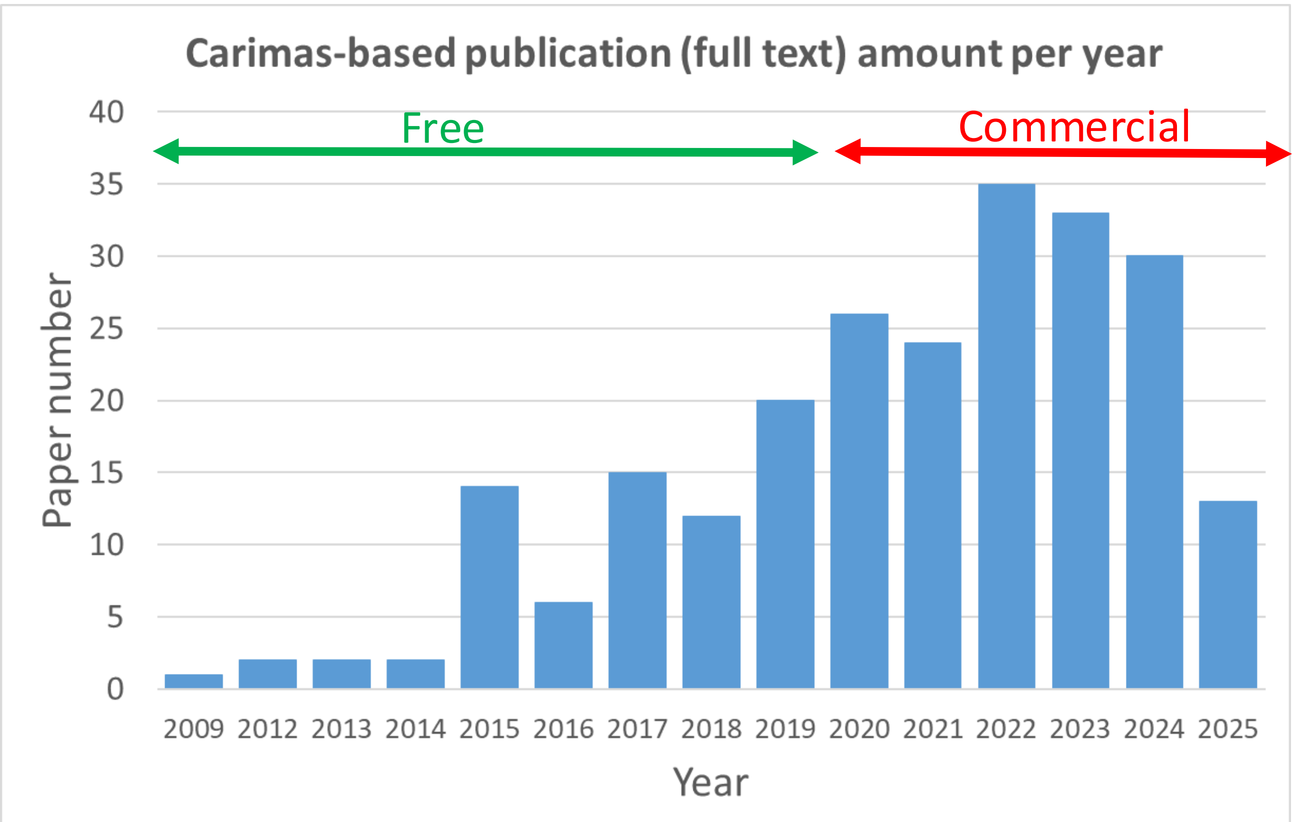

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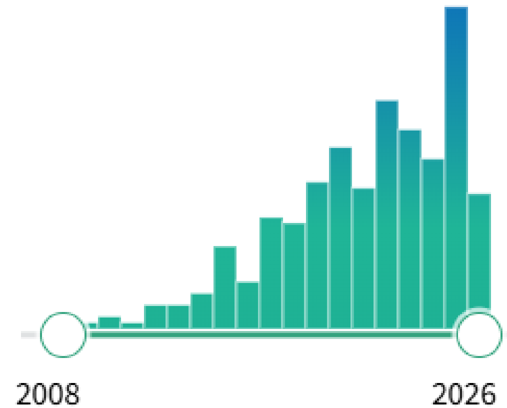

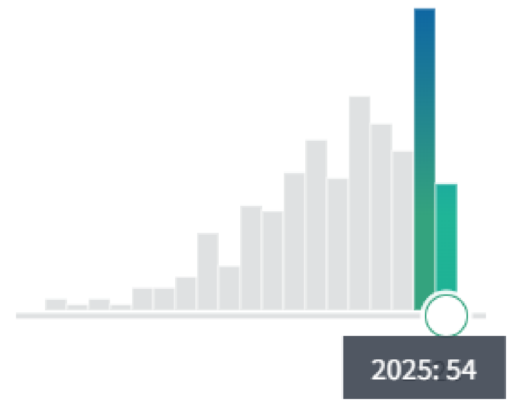

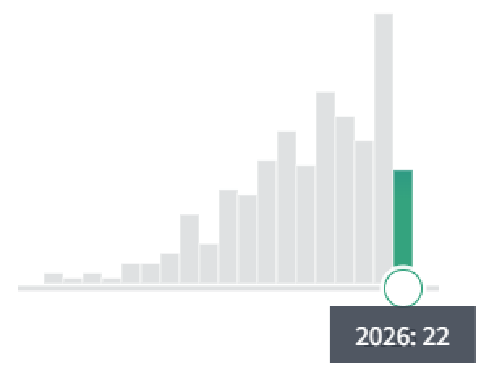

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1 Factors affecting the performance of a novel artificial intelligence-based coronary computed tomography-derived ischaemia algorithm
Peerapon Kiatkittikul, Teemu Maaniitty, Sarah Bär, Takeru Nabeta, Jeroen J Bax, Antti Saraste, Juhani Knuuti
Eur Heart J Imaging Methods Pract. 2024 Oct; 2(4): qyaf033. Published online 2025 Apr 17. doi: 10.1093/ehjimp/qyaf033
https://pmc.ncbi.nlm.nih.gov/articles/PMC12003262/pdf/qyaf033.pdf
pmc12003262

2 Advances in Imaging Techniques for Assessing Myocardial Microcirculation in People with Diabetes: An Overview of Current Techniques, Emerging Techn
Tine Willum Hansen, Rasmus S. Ripa
Diabetes Ther. 2025 May; 16(5): 785–797. Published online 2025 Mar 6. doi: 10.1007/s13300-025-01710-1
https://pmc.ncbi.nlm.nih.gov/articles/PMC12006633/pdf/13300_2025_Article_1710.pdf
pmc12006633

3 Emerging Applications of Positron Emission Tomography in Coronary Artery Disease
Anna Blach, Jacek Kwiecinski
J Pers Med. 2025 Mar; 15(3): 100. Published online 2025 Mar 3. doi: 10.3390/jpm15030100
https://pmc.ncbi.nlm.nih.gov/articles/PMC11943360/pdf/jpm-15-00100.pdf
pmc11943360

4 Measuring bone metabolic activity in dialysis patients with renal osteodystrophy using [18F]-Sodium Fluoride positron emission tomography- comparison b
Louise Aaltonen, Niina Koivuviita, Marko Seppänen, Vesa Oikonen, Anna K. Kirjavainen, Heikki Kröger, Eliisa Löyttyniemi, Kaj Metsärinne
BMC Nephrol. 2025; 26: 170. Published online 2025 Apr 2. doi: 10.1186/s12882-025-04063-w
https://pmc.ncbi.nlm.nih.gov/articles/PMC11963257/pdf/12882_2025_Article_4063.pdf
pmc11963257

5 Investigation of a deep learning-based reconstruction approach utilizing dual-view projection for myocardial perfusion SPECT imaging

250 Effects of patient movement on measurements of myocardial blood flow and viability in resting 15O-water PET studies
Kazuhiro Koshino, Hiroshi Watabe, Junichiro Enmi, Yoshiyuki Hirano, Tsutomu Zeniya, Shinji Hasegawa, Takuya Hayashi, Shigeru Miyagawa, Yoshiki
J Nucl Cardiol. 2012; 19(3): 524–533. Published online 2012 Feb 8. doi: 10.1007/s12350-012-9522-0
https://pmc.ncbi.nlm.nih.gov/articles/PMC3358554/pdf/12350_2012_Article_9522.pdf
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251 Cardiac Function, Perfusion, Metabolism, and Innervation following Autologous Stem Cell Therapy for Acute ST-Elevation Myocardial Infarction. A FIN
Maija T. Mäki, Juha W. Koskenvuo, Heikki Ukkonen, Antti Saraste, Helena Tuunanen, Mikko Pietilä, Sergey V. Nesterov, Ville Aalto, K. E. Juhani Airak
Front Physiol. 2012; 3: 6. Published online 2012 Jan 30. doi: 10.3389/fphys.2012.00006
https://pmc.ncbi.nlm.nih.gov/articles/PMC3277266/pdf/fphys-03-00006.pdf
pmc3277266

252 Assessment of myocardial perfusion and function with PET and PET/CT
Mouaz H. Al-Mallah, Arkadiusz Sitek, Stephen C. Moore, Marcelo Di Carli, Sharmila Dorbala
J Nucl Cardiol. Author manuscript; available in PMC 2011 Jun 1.Published in final edited form as: J Nucl Cardiol. 2010 Jun; 17(3): 498–513. doi: 10.1
https://pmc.ncbi.nlm.nih.gov/articles/PMC2871404/pdf/nihms-196823.pdf
pmc2871404

253 Low radiation dose imaging of myocardial perfusion and coronary angiography with a hybrid PET/CT scanner
S Kajander, H Ukkonen, H Sipilä, M Teräs, J Knuuti
Clin Physiol Funct Imaging. 2009 Jan; 29(1): 81–88. doi: 10.1111/j.1475-097X.2008.00838.x
https://pmc.ncbi.nlm.nih.gov/articles/PMC2701563/pdf/cpf0029-0081.pdf
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J Clin Endocrinol Metab	7	J Nucl Med	3
PLoS One	6	Int J Mol Sci	3
Mol Imaging Biol	6	J Neuroinflammation	3
J Cereb Blood Flow Metab	5	Diagnostics	3
Am J Nucl Med Mol Imaging	4	Nat Commun	3
Molecules	4	ACS Omega	3
Nutrients	4	J Transl Med	3
JACC Cardiovasc Imaging	3	Ann Nucl Med	3
Contrast Media Mol Imaging	3	Eur Heart J Cardiovasc Imaging	3
Int J Cardiovasc Imaging	3	Mol Pharm	2
iScience	3	Mol Imaging	2

Data from PubMed Central, until April, 22, 2025

A research paper on infarcted heart from China published on Nature Communication 2024

Two way workable microchanneled hydrogel suture to diagnose, treat and monitor the infarcted heart

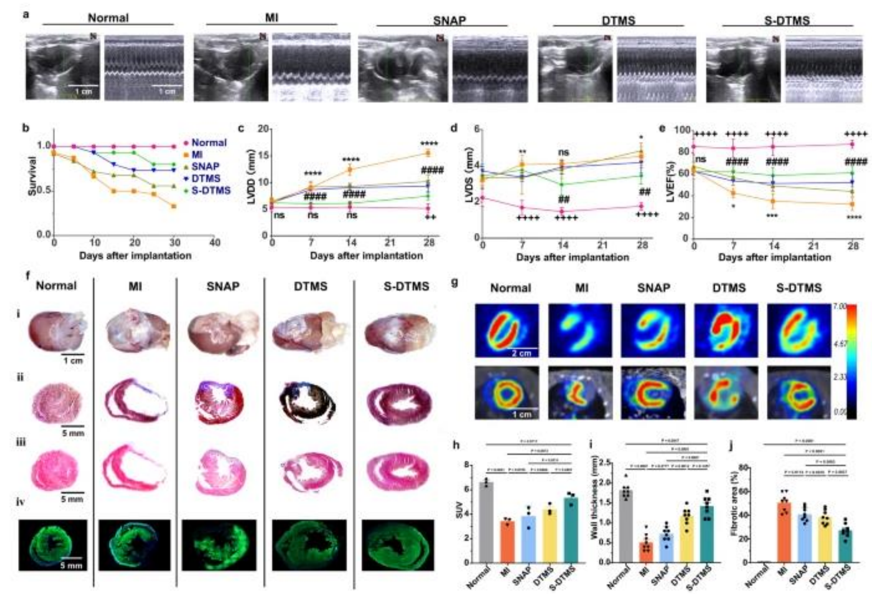
Fangchao Xue, Shanlan Zhao, Hao Tian, Haoxiang Qin, Xiaochen Li, Zhao Jian, Jiahui Du, Yanzhao Li, Yanhong Wang, Lin Lin, Chen Liu, Yongning Shang, Lang He, Malcolm Xing ✉ & Wen Zeng ✉

Nature Communications **15**, Article number: 864 (2024) | Cite this article

Abstract

During myocardial infarction, microcirculation disturbance in the ischemic area can cause necrosis and formation of fibrotic tissue, potentially leading to malignant arrhythmia and myocardial remodeling. Here, we report a microchanneled hydrogel suture for two-way signal communication, pumping drugs on demand, and cardiac repair. After myocardial infarction, our hydrogel suture monitors abnormal electrocardiogram through the mobile device and triggers nitric oxide on demand via the hydrogel sutures' microchannels, thereby inhibiting inflammation, promoting microvascular remodeling, and improving the left ventricular ejection fraction in rats and minipigs by more than 60% and 50%, respectively. This work proposes a suture for bidirectional communication that acts as a cardio-patch to repair myocardial infarction, that remotely monitors the heart, and can deliver drugs on demand.

Fig. 4: DTMS improving positively remodeling rat ventricle after MI.



PET and PET-CT imaging of the rat hearts

For PET imaging, rats were anesthetized and mechanically ventilated by inhalation of isoflurane, and 18F-FDG with 500 Ci was injected via tail vein injection, after 1 h later, rats were scanned using acquired images from the Trans-PET BioCaliburn 700 system. The PET images were processed using a 3DOSEM. Image analysis was performed in three axial, coronal, and sagittal directions using Carimas software.

A research paper from Turku PET Centre (Riku Klen's group) on machine learning
Published on Nature Scientific Reports, 2024

scientific reports

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Article | Open access | Published: 13 March 2024

Evaluation metrics and statistical tests for machine learning

Oona Rainio, Jarmo Teuho & Riku Klén

Scientific Reports **14**, Article number: 6086 (2024) | Cite this article

An Author Correction to this article was published on 08 July 2024

This article has been updated

Abstract

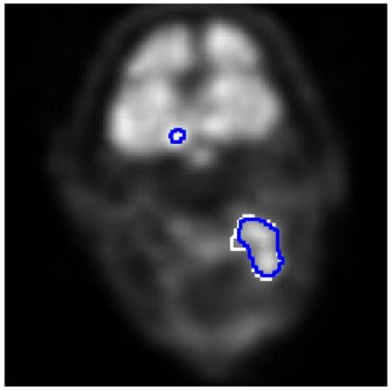
Research on different machine learning (ML) has become incredibly popular during the past few decades. However, for some researchers not familiar with statistics, it might be difficult to understand how to evaluate the performance of ML models and compare them with each other. Here, we introduce the most common evaluation metrics used for the typical supervised ML tasks including binary, multi-class, and multi-label classification, regression, image segmentation, object detection, and information retrieval. We explain how to choose a suitable statistical test for comparing models, how to obtain enough values of the metric for testing, and how to perform the test and interpret its results. We also present a few practical examples about comparing convolutional neural networks used to classify X-rays with different lung infections and detect cancer tumors in positron emission tomography images.

Examples

Software requirements

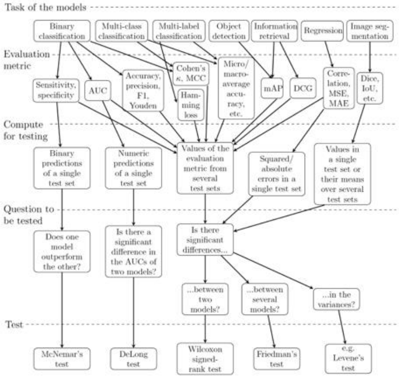
The CNNs were coded in Python (version: 3.9.9)[38] with packages TensorFlow (version: 2.7.0)[58] and Keras (version: 2.7.0)[59]. Most of the test were preformed in Python with scipy (version: 1.7.3)[41] or statsmodels (version: 0.14.0)[48]. The DeLong test was performed and Fig. 1 was plotted with pROC (version: 1.18.5)[52] in R (version: 3.4.1)[39]. The images of the third data set had been studied with Carimas (version: 2.10)[60], which was also used to draw their binary masks.

Figure 2



The binary tumor mask predicted by U-Net CNN with maximum dimensionality of 128 (in blue) and the ground-truth tumor mask drawn by a physician (in white) for one transaxial slice from a PET image of a head and neck cancer patient. The image is 128 × 128 pixels and the predicted segmentation mask contains 181 TP pixels, 16156 TN pixels, 17 FP pixels, and 30 FN pixels. This gives us Dice of 0.885, IoU of 0.794, and overall pixel accuracy of 0.997.

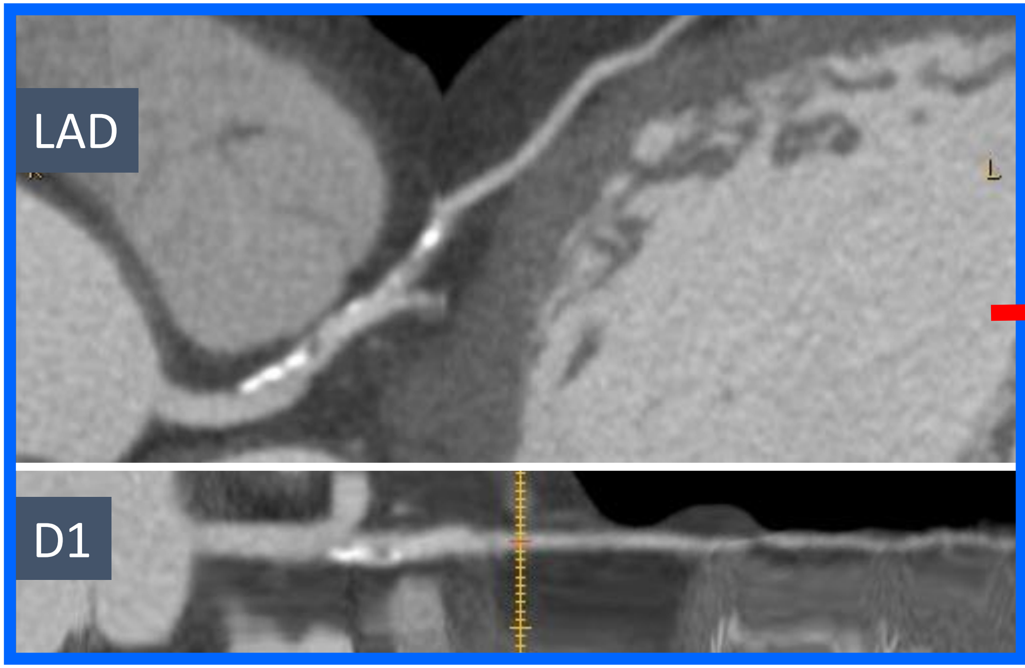
Figure 3

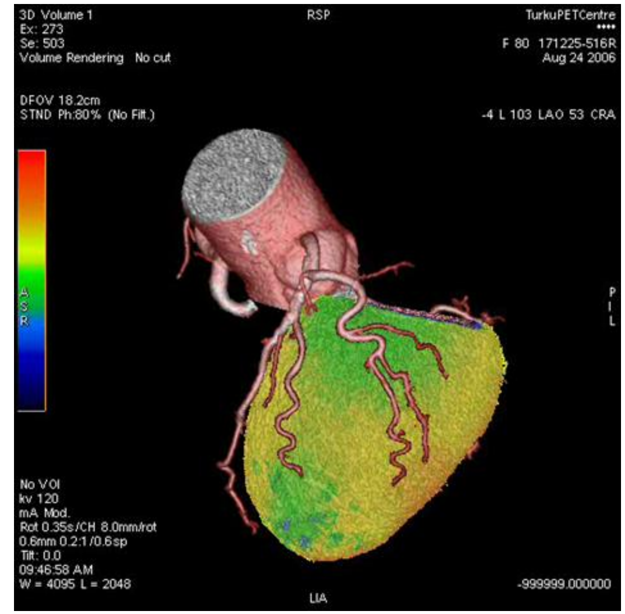


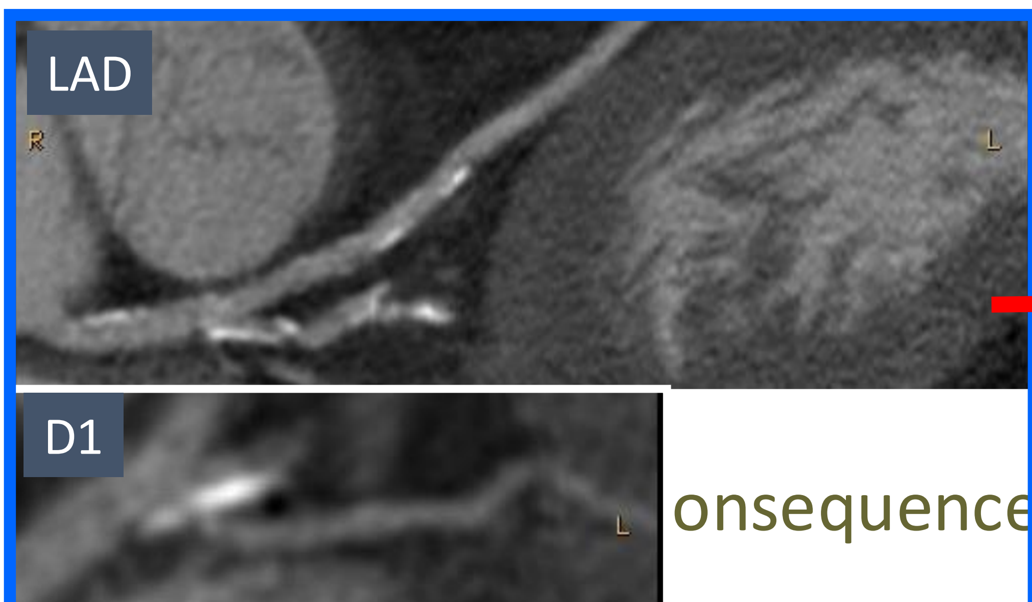
The possible tasks for a model, their evaluation metrics, the values of the evaluation metric that must be computed for each model before statistical testing, the potential questions a statistical test could answer in the situation, and the suitable test.

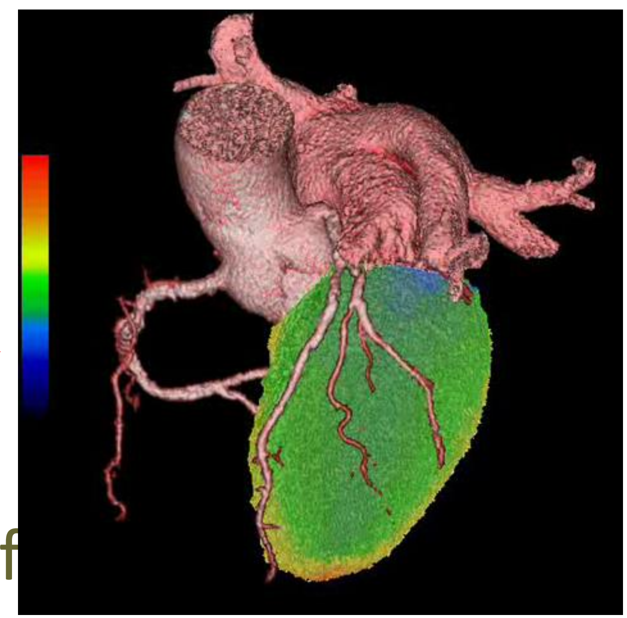
Full size image ›

heart









onsequences of

Turku PET Centre, Finland

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European Society of Cardiology

European Heart Journal (2017) **38**, 2547–2555
doi:10.1093/eurheartj/ehx352

CLINICAL RESEARCH
Coronary artery disease

Impact factor: 22.6(2019)

Adenoviral intramyocardial VEGF-D$^{\Delta N \Delta C}$ gene transfer increases myocardial perfusion reserve in refractory angina patients: a phase I/IIa study with 1-year follow-up

Juha Hartikainen[1,2], Iiro Hassinen[1], Antti Hedman[1], Antti Kivelä[1], Antti Saraste[3], Juhani Knuuti[3], Minna Husso[4], Hanna Mussalo[4], Marja Hedman[1,4], Tuomas T. Rissanen[1,5], Pyry Toivanen[6], Tommi Heikura[6], Joseph L. V Sotirios Tsimikas[7], and Seppo Ylä-Herttuala[1,6,8]*

[1]Heart Center, Kuopio University Hospital, Kuopio 70029, Finland; [2]Institute of Clinical Medicine, University of Eastern Finland, Kuopio 70211, Finl University Hospital, Turku 20521, Finland; [4]Center of Diagnostic Imaging, Kuopio University Hospital, Kuopio 70029, Finland; [5]Heart Center, Centr Joensuu 80210, Finland; [6]A.I. Virtanen Institute, University of Eastern Finland, Kuopio 70211, Finland; [7]University of California San Diego, La Jolla, Therapy Unit, Kuopio University Hospital, Kuopio 70029, Finland

Received 22 December 2016; revised 30 March 2017; editorial decision 12 May 2017; accepted 2 June 2017; online publish-ahead-of-print 31 July 2017

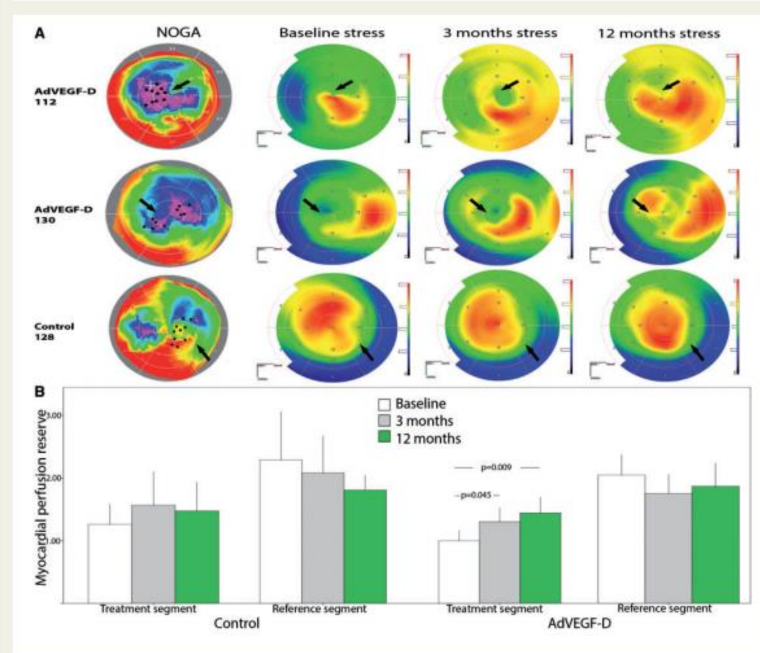
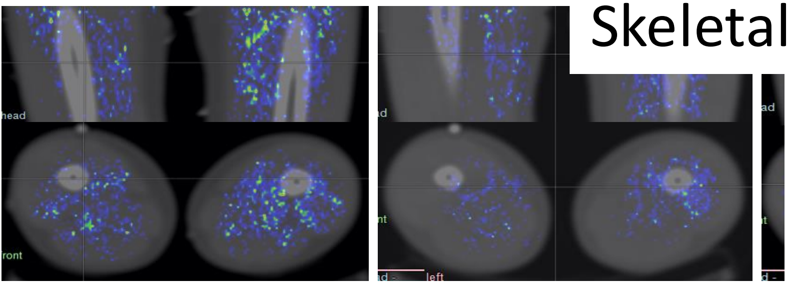
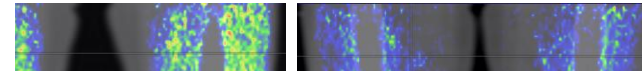


Figure 3 (A) Representative images of combined NOGA and stress PET radiowater images of two AdVEGF-D treated patients and one control patient. Black dots and arrows indicate sites for gene injections in viable but poorly perfused myocardium. Myocardial blood flow improved in the AdVEGF-D patients visualized as increases in red colour during the follow-up. Perfusion did not increase in the control patient. (B) Myocardial perfusion reserve in the treated and reference segments of the control and AdVEGF-D$^{\Delta N \Delta C}$-treated patients. Colour scales in NOGA and PET maps as in *Figure 1*. Values are mean ± standard deviation.



Skeletal muscle perfusion



J Appl Physiol 128: 1392–1401, 2020.
First published April 30, 2020; doi:10.1152/japplphysiol.00833.2019.

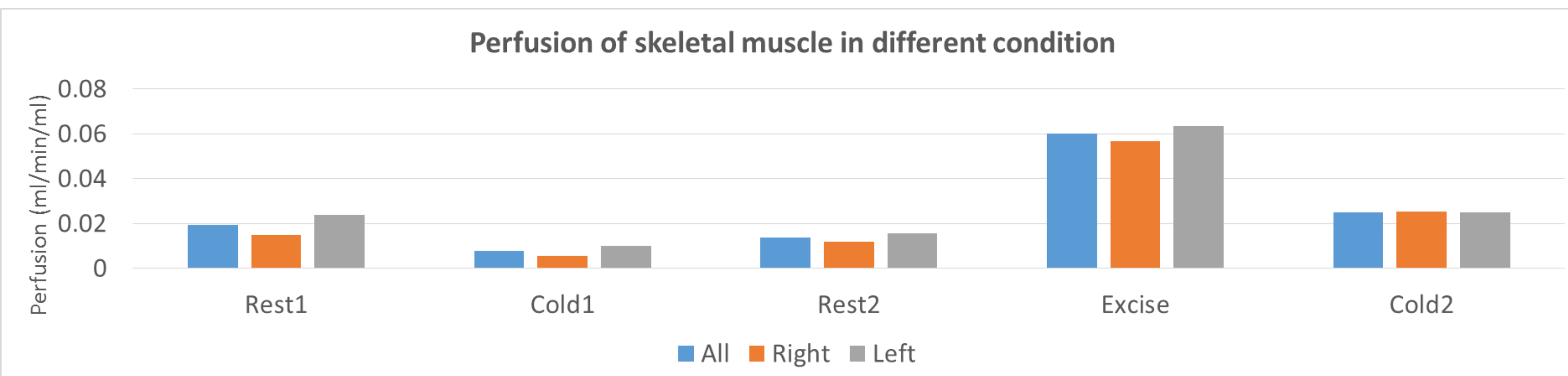
RESEARCH ARTICLE

Changes in quadriceps femoris muscle perfusion following different degrees of cold-water immersion

Chris Mawhinney,[1,2] Ilkka Heinonen,[3,4,8] David A. Low,[1] Chunlei Han,[3] Helen Jones,[1] Kari K. Kalliokoski,[3] Anna Kirjavainen,[3] Jukka Kemppainen,[3] Valter Di Salvo,[7] Matthew Weston,[5,7] Tim Cable,[6] and Warren Gregson[1,7]

PET **PET**

Rest1	Cold1	Rest2	Excise	Cold2
30 min rest	10 min CMI 8/18 °C	60 min rest	Cycling T 38 °C	10 min 8/18 °C



Rat PET brain function study

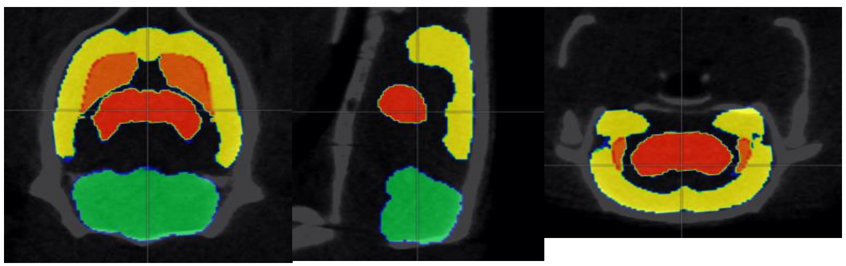
Seasonal Variation in the Brain μ-Opioid Receptor Availability

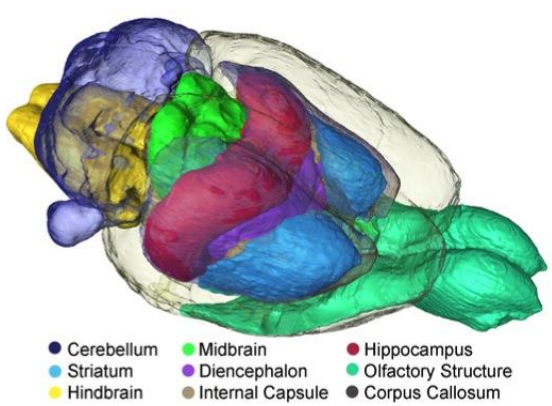
Lihua Sun, Jing Tang, Heidi Liljenbäck, Aake Honkaniemi, Jenni Virta, Janne Isojärvi, Tomi Karjalainen, Tatu Kantonen, Pirjo Nuutila, Jarmo Hietala, Valtteri Kaasinen, Kari Kalliokoski, Jussi Hirvonen, Harry Scheinin, Semi Helin, Kim Eerola, Eriika Savontaus, Emrah Yatkin, Juha O. Rinne, Anne Roivainen, and Lauri Nummenmaa

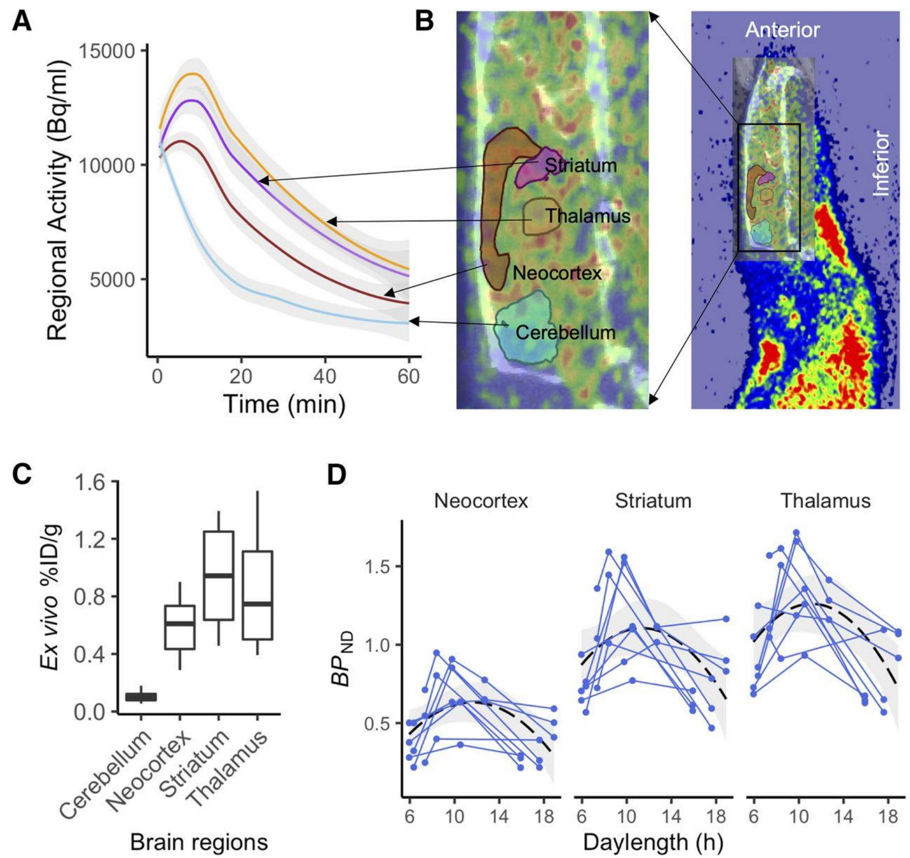
Journal of Neuroscience 10 February 2021, 41 (6) 1265-1273; DOI: https://doi.org/10.1523/JNEUROSCI.2380-20.2020

Dynamic PET images were analyzed using Carimas software (version 2.10.3.0) developed at the Turku PET Center. The PET datasets were reconstructed in 20 time frames using the OSEM3D

Journal of Neuroscience: IF=6.16







Accepted by EANMMI IF=9.2

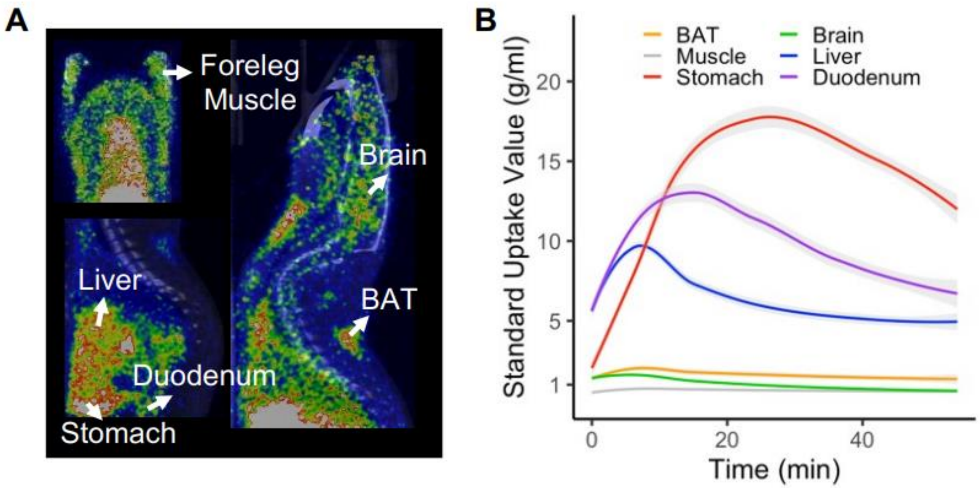


Figure 2. [^{11}C]carfentanil standardized update values (SUVs) in different tissues. **A.** PET-CT fusion image of a rat, with regions of interest labelled. **B.** Regional time-activity curves of the SUVs across scans. Shaded areas represent 95% Confidence Interval (CI).

NEWS

16/09/22 Rats, BATs and seasonal variation – new paper out! Sun, L., Aarnio, R., Atenico Herre, E., Kärnä, S., Palani, S., Virtanen, H., Liljebäck, H., Virta, J., Honkanemi, A., Oikonen, V., Han, C., Laurila, S., Bucci, M., Helin, S., Yatkin, E., **Nummenmaa, L.**, Nuutila, P., Tang, J., & Roivainen, A. (2022). Photoperiod modulates mu-opioid receptor availability in the brown adipose tissue. *European Journal of Nuclear Medicine and Molecular Imaging*.

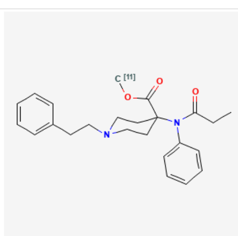
[^{11}C]Carfentanil

[^{11}C]CFN

Kam Leung, PhD.

Author Information

Created: March 24, 2007; Last Update: February 14, 2013.

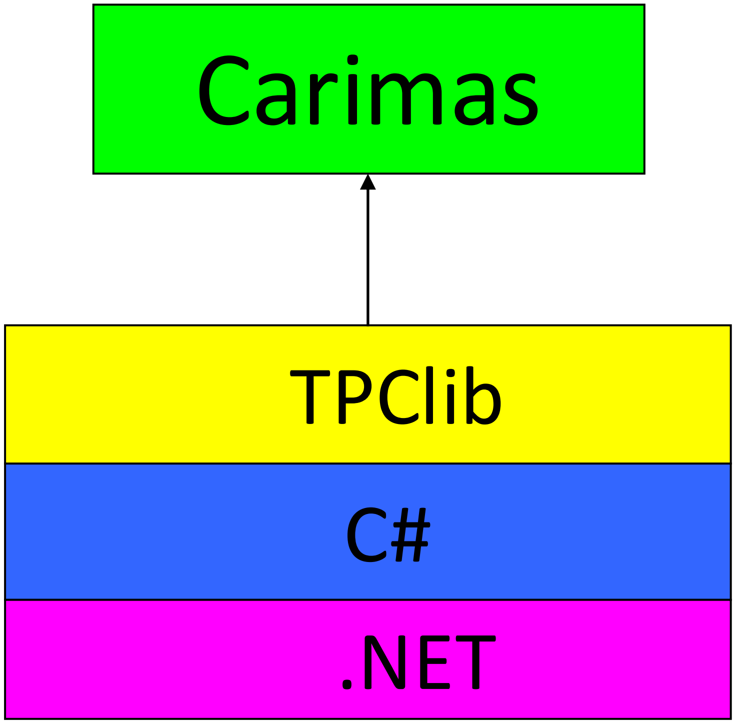
Chemical name:	[^{11}C]Carfentanil	
Abbreviated name:	[^{11}C]CFN, [^{11}C]CAR	
Synonym:		
Agent category:	Compound	
Target:	Mu (μ) opioid receptor	
Target category:	Receptor	
Method of detection:	PET	
Source of signal:	^{11}C	
Activation:	No	
Studies:	✓ *In vitro* ✓ Rodents ✓ Humans	Click on the above structure for additional information in PubChem.

Contribution of Carimas in this study

1. A template of rat brain was created
2. Copy of CT VOIs to PET imaging

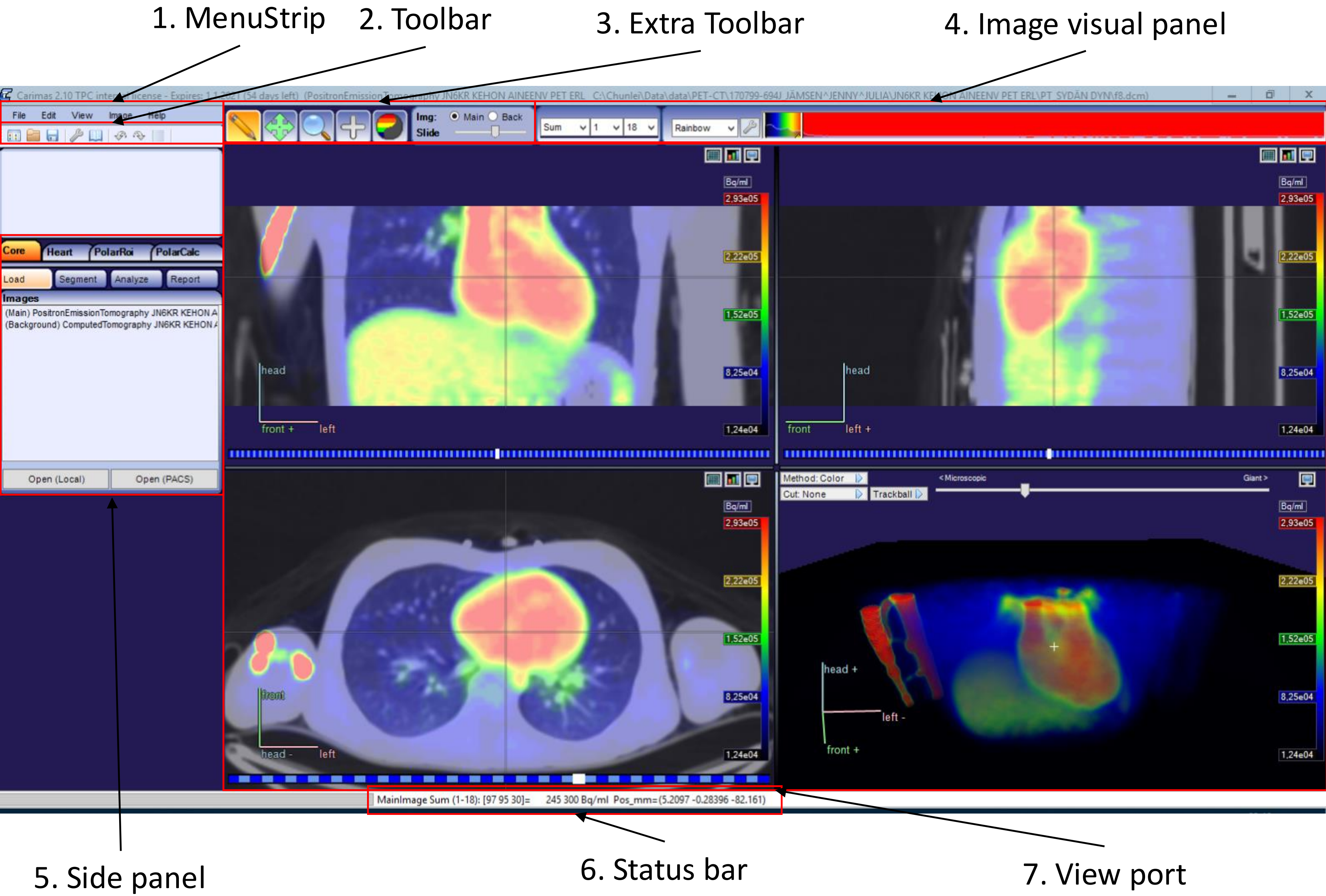
Contents

- Brief on Carimas
- ***Features and program structure***
- Demonstration



Mono will be used to generate Linux and Unix version
TPClib is developed in TPC, C# code, dataIO and modelling etc.

Main GUI of Carimas



Setting of ADW workstation and PC with Carimas

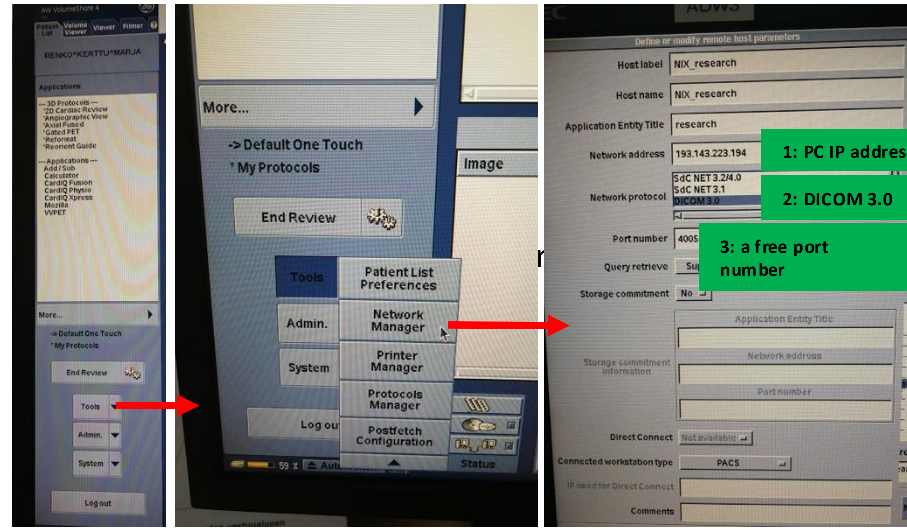
Carimas supports multi-PACs Dicom data communication

Key points:

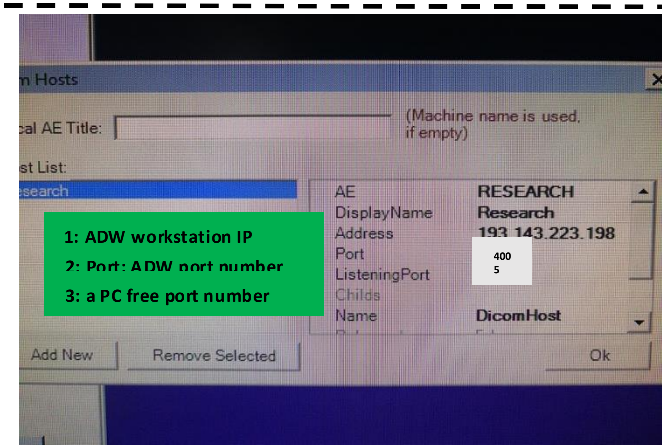
1. IP address must be matched each other.
2. Port number must be same.
3. PC listening port must be free, not be occupied.

Parametric images can be sent to selected PACs system after modelling in Polarmap window

ADW



PC

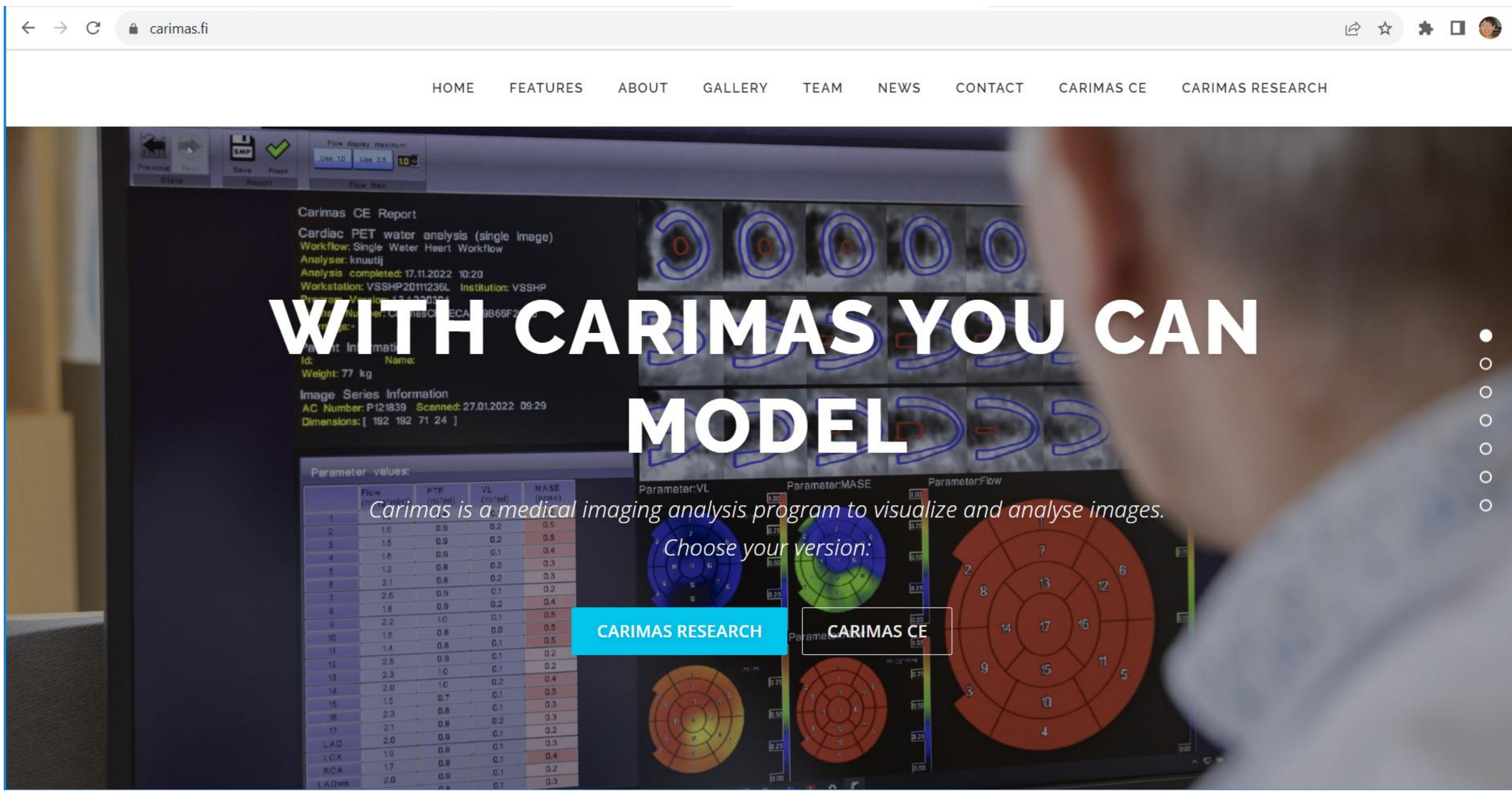


Carimas website

https://carimas.fi/

Carimas is a general medical imaging processing platform developed in Turku PET Centre in Finland. Originally, Carimas was designed for visualization, segmentation and modelling of PET data only. However, the latest versions support processing of imaging data from most medical imaging modalities, such as CT and MRI.

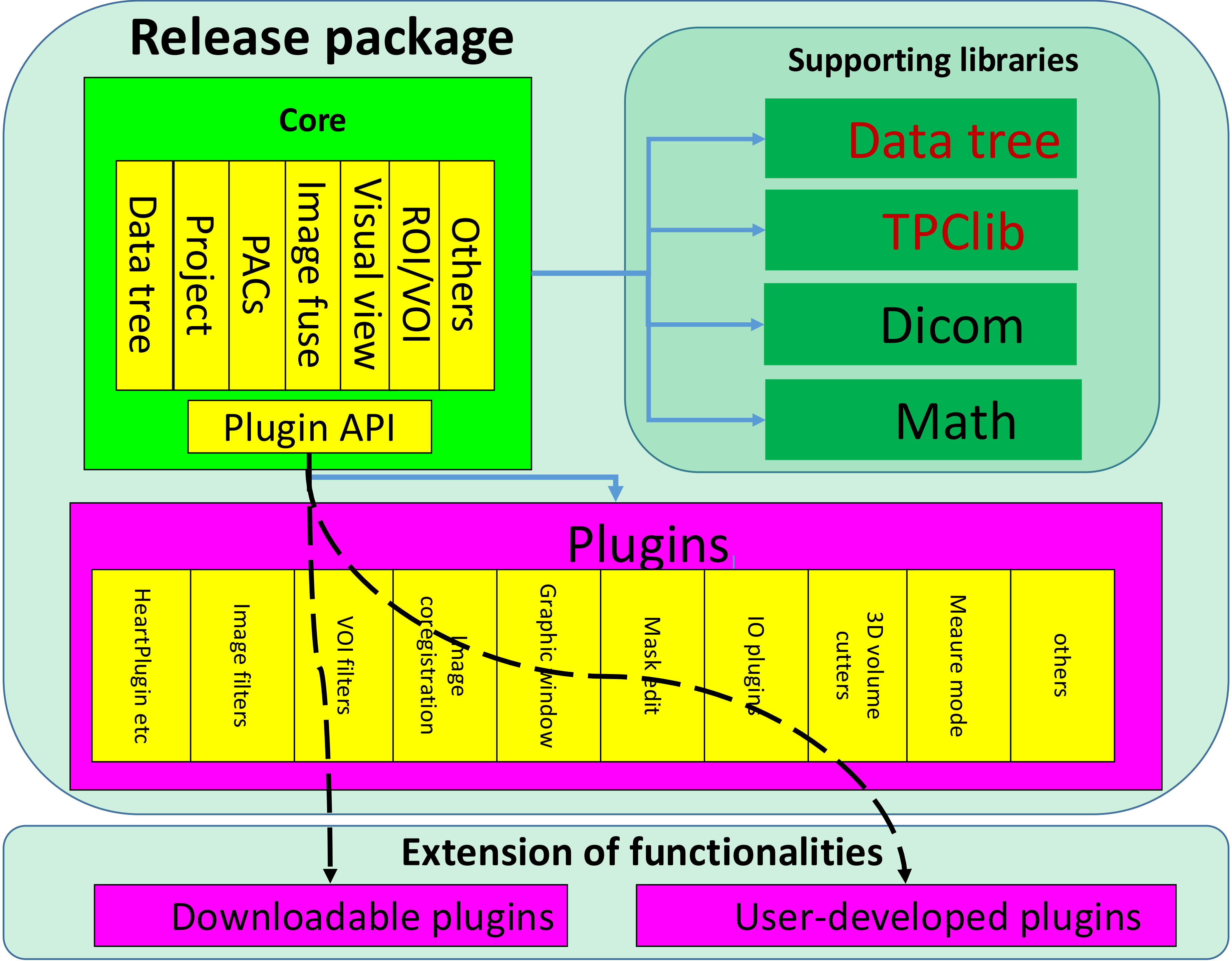
Using Carimas, you can easily visualize your imaging data in many different ways, such as in 2D or 3D, or fuse images from different modalities (PET/CT, PET/MRI). Furthermore, Carimas provides a lot of advanced functions for researchers. For example, using ROI/VOI tools, the user can draw a region/volume of interest in manual, semi-automatic or automatic manner; using the modelling tools, the user can perform advanced analysis for his/her research data; using Heart tools, cardiac researchers can easily analyze their PET studies.



Installation and license

- **System requirements:**
  .NET 4.0+ for (2.10) or 2.0+ for older.
- Currently, both CarimasCE and Research are commercial.

  License files can be loaded into Carimas from the help menu. Getting the full version requires registration. The registration can be done from the help menu. License file will be then sent to you that unlocks full functionality of the software.
- **Windows installers (msi installer):**
  Carimas 2.10
- **All operating systems (zip archive):**
  Carimas 2.10



Release package
Core
Data tree
Project
PACs
Image fuse
Visual view
ROI/VOI
Others
Plugin API
Supporting libraries
Data tree
TPClib
Dicom
Math
Plugins
HeartPlugin etc
Image filters
VOI filters
Image coregistration
Graphic window
Mask edit
IO plugins
3D volume cutters
Meaure mode
others
Extension of functionalities
Downloadable plugins
User-developed plugins

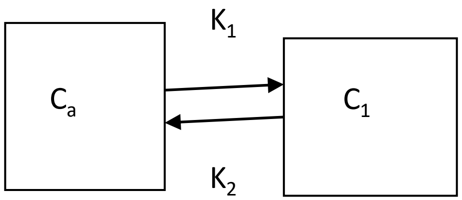
Models implemented in Carimas

1. Compartment model
    1. Tracer-specific model for heart
        1. 15O labeled water perfusion model (1TCM)
        2. 11C labeled acetate perfusion model (1TCM)
        3. 82Rb rubidium perfusion model (1TCM)
        4. 13N labeled ammonia perfusion model
            1. UCLA model (simplified 1TCM)
            2. Duke model (simplified 2TCM-K3)
            3. Michigan model (full 2TCM)
        5. 18F labeled flurpiridaz perfusion model (2TCM,K3)
    2. General model
        1. 1-tissue compartment model
        2. 2-tissue compartment model(k3)
        3. 2-tissue compartment model (k4)
        4. 3-tissue compartment model in parallel
        5. 3-tissue compartment model in series
2. Graphical analysis method
    1. Patlak
    2. Logan
    3. Kmono

TCM=tissue compartment model

15O-labeled radio water cardiac perfusion model

1-tissue compartment model



The perfusion calculations are based on three equations:

$$C_i(T) = f\int_0^T a(t)dt - \frac{f}{p}\int_0^T C_i(t)dt \quad (1)$$

$$ROI(T) = \alpha C_i(T) + V_a a(T) \quad (2)$$

$$LV(T) = \beta a(T) + (1-\beta)C_i(T) \quad (3)$$

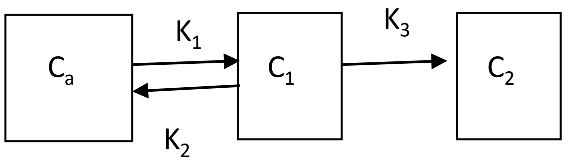
Table 1. Definition of symbols:

$C_i(t)$	True myocardial tissue radioactivity concentration at time t; radioactivity of perfusable myocardium [kBq ml^{-1}]
$a(t)$	True input function; radioactivity concentration in (coronary) arterial blood [kBq ml^{-1}]
$ROI(t)$	Time-activity curve of radioactivity of region-of-interest (ROI) which is drawn on the left ventricular (LV) myocardial region [kBq ml^{-1}]
$LV(t)$	Time-activity curve of radioactivity of ROI which is drawn on the LV cavity [kBq ml^{-1}]
f	Regional MBF; the blood flow of perfusable tissue [ml min^{-1} ml^{-1}]
p	Myocardium-to-blood partition coefficient of water [ml ml^{-1}]
α	Tissue fraction; volume of perfusable tissue in ROI [ml ml^{-1}]
V_a	Arterial blood volume; volume of arterial vascular space (including the spill-over from the chamber) in ROI [ml ml^{-1}]
β	Recovery coefficient of left-ventricular ROI ($0<\beta\leq 1$)
λ	Physical decay constant of ^{15}O [s^{-1}]

Modelling

UCLA Model

simplified 2-tissue compartment model (k3)



Fit parametres: , ***k₁,Vₐ***

Fit range: ***2 min***

$$\frac{dC_1}{dt} = k_1 C_a - (k_2 + k_3) C_1$$

$$\frac{dC_2}{dt} = k_2 C_1$$

$$\frac{k_1}{k_2} = 0.8$$

$$C_{PET} = V_a C_m + (1 - V_a)(C_1 + C_2)$$

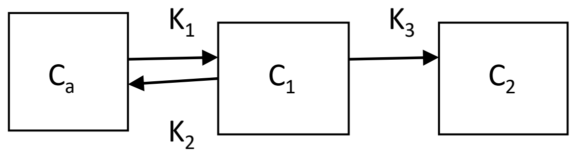
$$k_1 = f$$

Extraction fraction

$$K_3 = f\left(1.65 e^{\frac{1.25}{f}} - 1\right)$$

Michigan Model

full 2-tissue compartment model (k3)



k_1, k_2, k_3, V_a

10 min

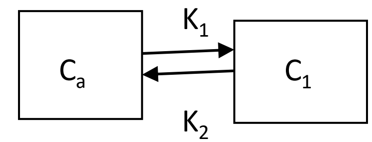
$$\frac{dC_1}{dt} = k_1 C_a - (k_1 + k_2) C_1$$

$$\frac{dC_2}{dt} = k_3 C_1$$

$$C_{PET} = V_a C_m + (1 - V_a)(C_1 + C_2)$$

Duke Model

1-tissue compartment model



k_1, k_2, V_a

4 min

$$\frac{dC_1}{dt} = k_1 C_a - k_2 C_1$$

$$C_{PET} = V_a C_m + (1 - V_a) C_1$$

C_a is metabolite corrected C_m

C_m is image-based LV input function

Extraction fraction option

1. $K_1 = f\left(1 - e^{-(108 + 2.34 f)/f}\right)$
2. $\text{Flow} = K_1$

Input function metabolite correction options:

1. van den Hoff

$C_a(t) = C_m(t)$ if $t <= t_{1/2}$

$C_a(t) = e^{-\ln 2 (\frac{t - t_0}{t_{1/2}})} C_m(t)$ if $t > t_{1/2}$

$t_0 = 0.48\ \text{min}$

$t_{1/2} = 6.69\ \text{min}$

2. DeGrado

$C_a(t) = C_m(1 - 0.4t)$ for dog

$C_a(t) = C_m(1 - 0.07t)$ for human

time unit is minute

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   2. Logan
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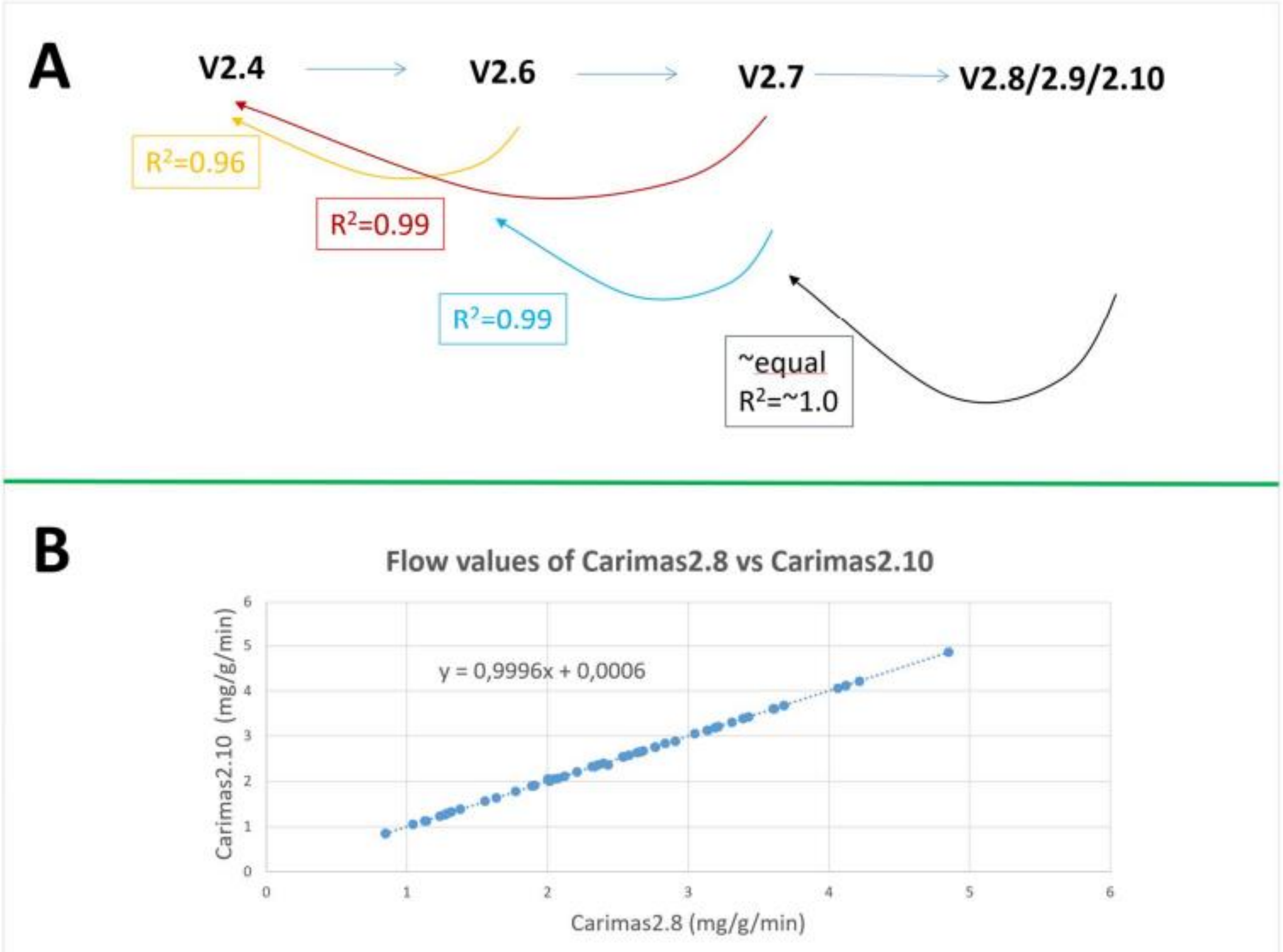
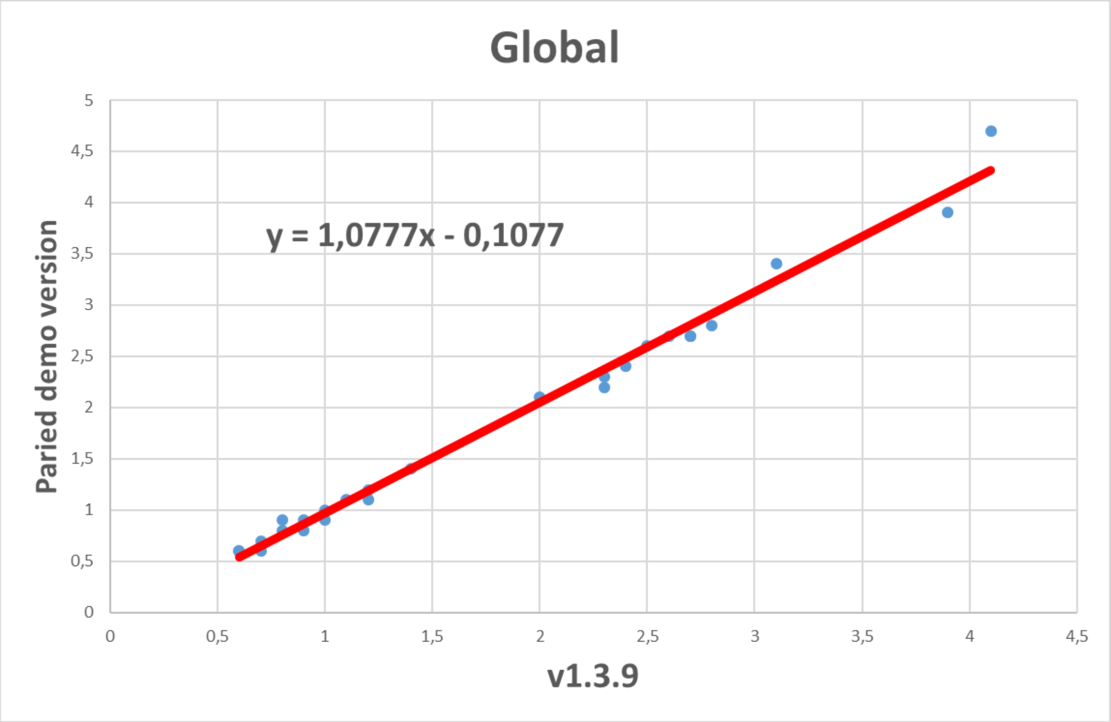
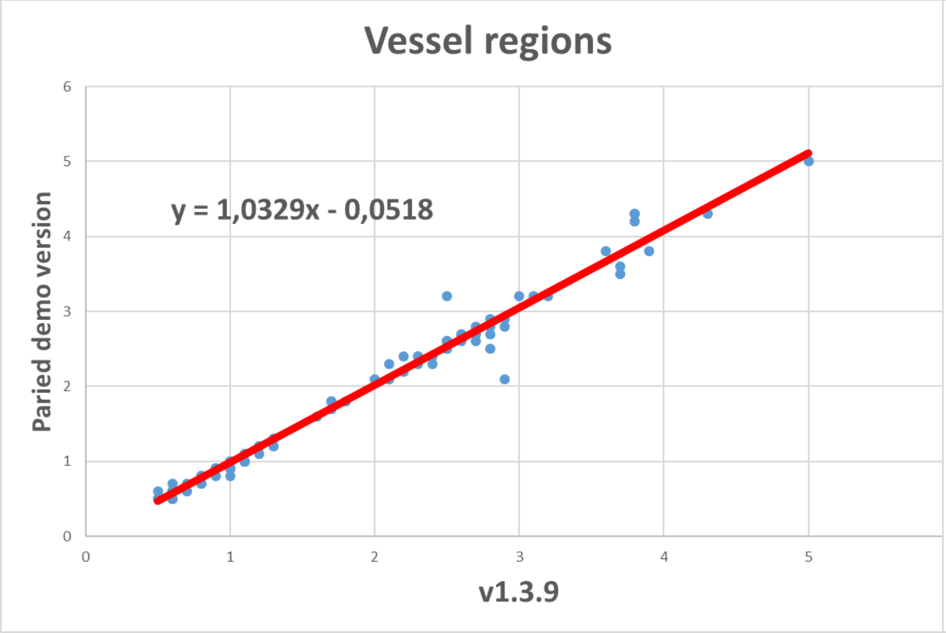
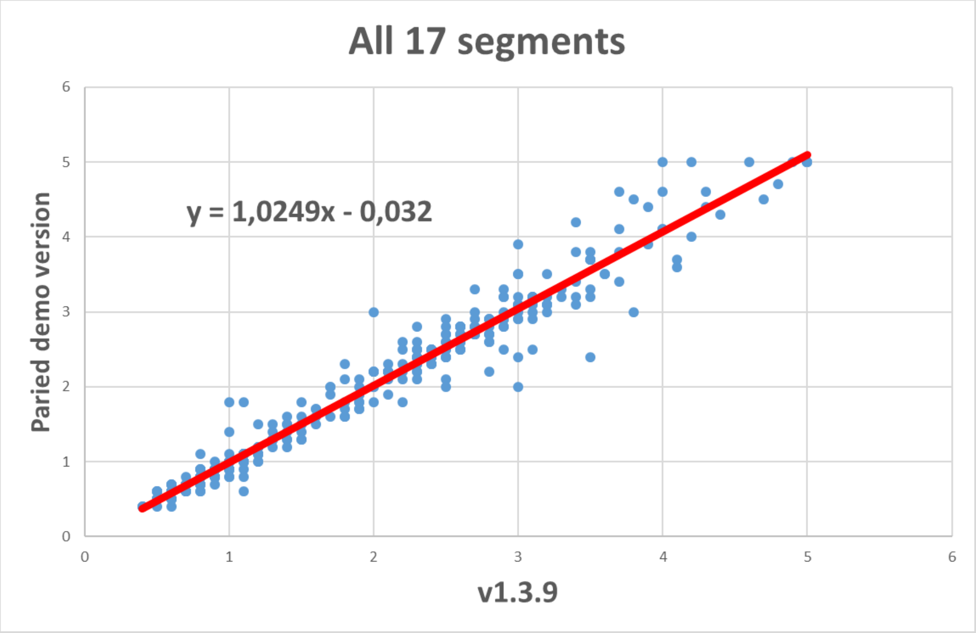
Summary of 3 common-used N13-ammonia models


A
V2.4
V2.6
V2.7
V2.8/2.9/2.10
R²=0.96
R²=0.99
R²=0.99
~equal
R²=~1.0
B
Flow values of Carimas2.8 vs Carimas2.10
y = 0,9996x + 0,0006
Carimas2.10 (mg/g/min)
Carimas2.8 (mg/g/min)


Global
y = 1,0777x - 0,1077
Paried demo version
v1.3.9


Vessel regions
y = 1,0329x - 0,0518
Paried demo version
v1.3.9


All 17 segments
y = 1,0249x - 0,032
Paried demo version
v1.3.9

Features 1/3

- **Input**
  - Multiple image data format support***: DICOM***, ECAT, Analyse, Interfile, Nifti, Interfile, MicroPET and general bitmap formats (JPG, TIFF, PNG and BMP)
  - PACS support: available to connect to hospital PACS system
- **Visualization**
  - View images from transaxial, coronal, sagittal or any free direction
  - 3D view with color rendering or MIP
  - Move and rotate images freely in 3D space
  - Visualize image histograms or cut profiler lines
- **Static image tools**
  - Calculate VOI statistics: mean, maximum, minimum, standard deviation, volume, etc…
  - SUV and percentage units
- **Dynamic images tools**
  - Easy and fast visualization of dynamic data
  - Calculate sum or difference images, or view individual frames
  - Analyze time activity curves from VOIs or individual voxels

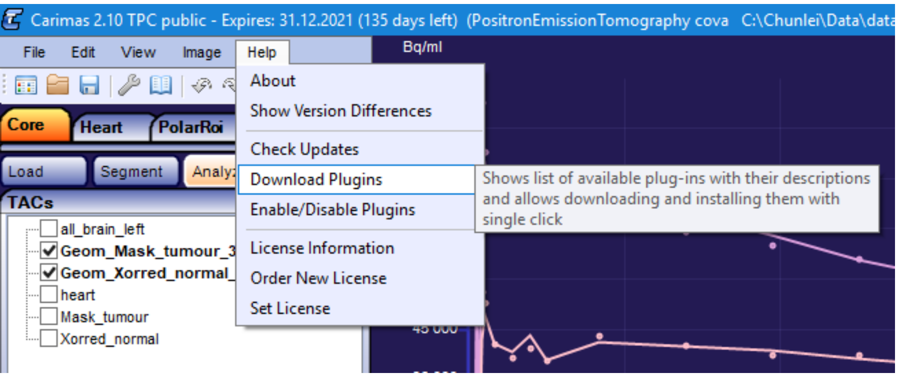
Features 2/3

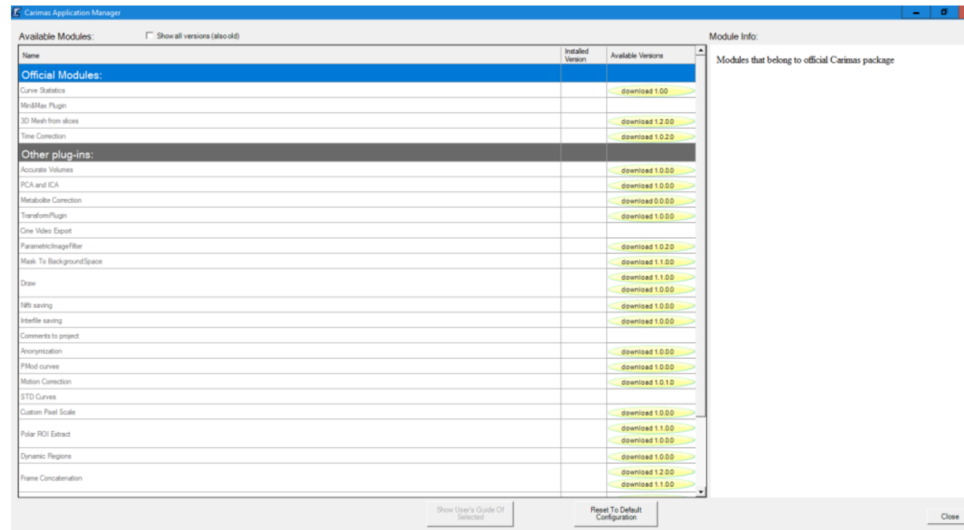
- **Segmentation tools**
  - 2D ROI sets or 3D VOIs
  - Histogram tool for selecting voxels at value range.
  - Start region definition from some predefined 3D shape or draw your own
  - Create VOIs using masking and countour tools
  - Some 3D region growing segmentation tools exist also as separate plugin, like “syringe” and threshod tools
  - Scale, move rotate, smooth, combine the VOIs with easy visual tools
  - Save and reuse the VOIs in multiple studies, regardless of image type or resolution
- **Image fusion**
  - File format independent image positioning
  - Coregistrate PET/MR/CT automatically
- **Modeling**
  - Use data from images or data files
  - Specify model parameters values and limits
  - Rescale data, define time ranges and exclude time points
  - Calculate parametric images from any model and parameter (separate plugin)

Features 3/3

- **Existing models (trial has only first two)**
  - Linear regression
  - Exponential fitting
  - Patlak
  - Logan
  - FUR index
  - Tracer specific models for water (with special license), ammonia, rubidium, acetate and flurpiridaz
  - Generic compartment models
- **Tools for heart analysis**
  - Semi-automatic heart segmentation with manual modification tools
  - Analyze polarmaps in 3, 4 or 17 segment modes, pixel by pixel or draw your own ROI to polarmap
  - Use any models from the Carimas modelling library to create parametric polarmaps
  - Compare results side by side or save to data files
- **Lots of other features as plug-ins**
  - Add to program easily from Carimas menu by just checking them from list
  - List of currently existing plug-ins can be found here: **Go to external plugins archive**

A plugin is an extentional function, which can be developed by other developers, not only from Carimas developers based on Carimas plugin API





The additional Carimas plug-ins

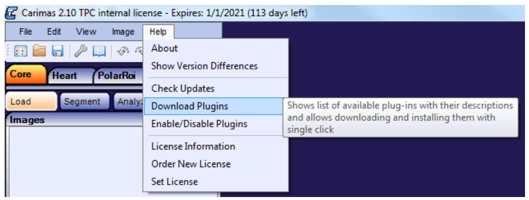
Name	Description
Accurate Volumes	Calculates more accurate volume of 3d region by placing cube with dimensions [DIM x DIM x DIM] around bounding box of VOI region and running masking. There is two plug-ins, one uses 1200 voxels for dimension, other asks it from user
PCA and ICA	Calculates principal and independent components for the dynamic image curves. User can define the amount of components extracted. The result will be parametric image for every component + dft file containing every component as curve. The plug-in will also create simulated image and error image for seeing, how much information the used components are actually carrying
Find Regions	Generate VOIs from image pixels. There is several region growing tools: contour, threshold and syringe
Metabolite Correction	Calculate TACs of authentic (unchanged) tracer and radioactive metabolite(s) from measured plasma TAC and fractions of authentic tracer
TransformPlugin	Transforms Images and VOIs from one transformation matrix space to another
Cine Video Export	Creates a video file (avi) where the 3D screen rotates whole 360 degrees around currently selected point. AForge library is used for video export. When installed, plugin can be run from Menu->Edit->Other Commands->Create Cine Video
ParametricImageFilter	With this plug-in you can calculate parametric images voxel by voxel from any existing model of Carimas. When installed, this plugin appears in the image filters menu in the Load tab. USAGE: 1) Load image 2) Select some model and fill it's possible input functions and other options in the Analyze tab 3) (optional) Select some VOI from segment tab if you want to calculate parametric map from only some specific region 4) Run the parametric image filter under the source image in the Load -tab.The parametric images will appear to image list (every parameter will have one). There can be also parametric maps of goodness of fit values among the results
Mask To BackgroundSpace	Converts mask to background image space. If the target mask has even little portion of masked area in source, the result is considered as masked, therefore the volume of result will be larger than source
Draw	Basic drawing tool for masks. Provides paint brush, trace and free hand tools for including and excluding voxels. Has also fill gaps and mask smooth features
Nifti saving	Allows saving images in Nifti -format
Interfile saving	Allows saving images in interfile -format
Comments to project	Allows writing text comments to projects. This plug-in appears to Edit->other commands -menu
Anonymization	Anonymizes Dicom images and saves them to disk
PMod curves	Allows and saving of PMod curve files
Reslicer	Reslices images to another image space. This plug-in gives two options, reslice to standard space that has component vectors of +x, +y, +z or to original image space
Motion Correction	Coregisters rigidly all image frames separately and saves the result frames as separate images
STD Curves	Calculates standard deviation curves
Custom Pixel Scale	The pixel range of image can be scaled to given range or multiplied with given factor
Polar ROI Extract	Adds the currently drawn heart polar ROI as mask VOI to Core
Image Exporting Tools	Contains several ways to export the image. All the frames or the currently visualized frame range (sum,diff,etc..) can be exported. All hidden voxels are left out from result image and automatic same value cropping can be used to save smaller image (good to be used together with voxel hiding). There is also option for reducing number of colors of the saved image
Dynamic Regions	Allows VOI region editing frame by frame so that the shape changes over time. If shape is edited in distant time points, all frames between are interpolated. The plug-in contains also tool for calculating curve from changing volume of the shape over time. Usage: Create normal 3D shape around the dynamic region. Convert it to dynamic from the tools list. Use single frame view and edit the voi with different frames. Volume curve can be created from the analyze TAB's curve tool list
Frame Concatenation	Combines many images (with same dimensions) and creates one dynamic image from them. When installed, this plug-in can be run from Edit menu->Other commands
Curve Tools	Tools for modifying Carimas curves: add, subtract, clone, interpolate, extrapolate and integrate curves or calculate frame weight curves
Nifti mask image	Saves VOIs, ROIs and masks as NIFTI images
PMod RoiSet	Loads ROI sets from PMOD .voi files.
Gausian Smooth & Spillover correction	Contains two plug-ins: Gausian convolution smoothing filter and spillover correction Spillover effect is removed by simulating the given region with given activity. After that, the area is removed with spillover included. The spilling region is assumed uniform. For small regions there exists also way to give multiplication factor for the area

Dicom anonymization plugin of Carimas

Very effectively and easily anonymize Dicom data

Download and installation of plugin

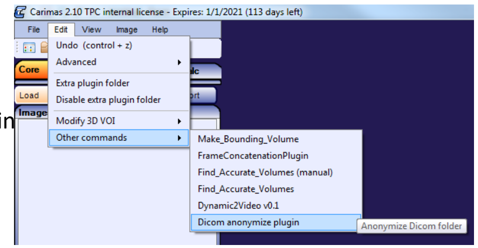
1. Help->Download Plugin
2. On Carimas plugin website, select: Dicom anonymization plugin
3. Restart Carimas.



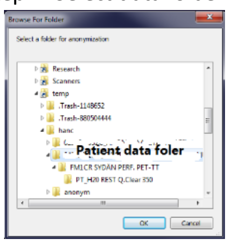
Anonymize Dicom data

Step 1:

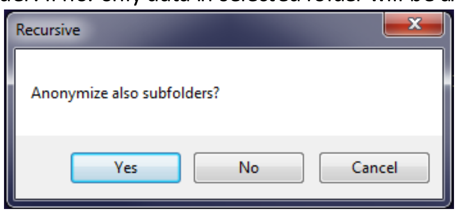
- Start Carimas
- Edit->Other commands->Dicom anonymize plugin



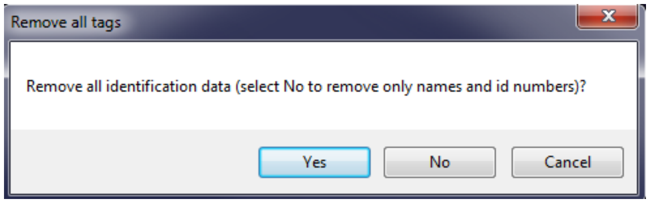
Step 2: Select data folder



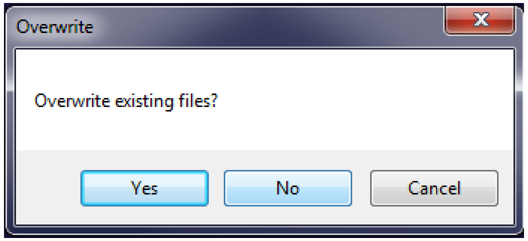
Step 3: Anonymize also subfolder?. If yes: anonymize all data in subfolder. If no: only data in selected folder will be anonymized



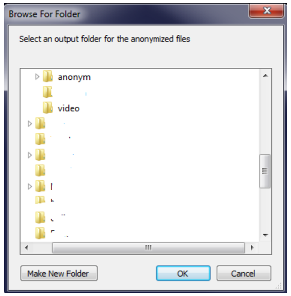
Step 4: Remove all or only name and ID



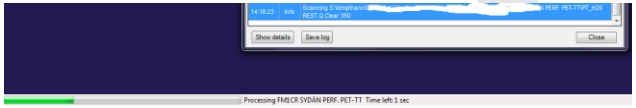
Step 5: option: overwrite or not?



Step 6: Select a folder for saving anonymize data



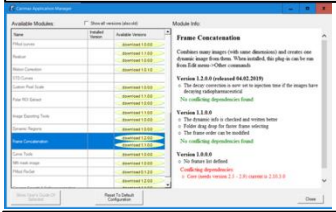
Step 7: Processing data and progress bar

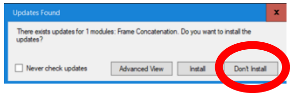


Frame concatenation plugin

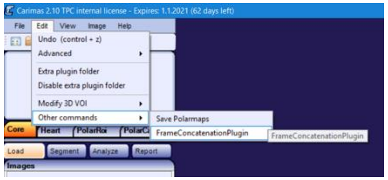
Key points:
1. This plugin is to concatenate single frame images to a complete dynamic data set.
2. From most scanners, dynamic images from all frames locate in one folder, from which Carimas can load all data at once. However, in some cases, frame images can be saved in separated folders. Therefore it needs to add all data into one folder.
3. .sif file is needed to hold frame timing information.

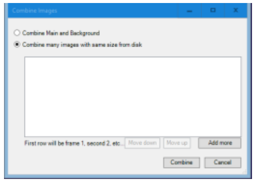
Important
- Version of 1.2.00 has bug, please update to 1.1.00
- If you have installed 1.2.00, you have to reset: Help->Download Plugins, then Reset to Default Configuration.
- Restart Carimas, don't install.





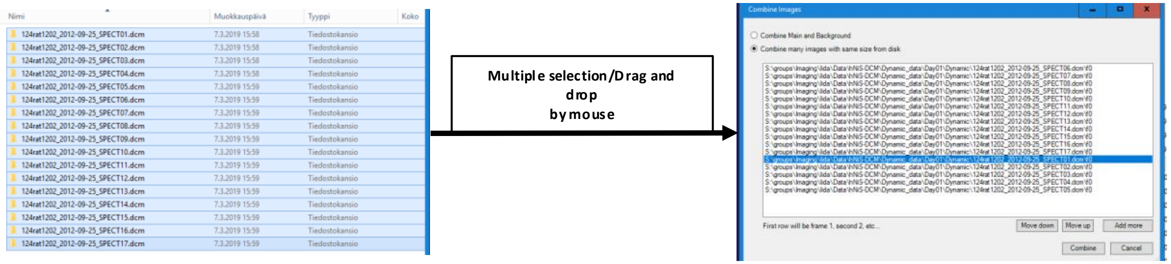
Start: Edit->Other commands->FrameConcatenationPlugin



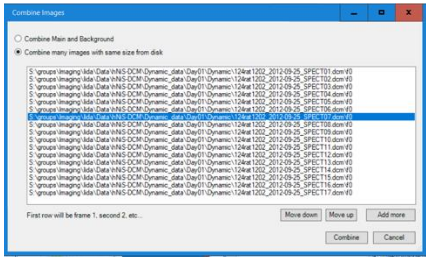


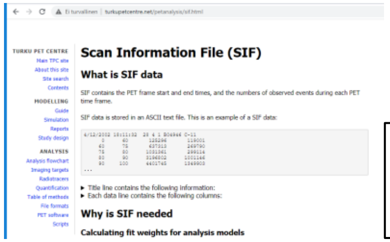
FrameConcatenationPlugin GUI:
Two options to combine
1. Main and background images.
2. Many images with same size from disk.

You can add frame one by one by button of "Add more", but more efficient way is to drag and drop by mouse



1. Frame order is created based on file order, which is often not correct, you can modify them by "Move down" and "Move up" buttons. Then, click button of "Combine", a dialog for saving folder will come.
2. Combined data will be saved in dicom format in selected folder.
3. You have to create a .sif file containing frame information and put it in the same folder, then Carimas will load dynamic data correctly.





.sif file is an ASCII format, more details to see from http://www.turkupetcentre.net/petanalysis/sif.html

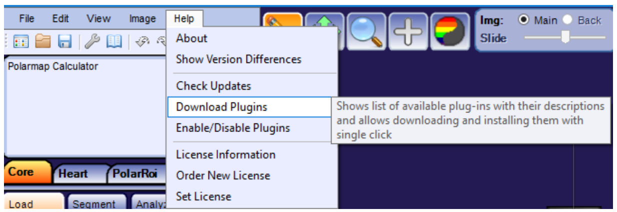
Carimas plugin: Image Export Tools/Export Visual Image

Function: to export currently visualized images in format of Dicom.

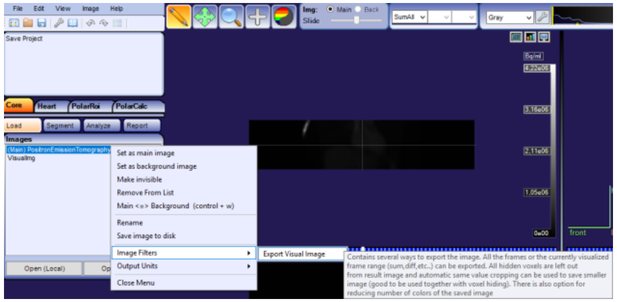
Features:

1. Currently visualized images can be exported in Dicom, such as sum image, diff image or single frame from dynamic data set.
2. Additionally, cropped images, images with user-defined value in masked regions and images with reduced bit can also be exported accordingly.

Installation of this plugin: Help->Download Plugins
In plugin list, select "Image Export Tools"



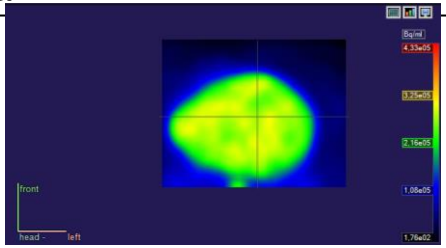
Start of plugin: Click left button of mouse on main images. On drop-down menu: Image Filter->Export Visual Image



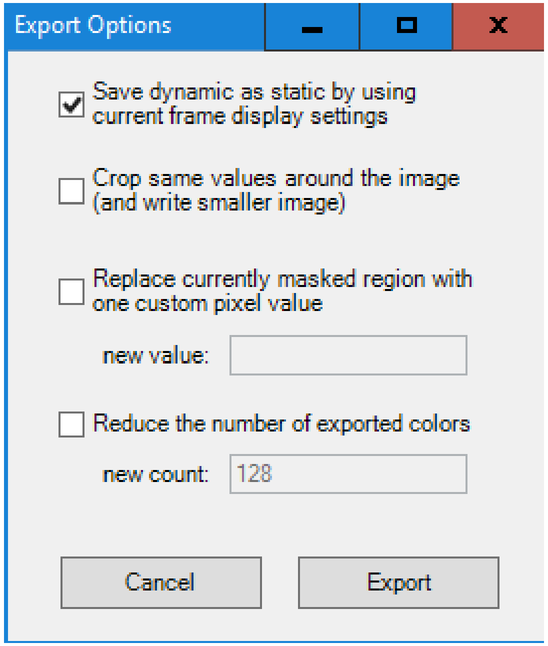
Usage

1. Save dynamic as static by using current frame display settings: depending on user's sitting, sum images, diff images, or single frame images can be saved and exported.
2. Crop same values around the image (and write smaller image):
   - VOIs are needed firstly defined and selected
   - Image->Show/Hide voxels->Show voxels outside…
3. Replace currently masked region with one custom pixel value: voxel in cropped volume will be filled with new value.
4. Reduce the number of exported colors: exported image bit will be replaced with new value.

Example: heart volume is generated as a new data set



Main GUI of Image Export Tools



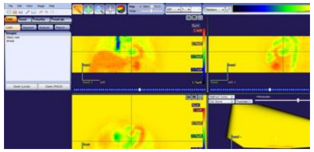
Generating paramatric images in Carimas using plugin of "Parametric image filter"

Key points:
1. All models implemented in Carimas can be used to generate parametric image (pixel-based parametric image).
2. Only pixels inside of selected ROIs/VOIs are calculated.
3. Output is dicom file, each of model parametres locates in its own folder.
4. It may be a time-consuming process, depending number of selected pixels, model and hardware system.

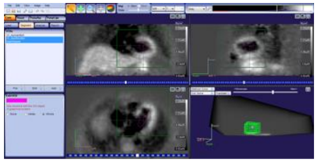
Download and installation of plugin of "Parametric image filter".
1. This plugin is not default in Carimas.
2. It is a free-downloadable plugin from Carimas website.
3. Carimas->Help->Download plugins.
4. Select "Parametric image filter".
5. Download and save it in a folder.
6. Carimas->Edit->Extra plugin folder: select plugin-saved folder
7. Restart Carimas.

Step of "Parametric image filter".
1. Load image.
2. Core->Segment->Define ROIs or VOIs. These include regions or volumes not only as parametric outputs, but also as input function.
3. Core->Analysis->Select a model, and define input function ROI or VOI.
4. Core->Segment->select ROIs or VOIs, in which parametric will be generated.
5. Core->Load: in image list, on select an image to click left button. On drop-down list, select "Parametric image filter"
6. On file dialog: select a folder for saving output parametric image.
7. Results: parametric images will be outputted in two ways:
   - Saved in selected folder as dicom files. Each subfolder holds a parametric. Subfolder name is parametric name.
   - Parametric images are added to image list.

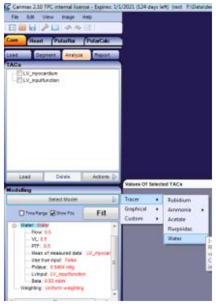
Step 1 Load image



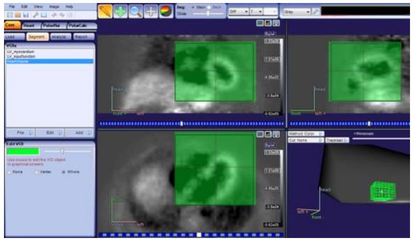
Step 2 Define ROIs/VOIs



Step 3 Select a model

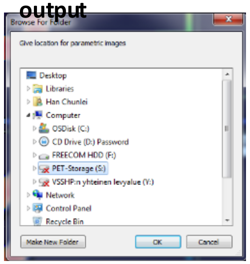


Step 4 Select ROIs/VOIs

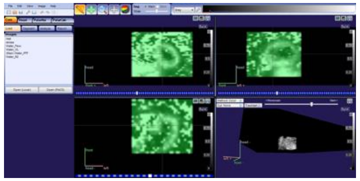


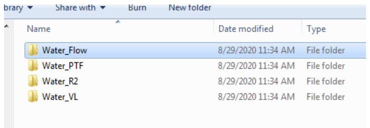
Step 5 To run parametric image filter

Step 6 Select folder for output



Step 7 Results





By Chunlei Han, Aug. 30,2020, Turku PET Centre, Turku, Finland

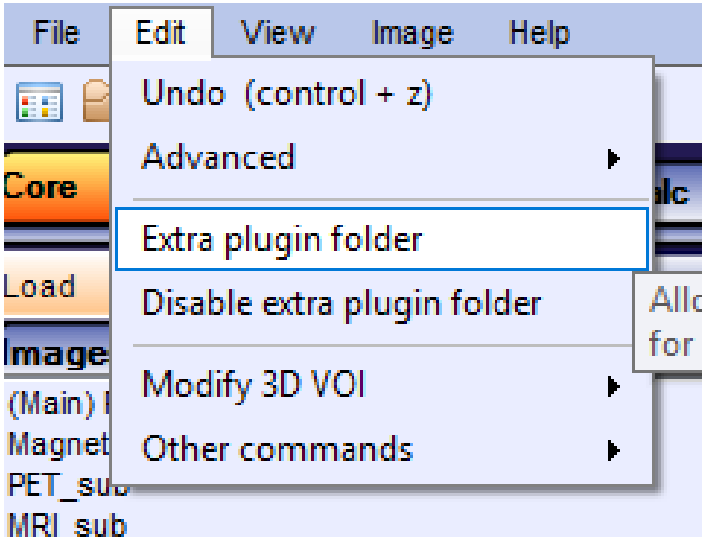
ImageIF
A Carimas plugin for image-derived input function

Chunlei Han, MD, Ph.D

Turku PET Centre and Turku University Hospital, Finland

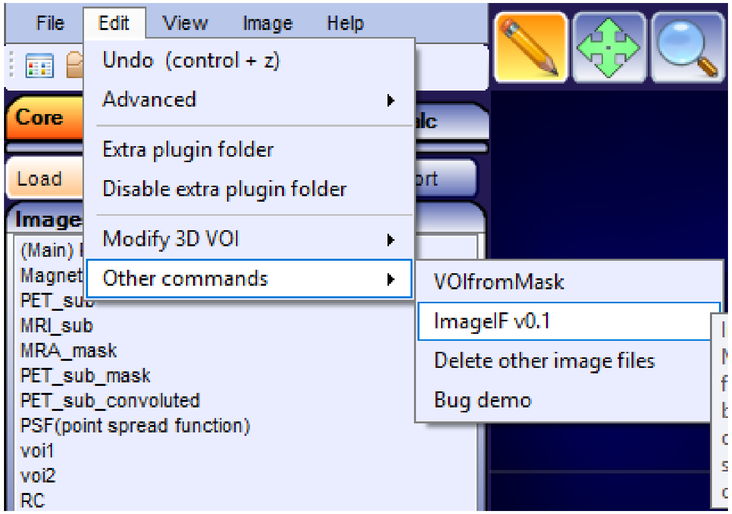
May 1, 2022, Turku, Finland

Installation and Run



Installation

1. Save ImageIF v0.1 package on local disc.
2. Carimas Edit->Extra plugin folder.
3. Locate ImageIF v0.1 folder.
4. Restart Carimas.



Run

1. Edit->Other commands->ImageIF v0.1

Image-derived input function

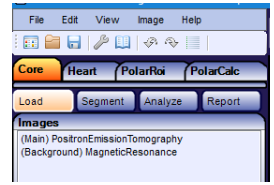
- For PET modelling, input function is the key data with PET imaging data. Ideally, it should be taken from the arteris nearing target organs or tissues.
- In practice, it is difficulty to perform.
- Image-derived input function is a method to take input function from image rather than from arteries using non-invasive procedures.
- ImageIF is a plugin for Carimas to extract IDIF from PET image based on MRA arterial anatomic volume for PETMRI dynamic studies.

Keys of ImageIF

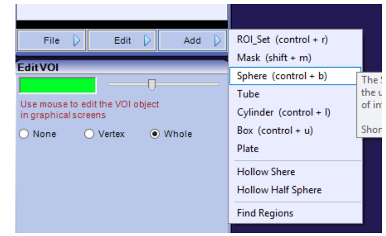
- A plugin of Carimas. It means that this package can only be run with Carimas.
- It is desiged to process brain PETMRI data with both dynamic PET and MRA (MR angiography).
- It may work for brain PETCT data with both dynamic PET and CT angiograpy (not test yet).
- SimpleITK is implemented in this package for segmentation and convolution.
- Segmentation is semi-automic: seeds, low and high values are needed.
- Three accessory tools included: VOIfromMask and ”Delete other image files”(remove of other images but not mainImage and backgroundImage). Thes two plus ImageIF can be found in Edit/Other commands. The third is MetCorrAmmonia (in Anayze->Curve->Curve filter.

Workflow of ”ImageIF”

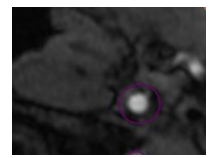
Load images:
1. dynamic PET as mainImage
2. MRA as backgroundImage



Load predefined seed VOIs and subvolume or define them manually in Carimas Core Segment:

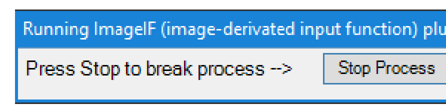


Fit seed VOIs and subvolume to you data manually

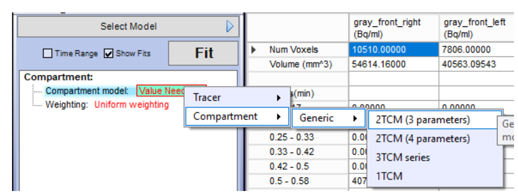


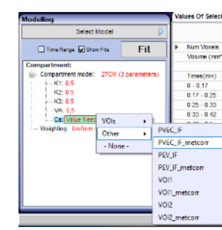
Give a low and high volume for segmentation. Note that the low value plays key role.

Start ”ImageIF”: Edit->Other commands->ImageIF v0.1

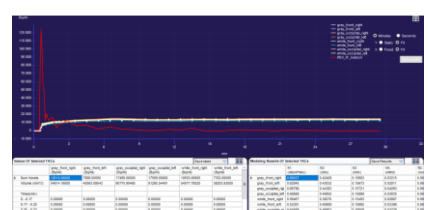


Analyze: select a model and input function: PVE_IF_metcorr is PVE and metabolic corrected input function.

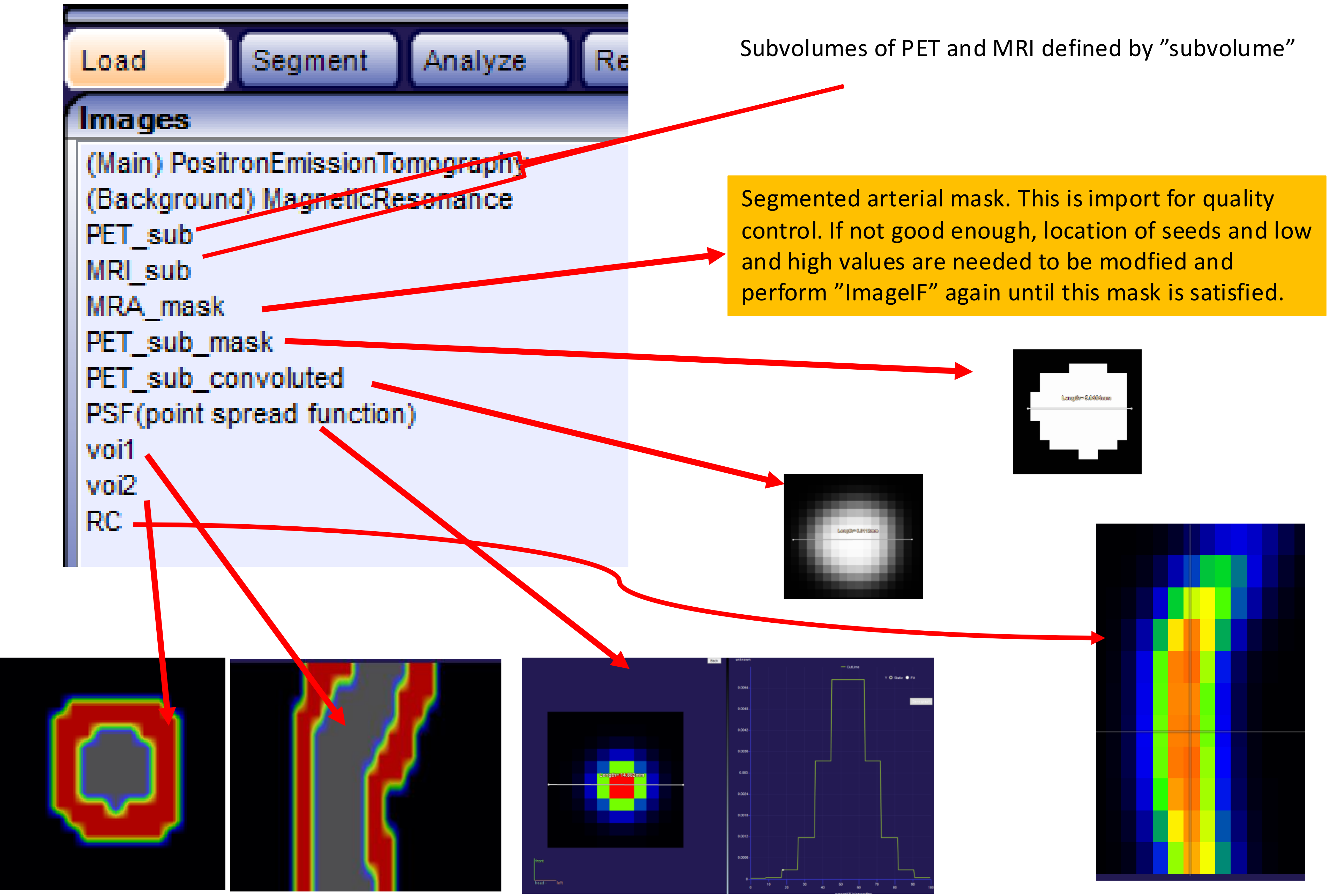




Modeling. Fit



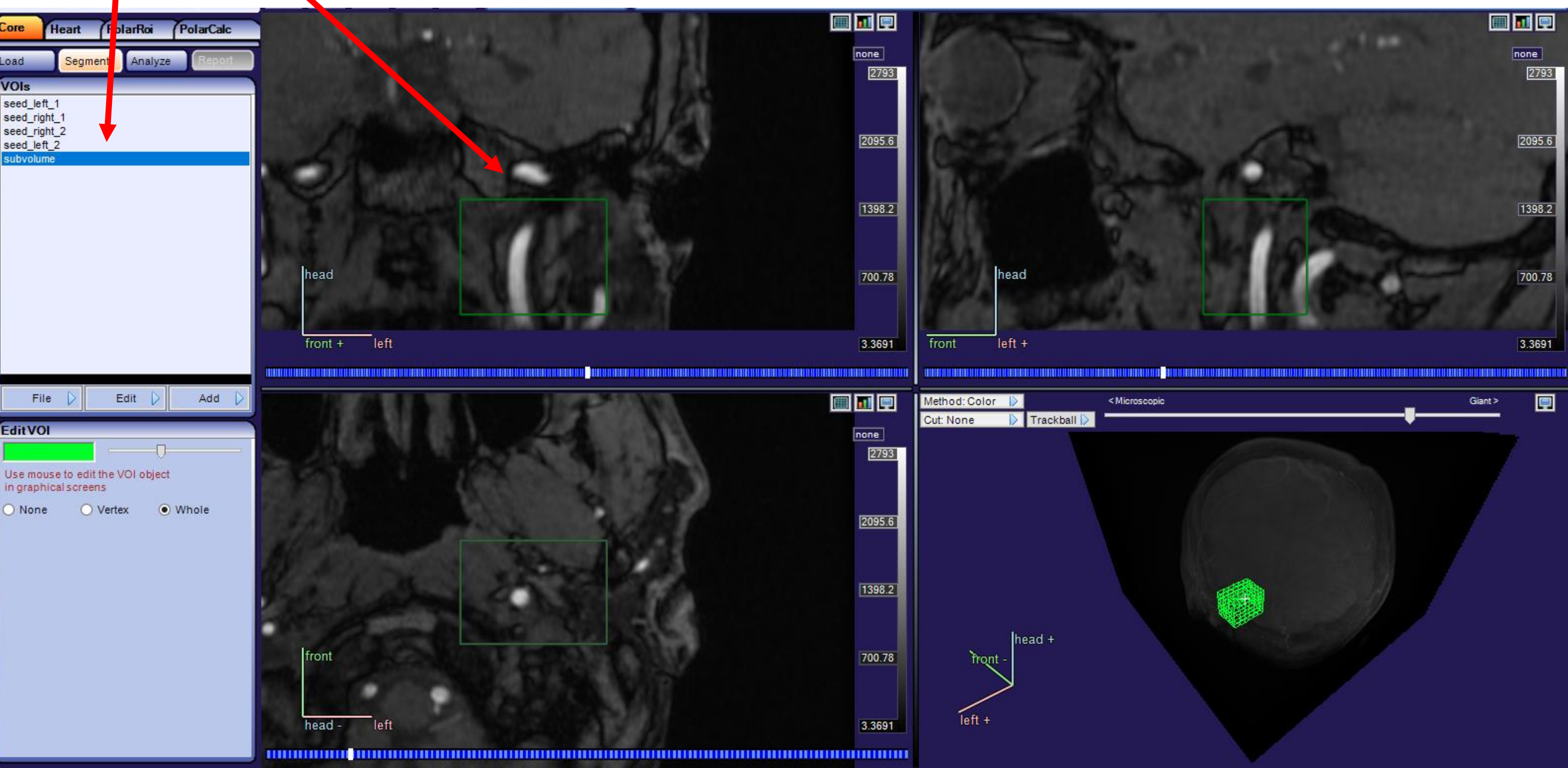
New images after running of ”ImageIF”



Predefined subvolume

1. Subvolume is a domain for segmentation.
2. You can modify it to fit your data (cover seed VOIs).
3. Only one subvolume is needed. If more than one subvolume, only first one is used, others ignored.
4. You can define your subvolume, but name must be ”subvolume…..”.
5. Subvolume should not contain cerebral tissue.
6. More bigger subvolume, more time will be taken for processing (most for deconvolution procedure).

subvolume

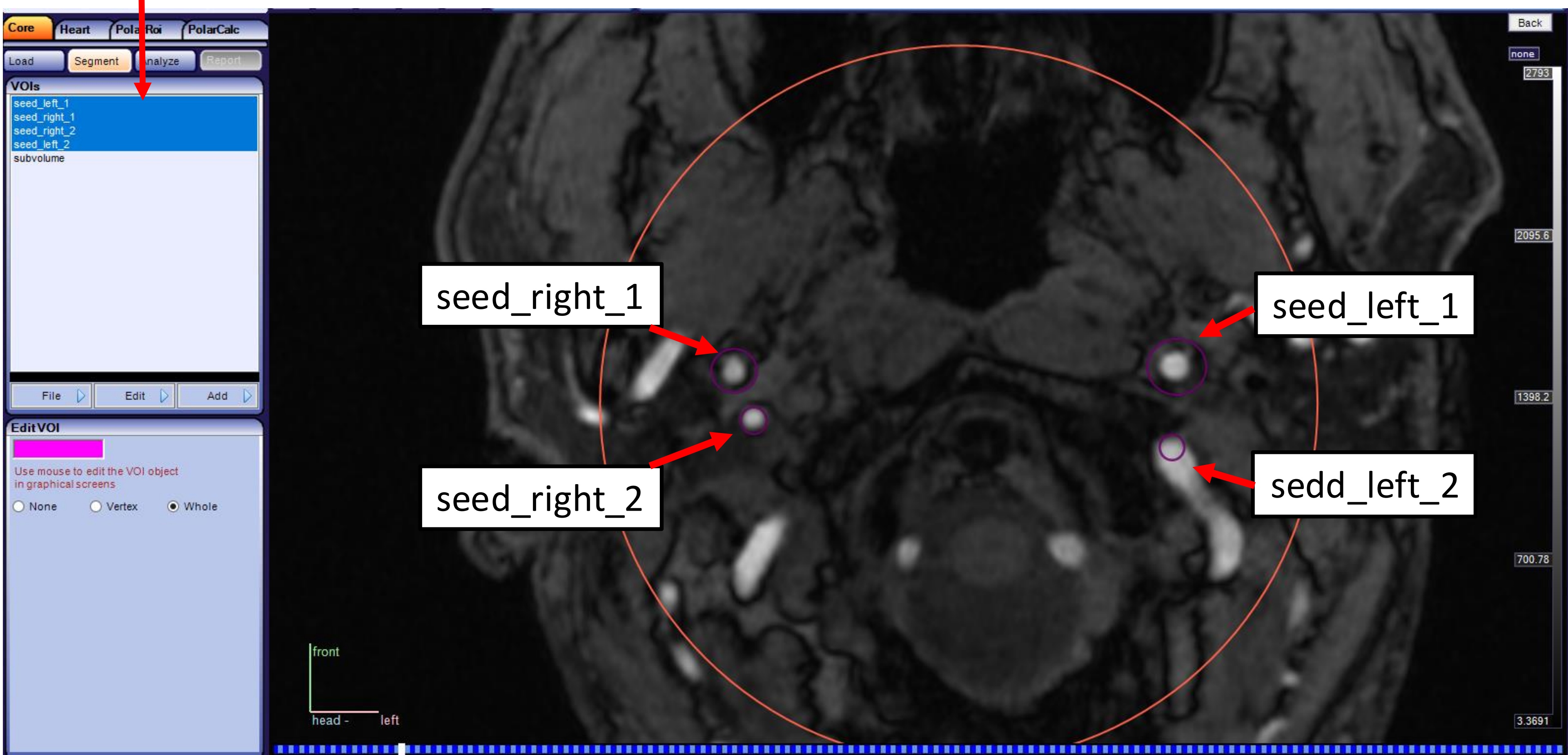


Predefined four seed VOIs for segmentation

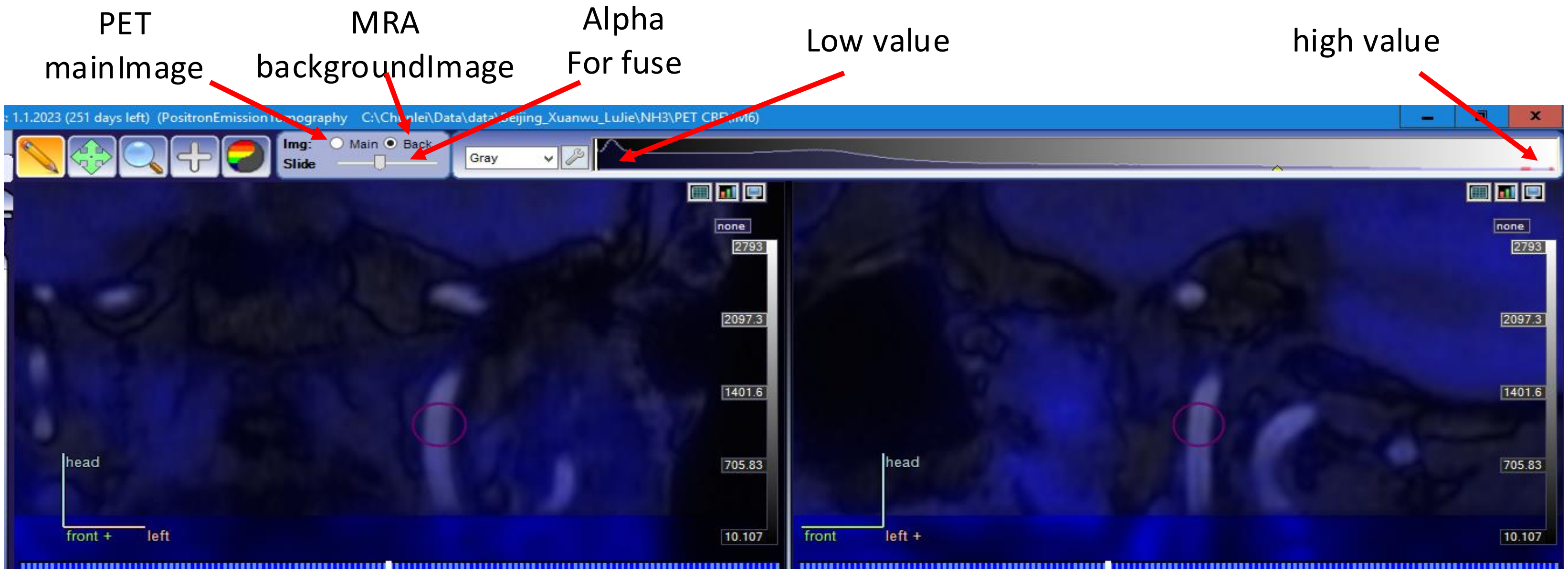
seed_left_1
seed_right_1
seed_right_2
sedd_left_2

1. You can use 1, 2, 3 or 4 of four previously defined seed VOIs.
2. Program only uses VOIs with name of ”seed_.....”. So if you only use one, you must remove ”seed” from other VOI names. Such as on the right definition, only first VOI is used.
3. You must modify the locations of VOIs to fit your data (to arteries).
4. You can use your own defined VOIs (must name them with ”seed......”).
5. Seed VOIs must be inside of subvolume.
6. Size of seed VOIS does not matter, program only uses the centre as seed location in segmentation.
7. Number of seed VOIs has no limit, but you must define at least one.

seed_left_1
_right_1
_right_2
_left_2



Pixel values of low and high limts on MRA



This is an example of setting and its segmentation result

- Low value plays a key role in segmentation, but high value does not. If segmentation is not good, you need to modify low value to perform segmentation again until satified.

Important factors of segmentation

1. Seed location (important)
2. Low value (very important)
3. High value (not very important)

Segmentation result

3D

transverse

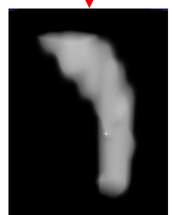
Algorithm of ”ImageIF”

Segmentation based on MRA

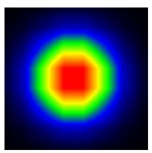
Semi-automatic

Depends on location of seed, low and high values

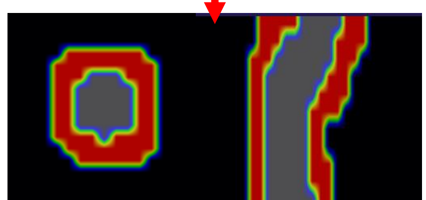
Mapping MRA mask to PET domain



PSF
(point spread function)

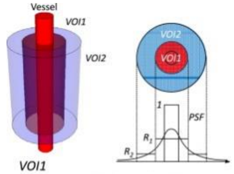


VOI1 and VOI2 / RC



Automatic

Curve



VOI1

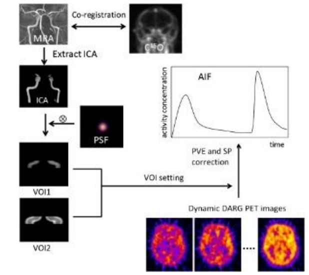
$C_1(t) = R_1 \times C_a(t) + (1 - R_1) \times C_t(t)$

VOI2

$C_2(t) = R_2 \times C_a(t) + (1 - R_2) \times C_t(t)$

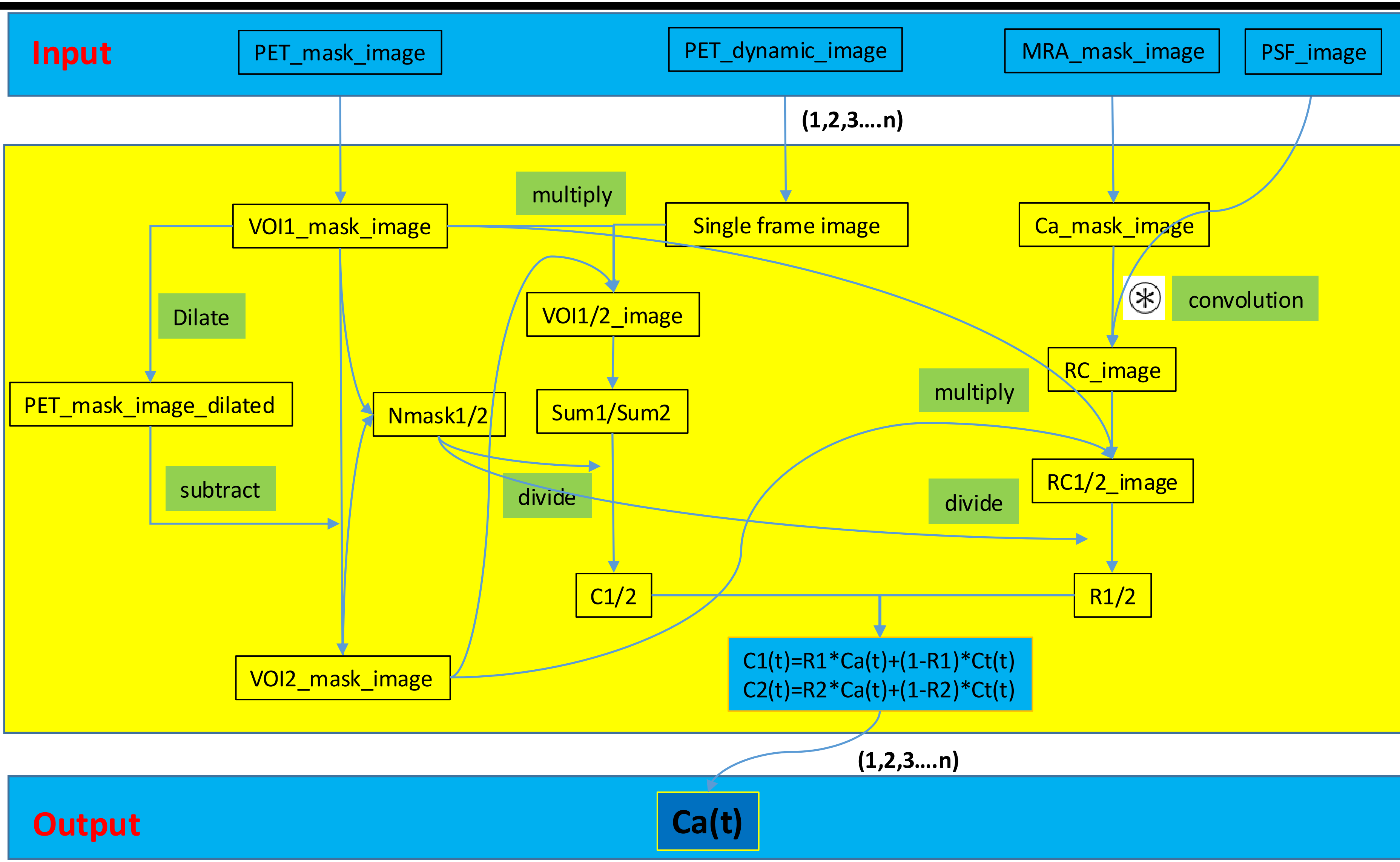
$C_1(t)$, $C_2(t)$: Activity concentration in VOI 1 and 2
R_1, R_2 : RC in VOI 1 and 2
$C_a(t)$: Radioactivity concentration in arterial blood
$C_t(t)$: Radioactivity concentration in surrounding tissue

Workflow of Image-derived input function



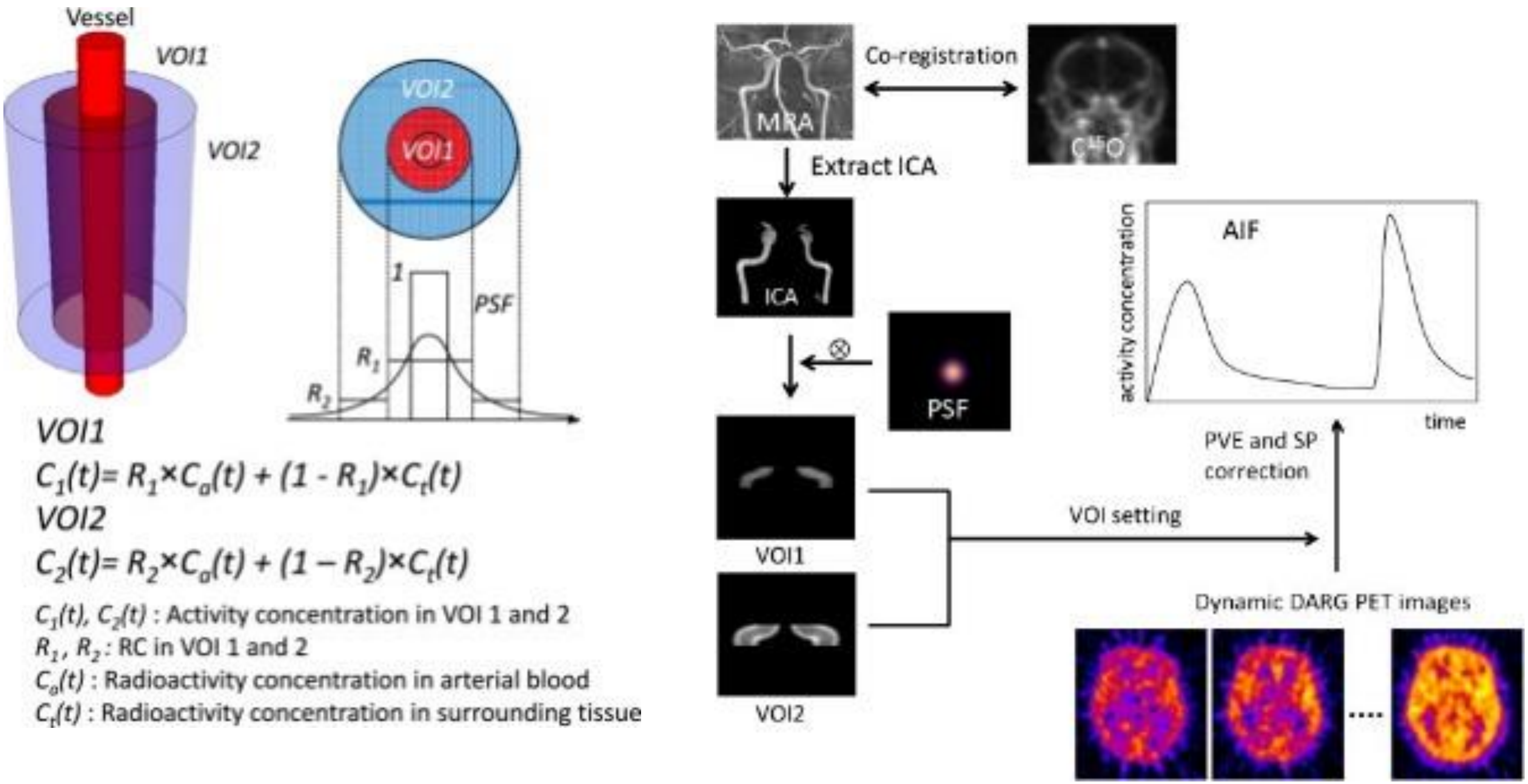
Chunlei Han. MD, Ph.D
Turku PET Centre and Turku University Hospital of Finland

Based on Iida 2013: https://www.sciencedirect.com/science/article/pii/S0168900212009084?via%3Dihub



Implementation of Iida' algorithm

[Based on Iida 2013: https://www.sciencedirect.com/science/article/pii/S0168900212009084?via%3Dihub](https://www.sciencedirect.com/science/article/pii/S0168900212009084?via%3Dihub)



BSA_Calculator v0.2

A Carimas plugin to calculate BSA(body surface area) based on total body CT images

Chunlei Han, MD, Ph.D

Turku PET Centre and Turku University Hospital,
Finland

May 12, 2022, Turku, Finland

Algorithm of BSA_Calculator

Remove bed based on VOIs with names of ”bed….”

↓

Mask body aerial cavities basd on VOIs with names of ”bodymask”

↓

Generation of body masked image with low pixel limit of -500 (CT Hounsfield units)

↓

Generation of triangle mesh of masked body

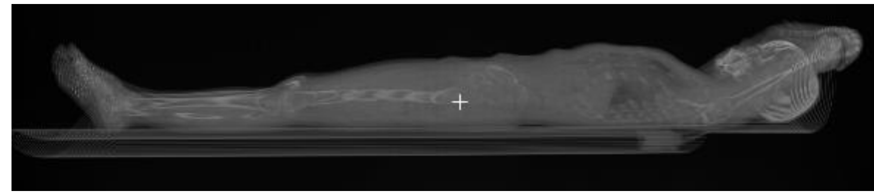
↓

Calculation of summy of triangle polgyon area in body mesh

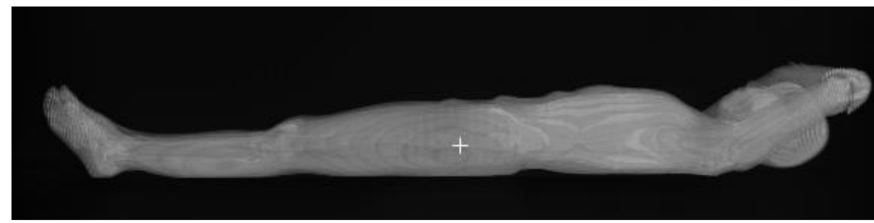
↓

BSA: body surface area

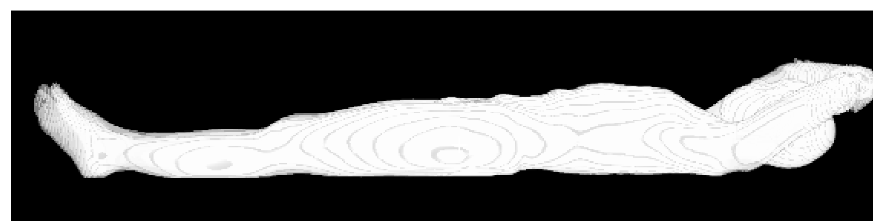
Origimal images



After bed removed



Masked total body



Triangle mesh of total body

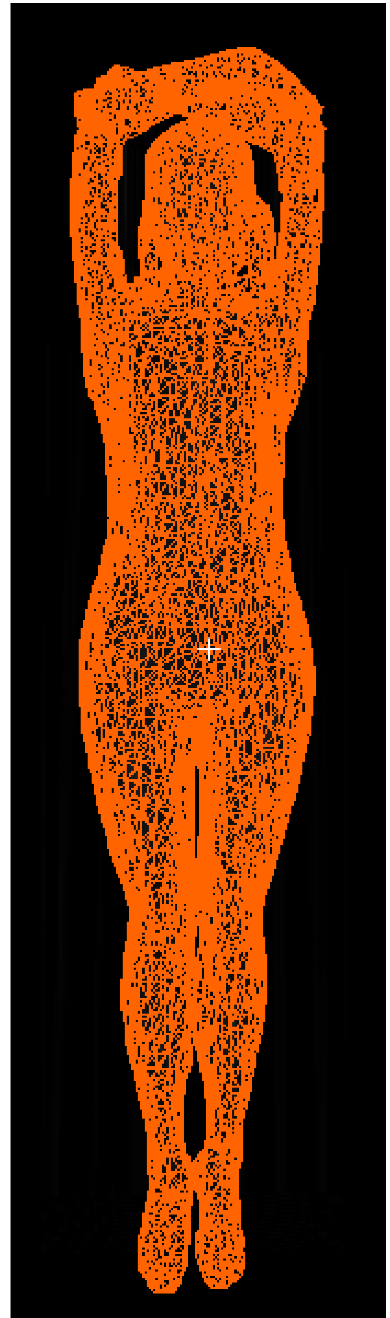
Example case: female, 46kg of weight, 160cm of height

BSA from BSA_Calculator: 1.36 m2

BSA estmated based on body weight and height

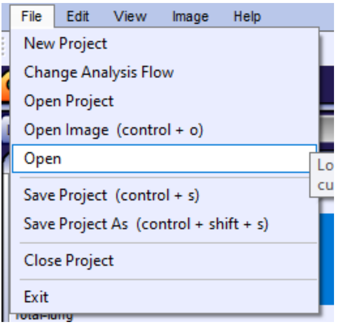
Formula	Results
Du Bois	1.45 m^2
Mosteller	1.43 m^2
Haycock	1.42 m^2
Gehan & George	1.44 m^2
Boyd	1.43 m^2
Fujimoto	1.40 m^2
Takahira	1.46 m^2
Schlich	1.36 m^2

https://www.calculator.net/body-surface-area-calculator.html

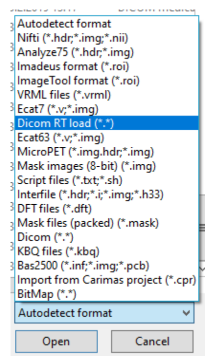


Carimas plugin: RSReader (Radiotherapy structure reader)

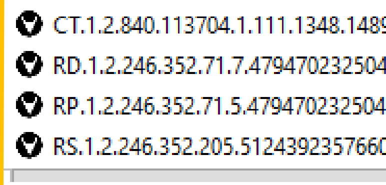
Step 1: File->Open



Step 2: Dicom RT LOAD



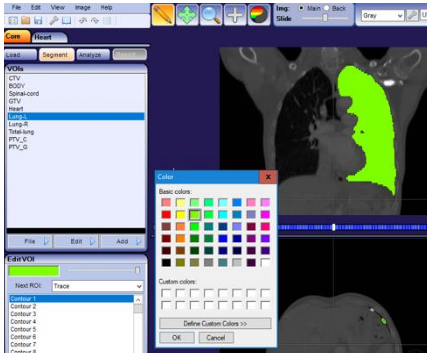
Step 3: Select RS



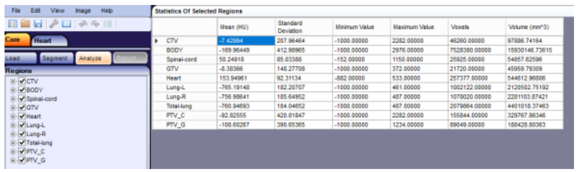
Abbreviation:

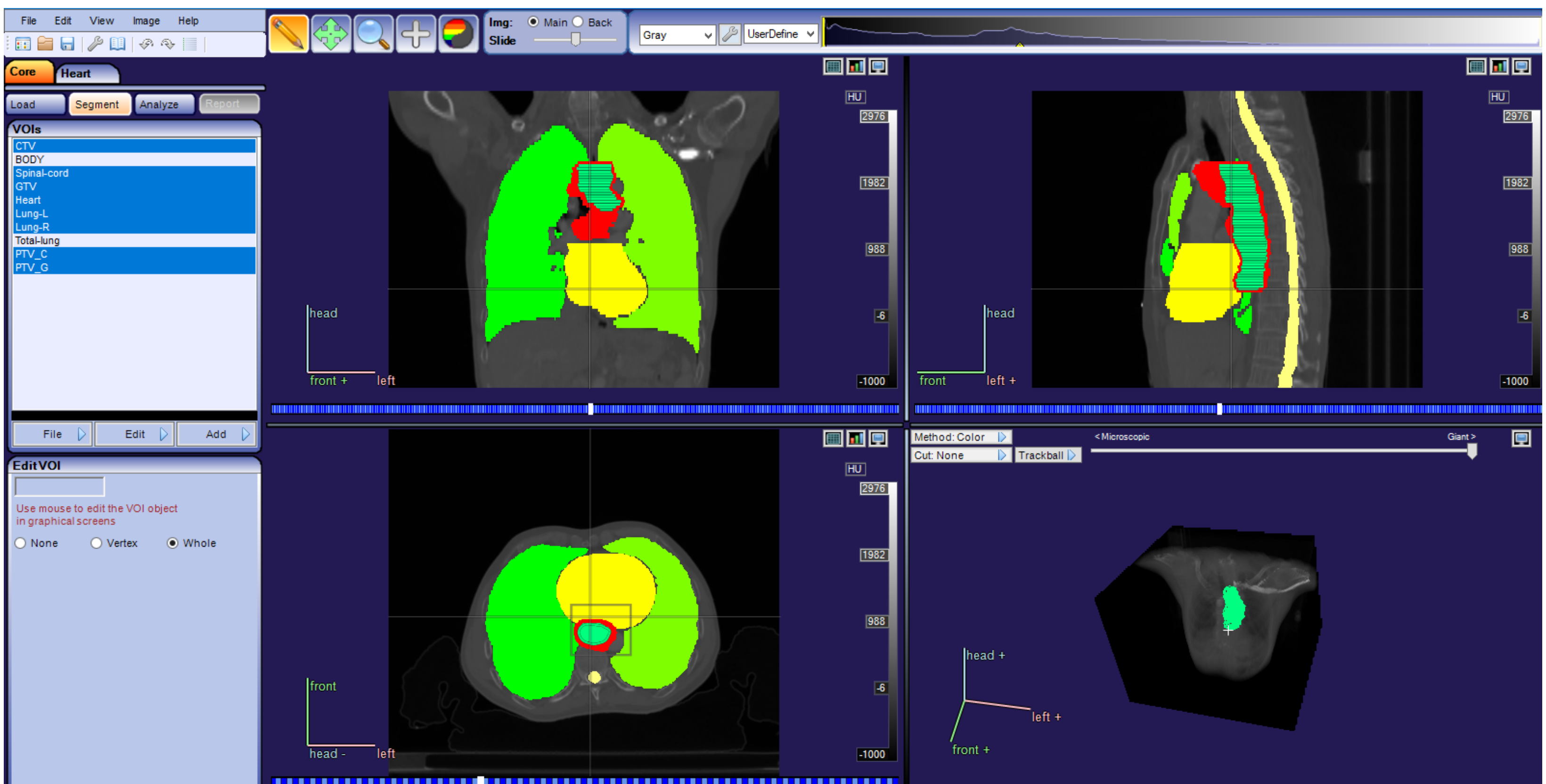
RD: Radiotherapy dose
RP: Radiotherapy plan
RS: Radiotherapy structure

Step 4: Option to change mask color



Step 5: Uptake value or curves or modelling





challenge of Carimas in AI era

Contents

- Brief on Carimas
- Features and program structure
- ***Demonstration***

Conclusions

- Carimas is useful tools for medical imaging-related researchers
- Additional functions can be very easily extended by plugin


Kiitos
Thank for your attention