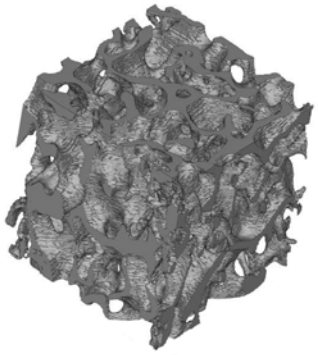
Materials Performance and Non-Destructive Testing



Validation of X-ray Micro-CT as Screening Tool for Bone Tissue Engineering Scaffolds

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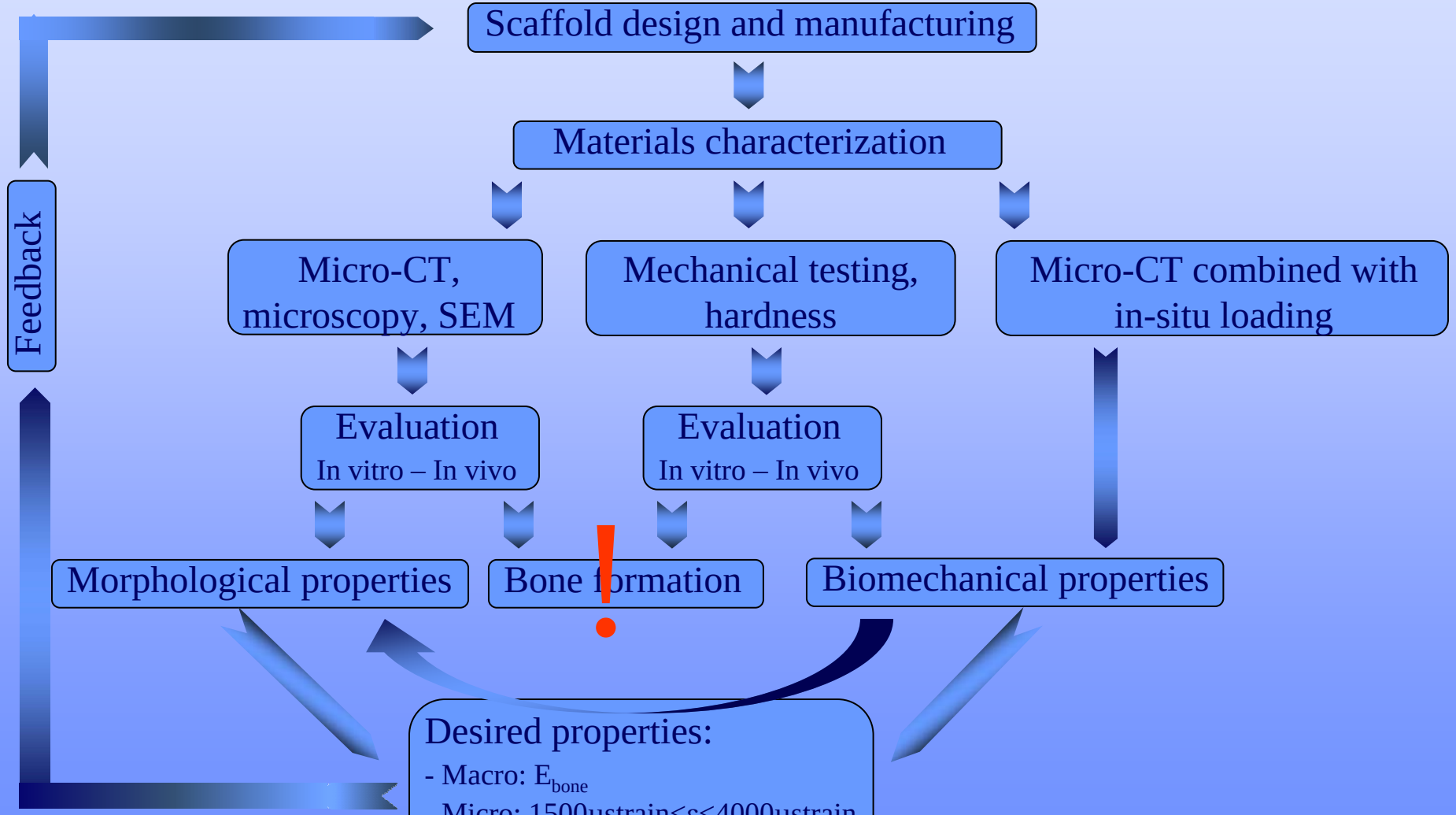
Department of Metallurgy and Materials Engineering

Framework: High throughput screening of bone scaffolds



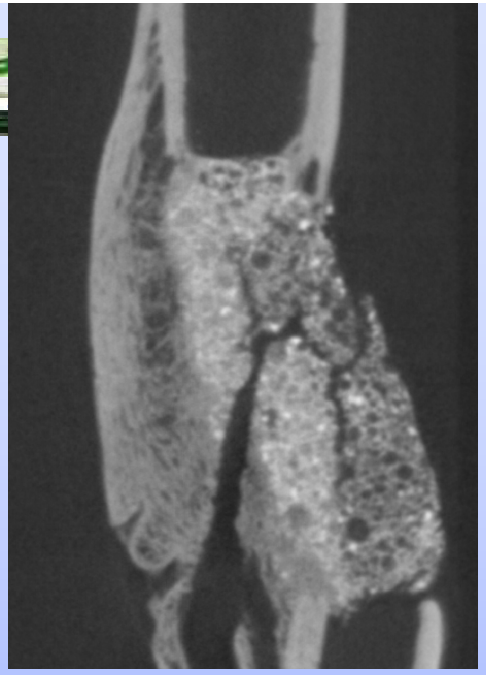
Materials

Naked scaffolds

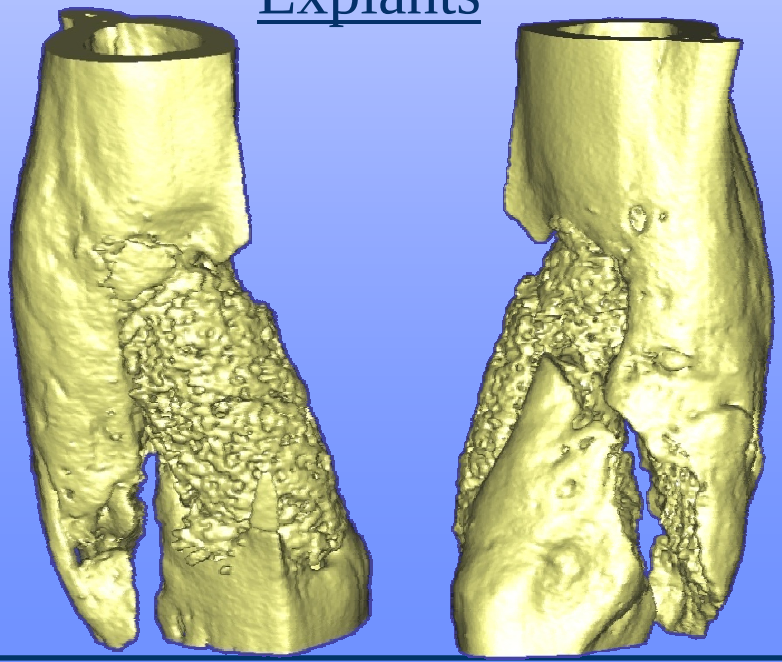
Ti bone scaffolds

HA bone scaffolds

Composite bone scaffolds



Explants

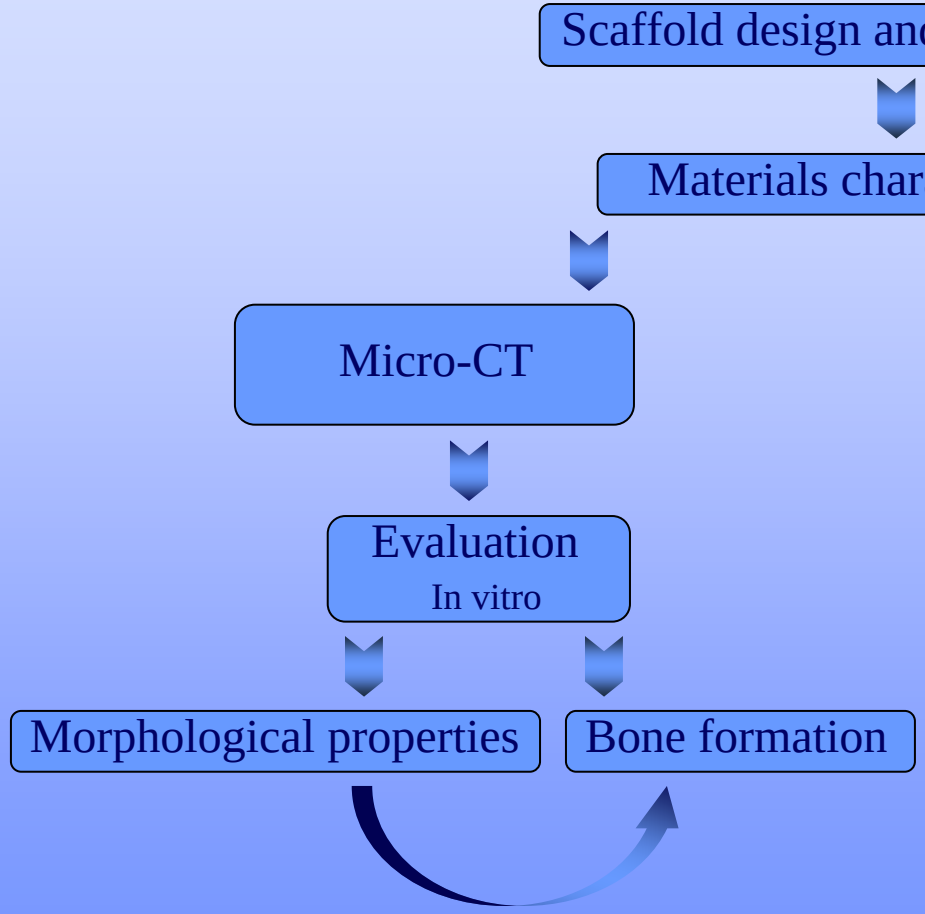


Materials

- Cylindrical or squared porous Ti structures (ø-h: 6-12 mm or w-h: 10 mm)
- Produced by gel casting
- 25 vol% Ti-powder + 3 wt% dispersion agent + foaming agent dispersed in distilled H_20
- Pore diameter can be adjusted to obtain the desired pore size distribution by altering the composition of the slurry and the stirring time
- Altering the sintering temperature influences the final mechanical and structural scaffold properties

Pore size:50 - 500 µm ; Strut size: 20 - 100 µm ; Global porosity: 80%

Framework: High throughput screening of bone scaffolds



Protocol for morphological quantification

Step 1: Protocol for acquisition and reconstruction of micro-CT images for different material classes

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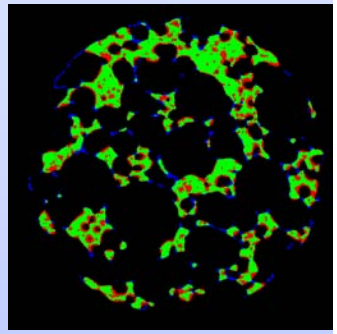
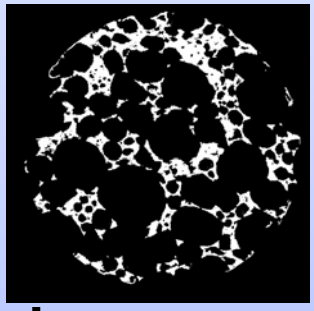
Step 2: Validation protocol and coupled to this a novel global thresholding method to define the visualisation and binarization error in the binary images

Validation protocol for 2D quantification



Overlay image

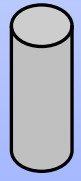
Image registration, binarization and overlay



Optical image/ histological slice

Sliced parts

Slicing/histology

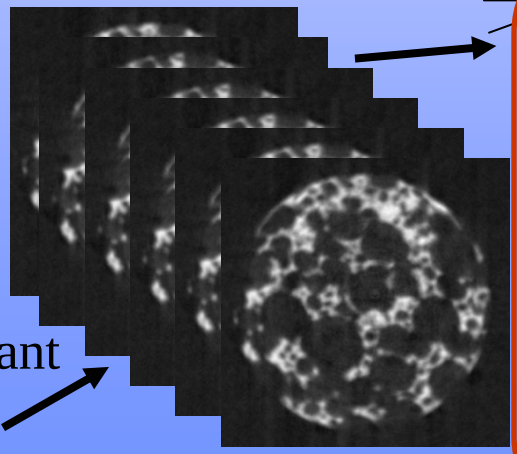


Full scaffold or explant

Micro-CT scanning angle ≠ Physical slicing angle

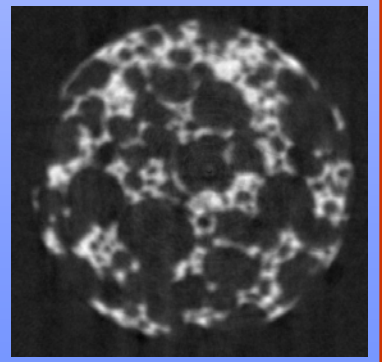
Philips HOMX 161 X-ray system with AEA Tomohawk CT-software

Full scaffold/explant micro-CT dataset



Micro-CT image dataset

Micro-CT image interpolation

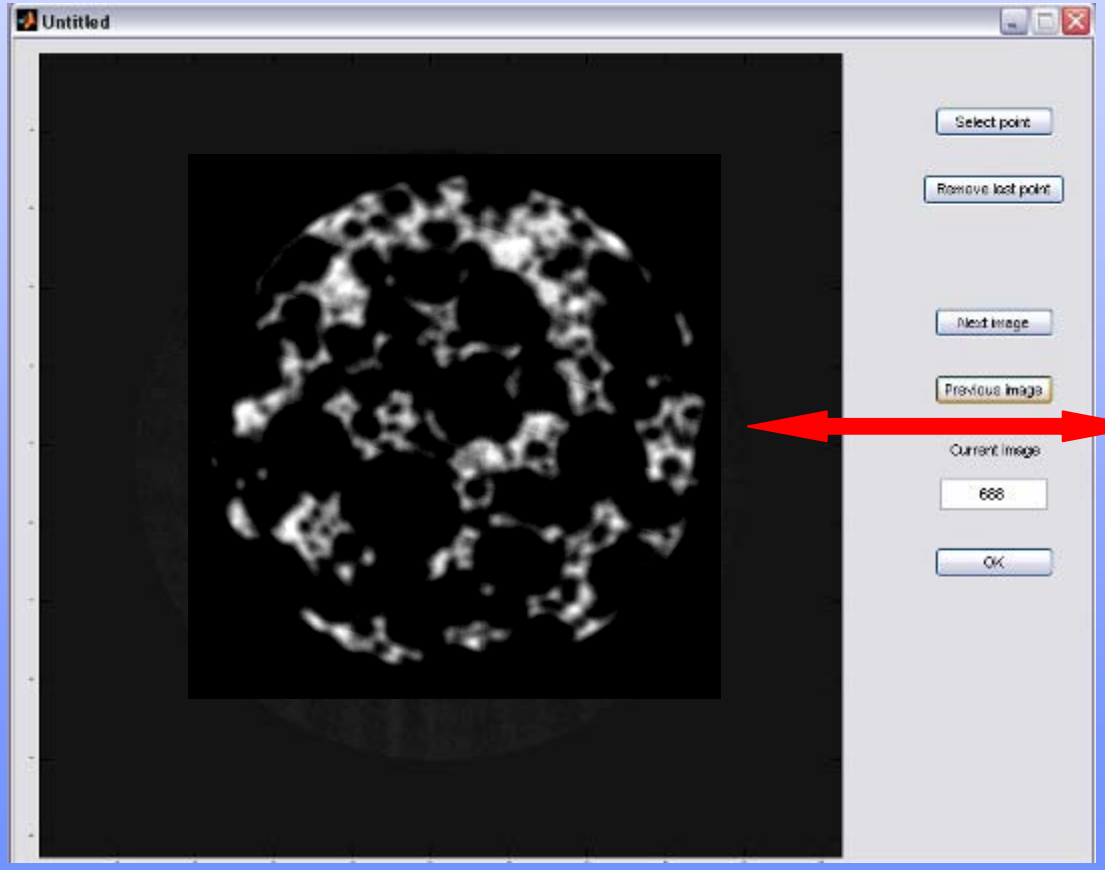


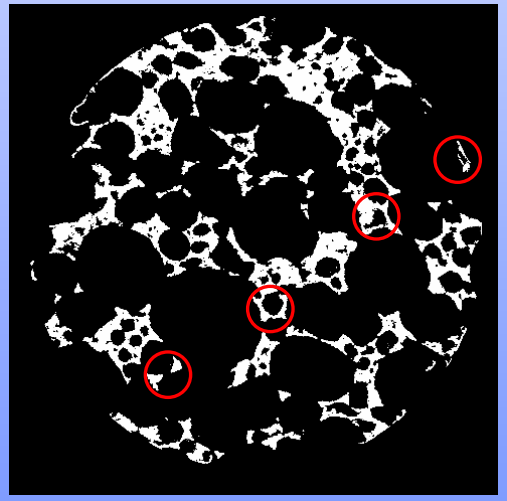
Interpolated micro-CT image

Experimental protocol

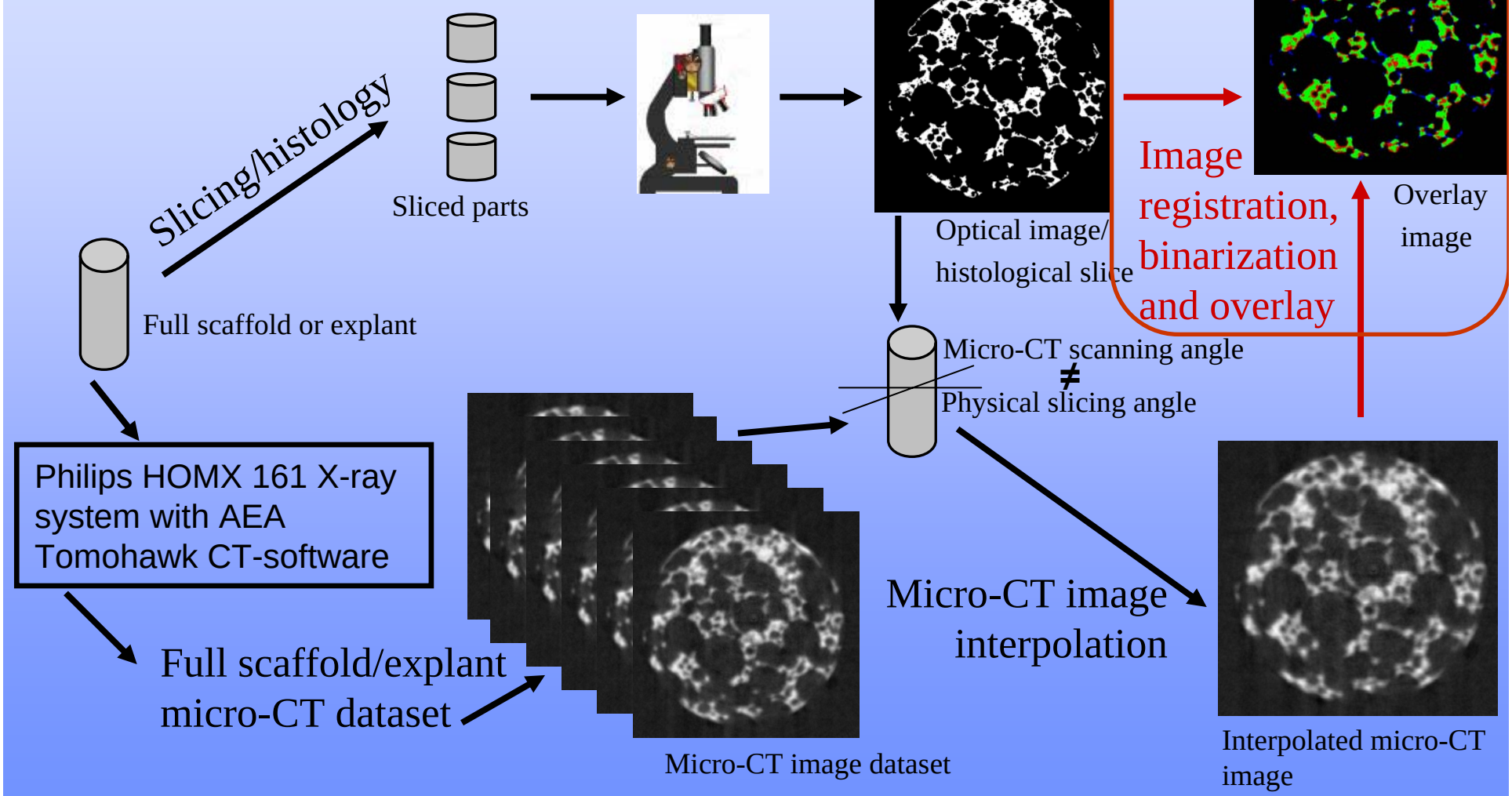
Interpolation of the micro-CT image

→ Finding the corresponding micro-CT image in the dataset



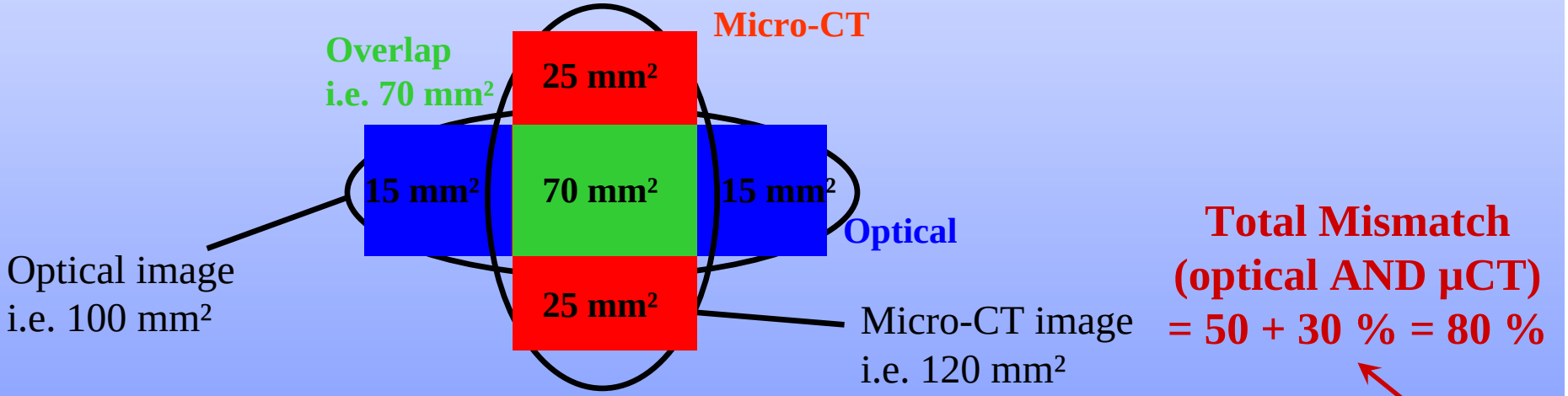


Validation protocol for 2D quantification



Matching

- Automatic image registration (Maes et al. 1997, 2003 - KULeuven)
- Result = overlapping binarized images



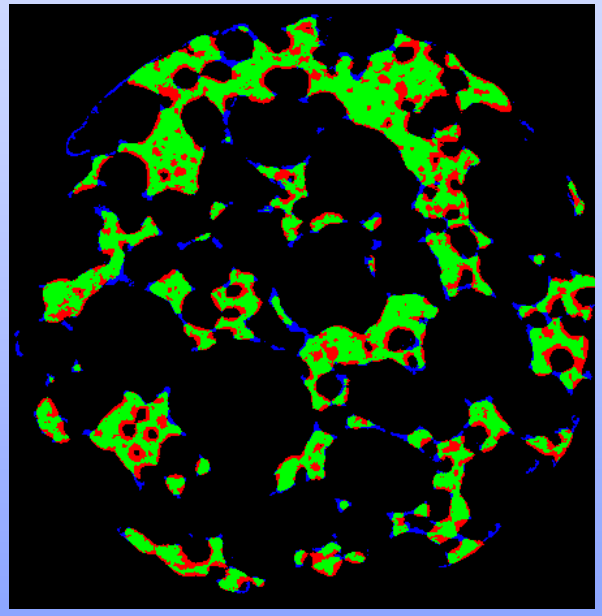
- **Solid overlap** = total green / (total blue + green) = 70 / (30+70) = 70 %
- **Solid micro-CT mismatch** = total red / (total blue + green) = 50 / (30+70) = 50 %
- **Solid optical mismatch** = total blue / (total blue + green) = 30 / (30+70) = 30 %

Overlap

Overestimation − **Underestimation** → **Mutual Mismatch**
= 50 - 30 % = 20 %

Thresholding method

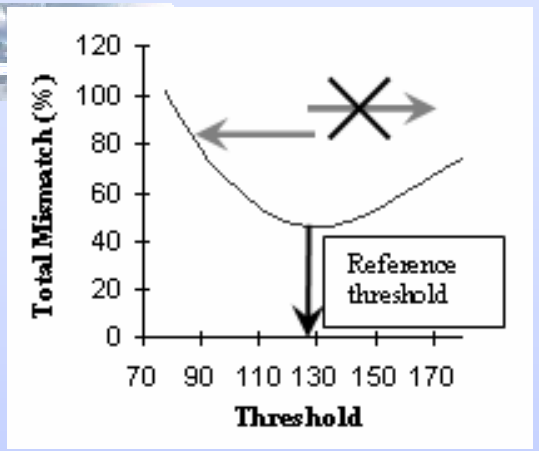
Overlap and mismatch: influence of threshold

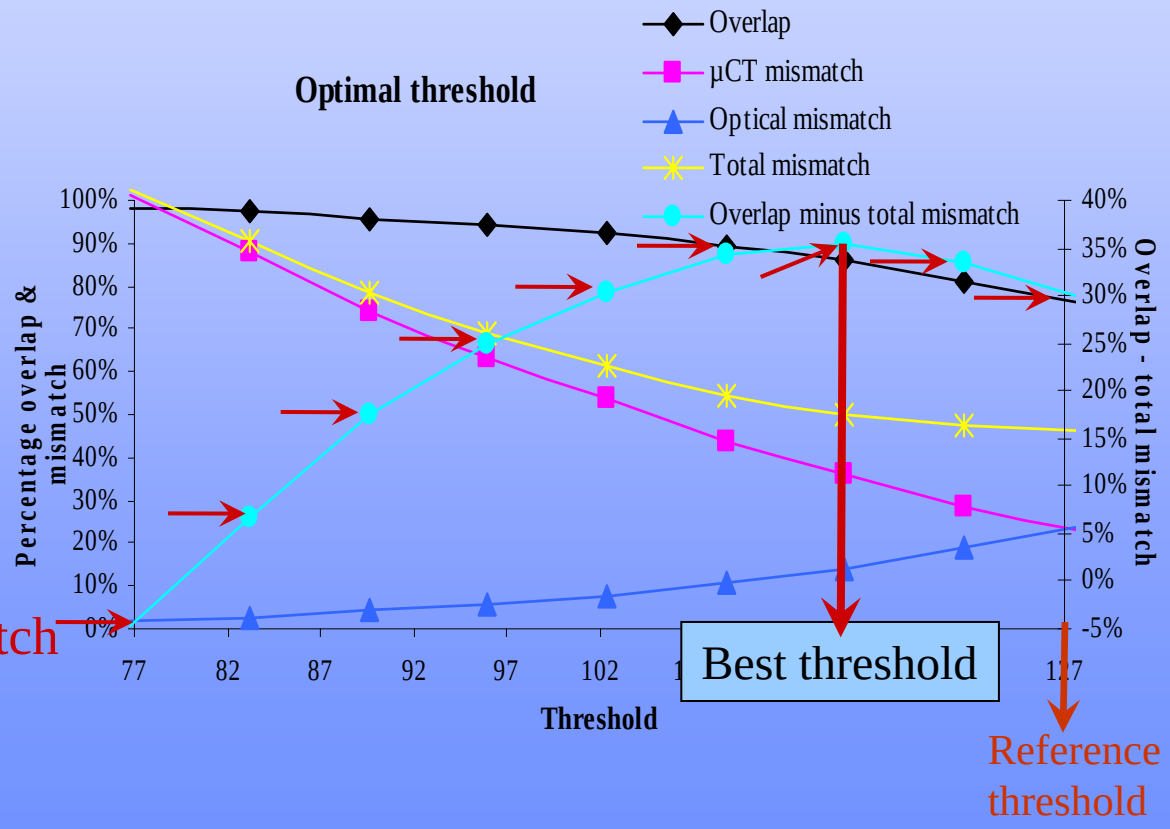


89.6 % solid overlap

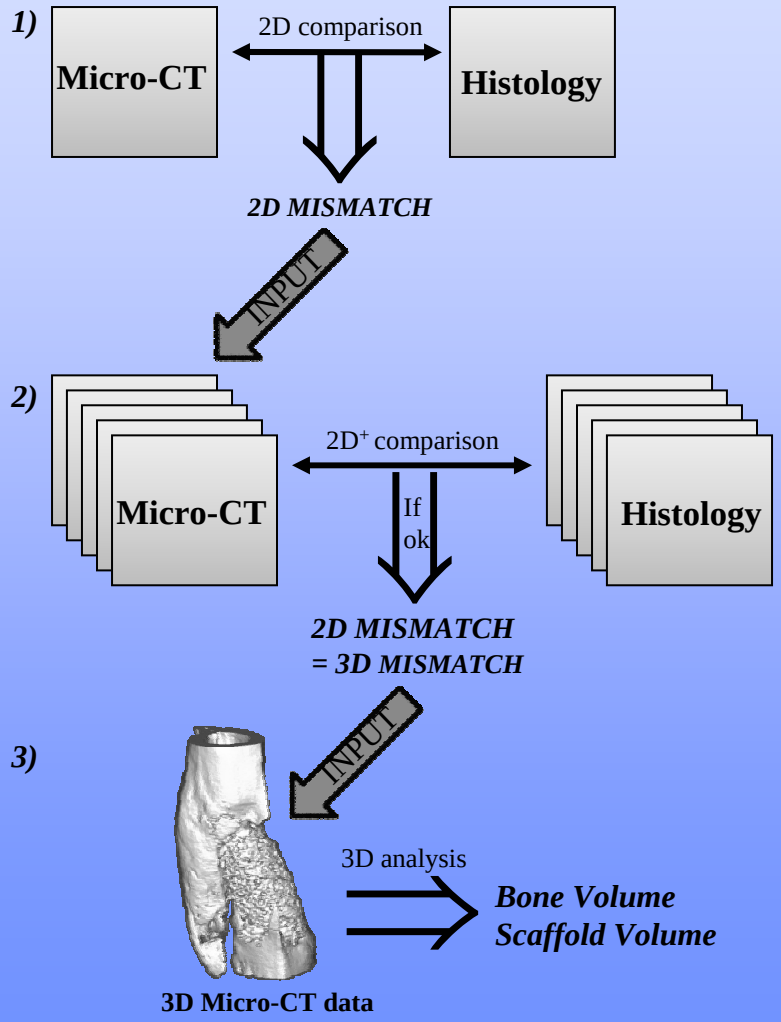
45.1 % solid micro-CT mismatch

10.4 % solid optical mismatch





3D quantification of bone formation: flow chart



Results: Overlap and total mismatch

Overlap, overestimation and underestimation for naked Ti scaffolds

83.4 ± 4.5 % overlap

44.2 ± 9.9 % overestimation + **16.6 ± 4.5 %** underestimation

- **Limits of the micro-CT device**
- **Limited field of view**
- **Large sample dimensions**
- **Complex structure of the sample**
- **Material of the sample**
- **Partial Volume Effect**

→ **Optimal threshold = 68**

Protocol for morphological quantification

Step 1: Protocol for acquisition and reconstruction of micro-CT images for different material classes

↓

Step 2: Validation protocol and coupled to this a novel global thresholding method to define the visualisation and binarization error in the binary images

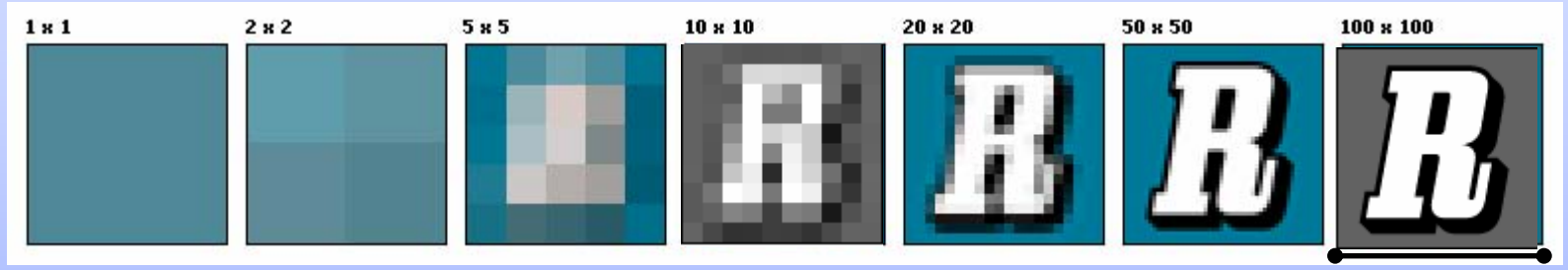
↓

Step 3: What is the influence of the resolution on the novel thresholding method and what is the effect on the visualisation and binarization error ?????

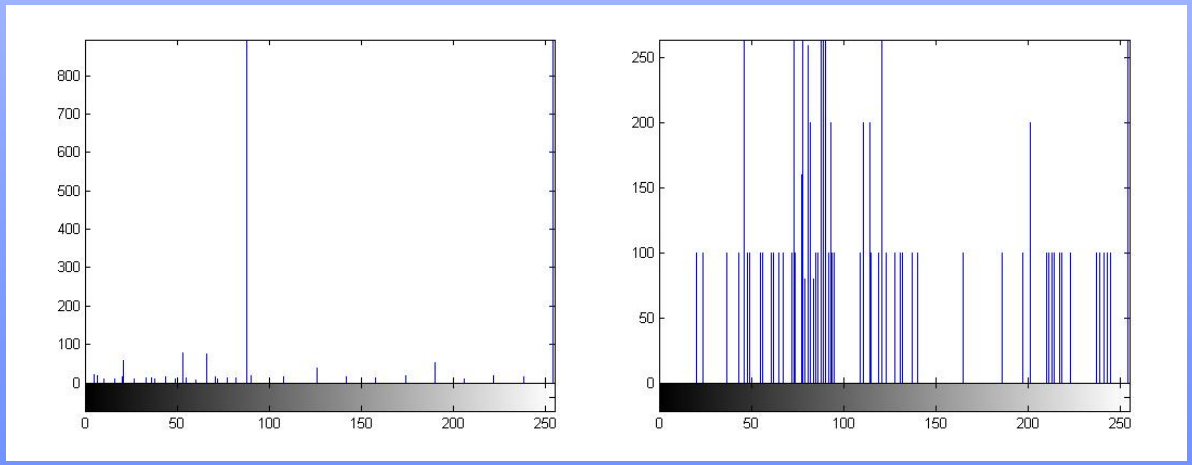
Lower resolution is wanted/required:
- when the sample is larger
- when limited CPU and memory is available
- …

Spatial resolution

= a measure of how closely details can be resolved in an image (Wikipedia)

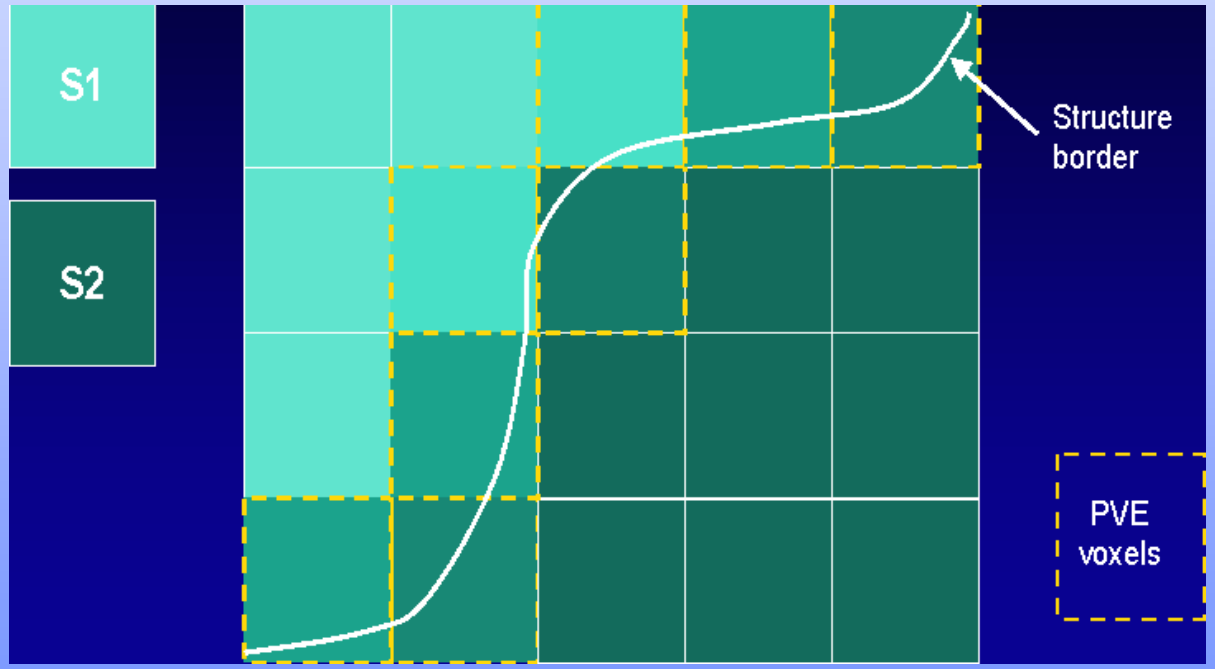


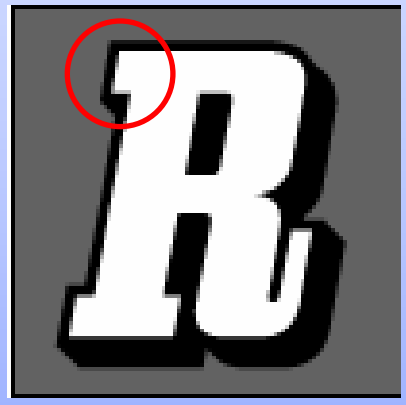
Pixel size = 10 mm	**Pixel size = 5 mm**	**Pixel size = 2 mm**	**Pixel size = 1 mm**	**Pixel size = 0.5 mm**	**Pixel size = 0.2 mm**	**Pixel size = 0.1 mm**

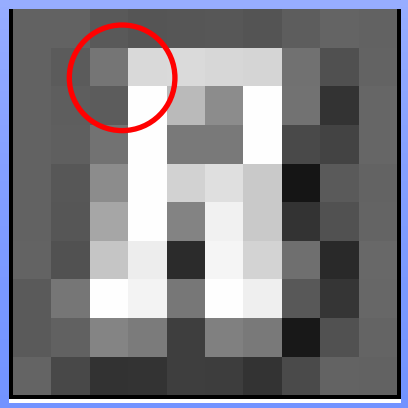


Partial Volume Effect (PVE)

= the effect wherein insufficient image resolution leads to a mixing of the different material types present in the image within a voxel







Influence of the resolution

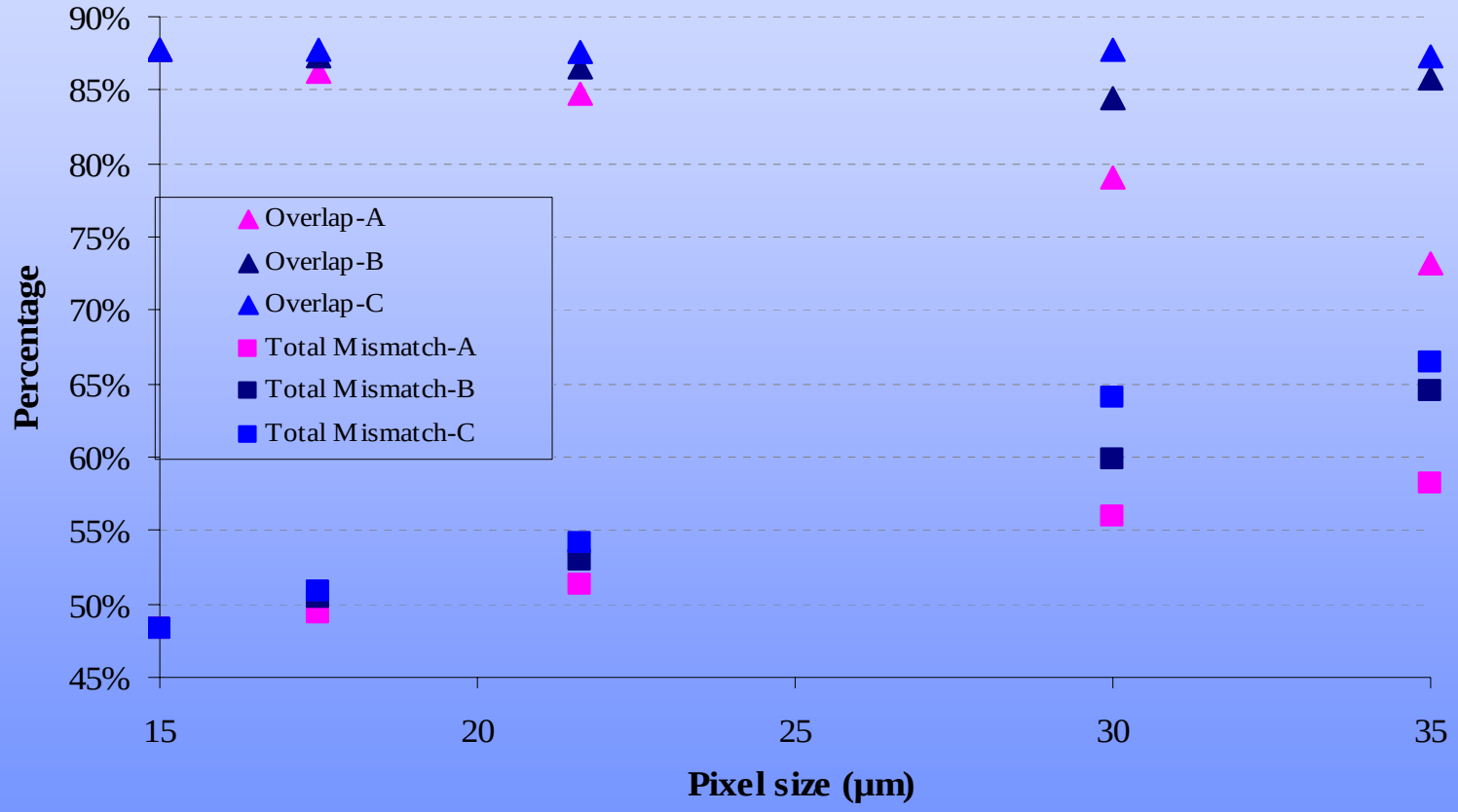
- If the resolution goes down, it is inherently known that the total mismatch increases
- Three options for binarizing images with lower resolution:

A) Use the same threshold as was determined 'optimal' for the highest resolution

B) Use the same technique as described previously (minimizing the total mismatch) for different resolutions

C) Keep the overlap and underestimation constant

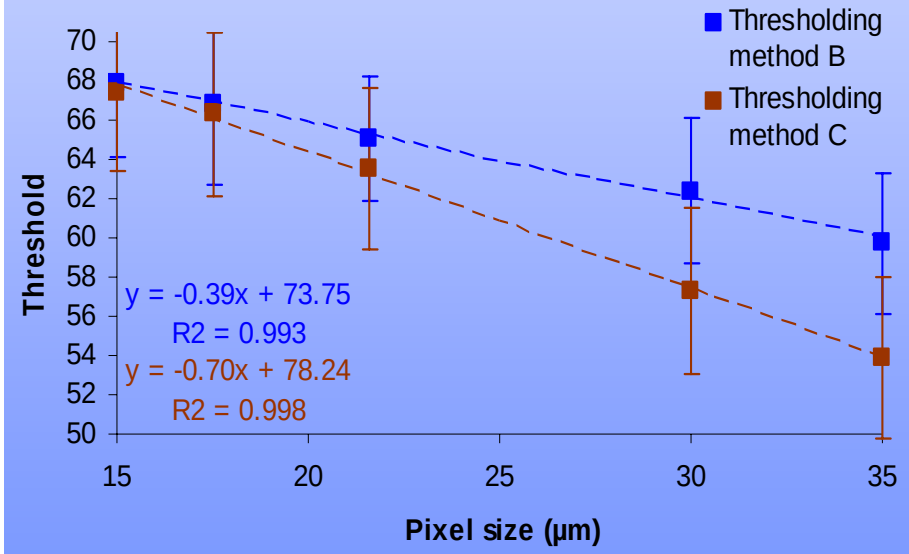
Overlap and total mismatch for different thresholding methods

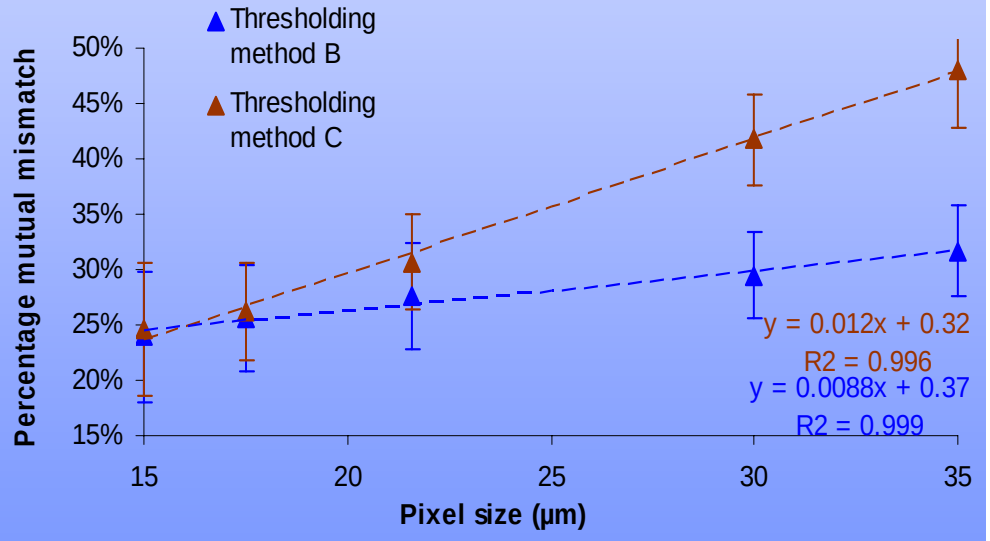


A) Use the same threshold as was determined 'optimal' for the highest resolution
B) Use the same technique as described previously (minimizing the total mismatch) for different resolutions
C) Keep the overlap and underestimation constant

Results

Optimal threshold and mutual mismatch in function of the pixel size for the different thresholding methods

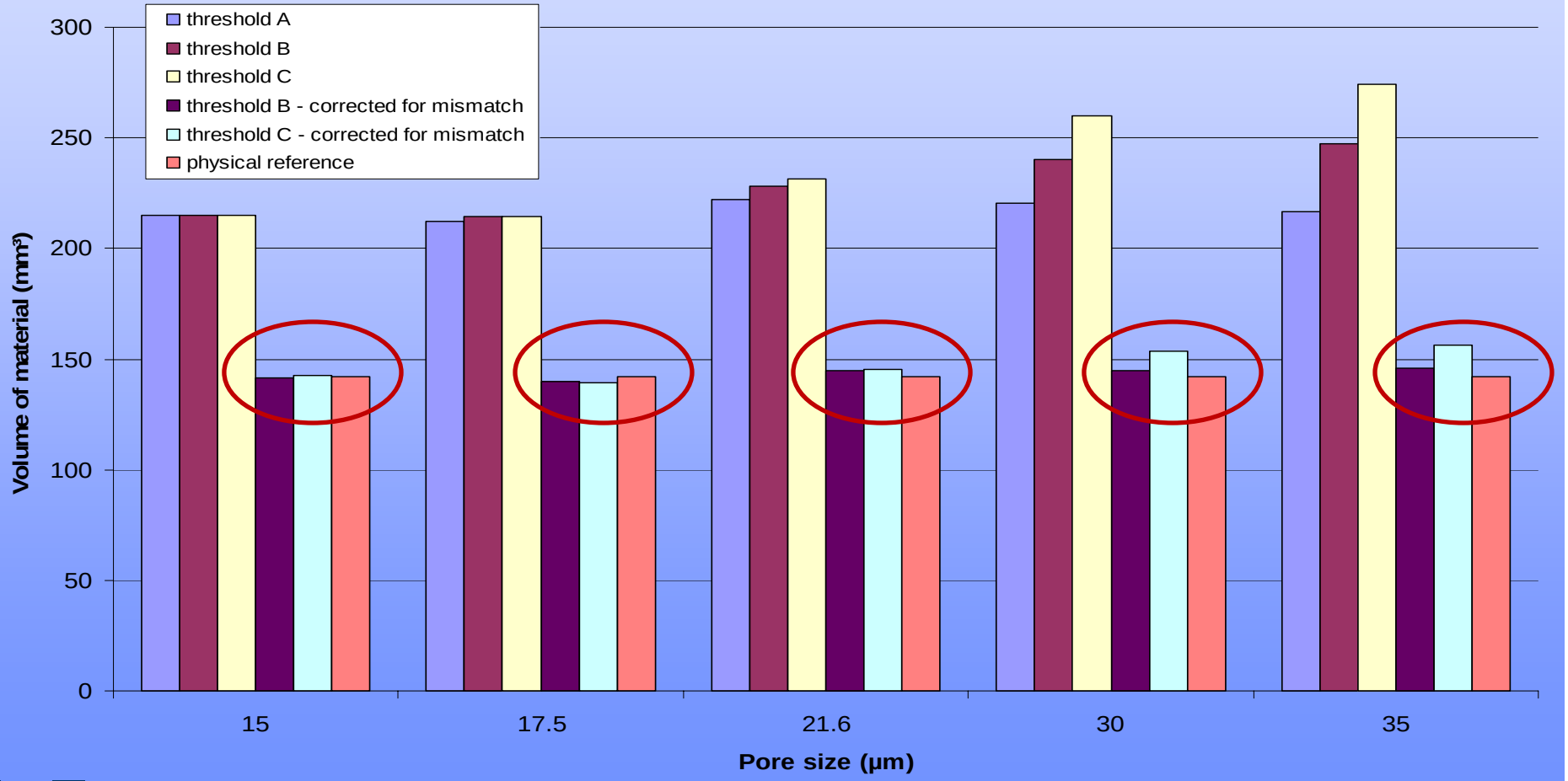




A) Use the same threshold as was determined 'optimal' for the highest resolution
B) Use the same technique as described previously (minimizing the total mismatch) for different resolutions
C) Keep the overlap and underestimation constant

Results

3D analysis and influence of the mismatch



Discussion and conclusions

- A validation protocol is developed by matching micro-CT tomograms to microscopic sections
- The validation protocol has 3 main advantages against existing protocols:
  - Opportunity for interpolation of the micro-CT images
  - A novel thresholding method was developed
  - A more detailed quantification of the visualization and binarization error
- Despite the morphological complexity of the Ti samples and the variety in structural feature dimensions ➔ sufficiently accurate quantification via micro-CT
- The mismatch found needs to taken into account in the structural analysis

Discussion and conclusions

- When decreasing the spatial resolution, the threshold cannot be kept constant → linear decrease in threshold
- Decreasing resolution results in a larger mutual and total mismatch
- When looking at 3D structural analysis, the best method for thresholding is looking for the combination of a maximum in overlap and a minimum in total mismatch
- Of course: the less the resolution will be, the less accurate the images

Discussion and conclusions

Validation and thresholding protocol

↓

Linear functions for threshold and mismatches in function of the spatial resolution

↓

When acquiring images on other resolutions, you can determine the 'optimal' threshold and its corresponding mismatches

Thank you for your attention!!!