EURATOM

# Project Deliverable

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| 212246 | SEDENTEXCT | Safety and Efficacy of a New and Emerging Dental X-ray Modality |

| Instrument: | Activity code: |
|---|---|
| Collaborative Project (Small or medium-scale focused research project) | Fission-2007-3.2-01 |

| Start date of project: | Duration: |
|---|---|
| 1 January 2008 | 42 months |

**Title:**
D4.2 Completed testing and comparison of the various CBCT and MSCT with the phantom models for segmentation, linear and diagnostic accuracy *in vitro*

| Contractual Delivery date: | Actual Delivery date: |
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| 30 June 2009 | Version 1.0: 24 June 2009<br>Version 1.1: 1 October 2009 |

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| Dissemination level: | | |
|---|---|---|
| PU | Public | **X** |
| PP | Restricted to other programme participants (including the Commission) | |
| RE | Restricted to a group defined by the consortium (including the Commission) | |
| CO | Confidential, only for members of the consortium (including | |

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Abstract:

This deliverable describes the methodology and results of the *in vitro* section using human jaw bones of WP4.

The approach was twofold: on the one hand, software-driven analyses were done to compare the segmentation accuracy of several Cone Beam CT (CBCT) devices in an automated way. On the other hand, observer studies were performed for linear accuracy testing and diagnostic accuracy testing of root and bone lesions.

For segmentation accuracy, CBCT images were compared to clinical and/or gold standards using surface registering as well as structural descriptions of the internal bone structure. These standards were multislice CT (MSCT) and microCT (µCT). Preliminary results could be obtained describing the optimal settings to obtain high segmentation accuracy for specific devices.

For linear accuracy, observers were asked to measure distances between anatomical landmarks. The influence of imaging parameters on these measurements could be evaluated.

For diagnostic accuracy, observers were asked to assess images of several devices and detect, locate and describe lesions on roots (resorption) or bone tissue. Again, a comparison of the devices could be made.

The deliverable ends with a note on ongoing research within the project and future research to be performed.

# Table of Contents

# 1. The Context

## 1.1 SEDENTEXCT aims and objectives

The aim of this project is the acquisition of the key information necessary for sound and scientifically based clinical use of dental Cone Beam Computed Tomography (CBCT). In order that safety and efficacy are assured and enhanced in the 'real world', the parallel aim is to use the information to develop evidence-based guidelines dealing with justification, optimisation and referral criteria and to provide a means of dissemination and training for users of CBCT. The objectives and methodology of the collaborative project are:

1. To develop evidence-based guidelines on use of CBCT in dentistry, including referral criteria, quality assurance guidelines and optimisation strategies. Guideline development will use systematic review and established methodology, involving stakeholder input.

2. To determine the level of patient dose in dental CBCT, paying special attention to paediatric dosimetry, and personnel dose.

3. To perform diagnostic accuracy studies for CBCT for key clinical applications in dentistry by use of *in vitro* and clinical studies.

4. To develop a quality assurance programme, including a tool/tools for quality assurance work (including a marketable quality assurance phantom) and to define exposure protocols for specific clinical applications.

5. To measure cost-effectiveness of important clinical uses of CBCT compared with traditional methods.

6. To conduct valorisation, including dissemination and training, activities via an 'open access' website.

At all points, stakeholder involvement will be intrinsic to study design.

## 1.2 Work package 4 (WP4) objectives

- To determine *in vitro* the segmentation, linear and/or diagnostic accuracy of various CBCT scanners versus MSCT (WP4.1)
- To assess the diagnostic accuracy of CBCT in an animal model (WP4.2)
- To determine the diagnostic accuracy of various CBCT scanners for specified clinical applications (WP4.3)

## 1.3 Deliverable D4.2

Deliverable D4.2 describes several outcomes, coming from WP4.1. It includes all *in vitro* studies except the animal model, which is described in D4.1. It aims for segmentation accuracy, based on scanning different skulls with several devices and comparing it to a gold standard. Linear accuracy was determined in skull phantoms as well, comparing the influence of imaging parameters. Next to that, *in vitro* diagnostic accuracy was assessed for bone lesions and root lesions.

## 1.4 Glossary

**CTCT:** Cone Beam Computed Tomography

**MSCT**: Multislice Spiral Computed Tomography

**Phantom models**: The phantoms mentioned here are referring to (parts of) human skulls with or without original soft tissue. In this, they differ from the phantoms used in WP2 and 3, which are synthetic and non-anthropomorphic (WP3) or an anthropomorphic combination of human and soft tissue equivalent material (WP2).

**Segmentation accuracy**: Segmentation accuracy is the accuracy with which a bone model can be derived from CBCT images. To define this accuracy the segmentation result is compared to a reference standard. In the current project, two reference standards were used: MSCT and µCT.

**Linear accuracy**: the accuracy of an observer's linear measurement of the distance between 2 points, compared to the actual distance between these points. The linear accuracy is presented as a deviation from the gold standard.

**Diagnostic accuracy**: the percentage of correct diagnoses in a series of cases. Diagnostic accuracy determines a test's ability to distinguish 'normal' and 'abnormal' cases. A gold standard must be available (normal – abnormal), which is most feasible in vitro studies, such as the ones described in the current deliverable. Diagnostic accuracy was assessed for two types of lesions here: bone lesions and root lesions. The third type of lesion, periapical, was evaluated within WP deliverable D4.1.

# 2. The Methodology

## 2.1 Segmentation accuracy

To simulate and evaluate various settings, we collected maxillary as well as mandibular bone, dry and including soft tissues, dentate as well as edentulous.

The first step was scanning the materials. For the CBCT, the samples were scanned at standard clinical settings of the devices, which sometimes meant several scans to be taken per device. An overview of the scans is given in the table below:

| | **Maxilla A** | **Maxilla B** | **Mandible A** | **Mandible B** | **Mandible C** | **Mandible D** |
|---|---|---|---|---|---|---|
| | **Soft tissue** | **Soft tissue** | **Soft tissue** | **Soft tissue** | **Dry** | **Dry Fragments** |
| Accuitomo | X | x | X | X | X | |
| Galileos | X | X | X | X | X | |
| i-CAT | X | X | X | X | | |
| Kodak 9000 | | X | X | X | X | |
| Picasso | | X | X | X | X | |
| Promax | | X | X | X | X | |
| Scanora 3D | X | X | X | X | X | X |
| Somatom (MSCT) | | X | X | X | X | |
| Skyscan (µCT) | X | X | X | X | | X |

CBCT scans were always compared to a reference standard: the gold standard µCT and/or the clinical standard (up to now) MSCT.

The images were analysed from two points of view: segmentation accuracy using the surface and segmentation accuracy using the internal bone structure (trabecular bone). For surface analysis, µCT and MSCT images were both used as a reference.

### 2.1.1 Surface

The reconstructed volumes of the scans were exported as DICOM-images to be segmented using Simplant Pro® by Materialise Dental NV (Haasrode, Belgium). The jaw bone models created were internally filled resulting in a 3D surface model using Mimics® and 3-Matic® by Materialise NV. The last was also used for comparative calculations. The differences in dimension were visualised in a histogram using a standardized range from -2mm to +2mm: expansion in red, shrinkage in blue, approximately corresponding surfaces in green (Figure 1). These same colours were projected on the jaw models. The percentage of surface exceeding -1mm to +1mm range was used to evaluate the reproducibility (Figure 2).

The following samples were used for surface analysis: Maxilla B, Mandible A, Mandible B and Mandible C.

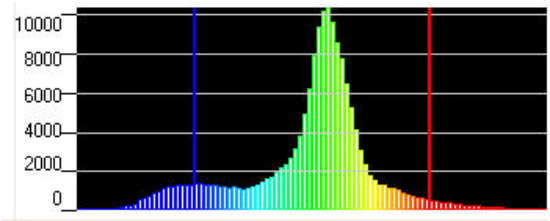



**Figure 1:** Example of histogram analysis: clear peak around 0-value. Red means enlargement, blue shrinkage compared to the reference standard. X-axis: Deviation extending from -2mm to 2mm. Blue and red vertical line at ±1 mm. Y-axis: Number of measuring points on the surface with deviation as on X-as.

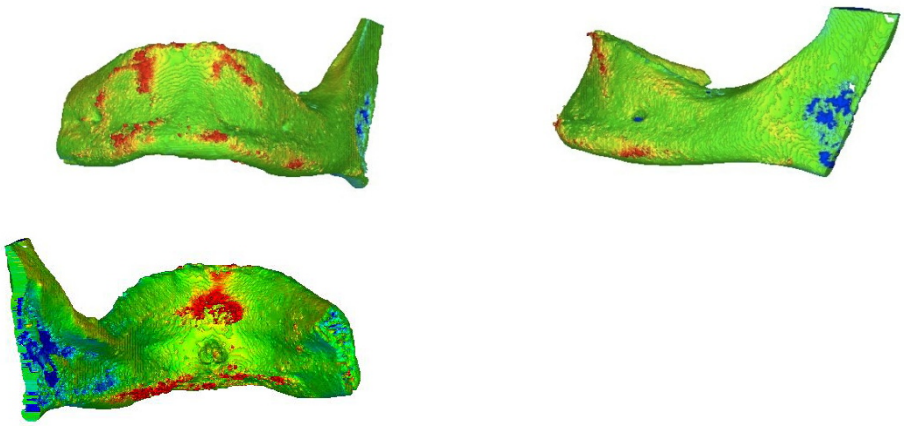


**Figure 2:** Frontal and lateral view of the distance calculation using images of Sirona Galileos 3D to match MSCT images. In the frontal region, we can see an enlargement, at the ramus part of the cortical surface is missing.

### 2.1.2 Trabecular bone

Description of the internal structure was made in analogy to histological analysis but with µCT as a gold standard. µCT is tomographic equipment that delivers images at µm-level resolution. It can be considered the "gold standard" because of its high resolution: the images contain the 'geometrical truth' about the samples. The advantage of using µCT instead of histology is time, cost and the fact that the description can be done in a non-destructive way, keeping the samples available for further scanning if necessary (new devices, repeated scans). (See Next Steps section).

## 2.2 Linear accuracy

For linear accuracy, three skull phantoms were scanned at several parameters with an I-Cat CBCT machine. An observer study on these images has been set up. Five observers will measure the distance from the cemento-enamel junction of the skull teeth to the alveolar bone crest. The gold standard is provided by direct measurements on the skulls. (See Next Steps section)

## 2.3 Diagnostic accuracy *in vitro*

For diagnostic accuracy *in vitro*, observer studies were also performed. Both bone lesions and root lesions were simulated and investigated.

### 2.3.1 Root lesions

A paediatric skull with early mixed dentition was obtained from the Department of Anatomy, Hasselt University, Belgium with ethical approval. This skull had an impacted maxillary left canine and therefore allowed a reliable simulation of this clinical situation. Simulated root resorption cavities were created in 8 extracted human maxillary left lateral incisors by the sequential use of ISO 160 µm diameter round burs in the distopalatal root surface. Cavities of varying depths were drilled in the middle or apical thirds of each tooth root according to three set-ups: slight (150, 200 and 250 µm), moderate (600 and 1000 µm), and severe (1500, 2000, and 3000 µm) resorption. The lateral incisors, two intact teeth, were repositioned individually in the alveolus of the paediatric skull with approximal contacts to the impacted maxillary left canine.

Six sets of CBCT images were obtained by using the Scanora 3D® (Soredex, Finland), Accuitomo® (J. Morita, Japan), Galileos® (Sirona, Germany), Kodak 9000® (IMTEC/Kodak dental System, USA), ProMax® (Planmeca, Finland) and Picasso® (EWoo Technology, Korea) for each tooth setup.

Six observers (postgraduate students in orthodontics as well as postgraduate research students in the oral imaging center) examined the sets of images for the presence of resorption cavities. The observers needed to assess the image quality, canine location, contact between canine and lateral incisors, severity (if present) of lateral incisor resorption and the location of the resorption.

### 2.3.2 Bone lesions

An *in vitro* model was used to simulate the bone lesions. A human dry edentulous cadaver skull was used for this study, after ethical approval was obtained from the commission of medical ethics of the University Hospitals, K.U.Leuven. The mandible was cut into five blocks. To establish a gold standard, simulated defects of known width and depth were prepared with an ISO 160 µm diameter round bur. Defects were created using a vertical milling machine. In every section, experimental lesions of various types were made with a round bur. Holes were drilled into each sections with a depth of 150 µm, 175 µm, 200 µm, 250 µm and 300 µm. The lesions were created in the trabecular bone, the cortical bone and in the cortico-trabecular area.

Six sets of CBCT images were obtained using the Scanora 3D® (Soredex, Finland), Accuitomo® (J. Morita, Japan), Galileos® (Sirona, Germany), Kodak 9000® (IMTEC/Kodak dental System, USA), ProMax® (Planmeca, Finland) and Picasso® (EWoo Technology, Korea).

Six observers (five dentists and one student), evaluated all digital images. The images from the different CBCT systems were analyzed and performed with at least a one week interval between each session. The observers were asked to make rankings on the presence or absence of lesions at three sites (cortex, trabecular bone and in the cortico-trabecular area) on a 5-point probability scale. The lesions seen in the CBCT were pointed out on schematic images showing the bone blocks separately.

# 3. The Results

## 3.1 Segmentation accuracy

### 3.1.1 Surface

Based on the histogram analysis for each CBCT imaging parameter, the optimal parameter for scanning was determined. Based on these parameter comparisons, all devices could be compared, using their optimal settings. Results for all scanners are provided in Appendix 1.

Optimal settings when comparing the surface to the surface determined with MSCT were:

- Sirona Galileos 3D: 85kV 21mA (14s scanning time)
- Soredex Scanora 3D: 85kV 10mA (20s scanning time)
- Kodak 9000 3D: All settings gave comparable results
- Morita Veraviewepocs 3D: 75kV 4mA (17.5s scanning time)
- Picasso Trio: 75kV 5mA (20s scanning time)
- Morita 3D Accuitomo: 70kV 4mA (17.5s scanning time)

### 3.1.2 Trabecular bone

The results for this study are not yet consolidated (See Next Steps section).

## 3.2 Linear accuracy

See Next Steps section

## 3.3 Diagnostic accuracy *in vitro*

### 3.3.1 Root lesions

The observer study was performed for two devices. The rest of the observer studies is currently ongoing (See Next Steps).

The percentages of correct assessment for all samples (including no resorption samples) with respect to resorption, degree of resorption, location of resorption, contact relationship, canine position are shown below.

| **Assessment** | **Accuitomo** | **Scanora 3D** |
|---|---|---|
| Image quality | Next step of research | |
| Canine location | 69% | 65% |
| Contact relationship | 73% | 84% |
| Presence of resorption | 91% | 90% |
| Degree of resorption | 40% | 41% |
| Location of resorption | 60% | 61% |
| Agreement | 19% | 28% |

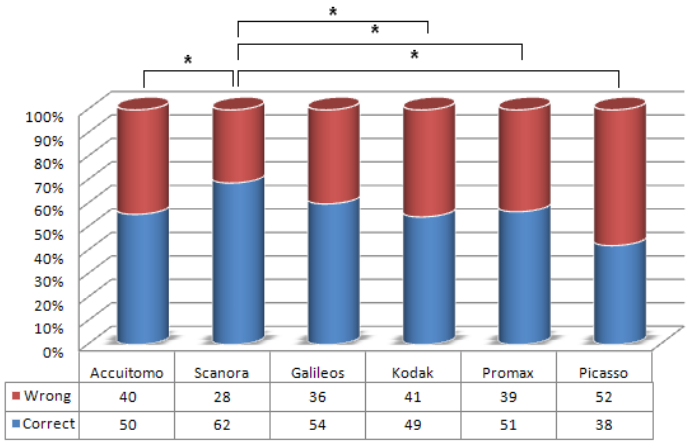
The sensitivity was 95% for Accuitomo CBCT and 94% for Scanora CBCT, and the specificity was 75% for both CBCT methods.

Sensitivity and specificity are measures of diagnostic accuracy: the sensitivity measures the ability of a test to detect a positive case (here: tooth with a lesion). Specificity measures the ability of a test to deny negative cases (here: intact tooth).

The differences in correct detection of root resorption for all resorption sizes (including teeth without resorption) were not significantly different between the Accuitomo and Scanora CBCT systems. Significant differences were found between both CBCT systems for correct classification of degree of resorption in the categories of slight and severe resorption. A significant Spearman correlation were observed between the agreement rate for the location of resorption and cavity size (p=0.01) when using the Accuitomo CBCT (Spearman rho=0.83). In addition, a significant relationship was found between agreement and size (p=0.02) for the Scanora CBCT (Spearman rho=0.78).

### 3.3.2 Bone lesions

This section first addressed the overall visibility of lesions, independent of their size and was therefore an evaluation of the CBCT systems. The scores collected from the observers were visualized in a graph (Figure 3) including frequency table (wrong-correct). A correct lesion identification and localisation was scored as 1 (correct); a false answer as 0 (wrong).




| | Accuitomo | Scanora | Galileos | Kodak | Promax | Picasso |
|---|---|---|---|---|---|---|
| Wrong | 40 | 28 | 36 | 41 | 39 | 52 |
| Correct | 50 | 62 | 54 | 49 | 51 | 38 |

**Figure 3:** Lesion detection and localisation for each device (* indicates significant difference $p < 0.05$)

The graph demonstrated a more correct detection of the bone lesions with the Scanora-images. Wilcoxon Matched Pairs Test, a non-parametric test to measure the difference between two samples, was performed between the different equipment scores for the detection of the simulated bone lesions. The Scanora had a significantly ($p \leq 0.05$) higher detection level compared with all the other CBCTs except for the Galileos, where no significant difference was found.

The second question addressed the visibility of the bone lesions according to their size. Holes were drilled with a different depth in five different slices. The scores of the observers were collected. Wilcoxon Matched Pairs Test was performed to

compare the detection of bone lesions of different sizes. The diagnostic accuracy was significantly higher for bone lesions with depths of 250 µm and 300 µm.

As a third analysis, the visibility of bone lesions of different sizes for the different CBCT devices was evaluated separately. Results are shown in Appendix 2. For the different CBCT systems, minimal detection threshold ranged from 175 µm to 250 µm. More specificly, for the Scanora 3D® the threshold was 175 µm. For ProMax 3D®, Kodak 9000®3D, Picasso® and 3D Accuitomo® it was 250 µm.

The fourth question addressed the detection of the bone lesions in the different regions: trabecular, cortico-trabecular and cortical area. The detection of the bone lesions in cortical area was significantly better than the detection in trabecular bone and in the cortico-trabecular area. Detection of the cortico-trabecular lesions was not significantly different compared with the detection of the trabecular lesions. Of the defects that perforated the cortex 72,2% were detected. The score dropped to 52,2% for the trabecular region and dropped to 44,4% for the defects in the cortico-trabecular area.

# 4. Conclusions

## 4.1 Segmentation accuracy

### 4.1.1 Surface

From this study, we could define the most convenient parameter settings to obtain optimal segmentation accuracy (See Results). Moreover, we defined the Picasso-based model to be best fitting the MSCT (clinical reference) images. Further comparative analysis will be performed using µCT as a gold standard.

### 4.1.2 Trabecular bone

See Next Steps section

## 4.2 Linear accuracy

See Next Steps section

## 4.3 Diagnostic accuracy *in vitro*

### 4.3.1 Root lesions

The results of this in vitro study suggest that the CBCT technique could be a reliable diagnostic tool for detecting canine impaction and associated lateral incisor root resorption. Lesions as small as 200 µm could be easily diagnosed. The thin slices and 3D information might increase the detection rate. The need for additional conventional panoramic radiographs is unnecessary, thus additional X-ray exposure of the patient may be avoided. In addition, the radiation dose of CBCT is significantly lower as compared to conventional CT, and the typical overlap of dental structures on panoramic radiography was not observed.

Since much work is needed to demonstrate the added value of CBCT in routine orthodontic cases of root resorption, similar comparative studies will be performed on patients with canine impaction to demonstrate the canine location and determine whether the accuracy of CBCT remains high. Further studies including randomized controlled prospective studies should also be performed to determine the clinical relevance and clinical threshold for symptomatic resorption.

We have not yet made a device-based comparison on accuracy. The observer studies for the remaining devices are ongoing (See Next Steps section).

### 4.3.2 Bone lesions

A number of defects remained undiagnosed in the CBCT images. This number differed depending on the CBCT scanners and on the size of the lesions. False negative defects were more frequently reported than false positive defects for CBCT radiographs. The result of this study shows that none of the created bone lesions could be identified on the intraoral radiographs. For the settings used in the current study, Scanora 3D® performed best, making the identification of lesions sized 175µm possible.

Further research should address less well-defined lesions, e.g. created using acid. This type of lesion might simulate clinical reality better. Furthermore, creating lesions surrounding the root apex should be performed in future research of this type. In the current project, this was achieved in workpackage 4.2, the animal study, but it should now be continued in human material.

# 5. Next steps

An overview of the work in progress and expected delivery dates can be found in the table below:

| Work section | Task | Expected delivery |
|---|---|---|
| Segmentation accuracy<br>Surface analysis | Data analysis using µCT | March 2010 |
| Segmentation accuracy<br>Trabecular bone analysis | Data analysis | March 2010 |
| Linear accuracy | Observers' analyses | January 2010 |
| Linear accuracy | Data analysis | February 2010 |
| Diagnostic accuracy<br>Root lesions | Observers' analyses | December 2009 |
| Diagnostic accuracy<br>Root lesions | Data analysis | April 2010 |

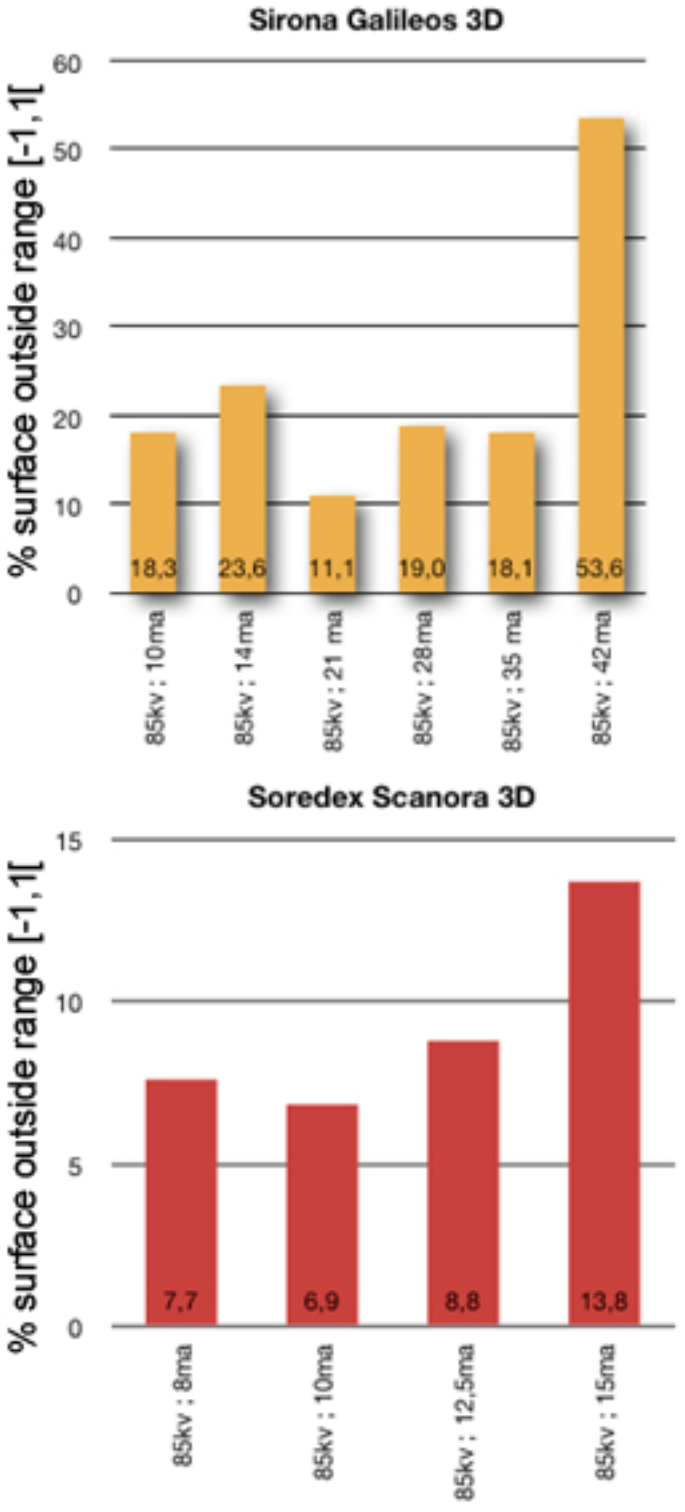
We expected the analysis using µCT images to be completed by now. The reasons for the delay in our centre are the practical problems arising during µCT scanning. We contacted Skyscan (Kontich, Belgium) directly, to have access to the latest µCT-model. The major advantage of having access to this was the larger field of view, compared to other models of µCT. However, since the model was new, there were several sessions necessary, not only to optimise scan settings, but also to optimise reconstruction algorithms, which were still being developed at the time of our cooperation. Apart from that, since the scanning of one jaw took several hours (up to five hours), there was a permanent risk of movement artefacts, making repeated scans necessary on several occasions. Third, the presence of soft tissue made the µCT scans even more challenging, since these tissues were shrinking due to the scanning process. Last, our contact person at the company, and the expert for this specific type of scans and the reconstruction process thereof fell sick. This caused a substantial delay in the scanning procedures.

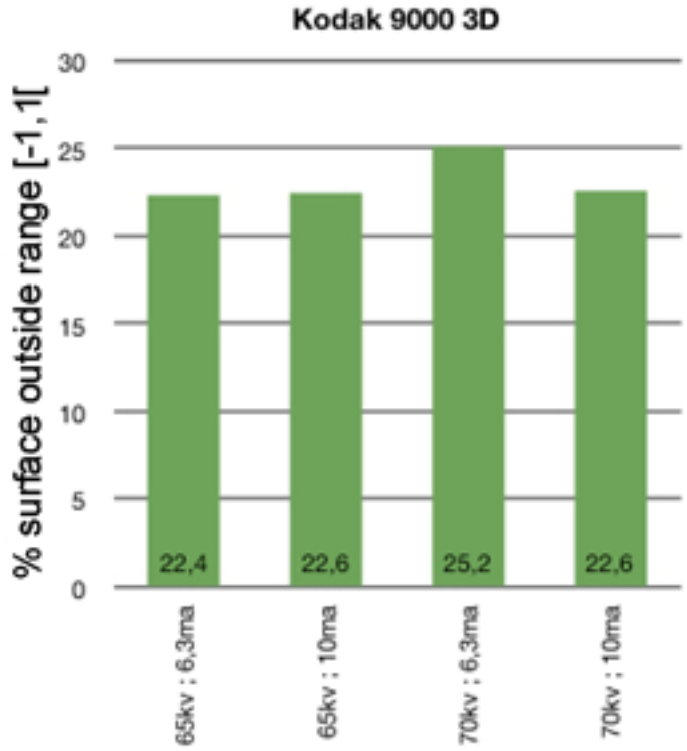
However, we feel confident these issues will not compromise the delivery of the report of the in vitro section of WP4, to be delivered at month 28.

# Appendix 1

Results for segmentation accuracy for all scanners and parameters. One rectangle showing the least deviation from the reference (showing 'optimal setting') is clearly visible.

X-axis: imaging parameter; Y-axis: % deviation over 1 mm.

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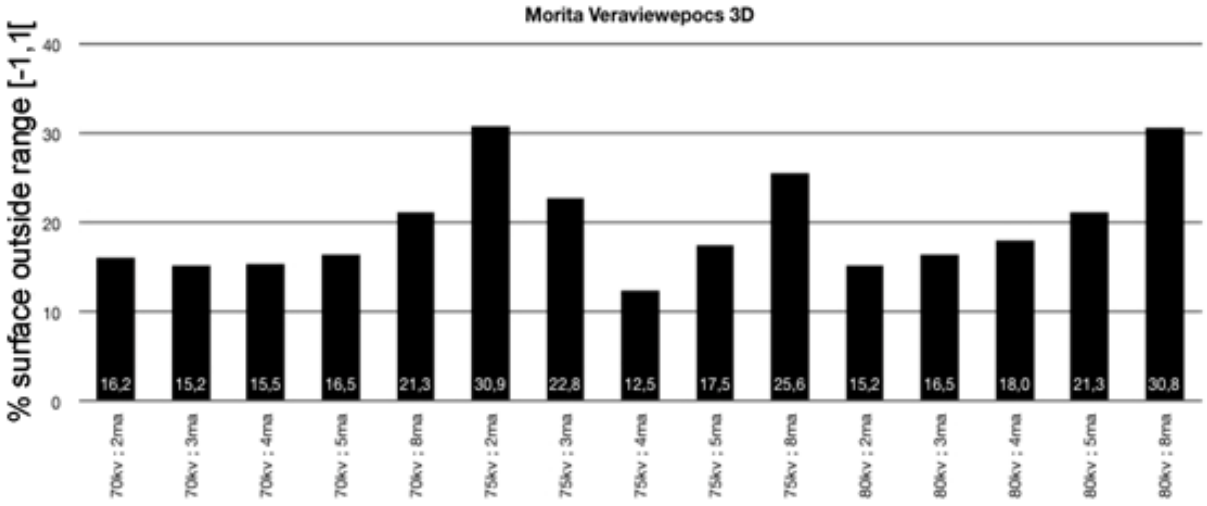
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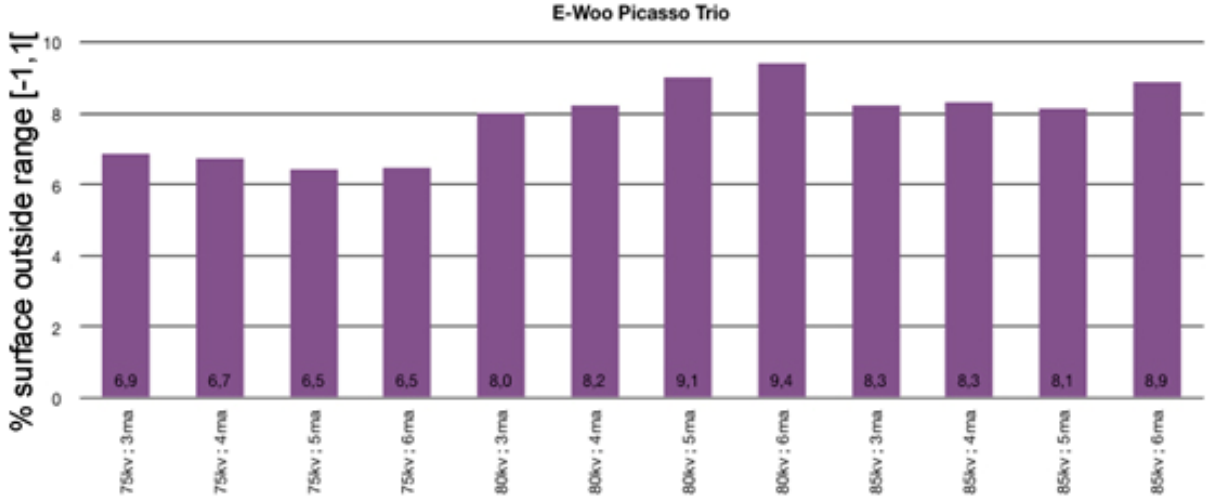
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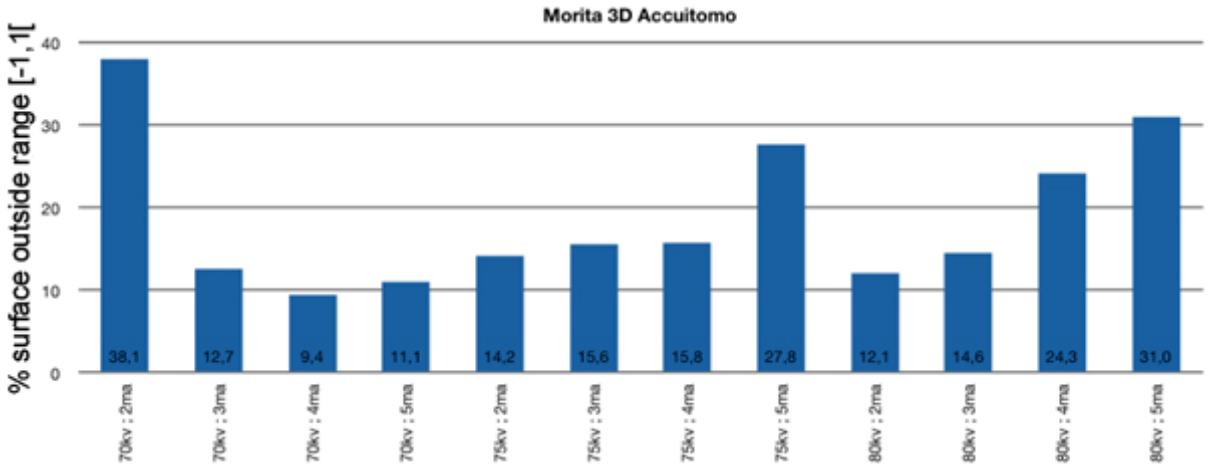
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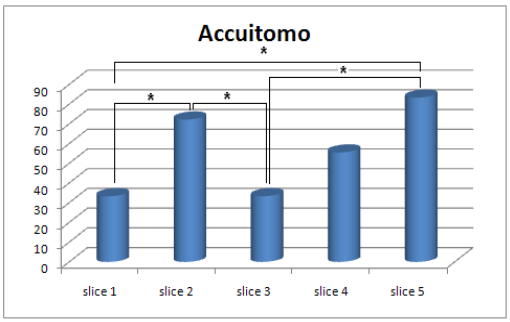
75kv : 4ma
75kv : 5ma
80kv : 2ma
80kv : 3ma
80kv : 4ma
80kv : 5ma

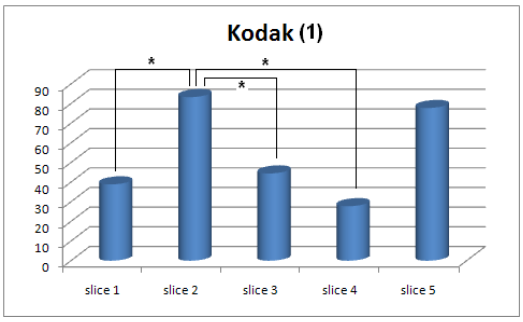
# Appendix 2

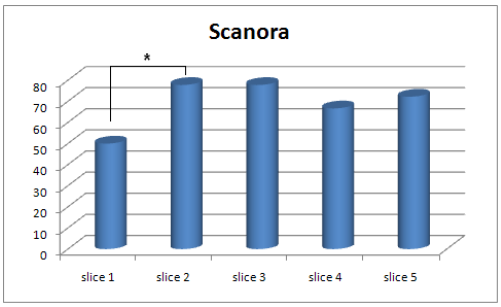
Detection of bone lesions for the different CBCT and bone blocks.

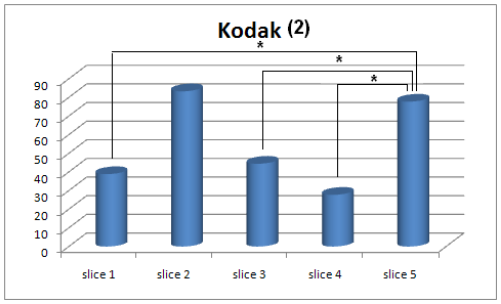
Legend of the tables: X-axis: Slice 1: 150 µm; Slice 2: 300 µm; Slice 3: 175µm; Slice 4: 200µm; Slice 5: 250 µm. Y-axis: Percentage of the lesions that is detected.

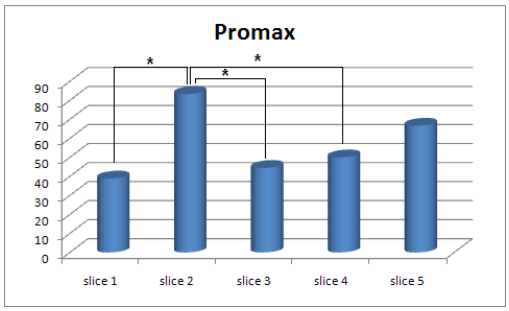
*: significant difference according to Wilcoxon test. Wilcoxon test of paired samples is a non-parametric test to measure the difference between 2 samples, in this case between the results for different lesion sizes.

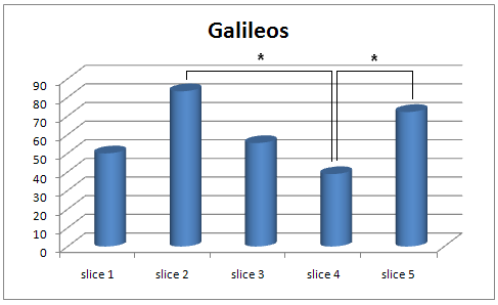


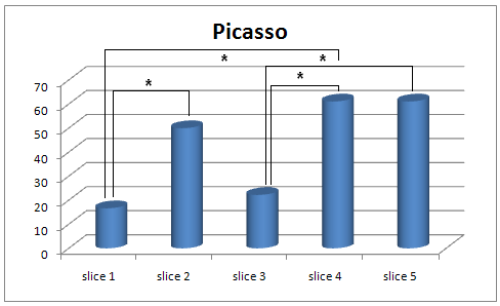

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