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A retrospective comparison of organ dose and effective dose in percutaneous vertebroplasty performed under CT guidance or using a fixed C-arm with a flat-panel detector

Joël Greffier^{1, 2,*}, Aymeric Hamard¹, Laure Berny¹, Fehmi Snene¹, Romain Perolat¹, Ahmed Larbi³, Pierre Viala¹, Djamel Dabli^{1, 2}, and Jean Paul Beregi¹.

1. Department of Medical Imaging, Nîmes University Hospital, Univ Montpellier, Medical Imaging Group Nîmes, EA 2992, France

2. Department of Medical Physics, CHU Nîmes, Univ Montpellier, Montpellier, France

3. ISERIS Imagerie médicale, 25 rue de Clémentville, Montpellier, France

* Corresponding author: Joël Greffier, CHU de Nîmes, Medical Imaging Group Nîmes, EA 2415,

Bd du Pr Robert Debré, 30029 Nîmes Cedex 9; Tel: +33.466.683.309; Fax: +33.466.683.308;

e-mail: joel.greffier@chu-nimes.fr

A retrospective comparison of organ dose and effective dose in percutaneous vertebroplasty performed under CT guidance or using a fixed C-arm with a flat-panel detector

Abstract:

Purpose:

To compare the organ-dose and effective-dose (E) delivered to the patient during percutaneous vertebroplasty (PVP) of one thoracic or lumbar vertebra performed under CT guidance or using a fixed C-arm.

Methods:

Consecutive adult patients undergoing PVP of one vertebra under CT-guidance, with optimized protocol and training of physicians, or using a fixed C-arm were retrospectively included from January 2016 to June 2017. Organ-doses were computed on 16 organs using CT Expo 2.4 software for the CT procedures and PCXMC 2.0 for the fixed C-arm procedures. E was also computed with both software. Dosimetric values per anatomic locations for all procedures were compared using the paired Mann-Whitney-Wilcoxon test.

Results:

In total, 73 patients were analysed (27 men and 46 women, mean age 78 ± 10 years) among whom 35 (48%) underwent PVP under CT guidance and 38 (52%) PVP using a fixed C-arm. The median E was 11.31 [6.54; 15.82] mSv for all PVPs performed under CT guidance and 5.77 [3.51; 8.11] mSv for fixed C-arm and the differences was significant ($p < 0.001$). For lumbar PVP, the organ doses of stomach, liver and colon were significantly higher with CT-scan than with the fixed C-arm: 113% ($p = 0.02$); 33% ($p = 0.032$) and 423% ($p = 0.003$), respectively. For thoracic PVP, the lung organ dose was significantly higher with CT-scan than with the fixed C-arm (188%; $p < 0.001$) and the oesophagus organ doses were not significantly different.

Conclusion:

This study showed that the E and the organ dose on directly exposed organs were both higher for PVP performed under CT-guidance than with the fixed C-arm.

Keywords:

Vertebroplasty; Multidetector computed tomography; Interventional radiology; Organ dose; Effective dose.

Abbreviations:

AK: Air Kerma

CTDI_{vol}: Volume CT dose index

DAP: Dose area product

DLP: Dose length product

E: Effective dose

PVP: Percutaneous vertebroplasty

Introduction

Percutaneous vertebroplasty (PVP) is a widespread micro-invasive technique first described for the treatment of aggressive haemangioma [1]. It is now also performed for painful osteoporotic vertebral compression fractures and painful metastases [1-3]. PVP consists in percutaneously injection of polymethyl methacrylate into the vertebral body. To follow the path of the needle and check the cement injection, PVP is performed under fluoroscopic control using a mobile or fixed C-arm or under CT-guidance [4-6]. The CT scan provides an excellent spatial resolution and contrast resolution, optimizes needle tracking and leads to a more accurate needle positioning. However, the choice of the imaging system is usually based on the operator's preference according to his/her experience and training and often also depends on the availability of the equipment. In this context, in our institution the fixed C-arm is often chosen for lumbar PVP, whereas CT-guidance is preferred for thoracic PVP.

The type of acquisition and therefore the dose distribution is different between these two imaging systems. With the fixed C-arm, this procedure is performed using 2D planar acquisitions in fluoroscopy and/or fluorography and 3D volume acquisition (Cone Beam CT; CBCT). Using the CT scan, 3D volume acquisitions are made in spiral, fluoroscopic or sequential mode. Since the dose delivered to the organs depends on the imaging technique, differences are expected between 2D and 3D acquisitions. 2D planar acquisitions will tend to expose organs located close to the X-ray tube, whereas for 3D acquisition all organs at the same height in the body are exposed. Otherwise, compared to the CT scan, CBCT was performed with only a partial rotation thus sparing the organs that are not directly exposed by the rotating beam.

Although many studies use organ dose and effective dose to assess the dose delivered to the patient with each of these systems [7-9], to our knowledge there has been no study comparing the dose delivered to the patient in PVP performed under CT guidance or with the fixed C-arm.

The purpose of the present study was to calculate and compare the organ-dose and effective-dose delivered to the patient during thoracic or lumbar PVP performed under CT guidance or using a fixed C-arm.

Materials and methods

Study patients and parameters

This retrospective monocentric study was approved by our institutional review board (20.06.02), and declared to the French National Commission for Computing and Liberties, CNIL (2203388 v 0). The requirement for written informed consent was waived, but a letter of non-opposition was sent to all patients included to inform them of the study and ensure that they did not object to participating in it. No patient informed us of their opposition to his/her inclusion in the study.

Data were acquired for all consecutive adult participants undergoing PVP of one thoracic or lumbar vertebra under CT-guidance or using a fixed C-arm at the Nîmes University Hospital from January 2016 to June 2017 (**Table 1**). The choice of the modality for each patient was only defined according to the availability and the vacations planned therein. PVPs were performed during dedicated vacations on Wednesday mornings on fixed C-arm and on Tuesday mornings for CT. PVPs were performed by four operators (AL, PV, FS, RP) with a 7 to 12-year experience in osteoarticular imaging. Before the study, they were trained to adapt their interventional practice to all the acquisition modes available on CT scan.

For all patients, clinical and dosimetric data were collected on the examination report, the dose report and the images directly from the Picture Archiving and Communication System (PACS) between September 2019 and April 2020. All patients for whom at least one of the items mentioned in the **Table 2** could not be collected were excluded.

X-ray sources

All procedures on the fixed C-arm were performed with an Allura Xper FD 20 (Philips Healthcare) equipped with a flat-panel detector. Three type of events were performed during PVP: fluoroscopy events (frontal and lateral angulations), direct radiography (only one image per event) and cone beam CT (CBCT), all taken into account in the dosimetry calculations. CBCT acquisition was used mostly at the end of the procedure for all patients and occasionally during the procedure for some patients.

All procedures under CT guidance were performed on a Somatom Definition AS+ (Siemens Healthineers) CT system equipped with an interventional module with helical (i-spiral), sequential (i-sequence) and fluoroscopy (not used in the present study) modes. For half of the patients, a conventional helical control CT acquisition was performed at the end of the procedure with the same acquisition parameters as for i-spiral acquisition, available with the interventional module. All helical (conventional and i-spiral) and sequential (i-sequence) acquisitions were taken into account in the dosimetry calculations.

Details about the parameters selected for each acquisition mode on both systems are depicted in **Table 1**.

Dosimetry

The organ dose and effective dose (E) were calculated for all procedures using the CT Expo software (v2.4) for procedures performed under CT guidance [10] and PCXMC software (v2.0) for procedures performed using a fixed C-arm [11].

For each software, organ doses were computed for 8 of the most radiosensitive organs listed in the ICRP 103 Table [12]: Thyroid, Oesophagus, Lungs, Stomach, Liver, Colon, Bone marrow and Skin. These organs were selected because they were potentially the most exposed to X-rays beam during thoracic or lumbar PVP. The organ doses were also computed for 8 other organs (**Supplementary data**).

CT Expo (version 2.4) uses a family of mathematical phantoms with a fixed height and weight (170 cm and 70 kg for ADAM and 160 cm and 60 kg for EVA). ADAM was used for men patients and EVA for women patients. The computation of the organ dose and effective dose were based on the methodology developed by Stamm and Nagel [10]. For each patient and each acquisition, the anatomical exposure area was manually placed, based on anatomical landmarks in the CT images. The area length was defined using the Z-position of the first and last CT images. Then, after CT system selection, the tube voltage, tube current, beam collimation and reconstructed slice thickness were entered. For helical acquisitions, the table feed per rotation was taken into account and the spiral mode

and the longitudinal dose modulation were selected if the tube current modulation was used. For each acquisition, the $CTDI_{vol}$ and DLP computed by the software were retrieved and compared to those of the dose report. For each acquisition, the organs and effective doses were recovered and added to obtain total values per procedure.

PCXMC (version 2.0) uses size-adjustable hermaphrodite phantoms to compute organ dose and effective dose based on the methodology previously defined [11; 13]. To improve the comparison between organ and effective doses computed between both software, we made the choice to use standard-sized male and female adult phantoms similar to Adam and Eva of CT-Expo. For all radiography acquisitions, the Source to Skin Distance (SSD) was calculated according to the following formula for frontal incidence [14; 15]:

$$SSD_{frontal} = Table\ Top\ Vertical\ Position + 81.0\ cm - 106.5\ cm + e_{mattress} \quad (1)$$

where : $e_{mattress}$ correspond to the compressed mattress thickness of 4 cm; 81 cm corresponds to the “Source Object Distance” and 106.5 cm to the “Height of system”. Both parameters are fixed for this system.

For the lateral incidence, the half-patient width (in X-axis) was deduced from the SSD as to take into account the SSD decrease for this incidence (Formula 2):

$$SSD_{lateral} = TableTopVerticalPosition + 81\ cm - 106.5\ cm + e_{mattress} - X_{1/2} \quad (2)$$

$X_{1/2}$: half-patient width measured on PCXMC after entering the patient’s weight and height.

The field size at the patient entrance was computed using the field size at the detector position and applying the inverse square law between the SSD and the Source to Detector Distance (SDD), as follows:

$$Field\ size_{patient\ entrance} = Field\ size_{detector\ position} \times \left(\frac{SSD}{SDD}\right)^2 \quad (3)$$

The patient's position (X_{ref} , Y_{ref} , Z_{ref}) was adjusted according to the anatomical landmarks on the radiography images.

- *Radiography event*

The X-ray spectrum was generated in PCXMC using the tube voltage recorded on the dose report and the total filtration: inherent (2.5 mmAl) and additional (0.1mmCu+ 1mmAl) and the value of DAP of the radiography event was used to generate the organ dose.

- *Fluoroscopy event*

Each fluoroscopy event was not systematically recorded. To take into account the dose delivered during each fluoroscopy event, a simulated fluoroscopy event was defined for each radiography event. The same geometric parameters than for the radiography event were used for each respective simulated fluoroscopy event.

To generate the X-Ray spectrum, a mean value for fluoroscopy tube voltage was calculated from fluoroscopy events recorded for the same incidence: frontal and lateral. The additional filtration defined previously for each incidence was used.

To calculate the organ-dose, the DAP of each simulated fluoroscopy event ($DAP_{fluoro,simulated}$) was calculated by multiplying the total fluoroscopy DAP ($DAP_{fluoro,tot}$) by the ratio of the radiography event DAP ($DAP_{graphy,event}$) associated with the simulated fluoroscopy and the total radiography DAP ($DAP_{graphy,total}$).

$$DAP_{fluoro,simulated} = DAP_{fluoro,tot} \times \frac{DAP_{graphy,event}}{DAP_{graphy,total}} \quad (4)$$

- *CBCT*

For CBCT acquisitions, the beam geometric parameters and patient position used were those of the last lateral radiography acquisition used at the clinic to center the patient before CBCT acquisition. CBCT acquisition was decomposed into 19 acquisitions with 10° steps and the total CBCT DAP was evenly distributed throughout these acquisitions.

Statistical analysis

Statistical analyses were performed using R software version 3.5.1 (R Core Team (2017); R: A language and environment for statistical computing. R Foundation for Statistical Computing). Data are presented as mean (\pm standard deviation) or median [1st quartile; 3rd quartile] according to the variable statistical distribution for the descriptive analyses. For all quantitative data, normality was tested using the Shapiro-Wilk test. The effective dose and organ dose for procedures performed under CT guidance and using a fixed C-arm were compared using the paired Mann-Whitney-Wilcoxon test. A p-value of less than 0.05 was considered significant.

Results

Study patients

During the study period, PVPs were conducted in 184 patients. 80 patients were non included because PVP were performed with more than one vertebra. 31 patients were excluded, because patient images were not available in the PACS (n=19), or because no dosimetric information was available in the dose report or in the DICOM information of the images (n=12) (**Figure 1**).

Finally, a total of 73 patients (27 men (37%) and 46 women (63%)) were included in the analysis (**Table 2**), among whom 35 (48%) underwent PVP under CT guidance and 38 (52%) underwent PVP using a fixed C-arm. The mean age was 78 ± 10 years, and the mean BMI was 26.5 ± 6.0 $\text{kg}\cdot\text{m}^{-2}$.

Fifteen thoracic PVPs and 20 lumbar PVPs were performed under CT guidance, and 16 and 22 using a fixed C-arm, respectively. Similar quantities of injected cement were found depending on the anatomical location and system used (5.2 ± 2.0 ml). PVPs were performed for traumatic fractures in 49 cases (67%), tumoral fractures in 21 cases (29%) and osteoporotic fractures in 3 cases (4%).

Dosimetric indicators and effective doses

For PVPs performed using a fixed C-arm, Dose Area Product (DAP), Air Kerma (AK) and E values tend to increase when PVP involves the lumbar spine compared to the thoracic spine but the differences were not significant ($p=0.10$; $p=0.20$; $p=0.39$, respectively). For thoracic spine, on average 31% of the total DAP was for fluoroscopy events, 16% for radiography events (47% for frontal and 53% for lateral incidences) and 53% for CBCT acquisition; for lumbar spine, the respective fractions were 28%, 17% (42% and 58%), and 55% respectively (**Figure 2**).

Similar values for CTDI_{vol} ($p=0.69$), Dose Length Product (DLP; $p=0.91$) and E ($p=0.91$) were found for thoracic and lumbar PVPs performed under CT guidance (**Table 4**). The explored lengths were greater for the thoracic spine than for the lumbar spine (26%). For the thoracic spine, on average

62% of the total DLP was for the helical mode, 22% for the sequential mode, 17% for the control CT acquisition; for lumbar spine, the respective fraction were 72%, 14%, and 14% (**Figure 2**).

Effective doses were significantly higher for all PVPs performed under CT guidance than with the fixed C-arm ($p < 0.001$). Significant differences were found between both imaging systems used for thoracic ($p = 0.003$) and lumbar ($p = 0.008$) PVPs.

Organ doses

The median values of all organ doses assessed for thoracic and lumbar spine PVPs according to the X-ray system used are shown in **Table 5**.

For the organs directly exposed by the X-Ray beam during thoracic or lumbar PVPs, the organ doses were significantly higher with CT-scan than with fixed C-arm ($p < 0.05$), except for the oesophagus ($p = 0.626$).

For the abdomen organs partially exposed to the X-ray beam during thoracic PVPs, the organ doses were in the same range for both systems ($p = \text{NS}$). Similar results were found for lungs and thyroid partially exposed during lumbar PVPs. The organ doses were higher with CT scan than with the fixed C-arm but the differences were not significant ($p = \text{NS}$). The opposite pattern was found for the oesophagus where the organ dose was significantly higher with the fixed C-arm than with the CT-scan ($p < 0.001$).

Figure 3 depicts, for the chest and abdominal organs and for each vertebra treated, the normalized organ dose as a function of total AK for fixed C-arm and of cumulated CTDI_{vol} for CT-scan.

Regarding thyroid, for both systems, the organ dose was higher when an upper thoracic spine vertebra (T1 to T4) was treated. This result explained the significant highest organ dose value obtained with the CT-scan compared to the fixed C-arm (**Table 5**). Indeed, the number of cases with treatment of an upper thoracic vertebra under CT scan was more important than with the fixed C-arm (**Table 2**).

For chest organs and with the fixed C-arm, the highest values for normalized organ doses (> 0.3) were found on T8 to T12 vertebrae for the oesophagus and on T5 to T11 for the lungs. With CT scan, the normalized organ doses seem to peak at T6 for both organs. For both systems, the normalized organ doses seem to peak from L1 to L3 for the stomach and from T12 to L3 for the liver. For the colon, the normalized organ doses increased when moving to the lower lumbar vertebrae.

Discussion

For the first time, the effective doses and organ doses delivered to patients undergoing thoracic or lumbar percutaneous vertebroplasty under CT guidance or with a fixed C-arm were compared. Our study showed that the organ and effective doses were higher for PVPs under CT-guidance than using a fixed C-arm. From a dosimetry point of view, PVP should preferentially be performed with the fixed C-arm rather than under CT-guidance.

The effective doses were significantly higher for PVPs performed with the CT scan than with the fixed C-arm for thoracic and lumbar PVPs. On each system, similar E values were found for thoracic and lumbar PVPs. For both software packages used, E was estimated using the tissue weighting factors proposed by the International Commission on Radiological Protection 103 recommendations [12] and the values of dosimetric indicators. The differences in E were therefore directly related to the technical and technological differences between the two systems used (such as tube voltage, tube-current-time product, inherent and additional filtration).

The doses delivered to organs directly exposed to X-rays were higher for PVPs performed with the CT scan than with the fixed C-arm. These differences were significant for all organs, except for the oesophagus directly exposed during thoracic PVPs. For skin and bone marrow, the results should be taken with caution because the dose was averaged over the whole phantom and it probably underestimates the peak skin dose. For organs partially exposed to the primary X-ray beam and exposed to the scattered beam, the results depended on the treated vertebra location. For abdominal organs exposed during thoracic PVP, the organ doses were similar for both systems but increased when lower thoracic vertebrae were treated. This opposite pattern was found for thyroid where organ dose increased as upper thoracic vertebrae were treated. For chest organs exposed during lumbar PVPs, different outcomes were found for lungs and oesophagus. Lungs organ doses were similar for both systems and increased as the upper lumbar vertebrae were treated. However, the oesophagus organ dose was significantly higher with the fixed C-arm than with the CT-scan. This result was related to the smaller exposure area with CT-scan (using shorter sequential and helical acquisitions)

than with the fixed C-arm. In addition, oesophagus being an elongated and partially-exposed and the organ dose being calculated over the whole organ, the greater the partially exposed area is, the greater the dose will be.

The differences in effective dose values and organ doses can be explained by differences in the software used. Indeed, in PCXMC, the effective dose is calculated using size-adjustable hermaphrodite phantoms (with breasts), and the phantom's morphology is adjusted according to the patient's weight and height [11, 13]. Using the CT-Expo software, only two reference mathematical phantoms can be used, a male and a female phantom with fixed height and weight [10]. Differences in morphology between the patient and the phantom used may affect the organ dose and effective dose calculation. With a smaller patient than the selected phantom, the number and volume of exposed organs can be increased, and conversely for a larger patient. To compensate this issue, we used the same phantom weight and height with the two software for men and women patients. In addition, using PCXMC software, we defined many assumptions related to the lack of data sent by the fixed C-arm. First, as fluoroscopy data was not systematically recorded, we chose to distribute the fluoroscopy dose according to the radiography dose distribution. Second, we gathered incidences between -15° and 15° in the frontal incidences and between 75° and 105° in the lateral incidences. Third, not having access to the table height, for all lateral events, the spine positioning into the software was done from radiography images of the patient in lateral position available in the PACS. These hypotheses, based on our institution's clinical practice are approximate and may therefore have an impact on the results.

The effective and organ doses were directly related to the values of dosimetric indicators. We found that the dosimetric indicators collected for the two systems were lower than national reference levels (RL) [5, 6]. For PVP performed under CT guidance, our median DLP were lower by -54% than RL [5] and with fixed C-arm, our median DAP was lower by -79% [6]. These low dose levels are related to the implementation of an approach to optimize interventional radiology practices and procedures at our institution. We optimized the CT-scan acquisition and reconstruction parameters and trained operators on which acquisition modes to use (sequential rather than fluoroscopic mode) and on the number and length of the helical acquisitions [4]. For PVPs performed with a fixed C-arm, the

operators were trained to work with the lowest possible fluoroscopy rate and mode and limit the number of radiography images and the fluoroscopy time. Operators only took radiography images with a single radiography event instead of using fluorography with a specific frame rate. The use of CBCT also allowed to reduce the number of radiography events. Having a very large acquisition surface, CBCT strongly affects the total DAP; however the value of the AK of the interventional reference point during its rotation is negligible (< 2 mGy).

Our results showed that the repartition of the dose over the exposed organs was almost equivalent for the two systems. Indeed, using the CT-scan allowed reaching a more evenly dose repartition for superficial and deep organs in an anterior or posterior position. However, with the C-arm, a greater organ exposure in anterior and lateral superficial positions was expected because of the prone position of the patient. 3D-CBCT acquisition, which contributes to 50% of the dose delivered to patients, resulted in a dose repartition quite similar to that of CT-scan.

From a dosimetric point of view, PVPs should preferably be carried out with a fixed C-arm rather than under CT guidance. However, dose is not the unique parameter taken into account to choose between these two modalities. First, both modalities are not available in all centres performing PVPs. The radiologist's experience also represents a factor of choice. Junior radiologists may prefer CT-scan guidance because it may appear safer than the fixed C-arm to control needle-path, whereas a senior may prefer the fixed C-arm guidance because of its smaller time costing especially when controlling polymethyl methacrylate injection into the vertebral body. Anatomic and pathologic considerations are also taken into account. CT-scan may be chosen for upper thoracic gestures, where multiple anatomic structures are not well-differentiated on 2D-projections, for better control of the needle path. It may also be chosen in a tumoral context (secondary lesions) for precise and repeated 3D-images: in this context, accurate needle positioning and safe cement injection is mandatory to avoid dangerous cement leak. Last, radiologists' habits also is a crucial factor of choice, even if one might consider that a musculoskeletal interventional radiologist should be able to perform PVPs on both modalities.

This study has several limitations. As mentioned above, the characteristics of the two software packages and their calculation methods are not identical which affected the results obtained and their comparisons. The lack of data (Radiation Dose Structured Reports) for the C-arm procedures also is a limit. We thus had to make more assumptions for these procedures based on our institutional clinical practice, but this may be different in other institutions. Also, the study lacked efficacy and complications parameters that can be different with the two modalities. The radiologist's confidence in the technique is essential and training should always be recommended as to adapt practices to the pathology and morphology of the patient and lesion. Finally, no measurements were performed on the anthropomorphic phantom to compare calculated and measured organ doses. This could not be done as no phantom with inserts suitable for the use of thermoluminescent or Optically Stimulated Luminescence detectors was available.

Conclusion

This study demonstrated that PVP on one vertebrae led to higher effective doses and organ doses under CT-guidance than with a fixed C-arm. The repartition of the dose over the exposed organs was found equivalent with both CT and fixed C-arm due to CBCT use together with the fixed C-arm. From a dosimetry point of view, our results suggest that use of the fixed C-arm for PVPs may be recommended when possible (compatible patient, presence of trained physician, availability of the equipment). PVPs with CT-guidance should be performed with optimized protocol and careful attention to dose management and dose protection.

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References

- [1] Anselmetti GC, Muto M, Guglielmi G, Masala S. Percutaneous vertebroplasty or kyphoplasty. *Radiol Clin North Am.* 2010;48:641-9.
- [2] Filippiadis DK, Marcia S, Masala S, Deschamps F, Kelekis A. Percutaneous Vertebroplasty and Kyphoplasty: Current Status, New Developments and Old Controversies. *Cardiovasc Intervent Radiol.* 2017;40:1815-23.
- [3] Buchbinder R, Johnston RV, Rischin KJ, Homik J, Jones CA, Golmohammadi K, et al. Percutaneous vertebroplasty for osteoporotic vertebral compression fracture. *Cochrane Database Syst Rev.* 2018;4:CD006349.
- [4] Greffier J, Pereira FR, Viala P, Macri F, Beregi JP, Larbi A. Interventional spine procedures under CT guidance: How to reduce patient radiation dose without compromising the successful outcome of the procedure? *Phys Med.* 2017;35:88-96.
- [5] Greffier J, Ferretti G, Rousseau J, Andreani O, Alonso E, Rauch A, et al. National dose reference levels in computed tomography-guided interventional procedures-a proposal. *Eur Radiol.* 2020;30:5690-701.
- [6] Etard C, Bigand E, Salvat C, Vidal V, Beregi JP, Hornbeck A, et al. Patient dose in interventional radiology: a multicentre study of the most frequent procedures in France. *Eur Radiol.* 2017;27:4281-90.
- [7] Falco MD, Masala S, Stefanini M, Bagala P, Morosetti D, Calabria E, et al. Effective-dose estimation in interventional radiological procedures. *Radiol Phys Technol.* 2018;11:149-55.
- [8] Hwang YS, Tsai HY, Lin YY, Lui KW. Investigations of organ and effective doses of abdominal cone-beam computed tomography during transarterial chemoembolization using Monte Carlo simulation. *BMC Med Imaging.* 2018;18:2.
- [9] Xiong Z, Vijayan S, Rudin S, Bednarek DR. Organ and effective dose reduction for region-of-interest (ROI) CBCT and fluoroscopy. *Proc SPIE Int Soc Opt Eng.* 2017;10132.
- [10] Stamm G, Nagel HD. [CT-expo--a novel program for dose evaluation in CT]. *Rofo.* 2002;174:1570-6.
- [11] Tapiovaara M, Siiskonen T. PCXMC: A PC-based Monte Carlo program for calculating patient doses in medical x-ray examinations Second ed: STUK - Radiation and Nuclear Safety Authority; 2008.
- [12] International Commission on Radiological Protection - The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103 Ann ICRP. 2007;37: 1-332.
- [13] Servomaa A, Tapiovaara M. Organ Dose Calculation in Medical X Ray Examinations by the Program PCXMC. *Radiat Prot Dosimetry.* 1998;80:213-9.

Table 1. Parameters selected for each acquisition mode used during percutaneous vertebroplasties performed with fixed the C-arm or under CT-guidance.

| Imaging system | Acquisition mode/type | Primary angulation | Additional filtration | Beam collimation | Acquisition parameters |
|----------------|--------------------------------------|-----------------------|-----------------------|-----------------------------|------------------------|
| Fixed C-arm | Low pulsed fluoroscopy (7,5 frame/s) | Frontal (0°) | 0.9 mmCu and 1 mmAl | - | - |
| | | Lateral (-90° or 90°) | 0.4 mmCu and 1 mmAl | - | - |
| | Direct radiography | Frontal and lateral | 0.1 mmCu and 0.2 mmAl | - | - |
| | Cone beam CT | From -90° to 90° | 0.9 mmCu and 1 mmAl | - | - |
| CT-scan | i-spiral | - | - | 64 x 0.6 mm | 100 kVp and 200 mAs |
| | i-sequence | - | - | 64 x 0.6 mm and 12 x 1.2 mm | 80 kVp and 60 mAs |

Footnote: For the CT-scan, the tube current modulation system was activated for the i-spiral but disabled for the i-sequence. Tube voltage was also adapted according to the patient's morphology. Many years before the study, acquisition parameters of the CT scan were optimized to improve the image quality for interventional procedures.

Table 2. Study patients

| Modality | Anatomical location | Patients | Age (years) | Sex (M/F) | BMI (kg/m ²) | Clinical indication (fracture type) | Vertebrae treated | Quantity of cement injected (ml) |
|-------------|---------------------|----------|-------------|-----------|--------------------------|---|---|----------------------------------|
| CT scan | Thoracic spine | 15 | 74.4 ± 10.1 | 8/7 | 26.8 ± 6.7 | Tumoral (n:5); Traumatic (n:10) | T2 (n:1); T4 (n:1); T5 (n:1); T6 (n:1); T8 (n:2); T9 (n:2); T10 (n:1); T11 (n:5); T12 (n:1) | 4.6 ± 2.0 |
| | Lumbar spine | 20 | 76.0 ± 11.1 | 3/17 | 27.3 ± 5.7 | Tumoral (n:10); Traumatic (n:10) | L1 (n:5); L2 (n:5); L3 (n:3); L4 (n:5); L5 (n:2) | 4.9 ± 1.8 |
| | All | 35 | 75.3 ± 10.5 | 11/24 | 27.1 ± 5.9 | Tumoral (n:15); Traumatic (n:20) | - | 4.7 ± 1.9 |
| Fixed C-arm | Thoracic spine | 16 | 81.3 ± 9.3 | 4/12 | 28.4 ± 8.9 | Tumoral (n:2); Osteoporotic (n:2); Traumatic (n:12) | T5 (n:2); T6 (n:1); T8 (n:1); T10 (n:3); T11 (n:2); T12 (n:7) | 5.3 ± 1.8 |
| | Lumbar spine | 22 | 78.9 ± 8.5 | 12/10 | 24.8 ± 3.7 | Tumoral (n:4); Osteoporotic (n:1); Traumatic (n:17) | L1 (n:5); L2 (n:7); L3 (n:4); L4 (n:4); L5 (n:2) | 5.9 ± 2.2 |
| | All | 38 | 79.9 ± 8.8 | 16/22 | 26.0 ± 6.1 | Tumoral (n:6); Osteoporotic (n:3); Traumatic (n:29) | - | 5.6 ± 2.0 |

BMI: Body mass index; L: Lumbar vertebra; T: Thoracic vertebra.

Table 3. Clinical and dosimetric data

| Clinical data | Dosimetric data | |
|---|---|---|
| | Fixed C-arm | CT-scan |
| Patient's weight and height, clinical indication for percutaneous vertebroplasty, the fracture type to be treated, the amount of cement injected. | <p>For each radiography event (direct or Cone Beam CT): tube voltage, additional filtration, primary and secondary angulation, source to detector distance, Air Kerma and Dose Area Product Field size at the detector position and the table top vertical position</p> <p>For each fluoroscopy event: Dose Area Product and fluoroscopic time</p> | <p>For each type of CT acquisition: tube voltage, tube-current-time product, rotation time, pitch factor, CTDI_{vol}, Dose Length Product and explored length</p> |

Footnote: For the fixed C-arm, the field size at the detector position and the table top vertical position of each radiography event was defined directly in the image DICOM information available in the PACS. For the CT-scan, the length of each CT acquisition was defined directly on images available in the PACS.

Table 4. Dosimetric indicators and effective dose for percutaneous vertebroplasty under CT guidance or with a fixed C-arm

| | | Thoracic spine | Lumbar spine | All |
|-------------|-------------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| CT scan | DLP (mGy.cm) | 514 (361; 723) | 562 (317; 780) | 526 (325; 789) |
| | Cumulated CTDI _{vol} (mGy) | 66.1 (53.9; 81.0) | 62.7 (51.1; 119.1) | 65.5 (50.5; 95.9) |
| | Length (cm) | 7.7 (6.4; 9.5) | 6.1 (5.2; 9.0) | 7.0 (5.4; 9.0) |
| | <i>E (mSv)</i> | <i>11.31 (7.25; 15.82)</i> | <i>11.24 (6.48; 14.99)</i> | <i>11.31 (6.54; 15.82)</i> |
| Fixed C-arm | DAP (mGy.cm ²) | 9351 (7630; 13330) | 14443 (10338; 19846) | 12824 (8508; 18451) |
| | AK (mGy) | 54.3 (31.7; 76.8) | 66.6 (52.2; 112.0) | 64.5 (45.0; 102.8) |
| | Area (cm ²) | 185 (146; 244) | 202 (137; 244) | 190 (137; 245) |
| | Fluoroscopy time (min) | 1.3 (1.1; 1.6) | 1.3 (1.0; 1.7) | 1.3 (1.0; 1.6) |
| | <i>E (mSv)</i> | <i>4.96 (3.70; 6.58)</i> | <i>7.40 (3.33; 9.41)</i> | <i>5.58 (3.33; 8.71)</i> |

AK: Air Kerma; DAP: Dose area product; DLP: Dose length product; E: Effective dose. Values are expressed in median (1st quartile; 3rd quartile)

Table 5. Organ doses (mGy) computed on 8 radiosensitive organs for percutaneous vertebroplasty under CT guidance or with a fixed C-arm

| Organs | Thoracic spine | | | Lumbar Spine | | |
|-------------|-----------------------------|----------------------------|---------|-----------------------------|-----------------------------|---------|
| | CT scan | Fixed C-arm | p-value | CT scan | Fixed C-arm | p-value |
| Thyroid | 1.18 (0.58; 10.67) | 0.25 (0.15; 0.6) | p<0.001 | <i>0.08 (0.02; 0.29)</i> | <i>0.04 (0.02; 0.13)</i> | 0.489 |
| Oesophagus | 14.61 (4.64; 43.69) | 9.94 (8.94; 15.22) | 0.626 | <i>0.51 (0.24; 1.80)</i> | <i>4.09 (1.70; 9.13)</i> | p<0.001 |
| Lungs | 30.16 (21.27; 32.41) | 13.26 (8.13; 14.83) | p<0.001 | <i>2.71 (1.43; 11.60)</i> | <i>2.02 (0.83; 5.84)</i> | 0.180 |
| Stomach | <i>6.27 (2.60; 10.98)</i> | <i>6.72 (0.73; 11.65)</i> | 0.654 | 31.60 (23.92; 44.72) | 16.07 (9.49; 29.95) | 0.002 |
| Liver | <i>9.60 (3.90; 15.95)</i> | <i>12.81 (1.82; 16.99)</i> | 0.988 | 27.26 (21.43; 39.15) | 22.52 (12.42; 31.78) | 0.099 |
| Colon | <i>0.43 (0.20; 0.85)</i> | <i>0.39 (0.06; 0.61)</i> | 0.446 | 19.23 (6.23; 34.43) | 4.05 (1.89; 8.64) | 0.002 |
| Bone marrow | 5.67 (4.12; 8.54) | 3.33 (2.59; 4.09) | 0.009 | 5.52 (3.03; 7.82) | 3.34 (1.49; 5.21) | 0.010 |
| Skin | 5.48 (4.33; 8.86) | 1.57 (1.27; 2.01) | p<0.001 | 6.30 (3.59; 8.92) | 2.33 (0.90; 3.09) | p<0.001 |

Values are expressed in medians (1st quartile; 3rd quartile). A p-value lower than 0.05 was considered significant.

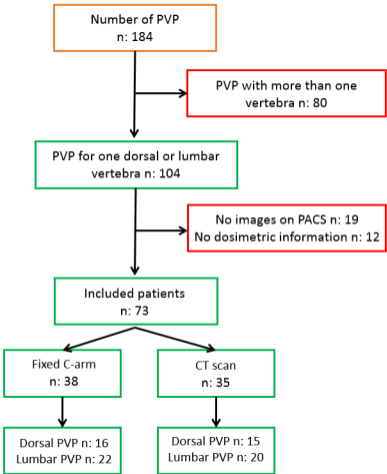
Values in bold correspond the organs directly exposed to the primary X-Ray beam and values in italic to the organs partially exposed.

Figure legends.

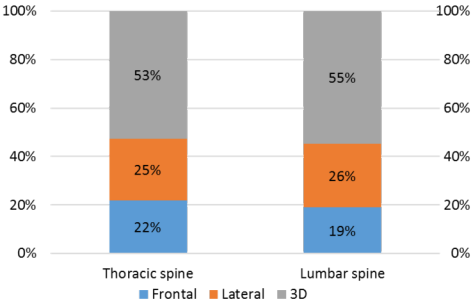
Figure 1. Flowchart of the study

Figure 2. Proportion of total Dose Area Product (DAP) for percutaneous vertebroplasties performed with a fixed C-arm depending on the acquisition type and X-Ray incidences and proportion of total Dose Length Product (DLP) for percutaneous vertebroplasties performed under CT guidance depending on the acquisition mode.

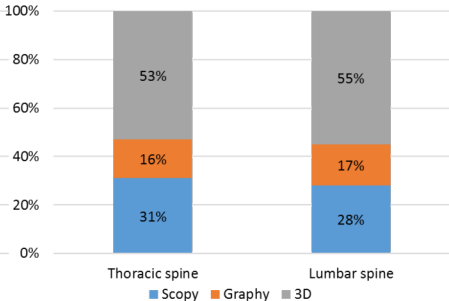
Figure 3. Normalized chest and abdomen organ doses as function of the total Air Kerma for the fixed C-arm and as function of the cumulated $CTDI_{vol}$ for CT scan for each vertebra treated with percutaneous vertebroplasty.



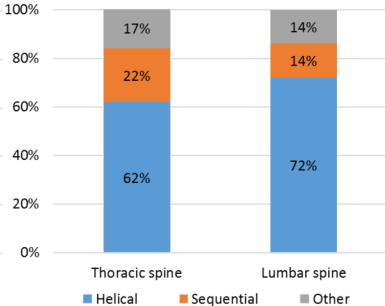
Mean proportion of total DAP: X-ray incidences



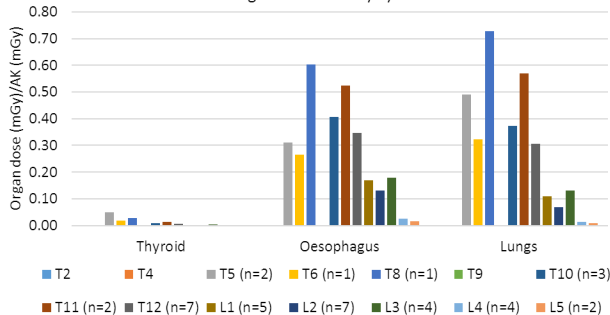
Mean proportion of total DAP: Acquisition type



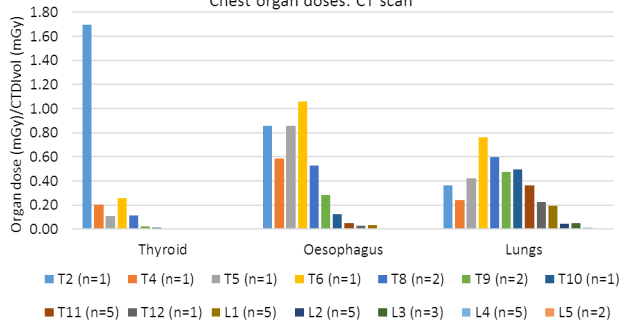
Mean proportion of DLP: Acquisition mode



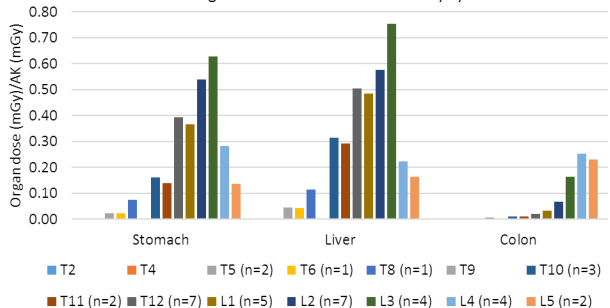
Chest organ doses: X-Ray system



Chest organ doses: CT scan



Abdomen organ doses: Interventional X-Ray system



Abdomen organ doses: CT scan

