Research Article

Open Access | CrossMark

Estimation of foetal radiation dose in a comparative study of pelvimetry with conventional radiography and different computer tomography methods

Abstract

Introduction: Conventional radiography and computed tomography (CT) can result in different radiation doses to the foetus when pelvimetry needs to be performed before childbirth. New techniques in diagnostic imaging provide the basis for the optimization of radiation dose and create opportunities for higher measurement accuracy. The purpose of the study was to estimate the radiation dose to the foetus from pelvimetry performed using conventional radiography compared to different CT methods, namely: the topogram method, cross-sectional method, short-spiral method, standard-spiral method, and flash-spiral method.

Methods: An anthropomorphic phantom and thermoluminescent dosemeters (TLD) were used for the dose measurements. Bags with sodium chloride were placed on top of the phantom's abdomen and were used to simulate the last month of pregnancy. The foetal radiation dose was equated to the absorbed energy to the TLDs placed at the area of the birth canal (uterus).

Results: The mean absorbed dose to the foetus was measured with conventional radiographic technique to 0.16mGy. The mean absorbed dose to the foetus with the various CT methods resulted in 0.17mGy (topogram), 0.21mGy (cross-sectional), 0.45mGy (short-spiral), 0.57mGy (standard-spiral), and 0.75mGy (flash-spiral). **Conclusion:** Although the absorbed dose to the foetus was higher in the CT pelvimetry methods, the dose levels are low. The CT spiral methods allowed adjustments in multiplane image reconstructions which could increase measurement accuracy. However, further studies are needed to investigate different CT pelvimetry methods in relation to measurement accuracy.

Keywords: absorption radiation, diagnostic imaging, pelvimetry, phantoms imaging, multidetector computed tomography

Erika Phexell,[1] Marcus Söderberg,[2] Anetta Bolejko[1]

[1]Department of Medical Imaging and Physiology, Skåne University Hospital, Sweden

[2]Department of Translational Medicine, Lund University, Skåne University Hospital, Sweden

Correspondence: Erika Phexell, Department of Medical Imaging and Physiology, Skåne University Hospital, SE-205 02 Malmö, Lund University, Box 157, SE- 22100 Lund, Sweden, Email erika.phexell@skane.se, erika.phexell@med.lu.se

Abbreviations: CT, computed tomography; TLD, thermoluminescent dosemeters; MRI, magnetic resonance tomography; USG, ultrasound; AEC, automatic exposure control; AP, Anteroposterior; kV, kilovolt; mAs, milliampere seconds; DAP, dose-area product; MPR, multiplane image reconstructions

Introduction

A narrow pelvis prolongs labour and might result in emergency caesarean section.[1] A breech presentation pregnancy also increases the risk of prolonged labour and eventually emergency caesarean section.[2,3] Emergency caesarean section might result in acute complications such as hematoma or infections with a risk for uterine rupture and pelvic thrombophlebitis.[4] The size of the birth canal might be estimated in order to plan delivery and prevent complications. Several studies demonstrate the use of X-ray pelvimetry as a reliable method to estimate the size of the birth canal.[2,3,5,6] Some show the use of magnetic resonance tomography (MRI)[7] and ultrasound (USG)[8] being advantages of not using ionising radiation. On the other hand, access to the MRI is usually limited and measurement accuracy of the USG pelvimenty need further studies.[7,8] Technologies used in X-ray pelvimetry vary. Clinical experience demonstrates that some radiology departments use the conventional radiography while others use computed tomography (CT) in line with the development of new techniques in CT. In addition, women can experience pelvimetry performed using conventional radiography as unpleasant.[9] Clinical experience indicates that radiographers find it difficult to position

women during pelvimetry performed using conventional radiography. That may lead to supplementary imaging and thus increase the radiation dose to the foetus. CT pelvimetry seems to provide a basis for a more comfortable examination and is also easier to perform.[9] The radiation dose in CT is in general higher compared with conventional radiography.[10] On the other hand, CT might improve the accuracy of the birth canal measurement, and new CT technology may introduce reduction of the foetal radiation dose, using among others, automatic exposure control (AEC), iterative reconstruction algorithms and detectors with increased sensitivity.[11] Previous studies demonstrate that CT pelvimetry can be performed with various methods which generate varying radiation doses to the foetus.[12–17] Most of these studies are rather dated[5,13–15,18] and few newer studies compare radiation dose to the foetus between different CT pelvimetry methods.[16-17,19] The purpose of this study was to estimate the radiation dose to the foetus in a comparative study of pelvimetry performed using conventional radiography and different CT methods.

Methods

A phantom study was performed. Philips Eleva (Philips Medical Systems, Best, Netherlands) multi diagnostic X-ray equipment was applied for the pelvimetry performed using conventional radiography and Siemens Somatom Definition Flash (Siemens Healthcare, Forchheim, Germany) was used for the CT. Dose measurements were done in an anthropomorphic Alderson Rando man phantom (The Phantom Laboratory, Salem, USA) using thermoluminescent

Estimation of foetal radiation dose in a comparative study of pelvimetry with conventional radiography and different computer tomography methods

Copyright:
©2018 Phexell et al.   **244**

dosemeters (TLDs). The model name and the material of the TLD was TLD-100, LiF:Mg,Ti. Harshaw 5500 TLD reader was used.

The phantom is equivalent to a 175cm and 73.5kg adult male and is made of a natural human skeleton with tissue simulating plastic around (Z_{eff}=7.30). The phantom consists of 35 sections with a thickness of 2.5cm and beginning at the neck as section 1. Five TLDs were placed in sections 31, 32 and 33, respectively, which corresponds to the area of the birth canal (uterus). Ten TLDs were used for background radiation dose measurements. In total, 25 TLDs were used. A self-made bag, containing 9 litre bags of sodium chloride, was used to simulate the last month of pregnancy. The bag was fixed upon the phantom (Figure 1).

Figure 1 Alderson Rando phantom with sodium bags on top to simulate the third trimester of pregnancy. In the phantom sections 31-35 which corresponds to the uterus, 15 thermoluminescent dosemeters (TLD) were placed to measure radiation dose to the foetus.

Pelvimetry performed using conventional radiography

Three images were taken using the phantom. The images corresponded to the on-site conventional X-ray pelvimetry. Anteroposterior (AP) views of the left and the right sides of spina ischiadica (Figure 2a & Figure 2b) were taken, using 60kilovolt (kV) and 20 milliampere seconds (mAs). The angle of the X-ray tube was 22 degrees in the caudal direction.[18] The focus to detector distance was 125cm and the collimation was set to 7cm width and 18cm length. The top of the collimation was 3cm from the upper edge of the symphysis. One lateral view was taken (Figure 2c) viewing the sacrum and symphysis using 90kV and 64mAs.[3,19] Collimation was set to 26cm width and 24cm length and centred in height with symphysis and laterally over the trochanter major. Five exposures were executed for each view during the pelvimetry performed using conventional radiography to increase the reliability of the measurement. Thus, the result of the reading for each TLD was divided by 5 prior to additional calculations that are further described in the analysis section.

CT pelvimetry

Different CT methods were evaluated: the topogram method, cross-sectional method, short-spiral method, standard-spiral method, and flash-spiral method. The topogram method contains a posteroanterior (PA) and a lateral topogram (Figure 3) when viewing the pelvis.[12] The tube voltage was set to 100kV in both topograms while the tube current was 20mA in the PA topogram and 60mA in the lateral topogram. The cross-sectional method (Figure 3) contains the topogram method and two cross-sectional images of fovea caput.[20] The parameters for this method were set to 14 quality reference

effective mAs with automatic exposure control (AEC) activated, 1×5cm collimation and 120kV tube voltage. The short-spiral method contains the topogram method and spiral imaging which only includes the area around the head of femur (Figure 3). The standard -, and flash-spiral method contain only a PA topogram and spiral imaging of the pelvis including lumbar vertebra 5 to the ischial tuberosity. The flash scan uses two sets of X-ray tubes. The scanning parameters for the spiral methods are presented in Table 1. The CT images were reconstructed using iterative reconstruction (SAFIRE).
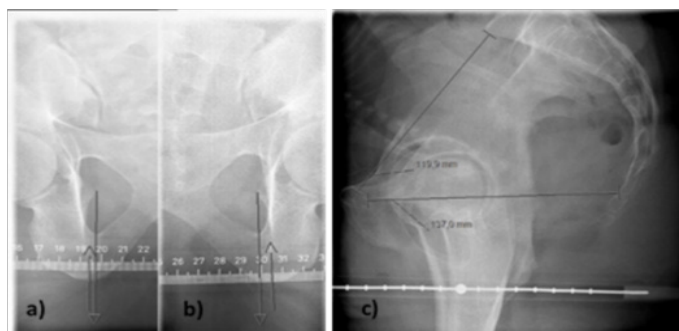

Figure 2 Pelvimetry performed using conventional radiography included with measurement points. Frontal projection (a, b) imaging the measurement points of the ischial spine and ischial tuberosity. The lateral projection (c) imaging the inlet and outlet diameters of the pelvis together with a lead ruler for correction of magnification/minification, placed between the women's thighs.
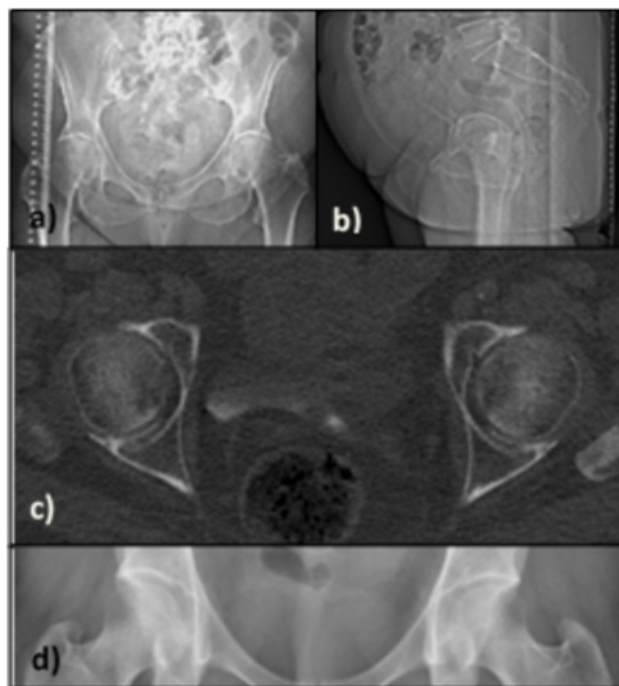

Figure 3 Images of topogram- (a, b) and cross-sectional (c) methods, together with the area of the short-spiral (d).

Analysis

This is a phantom study and no measurements were performed on humans. The foetal radiation dose was calculated based on the absorbed energy during irradiation of the TLDs that were placed in the phantom. When reading, the TLDs are warmed up gradually to

Estimation of foetal radiation dose in a comparative study of pelvimetry with conventional radiography and different computer tomography methods

Copyright:
©2018 Phexell et al. **245**

300 degrees Celsius while the released light is counted. The light is proportional to the absorbed dose of radiation. For each method investigated in the study mean, minimum, and maximum absorbed dose for all TLDs in phantom section 31, 32 and 33, was calculated.

The mean and the highest maximum value for all three sections and for each method corresponds approximately to the dose absorbed by the foetus.

Table 1 Scanning parameters for the CT spiral methods

Spiral methods	Topo†. PA‡	Topo. lat.§	kV	Ref eff mAs¶	Detector configuration	Pitch	AEC††	Rotation time (s)
Short	100kV, 20mA	100kV, 60mA	120	10	128×0.6	1	Yes	0.5
Standard	100kV, 20mA	-	120	10	128×0.6	1	Yes	0.5
Flash	100kV, 20mA	-	120	10	128×0.6	3	Yes	0.28

†Topo, topogram; ‡PA, posterior-anterior; §Lat, lateral; ¶Ref eff mAs, reference effective mAs; ††AEC, automatic exposure control

In addition, the dose-area product (DAP; $mGycm^2$) was registered as an estimation of the radiation dose to the women in pelvimetry performed on the phantom using conventional method. To evaluate the equivalence between the study measurements and clinical practice pelvimetry on site the mean value of the DAP from pelvimetry performed using conventional radiography on pregnant women was calculated. DAP values from all conventional pelvimetry scans (i.e. 33 examinations) that were performed at site during the last year prior to this study were included. An estimation of effective dose to the women was calculated by multiplying the DAP by a conversion coefficient of $0.00014 mSv/mGycm^2$.[21]

The maximum volume CT dose index ($CTDI_{vol}$; mGy) was registered as a measure of the radiation dose output for each CT method. In addition, total dose-length product (DLP; mGycm), including the topograms, for each CT method was registered. An estimation of effective dose to the women was calculated by multiplying DLP by a conversion coefficient of $0.0143 mSv/mGycm^2$.[22]

Results

Mean and maximum values of absorbed dose for each phantom section and different pelvimetry methods are shown in Table 2. Absorbed dose measured using the topogram method was equivalent to conventional radiography. The dose increased with the cross-sectional method but was still equivalent to radiation dose in conventional radiography. The flash-spiral method generated a higher radiation dose than the conventional radiographic technique and the other CT methods (Figure 4).

The mean DAP value from the clinical practice pelvimetry on site ($1840 mGycm^2$) was 52% higher compared to the phantom measurement (Table 2). The estimated effective dose to the women investigated in clinical practise pelvimetry on site was calculated to be 0.26mSv. The effective dose from the spiral CT methods was comparable and the effective dose from topogram- and cross-sectional method was lower (Table 2).

Table 2 Radiation doses from the different pelvimetry methods

Methods	Total DAP† (mGycm²)	CTDIvol‡ (mGy)	Total DLP§ (mGycm)	Effective dose (mSv)	Absorbed dose to foetus (mGy)		
					Section 31 mean/max	Section 32 mean/max	Section 33 mean/max
Conventional radiography	1214			0.17	0.17/0.25	0.16/0.24	0.16/0.24
Topogram		0.14	6.0	0.09	0.20/0.29	0.17/0.23	0.15/0.19
Cross-sectional		0.62	6.6	0.09	0.21/0.29	0.19/0.25	0.23/0.31
Short-spiral		0.61	12.3	0.18	0.37/0.51	0.47/0.55	0.51/0.57
Standard-spiral		0.61	14.7	0.21	0.59/0.62	0.57/0.59	0.56/0.61
Flash-spiral		0.83	23.0	0.33	0.74/0.81	0.74/0.78	0.78/0.88

†DAP, dose-area product; ‡CTDIvol, CT dose index by volume; §DLP, dose-length product.

Discussion

The conventional radiographic technique resulted in the lowest absorbed dose to the foetus, measured on the phantom. Two CT methods, the topogram- and cross-sectional methods, generated equivalent absorbed doses to the foetus in relation to conventional radiographic technology. The short-spiral method demonstrated an acceptable value followed by the standard-spiral method. The flash-spiral method measured the highest absorbed dose to the foetus, but still a low dose.
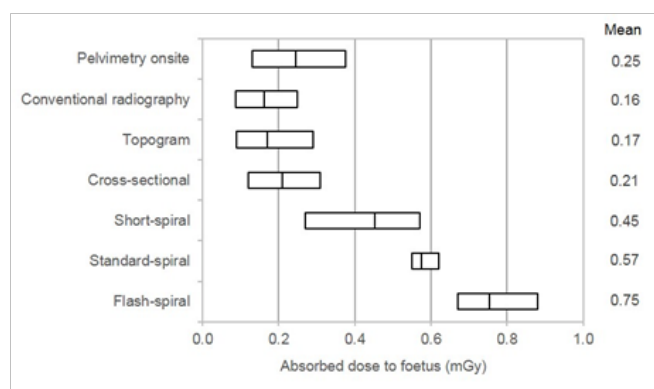
Figure 4 Radiation absorbed dose to foetus presented for pelvimetry performed using conventional radiography and different Computed Tomography (CT) pelvimetry methods measured on a phantom as well as the corrected dose escalation of 52% from pelvimetry performed using conventional radiography onsite (clinical practice pelvimetry). The bottom and top of the box are minimum and maximum value, and the band inside the box is the mean value. Radiation dose unit presented in milligray, mGy.

The topogram method was executed without tilting the gantry, which was used in earlier studies in order to view the ischial spine for calculation of the inter spinal distance.[9,12] In addition, Siemens Definition Flash cannot be tilted. Morris et al.,[12] described this method as time-consuming because some correction of magnification/minification was required if the patient was not centred in the isocenter. However, the topogram method with the tilted gantry would be enough to calculate the size of the birth canal. Considering the low radiation dose to the foetus, the topogram-method has great potential to be used for CT pelvimetry. Nevertheless, it needs to be studied further in terms of both performance and correction for magnification/minification.

The cross-sectional method includes, besides two topograms, two cross-sectional image acquisitions of the fovea. The reason why two, rather than one image acquisition of the fovea was chosen is that Aronson et al.,[20] questioned the fovea as a landmark and considered it untrustworthy due to anatomical variations. They claimed that in 65% of pregnant women and 35% of non-pregnant women the ischial spines were distal to the fovea. Also, Morris et al.,[12] and Ferguson et al.,[14] described the same phenomenon which indicates that two or sometimes more cross-sectional scans are needed to determine the place of the ischial spine. This method also requires that the women are positioned as straight as possible and that they do not have abnormal anatomy because no reconstructions can be made retrospectively. More studies with larger samples are needed to determine whether the fovea is suitable as a landmark in the visualization of the ischial spine.

The short-spiral method is a compromise between a volume and cross-sectional imaging. As the image is a volume, multiplane image reconstructions (MPR) are possible. The spiral method eliminates the potential uncertainty in the measurement of the internal diameter of the ischial spine as presented in the cross-sectional method. This means that the positioning of the pregnant woman becomes easier, but also means that anatomical abnormalities no longer play a major role. The standard-spiral method and flash-spiral method are implemented in the same way. The difference is in the setting of pitch (Table 1). With its dual-tube and detectors, the flash-spiral method enables faster data collection and the ability to reduce the radiation dose. In

the flash-spiral method, the length of the irradiated area is bigger than needed, the so-called "over scan". Adaptive collimation is used to minimize the effect of this over scan. However, based on this phantom experience, the pelvic area is too short for the adaptive collimation to be effective in the flash-spiral method, which resulted in the highest radiation dose of all CT methods. Although the absorbed dose by the flash-spiral method is higher, the dose was just as low as cross-section measurements in the study of Martinsen et al.[16] However, this study was made on a CT from General Electric and with a higher tube voltage. The similarity in dose may possibly indicate that the dose reduction is due to, among other things, the newer technology of today´s CT machines.[11] Although the absorbed doses in short-, standard- and flash-spiral methods are higher compared with pelvimetry performed using conventional radiography, they are still of an acceptable level.

A comparison of DAP values between pelvimetry performed using conventional radiography, executed on the phantom, and pelvimetry in clinical practice was made. The DAP value from the clinical practice pelvimetry examinations was 52% higher compared to the phantom study which can be explained by the supplementary images taken during the clinical practice pelvimetry examinations. The mean number of images in clinical practice pelvimetry was four (range 3-7) instead of three images as in the ideal case in the phantom study of pelvimetry performed using conventional radiography. Another explanation of the inconsistency of DAP values might be that pregnant women have a larger size than our phantom, which means that larger radiation field was used, thus the DAP value was higher. After correction for the 52% higher DAP value, when compared with all CT methods, the flash-spiral method still generated the highest foetal dose. However, the difference in radiation dose between the corrected value for conventional radiography and the short-spiral method was quite small. The absorbed mean radiation dose to the foetus using the short-spiral method is considered low, especially when the dose is related to the 99.7% probability that a child (0-19 years) will not develop a malignancy from the absorbed doses ≤5mGy.[10]

The risk for the foetus to develop cancer after the mother has undergone any kind of radiological examination during pregnancy has been investigated and found to be minimal by Bailey et al.,[23] and has also been reported in ICRP.[10] The radiation dose in the spiral method was lower than 1mGy. In addition, the measurement accuracy is expected to be the best in the CT spiral method of all tested techniques and methods. However, the diagnostic accuracy was not studied in this study, which may be the next step in the development of the methodology for pelvimetry examination. Since the absorbed dose to the foetus, using CT technology, appears to be at a low level, the technology should be further investigated to ensure its full potential for optimal diagnostic accuracy. It is of the utmost importance that the measurement values, which are results of the CT examination, are correct with as low a margin of error as possible when a decision about childbirth method is based on these measurements. An acceptable margin of error is ≤4mm according to Anderson et al.[24]

Due to the ionising radiation, the measurements in this study were executed on an anthropomorphic phantom and bags of sodium chloride were chosen for simulation of the pregnancy in the third trimester, especially week >36. However, no bone components exist in phantom sodium bags and there is a possibility that a different material used for the pregnancy simulation would have given a different result regarding absorbed dose. A male phantom was used to better represent the weight of a pregnant woman.

Several, well-known, CT methods were examined in the study to compare their foetal dose with foetal dose of the conventional radiographic technique, which is considered as strength of the study. Prior to starting the study, scanning parameters for the various CT methods were tested out on a phantom in order to ensure that the image quality was acceptable, even though the radiation dose was low. Further studies are needed to investigate measurement accuracy in relation to the CT methods evaluated in this study.

Conclusion

Although the radiation absorbed dose to the foetus was higher in the CT pelvimetry methods, the dose levels are low. CT methods are considered to be more beneficial both for the patient and the radiographer; woman may experience the conventional pelvimetry as an unpleasant examination and for the radiographers it is easy to perform. However, CT pelvimetry need to be further investigated, in particular in terms of diagnostic accuracy. CT spiral methods are expected to provide high performance characteristics as adjustments can be made to image reconstructions, such as adjusting the position of the pelvis on the images regardless of individual anatomical abnormalities. Thus, CT has the possibility of improving the decision-making basis regarding the delivery method in women with a narrow pelvis and breech presentation pregnancy.

Acknowledgements

Conflict of interest

The author declares no conflict of interest.

References

1. Vistad I, Cvancarova M, Hustad BL, et al. Vaginal breech delivery: results of a prospective registration study. *BMC Pregnancy Childbirth.* 2013;13:153–160.

2. Stålberg K, Bodestedt Å, Lyrenäs S, et al. Narrow pelvic outlet increases the risk for emergency cesarean section. *Acta Obstet Gynecol Scand.* 2006;85(7):821–824.

3. Gimovsky ML, O´Grady JP, Morris B. Assessment of computed tomographic pelvimetry within a selective breech presentation management protocol. *J Reprod Med.* 1994;39(7):489–491.

4. Rodgers SK, Kirby CL, Smith RJ. Imaging after Cesarean Delivery: Acute and Chronic Complications. *Radiographics.* 2012;32: 1693–1712.

5. Kopelman JN, Duff P, Karl RT, et al. Computed Tomographic pelvimetry in the evaluation of breech presentation. *Obstet Gynecol.* 1986;68(4):455–458.

6. Christian SS, Brady K, Read JA, et al. Vaginal breech delivery: A five-year prospective evaluation of a protocol using computed tomographic pelvimetry. *Am J Obstet Gynecol.* 1990;163(3):848–855.

7. Korhonen U, Solja R, Laitinen J, et al. MR pelvimetry measurements, analysis of inter- and intra-observer variation. *Eur J Radiol.* 2010;75:e56–e61.

8. Daghighi MH, Poureisa M, Ranjkesh M. Association between Obstetric Conjugate Diameter measured by transabdominal Ultrasonography during pregnancy and type of delivery. *Iran J Radiol.* 2013;10(3):185–187.

9. Lotz H, Ekelund L, Hietala SO, et al. Low dose Pelvimetry with Biplane Digital Radiography. *Acta Radiol.* 1987;28:577–580.

10. International Commission on Radiological Protection. *Pregnancy and Medical Radiation.* ICRP Publication 84. Ann ICRP 30; (2000).

11. Kalender WA. Dose in x-ray computed tomography. *Phys Med Biol.* 2014;59(3):129–150.

12. Morris CW, Heggie JCP, Acton CM. Computed tomography pelvimetry: accuracy and radiation dose compared with conventional pelvimetry. *Australas Radiol.* 1993;37(2):186–191.

13. Federle MP, Cohen HA, Rosenwein MF, et al. Pelvimetry by Digital Radiography: A Low-Dose Examination. *Radiology.* 1982;143(3):733–735.

14. Ferguson JE, DeAngelis GA, Newberry YG, et al. Fetal radiation exposure is minimal after pelvimetry by modified digital radiography. *Am J Obstet Gynecol.* 175(2):260–267.

15. Moore MM, Shearer DR. Fetal dose estimates for CT pelvimetry. *Radiology.* 1989;171(1):265–267.

16. Martinsen ACT, Risdal M, Bay T, Drolsum A. Bekkenmåling med computertomografi. *Tidsskr Nor Lægeforen.* 2005;125:2023–2025.

17. Hjemly H, Barlien B, Konst B, et al. CT Pelvimetri – lavdose volumopptak med postprosessering i MPR og 3D. *Hold pusten.* 2008;35:28–30.

18. Johnson TM, Brown M. Twenty degree angle modification for pelvimetry. *Radiol Technol.* 1976;48(2):149–151.

19. Harper LM, Odibo AO, Stamilio DM, et al. Radiographic measures of the mid pelvis to predict cesarean delivery. *Am J Obstet Gynecol.* 2013;208(6):460-466.

20. Aronson D, Kier R. CT Pelvimetry: The Foveae Are Not an Accurate Landmark for the Level of the Ischial Spines. *Am J Roentgenol.* 1991;156(3):527–530.

21. https://pdfs.semanticscholar.org/d90f/22c2c119c618c6822eb094087464e5ca3c4b.pdf

22. Huda W, Magill D, He W. CT effective dose per length product using ICRP 103 weighting factors. *Med Phys.* 2011;38(3):1261–1265.

23. Bailey HD, Armstrong BK, de Klerk NH, et al. Exposure to Diagnostic Radiological Procedures and the Risk of Childhood Acute Lymphoblastic Leukemia. *Cancer Epidemiol Biomarkers Prev.* 2010;19(11):2897–2909.

24. Anderson N, Humphries N, Wells JE. Measurement error in computed tomography pelvimetry. *Australas Radiol.* 2005;49:104–107.