Local diagnostic reference levels for skeletal surveys in suspected physical child abuse

McFadden, S. (2020). Local diagnostic reference levels for skeletal surveys in suspected physical child abuse. *Radiography*, *27*(2), 425-429. Advance online publication. https://doi.org/10.1016/j.radi.2020.10.005

Published in:
Radiography

Publication Status:
Published online: 21/10/2020

DOI:
10.1016/j.radi.2020.10.005

Document Version
Author Accepted version

Local diagnostic reference levels for skeletal surveys in suspected physical child abuse

Bo Mussmann[1,2,3], Maryann Hardy[4], Raheis Rajalingam[5], Daniel Peters[6], Sonyia McFadden[7], Ahmed Jibril Abdi[1,2]

Affiliations:

1. Department of Radiology, Odense University Hospital, Denmark
2. Research and Innovation Unit, University of Southern Denmark
3. Faculty of health Sciences, Oslo Metropolitan University, Norway
4. Faculty of Health Studies, University of Bradford, UK
5. Department of Radiography, University College Lillebaelt, Denmark
6. Lillebaelt Hospital, Department of Radiology, Denmark
7. School of Health Sciences, University of Ulster, UK

Corresponding author:

Bo Mussmann

Department of Radiology, Odense University Hospital

Sdr. Boulevard 29

5000 Odense C, Denmark

Phone: +45 20 59 88 56

e-mail: bo.mussmann@rsyd.dk

Conflict of Interest: The authors declare that they have no conflict of interest.

Abstract

Introduction

The purpose was to determine if an age based, local diagnostic reference level for paediatric skeletal surveys could be established using retrospective data.

Methods

All children below two years of age referred for a primary skeletal survey as a result of suspected physical abuse during 2017 or 2018 (n=45) were retrospectively included from a large Danish university hospital . The skeletal survey protocol included a total of 33 images. Dose Area Product (DAP) and acquisition parameters for all images were recorded from the Picture Archival and Communication System (PACS) and effective dose was estimated. The 75th percentile for DAP was considered as the diagnostic reference level (DRL).

Results

The 75th percentile for DAP was 314 mGy*cm^2, 520 mGy*cm^2 and 779 mGy*cm^2 for children <1 month, 1-11 months and 12<24 months of age respectively. However, only the age group 1-11 months had a sufficient number of children (n=27) to establish a local DRL. Thus, for the other groups the DAP result must be interpreted with caution. Effective dose was 0.19, 0.26 and 0.18 mSv for children <1, 1-11 months and 12<24 months of age respectively.

Conclusion

For children between 1 and 11 months of age, a local diagnostic reference level of 520 mGy*cm^2 was determined. This may be used as an initial benchmark for primary skeletal surveys as a result of suspected physical abuse for comparison and future discussion.

Implications for practice

While the data presented reflects the results of a single department, the suggested diagnostic reference level may be used as a benchmark for other departments when auditing skeletal survey radiation dose.

Key words:

Diagnostic reference level

Paediatric radiology

Suspected physical abuse

Non-accidental injury

PI-DRL

Introduction

Suspected Physical Injury (SPI) and physical abuse in children is an international phenomenon that extends across all societal demographics [1]. The incidence of reported physical abuse varies between countries (e.g. 11.5 per 100,000 in Sweden to 118.9 per 100,000 in Western Australia) [2, 3] with more than 50% of abused children presenting to health and social care agencies being under 1 year of age, resulting in approximately 60 per 100,000 children <1 year of age being hospitalized annually in the United States [4]. Importantly, these cases represent only those identified through Health and Social Care Agencies and it is suspected that a large number of abuse events remain unrecognized [5]. Reported mortality rates for children experiencing physical abuse also vary, ranging from 15% to 38% [6, 7] and therefore the consequences of missed diagnosis can be catastrophic.

The radiographic skeletal survey, including images of the entire skeleton, is often the first line of investigation where physical abuse in children is suspected [8]. The rationale for this is that skeletal fractures are the second most common finding, after bruises and contusions, in physical abuse [9, 10] being identified in approximately 25% of cases [11]. Further, due to predictable fracture healing patterns in children, radiographic findings may identify fractures that are highly or moderately specific to abuse [12] as well as provide an estimate of their age. However, osseous signs of physical injury, such as metaphyseal lesions, may be subtle and easily overlooked in poorly positioned, blurred or noisy images. Consequently, high quality image acquisition techniques are essential and, as children are more sensitive to radiation exposure and have a long life expectancy, this should include consideration of the associated risks of cumulative radiation dose [13, 14].

In the joint 2018 guidelines published in the United Kingdom by The Royal College of Radiologists and The Society & College of Radiographers [15], emphasis was placed on documenting Dose Area Product (DAP) values as a method of monitoring child radiation exposure. The European guidelines (2018) on diagnostic reference levels for paediatric imaging state that comparing DAP readings against diagnostic reference levels (DRLs) is useful for optimizing imaging procedures. This provides a tool for radiographers to monitor and audit their performance [16] as DRLs are not intended to be applied to individual children or to be used as a dose limit [17]. A DRL is a particularly relevant component for determining practice quality where the collective dose is high or in less common, high dose examinations. However, no established Danish DRL exists for the paediatric skeletal survey, an examination that may be considered less common and high dose compared to regular paediatric skeletal examinations as all body regions are irradiated through multiple projections and, in many cases, follow-up surveys are performed 10-14 days after the initial examination. Consequently, the purpose of this study was to determine if an age based local DRL (LDRL) for paediatric skeletal surveys could be established using retrospective data to permit skeletal survey image acquisition practices to be monitored and facilitate comparison.

Methods

Due to the retrospective and anonymised nature of the data acquisition for this study, The Regional Committee on Health Research Ethics for Southern Denmark (Journal No. S-20202000-92) confirmed that ethical approval was not required according to Danish legislation. Authorisation of data capture was provided by the hospital manager. Data were collected from a single Danish public radiology department covering a geographical area of 12,000km^2 and serving a population of 1.2 million with approximately 12,000 births per annum. The department performs 350,000 radiological procedures annually of which approximately 19,000 are paediatric and 4,700 pertain to children < 2 years of age. All children referred with suspected physical abuse in the geographical area are examined at this department accounting for approximately 25-30 children annually.

All children below two years of age referred for a primary skeletal survey as a result of suspected physical abuse during 2017 and 2018 were included in the study. The standard skeletal survey protocol comprised a total of 33 radiographic projections (Table 1). All children were examined in the same room using a Siemens YSIO digital radiography system (Siemens Healthineers, Erlangen, DE) with a source to image detector distance (SID) of 115cm, no anti-scatter grid and manual exposure settings individually adjusted from a standard exposure chart for children weighing 3.5kg. For the chest projections only, an additional 0.2 mm external copper filtration was used. The paediatric team consisted of seven specialist radiographers who had received in-house training in skeletal survey imaging where physical abuse is suspected. Maintenance of radiographic competencies was maintained through continued peer observation, case discussion with peers and paediatric radiologists and participation in annual interdisciplinary audit of skeletal survey practice involving radiologists, paediatricians, paediatric nurses and forensic pathologists.

Each skeletal survey involved three radiography team members: one supporting and positioning the child in co-operation with one of the parents; one positioning the equipment; and one managing the exposure settings. A paediatric nurse was also present during the examination to monitor the wellbeing of the child and observe proceedings. All persons who were in the room during the examination wore protective shielding (lead rubber protection).

Examination data (DAP, field size and exposure parameters for each projection) were identified in the DICOM header and manually recorded from the hospital PACS system (Centricity PACS, GE Healthcare, Waukesha IL, USA) by two radiographers working in collaboration and entered into an Excel spreadsheet. To reduce human error in data transfer and input, both radiographers individually checked each data point and compared results.

DAP meter operation was routinely quality assured in accordance with the statutory quality control of X-ray equipment as outlined by the National Health Authority. The recorded cumulative DAP value for the skeletal survey was used for the calculation of effective dose by the regional physicist using PCXMC version 2.0.1 Monte Carlo patient simulation software (STUK, Helsinki, Finland). To calculate the effective radiation dose associated with the skeletal survey examination, overall DAP values for examinations within each of the three defined age groups (<1 month, 1 to <12 months and 12-24 months) were determined to identify the patient most closely representing the 75th percentile in each age category. For this patient the collimation field size was determined for each anatomical image as weight data was not routinely collected as part of radiography referral data. Calculations were then based on common age groupings with each age group representing an approximate 5kg difference in weight as defined by World Health Organisation child growth standards [https://www.rcpch.ac.uk/resources/uk-who-growth-charts-0-4-years] with direct comparison to age and weight equivalence published in the European guidelines on diagnostic reference levels for paediatric imaging (PI-DRL) [16]. Descriptive statistics were performed using STATA/IC 16 (StataCorp LP, College Station, TX, USA).

Results

A total of 60 skeletal surveys for suspected physical abuse were recorded as having taken place during the defined time period. 10 of these related to children older than two years of age and thus not eligible. A further five cases were excluded due to only supplementary or incomplete skeletal survey data being available (figure 1). The sample therefore consisted of 45 child skeletal survey examinations (Table 2).

Supplementary (repeat) projections were performed in 29 children (Table 3). While the reason for repeat or supplementary projection was not routinely recorded, subsequent review of images suggests that movement unsharpness and the anatomical area of interest being outside the primary beam were the primary reasons. A total of 1534 images were evaluated. A summary of mean exposure factors per anatomical projection is provided in Table 4.

The range of cumulative DAP readings including supplementary images were analysed for the different age groups to provide DAP percentile data (Table 5). Unfortunately, as the number of cases in the age groups <1 month and 12- <24 months was 9 rather than the 10 advocated by PI-DRL [16], accurate DRL values could not be determined. (However, in the absence of published data these values can be used as a benchmark for internal audit and comparison with other centres.

Effective dose was estimated to be 0.19, 0.26 and 0.18 mSv for children <1, 1 to <12 months and 12 - <24 months, respectively.

Discussion

Skeletal surveys are of great importance in cases of suspected physical abuse, particularly in children under two years of age as they are less able to verbalise or communicate the cause of their trauma. Many international organizations and professional bodies advocate minimizing radiation exposure to children due to associated radiation risks [18]. However, without DRLs against which to compare practice, the monitoring and audit of practice is impossible. This small, single centre study goes some way towards addressing this gap for children attending for skeletal survey examinations for suspected physical abuse by establishing age based DRLs based on retrospective data.

The creation of a LDRL was possible, in part, due to the standard protocol for image acquisition and fixed range of projections undertaken. This was further enhanced by a small team of highly motivated radiographers who undertake these examinations resulting in minimal variation in practice between patients. Finally, all images were acquired in a single room using the same equipment over a two-year period therefore making the sample measures representative for all children attending for a skeletal survey and ideal for LDRL determination.

The gender of the included children showed a slight majority of males (male 53.3%, female 46.7%) which reflects the international perspective that the prevalence of physical abuse is higher amongst boys [19]. However, the risk of being hospitalised as a consequence of physical abuse in Denmark has been reported as being marginally higher amongst girls [20] and therefore the gender distribution may reflect the relatively small sample size.

This study calculated a LDRL for three child age groups against which local practice can be audited and practice in other departments can be compared. Our results compare favourably against published studies reporting effective doses of 0.2 mSv for a skeletal survey acquired using comparable digital equipment, but acquiring only 13-22 images as compared to our 33 standard projections [21, 22]. However, unreported differences in acquisition practices in relation to SID, physical filters and collimation in those studies may also have contributed to the differences. Furthermore, one study [21] did not report the age of the children included. While careful attention must be given to the justification of the skeletal survey examination, this study has determined that, where justified, the associated risks of the suggested LDRL may be considered low compared to the risk of not undertaking the skeletal survey [23]. However, this study focused only on the primary skeletal survey examination and in many cases, a limited projection follow-up survey without images of the pelvis, spine and skull is performed 10 to 14 days after the initial survey increasing the patient dose by approximately 40% when considering DAP data for these projections identified in this study (Table 4). Further imaging to evaluate potential cerebral injury may also increase patient dose where Computed Tomography (CT) rather than Magnetic Resonance Imaging (MRI) is undertaken and in our study, a supplementary head CT scan was undertaken in six cases. The variability in follow-up procedures and small sample size meant that it was impossible to use the data to determine routine practice but the additional dose and risks associated with follow-up imaging should be carefully considered as part of the justification process before deciding to undertake the initial skeletal survey.

No independent measure of image quality was undertaken as part of this study but local practice is for images to be approved by a paediatric radiologist prior to the patient leaving the department and images being transferred to PACS. Consequently, diagnostic image quality was assumed although it remains uncertain why five of the included skeletal survey examinations were incomplete, each with a single radiographic projection missing.

The use of a three-member radiography team, each performing separately defined tasks, differs from UK guidelines recommending two specialised radiographers to undertake the examination. However, this ‘one radiographer, one task’ approach optimises child positioning and image acquisition processes enabling the skeletal survey to be undertaken in 20-30 minutes rather than the 45-60 minutes reported previously in the department when using a team of 2 radiographers. The larger team also creates greater opportunity for peer learning and observation, crucial for assuring standards are maintained.

The findings of this study may be criticised as a LDRL is usually established using data from several rooms and facilities in a part of a country, whereas data from a single room or facility may be referred to as a ‘typical value’ based on median value alone [17]. However, due to the large volume of projection data available in this study, we adopted the method for determining a LDRL identifying the 25^{th} and 75^{th} percentiles as this provided radiographers with a familiar concept value against which to audit practice. For future audits we recommend the prospective collection of patient weight. In hindsight it would also have been advantageous to extend the data collection period to ensure the threshold number of patients (i.e. 10 patients per age/weight group) were included.

No weight data were available for the children examined and therefore we were unable to follow the weight based grouping as recommended in international guidelines [16] and used age-based grouping instead. However, we believe weight variation within the sample for specified age groups to be limited due to moderate variation in the exposure settings and assumed acceptable image quality.

Conclusion

This study has demonstrated that an age based LDRL can be established from retrospective skeletal survey data where a consistent approach to imaging is established. The findings suggest that a LDRL of 520 mGy*cm^2 for children between 1 and <12 months of age referred for skeletal surveys is implemented and used as a practice benchmark locally. For children aged less than 1 month and 12 - <24 months, LDRL measures of 314 mGy*cm^2 and 779 mGy*cm^2 are suggested but these should be adopted with caution as estimation is based on only 9 cases rather than the 10 cases advocated by PI-DRL [16]. While the findings of this study and proposed LDRL may not be representative of wider facilities and sites, the study has provided a rigorous approach for establishing a standard using retrospective data against which future practice can be audited. Further, the creation of the LDRL for a relatively high dose (compared with regular paediatric skeletal examinations) and uncommon examination such as the skeletal survey in young children addresses the requirement to assure image acquisition standards and adoption of the ALARA principle in practice.

Fig 1 Flow-chart for patient inclusion in the study

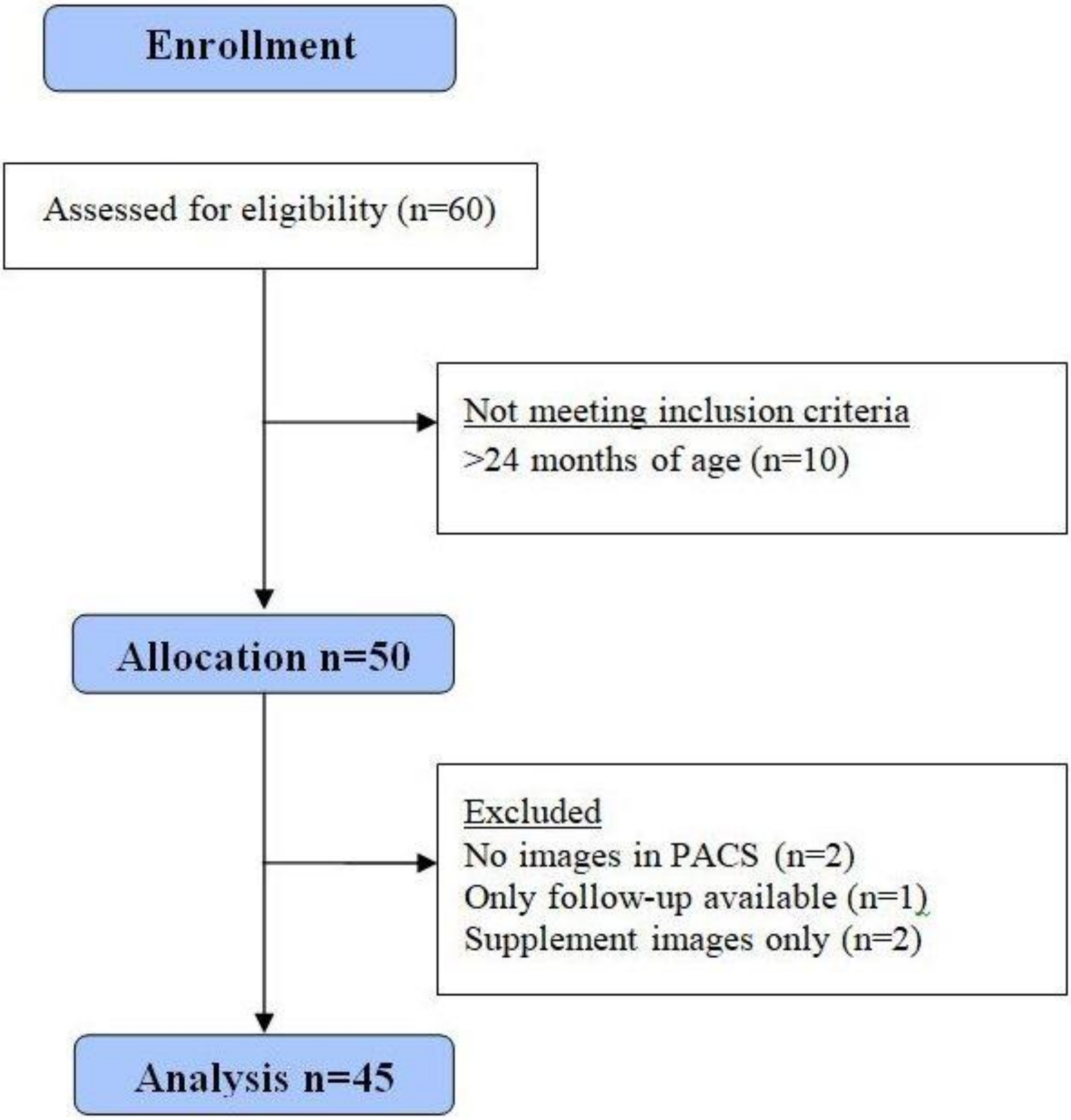

Table 1. Anatomical regions and projections included in the skeletal survey (n = 33)

Anatomical region	Projection
Foot (R/L)	Dorsi Plantar (DP)
Coned ankle (R/L)	Antero Posterior (AP), Lateral (Lat)
Lower leg (R/L)	AP
Coned knee (R/L)	AP, Lat
Femur (R/L)	AP
Pelvis/abdomen	AP
Hand (R/L)	DP
Coned wrist (R/L)	Lat
Forearm (R/L)	AP
Coned elbow (R/L)	Lat
Humerus (R/L)	AP
Spine	Lat
Chest	AP, Lat, Oblique (R/L)
Skull	AP, Lat

Table 2. Child demographics

Age	Male (%)	Female (%)	Total
<1 month	6 (66.7)	3 (33.3)	9
1 to <12 months	14 (51.9)	13 (48.1)	27
12 to 24 months	4 (44.4)	5 (55.6)	9
Total	24 (53.3)	21 (46.7)	45

Table 3 Number of supplementary images in each anatomical area and per. child.

Projection	1st repeat	2nd repeat	Total
Ankle Lat	6	2	8
Crus AP	2	1	3
Femur AP	2	-	2
Pelvis	2	-	2
Hand PA	1	-	1
Wrist Lat	8	1	9
Elbow Lat	2	-	2
Skull Lat	3	1	4
Skull AP	14	2	16
Chest AP	3	-	3
Chest Obl	2	1	3
Chest lat	3	-	3
Total	48	8	56

Distribution of supplementary images per. child (n=29) (no supplementary images n=16)

	n
+1 image	15
+2 images	9
+3 images	2
+5 images	2
+7 images	1
Total	29

Table 4. Mean tube voltage (kV), tube load (mAs) and DAP (mGy*cm^2) with associated standard deviation (SD) pooled for all patients.

Projection (No. of obs.)	Mean kV (SD)	Mean mAs (SD)	Mean DAP (SD)
Foot AP (90)	49.90 (0.74)	1.80 (0.23)	1.55 (1.16)
Ankle Lat (90)	48.68 (1.12)	1.96 (0.32)	1.93 (1.50)
Lower leg AP (88)	49.94 (0.75)	2.04 (0.29)	5.30 (3.58)
Knee AP (90)	50.33 (1.17)	2.76 (0.45)	4.05 (2.35)
Knee Lat (90)	50.35 (1.15)	2.76 (0.46)	4.45 (3.17)
Femur AP (89)	53.70 (1.65)	2.94 (0.49)	13.13 (8.17)
Pelvis (44)	54.3 (1.51)	3.49 (0.43)	26.94 (14.11)
Hand AP (90)	47.87 (0.99)	1.66 (0.19)	1.57 (1.19)
Wrist Lat (90)	48.58 (1.20)	1.82 (0.19)	1.14 (1.46)
Forearm AP (89)	49.88 (0.96)	2.05 (0.32)	3.17 (2.21)
Elbow AP (90)	50.38 (1.33)	2.45 (0.27)	2.12 (1.21)
Elbow Lat (90)	50.25 (1.35)	2.45 (0.29)	2.45 (1.69)
Humerus AP (89)	52.98 (1.31)	2.79 (0.48)	8.43 (5.15)
Lumbar spine (45)	54.26 (1.47)	7.52 (1.11)	35.90 (19.12)
Cervical spine (45)	54.23 (1.53)	6.95 (1.18)	23.29 (13.34)
Skull Lat (45)	54.38 (1.57)	6.75 (0.72)	71.69 (32.19)
Skull AP (43)	54.26 (1.48)	6.67 (0.84)	71.87 (34.54)
Chest AP (45)	61.22 (1.86)	2.87 (0.51)	12.54 (8.10)
Chest Obl. (90)	63.68 (2.00)	3.76 (0.32)	18.58 (8.56)
Chest Lat (45)	64.04 (1.93)	4.58 (4.96)	16.89 (7.80)

Total No. of observations = 1,477

Table 5. DAP percentiles (mGy*cm^2) merged for each age group.

Age (months)	**<1**	**1-11**	**12-24**	**Total**
Percentile	(n=9)	(n=27)	(n=9)	(n=45)
25th	209	269	535	264
50th	256	344	607	357
75th	314	520	779	552

References

1. Kellogg ND. Evaluation of suspected child physical abuse. Pediatrics. 2007;119(6):1232-41.
2. Högberg U, Lampa E, Högberg G, Aspelin P, Serenius F, Thiblin I. Infant abuse diagnosis associated with abusive head trauma criteria: incidence increase due to overdiagnosis? Eur J Public Health. 2018;28(4):641-6.
3. Gilbert R, Fluke J, O'Donnell M, Gonzalez-Izquierdo A, Brownell M, Gulliver P, et al. Child maltreatment: variation in trends and policies in six developed countries. The Lancet. 2012;379(9817):758-72.
4. Leventhal JM, Gaither JR. Incidence of serious injuries due to physical abuse in the United States: 1997 to 2009. Pediatrics. 2012;130(5):e847-52.
5. Schilling S, Christian CW. Child physical abuse and neglect. Child Adolesc Psychiatr Clin N Am. 2014;23(2):309-19, ix.
6. Oehmichen M, Auer RN, König HG. Forensic Neuropathology and Associated Neurology. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg; 2006.
7. Mussmann B, Poulsen MR. Guidelines for skeletal surveys in suspected child abuse. Radiography Open. 2015;1(1):8. doi.org/10.7577/radopen.1190
8. Paine CW, Wood JN. Skeletal surveys in young, injured children: A systematic review. Child Abuse Negl. 2018;76:237-49.
9. Offiah A, van Rijn RR, Perez-Rossello JM, Kleinman PK. Skeletal imaging of child abuse (non-accidental injury). Pediatr Radiol. 2009;39(5):461-70.
10. van Rijn RR, Sieswerda-Hoogendoorn T. Educational paper: imaging child abuse: the bare bones. Eur J Pediatr. 2012;171(2):215-24.
11. Barber I, Perez-Rossello JM, Wilson CR, Kleinman PK. The yield of high-detail radiographic skeletal surveys in suspected infant abuse. Pediatr Radiol. 2015;45(1):69-80.

12. Kleinman PK. Diagnostic imaging in infant abuse. Am J Roentgenol. 1990;155(4):703-12.
13. Nguyen A, Hart R. Imaging of non-accidental injury; what is clinical best practice? J Med Radiat Sci. 2018;65(2):123-30.
14. Bajaj M, Offiah AC. Imaging in suspected child abuse: necessity or radiation hazard? Arch Dis Child. 2015;100(12):1163-8.
15. Halliday K, Debelle G, Constantine F, Jaspan T, Johnson S, Freeman C, et al. The radiological investigation of suspected physical abuse in children. Revised first edition. the Royal College of Radiologists (RCR) and the Society & College of Radiographers (SCoR); 2018.
16. European Commision. European Guidelines on Diagnostic Reference Levels for Paediatric Imaging. 2018. Report No.: RADIATION PROTECTION N° 185.
17. Vañó E, Miller DL, Martin CJ, Rehani MM, Kang K, Rosenstein M, et al. ICRP Publication 135: Diagnostic Reference Levels in Medical Imaging. Ann ICRP. 2017;46(1):1-144.
18. Boylan JK. Image Gently((R)) at 10 Years. J Am Coll Radiol. 2018;15(8):1193-5.
19. Moody G, Cannings-John R, Hood K, Kemp A, Robling M. Establishing the international prevalence of self-reported child maltreatment: a systematic review by maltreatment type and gender. BMC Public Health. 2018;18(1):1164.
20. Christoffersen MN. Børnemishandling i hjemmet. København; 2010.
21. Berger RP, Panigrahy A, Gottschalk S, Sheetz M. Effective Radiation Dose in a Skeletal Survey Performed for Suspected Child Abuse. J Pediatr. 2016;171:310-2.
22. Rao R, Browne D, Lunt B, Perry D, Reed P, Kelly P. Radiation doses in diagnostic imaging for suspected physical abuse. Arch Dis Child. 2019;104(9):863-8.
23. Slovis TL, Strouse PJ, Strauss KJ. Radiation Exposure in Imaging of Suspected Child Abuse: Benefits versus Risks. J Pediatr. 2015;167(5):963-8.