# Online Supplement File 3:

# MOBI-kids dose estimation from medical diagnostic examinations: Details of the procedures

**The aim of this work was to calculate for each participants of MOBI-kids study the cumulative absorbed dose to the brain from medical exposure.** This was achieved with the following steps:

1. Determine the absorbed dose to the brain from each procedure. Due to the lack of availability of individual specific data for individual dose reconstruction, organ doses were estimated for each reported examination based on typical dose values by time period and age at exposure.
2. For each subject, the cumulative lifetime brain dose was obtained as the sum of the organ doses attributed to each examination, as reported in the personal interview.

**The present document contains:**

**Figure S3.1: Visual summary of the process**

Description: Flowchart summarizing each steps of the dose estimation in the study

**Table S3.1** List of questions of the questionnaire’s medical radiation section that were used in the analysis.

**Table S3.2** List of publication retrieved with the literature review. Selected publications report common technical parameters or estimation of typical organ dose across age-time period for each radiological procedures considered in this study.

**Table S3.3**: Details on the age categories used for simulation on the PCXMC software

**Table S3.4**: Details on the location of the x-ray beam used for simulation on the PCXMC software

**Graph S3.1:** Details on the use of information on HVL when lacking of information on filtration on the PCXMC simulations

**Table S3.5:** Details on the steps conducted to build the look up table

**Table S3.6**: Common number of projection for a single radiographic procedure

**Table S3.7**: List of assumptions made when merging the look up table with the information collected in the MOBI-kids study

## Figure S3.1: Visual summary of the process

Dose estimation task

Study database

Overall process has been described in the methods section of the Manuscript. Details and assumptions made in each step may be found in the present document.

Literature review (**Table S3.2** in this document)

1) Interview: collection of individual radiological history (Table S3.1 in this document)

19 Publications reporting a value of brain dose for a given examination type, period and age frame *(Example Table 4 in Lee 2016)*

9 publications reporting technical parameters combinations commonly used in a given decade for a given examination type and age frame *(Example Table 1 in Gogos 2003)*

PCXMC simulations: Estimation of brain dose for each given combination of technical parameters

Details: **Table S3.3; S3.4; Graph S3.1** in this document

Summary look up table

Table **S3.5 and S3.6** in this document

(Look up table provided in the Online Supplement File S2)

Merge by examination type, year and age of performance (Table S3.7 in this document)

Sum brain dose estimated for each examination by subject

Obtain a final dataset with the cumulative dose estimated for each subject

##  Information collected in the MOBI-kids study

Within the MOBI-kids study, detailed information on medical radiological history has been collected via personal interview. Information consists in a list of potential medical diagnostic procedures that the subject could have had during his life. In addition, interviewers had images of each examination type to avoid confusion between procedures. The table below detailed how questions to collected radiological history were formulated in the two questionnaires (Main questionnaire to the participants, Parental questionnaire to the mother of participant).

## Table S3.1 List of questions of the questionnaire’s medical radiation section that were used in the analysis.

|  |  |  |
| --- | --- | --- |
| **Type of radiological examination** | **Question formulation** | **If “Yes” detailed collected** |
| **Main questionnaire** |
| **Conventional head and neck x ray** | Have you ever had x-rays of the head or neck? | How many of these types of x-rays did you have in your lifetime?For each one:How old were you?Body Part in X-RayReason for X-Ray |
| **CT-scan** | In your lifetime, have you ever had a CT or PET CT scan of the head, neck or whole body (including the head)? | How many of these types of tests did you have in your lifetime?For each one:How old were you?Body Part in CTReason for CT |
| **Intraoral x-ray** | In your lifetime, have you ever had a bite-wing x-ray? | Please tell me how frequently you had bite-wing x-rays at different stages in your life:<10; 10-14, 15-19, 20-24 age |
| **Full mouth x-ray** | In your lifetime, have you ever had a full mouth x-ray? | Please tell me how frequently you had full mouth x-ray at different stages in your life:<10; 10-14, 15-19, 20-24 age |
| **Panorex x-ray** | In your lifetime, have you ever had a panorex x-ray? | Please tell me how frequently you had panorex x-ray at different stages in your life:<10; 10-14, 15-19, 20-24 age |
| **Dental CT** | In your lifetime, have you ever had a dental CT? | Please tell me how frequently you had dental CT at different stages in your life:<10; 10-14, 15-19, 20-24 age |
| **Maternal questionnaire** |
| **Any examination during pregnancy** | During the pregnancy with the index, were any X-rays (including dental X-rays), CT scans or MRI examinations or any radiation treatments carried out? | For each one:**Type of exam** (X-ray; dental bite wing; dental full mouth; dental panoramic; dental CT; angiography; isotope scanning; fluoroscopy; CT; MRI; therapeutic radiation; other **Part of the Body** (head & neck, teeth, thorax, abdomen, extremities,| whole body, other**Reason****Trimester during pregnancy****Was the abdomen protected from X-rays by lead shielding?** |
| **Any examination of the child during the first year of life** | Was the infant subjected to any X ray or nuclear medicine during the birth hospitalization and/or during the first year of life? | **Body parts that were imaged**: head & neck, thorax, abdomen, extremities, whole body**Type of exam** (x-ray, CT, MRI, Nuclear medicine)**Number of exams** |

Notes regarding the cleaning of this database:

1. **CT scan**: There were reported 28 head CT with reason “appendicitis”. In such cases, we changed the body part to the abdomen.

## Table S3.2 List of publication retrieved with the literature review

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ref** | **Country** | **Exam** | **Body part #** | **Information extracted** | **Number of rows(\*) extracted** | **Age covered** | **Period covered** | **Study type** | **Relevance score****$** |
| Fontana 2019 (1) | Level I countries | Conventional | Dental, Full mouth | Brain dose | 6 | Adult | 1980-1989, 1990-1999, 2000-2010 | Estimation of organ doses from collection of technical parameters in a literature review | 4 |
| Gogos 2003 (2) | Greece | Conventional | Skull , Full spine | Technical parameters | 59 | 1, 5, 10, 15 | 2000-2010 | Measurement of Entrance Surface Dose and collection of parameters in a large pediatric hospital | 3 |
| Ruiz 1991 (3) | Spain | Conventional | Full spine, Skull | Technical parameters | 52 | 5, 10, 15 | 1980-1989 | Measurement of entrance surface dose and collection of parameters in an hospital | 3 |
| Mazonakis 2004 (4) | Crete | Conventional | Skull | Technical parameters | 12 | 5, 10 | 2000-2010 | Measurement of dose and collection of parameters | 3 |
| Martin 1994 (5) | UK | Conventional | Skull | Technical parameters | 40 | 1, 5, 10, 15 | 1990-1999 | Measurement of entrance surface dose and dose-area product in an hospital  | 3 |
| McDonald 1996 (6) | UK | Conventional | Skull | Technical parameters | 42 | 0, 1, 5, 10, 15 | 1990-1999 | Measurement of entrance surface dose and dose-area product in an hospital | 3 |
| Gallini 1992 (7) | Italy | Conventional | Skull | Technical parameters | 72 | 1, 5, 10, 15 | 1980-1989 | Measurement of dose and collection of parameters in 7 hospital belonging to the same region | 4 |
| Sonawane 2011 (8) | India | Conventional | Skull | Technical parameters | 91 | 0, 1, 5, 10, 15 | 2000-2010 | DRL publication: Collection of parameters for the definition of DRL levels (2240 measurement in 22 public and private hospitals | 4 |
| Begum 2001 (9) | Bangladesh | Conventional | Skull | Technical parameters | 6 | Adult | 2000-2010 |  | NA |
| Knight 2014 (10) | Australia | Conventional | Skull, Neck soft, Cspine | Technical parameters | 50 | 0, 1, 5, 10, 15, Adult | 2000-2010 | Suggested optimal value (review of optimization strategy) | 2 |
| Melo 2016 (11) | US | Conventional | Skull, Paranasal sinus, Neck soft, Cervical spine | Brain dose | 12 | Adult | 1980-1989, 1990-1999, 2000-2010 | Estimation of organ doses from collection of technical parameters in a literature review | 4 |
| Kiljunen 2008 (12) | Finland | Conventional | Skull, Sinus, abdomen, thorax | Brain dose | 20 | 0, 1, 5, 10, 15 | 2000-2010 | Collection of examination parameters in 24 Finnish hospitals | 5 |
| Hayakawa (13) | Japan | Panoramic | Dental | Brain dose | 8 | Adult, NA | 2000-2010 | Phantom measurement using lowest exposure (but still enough to take image) and highest exposure scenario | 4 |
| Gibbs 1988 (14) | worldwide | Panoramic, Conventional | Dental, Full mouth | Brain dose | 5 | Adult | 1980-1989 | Phantom measurement using standard protocol | 4 |
| Lecomber 2001 (15) | worldwide | Panoramic, Scan | Dental | Brain dose | 2 | Adult | 2000-2010 | Phantom measurement using standard protocol | 4 |
| Lee 2016 (16) | UK | Scan | Head | Brain dose | 18 | NA | 1980-1989, 1990-1999, 2000-2010 | Estimation of doses from parameters as collected form a sample of 1073 CT-scans from 36 hospitals. | 5 |
| Fenig 2001 (17) | US | Conventional | Abdomen, Barium enema, Dental, Extremities, Mammography, Pelvimetry, Skull, Thorax | Brain dose | 8 | Fetal | 2000-2010 | Review reporting organ dose estimation | 2 |
| Wagner 1995 (18) | US | Conventional | Abdomen, Barium enema, Dental, Extremities, Mammography, Skull, Thorax | Brain dose | 15 | Fetal | 1990-1999 | Review reporting organ dose estimation  | 2 |
| Tung and Tsai 1999 (19) | china | Conventional | Abdomen, Thorax | Brain dose | 2 | Fetal | 1990-1999 | National survey | 5 |
| Chahed 2000 (20) | tunisia | Conventional | Mammography, Thorax | Brain dose | 2 | Fetal | 1990-1999 | Dose estimation in a cohort of pregnant women | 5 |
| Fergurson 1996 (21) | US | Conventional | Pelvimetry | Brain dose | 1 | Fetal | 1990-1999 | Phantom measurement using standard protocol | 2 |
| Toppenberg 1999 (22) | US | Conventional, Scan | Abdomen, Barium enema, Dental, Extremities, Skull, Thorax, Head | Brain dose | 9 | Fetal | 1990-1999 | Review reporting organ dose estimation | 2 |
| Osei 1999 (23) | UK | Conventional, Scan | Abdomen, Barium enema, Skull, Thorax | Brain dose | 14 | Fetal | 1990-1999, 2000-2010 | Dose estimation from parameter collection in a cohort of 50 pregnant women | 4 |
| Sharp 1998 (24) | UK | Conventional, Scan | Abdomen, Barium enema, Skull, Thorax, Head | Brain dose | 11 | Fetal | 1990-1999 | NRPB national survey | 5 |
| Parry 1999 (25) | US | Conventional, Scan | Abdomen, Barium enema, Thorax | Brain dose | 4 | Fetal | 1990-1999 | Radiological textbook | 2 |
| Helmrot 2003 (26)  | Sweeden | Conventional, Scan | Abdomen, Barium enema, Thorax | Brain dose | 6 | Fetal | 2000-2010 | Estimation of organ doses based on data registered in the Radiological Information System/Picture Archive and Communication System of one hospital | 3 |
| Linet 2009 (27) | worldwide | conventional | various | Brain dose | 1 | Fetal | Not reported | Not reported | 2 |
| Kettunen 2004 (28) | Finland | conventional | thorax, thorax and abdominal | Brain dose | 9 | 0 | 1990-1999 | Nationwide survey | 5 |
|  |  |  |  |  |  |  |  |  |  |
| \* as row we identify here: a) The number of different parameters combination (each combination is resulting in a dose estimation with the PCXMC software; or b) The number of different value of the brain doses reported(#) For neck procedures, manuscript reporting full spine or scoliosis projection was considered as projection for cervical spine. Justification: Cervical spine is included in full spine projection and scoliosis projection. Some of the reported reason for a neck x-ray was “scoliosis”.$ Relevance score: To each of the publication found we gave a relevance score. Relevance refer to the specific aim of this work, which is to obtain the dose which could be taken as most representative of the practice of a given age and time period. Thus, if parameters/estimation comes from a collection of parameters/measurement at national level a high score is given. For more details around this score see Fontana 2019 (1) |

## PCXMC simulation details

## Table S3.3: Details on the age categories used for simulation on the PCXMC software

PCXMC use the following age group (in years of age) 0 (0 to 0.5); 1 (0.5 to 2.5); 5 (2.5 to 7.5); 10 (7.5 to 12.5); 15 (12.5 to 17) and adult. Age reported in the publication may not match with these categories. Here we report first the age category as reported in the publication, and after the age categories that were used for the simulation

|  |  |  |
| --- | --- | --- |
| **Reference** | **Age categories reported in the manuscript** | **Age categories used in the simulations** |
| Sonawane 2011 | <1y | 0 (0 to 0.5) years of age |
| Sonawane 2011 | 1-4 y | 1 (0.5 to 2.5) AND 5 (2.5 to 7.5) years of age |
| Sonawane 2011 | 5-9y | 5 (2.5 to 7.5) AND 10 (7.5 to 12.5) years of age |
| Sonawane 2011 | 10-15 y | 10 (7.5 to 12.5) AND 15 (12.5 to 17) years of age |
| Knight 2014 | 0-6 months | 0 (0 to 0.5) years of age |
| Knight 2014 | 6-18 months | 1 (0.5 to 2.5) years of age |
| Knight 2014 | 18-36 months | 1 (0.5 to 2.5) years of age |
| Knight 2014 | 3-7 years | 5 (2.5 to 7.5) years of age |
| Knight 2014 | 8-12 years | 10 (7.5 to 12.5) years of age |
| Knight 2014 | 13-17 years | 15 (12.5 to 17) years of age |
| Ruiz 1991 | 0-1y | 0 (0 to 0.5) years of age |
| Ruiz 1991 | 1-5y | 1 (0.5 to 2.5) AND 5 (2.5 to 7.5) years of age |
| Ruiz 1991 | 5-10y | 5 (2.5 to 7.5) AND 10 (7.5 to 12.5) years of age |
| Ruiz 1991 | 10-14y | 10 (7.5 to 12.5) AND 15 (12.5 to 17) years of age |
| Gallini 1992 | 1-14 y (Mean 5.8 y; SD 4.1) | 0 (0 to 0.5) AND 1 (0.5 to 2.5) AND 5 (2.5 to 7.5) AND 10 (7.5 to 12.5) AND 15 (12.5 to 17) years of age |
| Gogos 2003 | 0.5-2 | 1 (0.5 to 2.5) years of age |
| Gogos 2003 | 3-7y | 5 (2.5 to 7.5) years of age |
| Gogos 2003 | 8-12y | 10 (7.5 to 12.5) years of age |
| Gogos 2003 | 13-18 y | 15 (12.5 to 17) years of age |
| McDonald 1996 | infant | 0 (0 to 0.5) years of age |
| McDonald 1996 | 1-5 y | 1 (0.5 to 2.5) AND 5 (2.5 to 7.5) years of age |
| McDonald 1996 | 5-10 y | 5 (2.5 to 7.5) AND 10 (7.5 to 12.5) years of age |
| McDonald 1996 | 10-15 y | 10 (7.5 to 12.5) AND 15 (12.5 to 17) years of age |
| Martin 1994 | 1-5 y | 1 (0.5 to 2.5) AND 5 (2.5 to 7.5) years of age |
| Martin 1994 | 6-10 y | 10 (7.5 to 12.5) years of age |
| Martin 1994 | 11-15 y | 12.5 to 17) years of age |

## Table S3.4: Details on the location of the x-ray beam used for simulation on the PCXMC software

PCXMC required to specify the location of the x-ray beam with respect to the phantom by imputing the coordinates (x,y,z) of the point inside the phantom, through which the central axis of the x-ray beam passes. The following values were inserted:

* Skull xray

|  |  |  |  |
| --- | --- | --- | --- |
| **Age** | **ref point x** | **y** | **z** |
| adult | 0 | 0 | 89 |
| 15 | 0 | 0 | 79 |
| 10 | 0 | 0 | 65 |
| 5 | 0 | 0 | 53 |
| 1 | 0 | 0 | 40 |
| 0 | 0 | 0 | 17 |

* Neck x-ray

|  |  |  |  |
| --- | --- | --- | --- |
| **Age** | **ref point x** | **y** | **z** |
| Neck |
| adult | 0 | 0 | 75 |
| 15 | 0 | 0 | 69 |
| 10 | 0 | 0 | 53 |
| 5 | 0 | 0 | 43 |
| 1 | 0 | 0 | 33 |
| 0 | 0 | 0 | 20 |
| Full spine |
| adult | 0 | 0 | 67 |
| 15 | 0 | 0 | 57 |
| 10 | 0 | 0 | 43 |
| 5 | 0 | 0 | 33 |
| 1 | 0 | 0 | 23 |
| 0 | 0 | 0 | 15 |

## Graph S3.1: Details on the use of information on HVL when lacking of information on filtration on the PCXMC simulations

In some publication Half Value Layer (HVL) were reported instead of total filtration. The half value layer is the amount of absorbing material (i.e. the thickness of a standard material), which is needed to reduce the intensity of the x-ray beam by 50%. We used the following graph to derive the total mmAl filtration (Consider that CDA is HVL in French)

Reference of the graph personal communication Carlo Maccia

## Table S3.5: Details on the steps conducted to build the look up table

|  |  |  |
| --- | --- | --- |
| Step Number | Identification of the step | Details |
| 1 | Combination of technical parameters (dose quantity and Kv) | We used the mean, minimum and maximum of the dose quantity (either air kerma, mAs…) combined with the reported mean kV. We further refer to these combinations as combinations with central values, minimum values and maximum values, respectively. |
| 2 | Creation of a dose database | Putting together values coming from different simulations and the values of brain dose as found in the literature, we obtain a database. For each examination, period, and age frame (example for conventional head x-ray in 2000-2010 for a child age 5 to 10) we complied several values (depending on the number of publications found). |
| 3 | Creation of a look up table | To obtain a look up table with one entry per each examination, period, and time frame we proceeded as follows:We grouped observation by time period, age, type examination and relevance score. For each group we calculated a summary of measures: Arithmetic mean, minimum, maximum, Geometric mean, Standard deviation. For dose values coming from simulations with PCXMC, as a first choice we selected values coming from “combinations of central values”, thus we didn’t considered dose resulted from combination of a minimum/maximum dose value (Air kerma, mAs) with the mean kV values. It is important to note that the difference between values estimated from combination with extreme parameters in comparison with values estimated from central parameters were in the order of few decimals. This indicates that, even considering a large variation in the parameters used by radiologists (which is very likely and represented by the maximum and minimum values), the resulting estimation is in good agreement with the one selected for imputation (i.e “combinations of central values”).  |
| 4 | Calculation of dose for each single examination (Combination of dose per projection) | Another important issue when summarizing information is the difference between projection and examination. A single exam (for example a skull x-ray) is the result of various projections. Here we list the most common number of projections for conventional x-ray by time period. Therefore, when we report a value of organ dose for a single projection (i.e. skull Anterior-Posterior), the value of brain dose for the full examination is obtained by multiplying according to the number of projection usually required to perform the given examination (see table S3.6) |

## Table S3.6: Common number of projection for a single radiographic procedure

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Body part** | **Period range** | **Age** | **Number of projections** | **Reference** |
| Neck | 1980-1989 | adult | 2 | Melo 2016 (11) |
| Neck | 1980-1989 | children | 2 | Kirks 1998 (29) |
| Neck | 1990-1999 | adult | 2 | Melo 2016 (11) |
| Neck | 1990-1999 | children | 2 | Kirks 1998 (29) |
| Neck | 2000-2010 | adult | 2 | Melo 2016 (11) |
| Neck | 2000-2010 | children | 2 | Coley 2013 (Caffey’s Paediatric diagnostic imaging) (30) |
| sinus | 1980-1989 | adult | 5 | Melo 2016 (11) |
| sinus | 1980-1989 | children | 2 | Swischuk 1982 (31) |
| sinus | 1990-1999 | adult | 3 | Melo 2016 (11) |
| sinus | 1990-1999 | children | 3 | Diament 1992 and Kirks 1998 (32) |
| sinus | 2000-2010 | adult | 3 | Melo 2016 (11) |
| sinus | 2000-2010 | children | 2 | Clark 2005 (33) |
| skull | 1980-1989 | adult | 5 | Melo 2016 (11) |
| skull | 1980-1989 | children | 4 | Kirks 1998 (29) |
| skull | 1990-1999 | adult | 3 | Melo 2016 (11) |
| skull | 1990-1999 | children | 4 | Kirks 1998 (29) |
| skull | 2000-2010 | adult | 4 | Melo 2016 (11) |
| skull | 2000-2010 | children | 4 | Glass 2004 (34) |
| spine | 1980-1989 | adult | 4 | Melo 2016 (11) |
| spine | 1980-1989 | children | 3 | Kirks 1998 (29) |
| spine | 1990-1999 | adult | 5 | Melo 2016 (11) |
| spine | 1990-1999 | children | 3 | Kirks 1998 (29) |
| spine | 2000-2010 | adult | 5 | Melo 2016 (11) |
| spine | 2000-2010 | children | 2-3 | Lustrin 2003 (35) |

## Merge the dose with the MK database

## Table S3.7: List of assumptions made when merging the look up table with the information collected in the MOBI-kids study

We matched the look up tables with the database containing the list of reported radiological examination by type of examination, body part, decade and age. In doing so some assumptions has been made.

|  |  |
| --- | --- |
| **Identification of assumption** | **Description** |
| Identifying the correct examination type | The level of details on the information collected does not distinguished between the different types of head (or neck x-rays, as such type of details would have been impossible to capture in a self-reported questionnaire.For example a head conventional x-ray could be different examination types (i.e. skull x-ray or sinus x-ray) and a neck conventional x-ray could be a soft neck tissue x-ray or a cervical spine examination. We proceeded as following:* Head conventional: if the specified reason was “sinusitis” >> the examination was considered as a sinus x-ray, otherwise a skull.
* Neck conventional: the mean between spine and neck was calculated for each period and age group. When, for a given period/age, either dose for spine or neck examination was missing, the only available value was considered. The two examinations were almost comparable in terms of brain absorbed dose, spine being slightly higher (few decimals of mGy).
 |
| Missing information on the dose | For some of the reported radiological examinations, the brain dose value was missing, with main reasons being: * Type A: Missing info in the MOBI-kids database when reported data was of poor quality (missing type of exam, and age at examination). Decisions taken in each case are reported in Online Supplement File S2 (Missing table).
* Type B: Dose for the type of examination was not available, for a given period and age group. Decisions taken in each case are reported in Online Supplement File S2 (“Unmatched table”).
 |

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