



Imaging Human Development

Bernadette de Bakker, MD PhD
Assistant Professor





3D EMBRYO
ATLAS



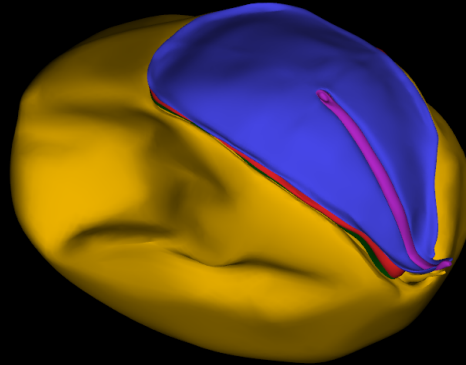
3D FETAL
ATLAS



3D Ultrasound
ATLAS

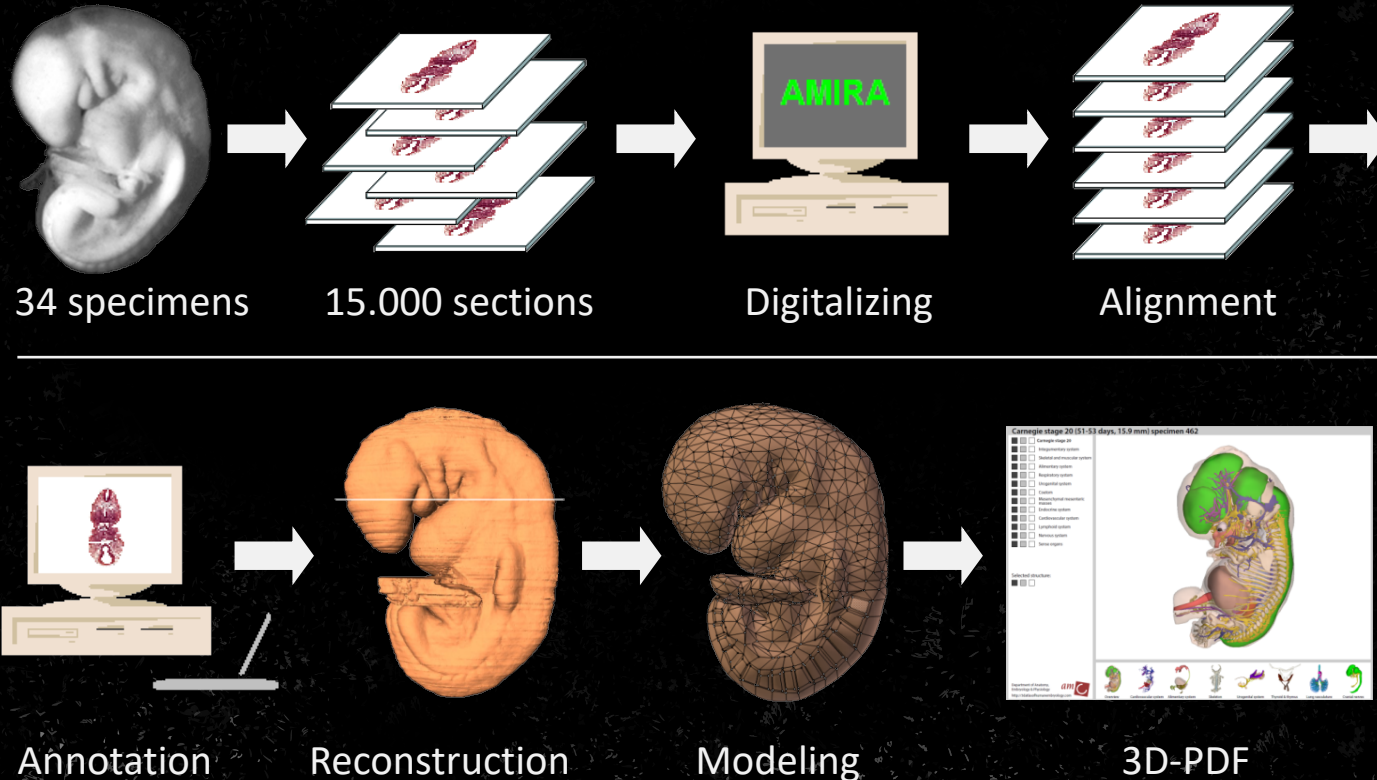


Embryonic period



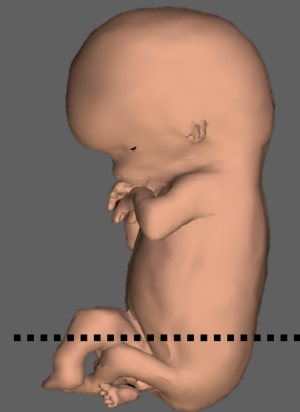
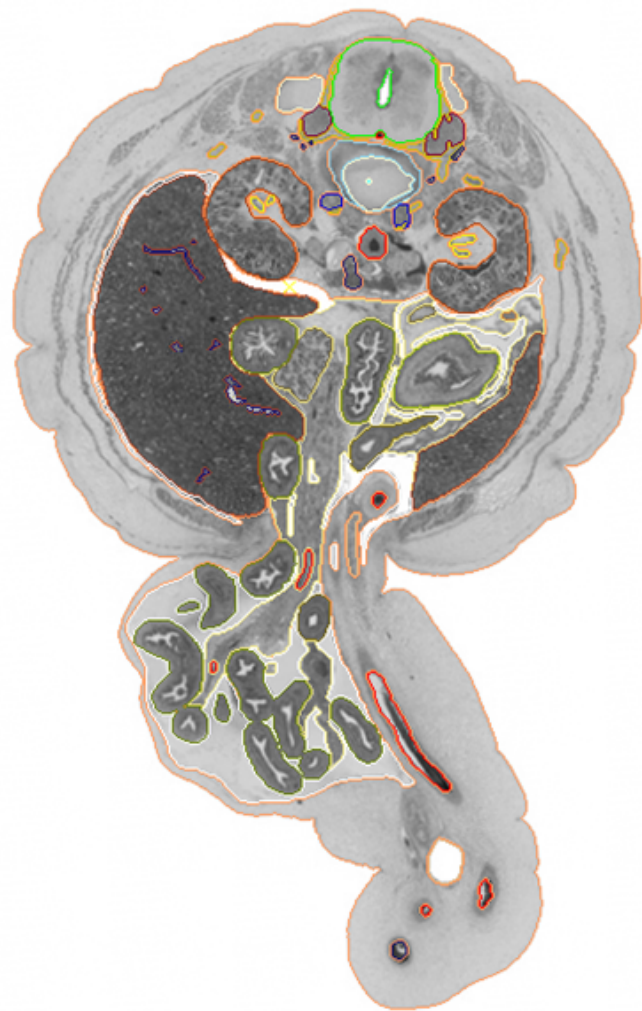


From embryo to 3D-PDF





324/419 [XY]



1 cm

CS23
(56 d)





RESEARCH ARTICLE SUMMARY

HUMAN DEVELOPMENT

An interactive three-dimensional digital atlas and quantitative database of human development

Bernadette S. de Bakker,* Kees H. de Jong, Jaco Haggoort, Karel de Bree, Clara T. Besseling, Froukje E. C. de Kanter, Tjans Veldhuis, Babette Bais, Reggie Schildwiler, Jan M. Ruijter, Rodolf Jan Oostra, Vincent M. Christoffels, Anton F. M. Moorman†

INTRODUCTION: The basic human body plan, the arrangement of organs in the body, is laid down during embryonic development. Insight into the formation of this plan informs researchers and clinicians about normal development versus the development of congenital malformations, the latter of which have an incidence of 3% in the human population and cause up to one-quarter of all neonatal deaths. Despite modern technologies such as three-dimensional imaging, the intricate morphogenesis of the developing human body is difficult to understand. Textbooks on human development are often based on the works of early embryologists, some published more than 100 years ago. Because of the limited availability of human embryonic specimens, it is difficult or impossible to independently verify the information carried

in these textbooks, or even to assess whether this information is derived from studies on human or animal models.

RATIONALE: Current imaging and computer technology make it possible to reconstruct human development with sufficient resolution to visualize organ development. Stained histological sections (mainly from the Carnegie Collection of human embryos) were digitized, tissues and organs were identified, and knowledge-driven modeling was applied to correct imperfections in the three-dimensional reconstructions.

RESULTS: We created a digital atlas with 14 interactive three-dimensional models of human embryology and a database encompassing 34

embryos spanning the first 2 months of human development. Approximately 15,000 histological sections from the Carnegie Collection were analyzed by trained biomedical students under expert supervision, and up to 150 organs and structures were identified and digitally labeled in each section. The labeled structures were then spatially reconstructed in such a way that the relation between the reconstruction and the original images was preserved. We tested the reproducibility of the manual tracing of the different organs and found that the variability in volumes of segmented structures ranged from 0.3% to 2% between students for simple and complex structures, respectively. The 3D models, supplemented by an object tree with structures named in accordance with the international standard of embryonic terminology, the Terminologia Embryologica, are presented as interactive 3D-PDFs, which facilitates

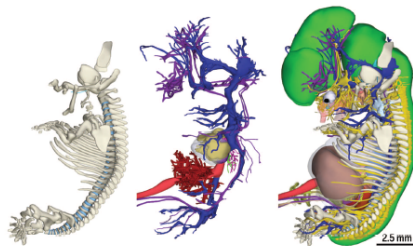
ON OUR WEBSITE:

Read the full article at <http://dx.doi.org/10.1126/science.aag0053>

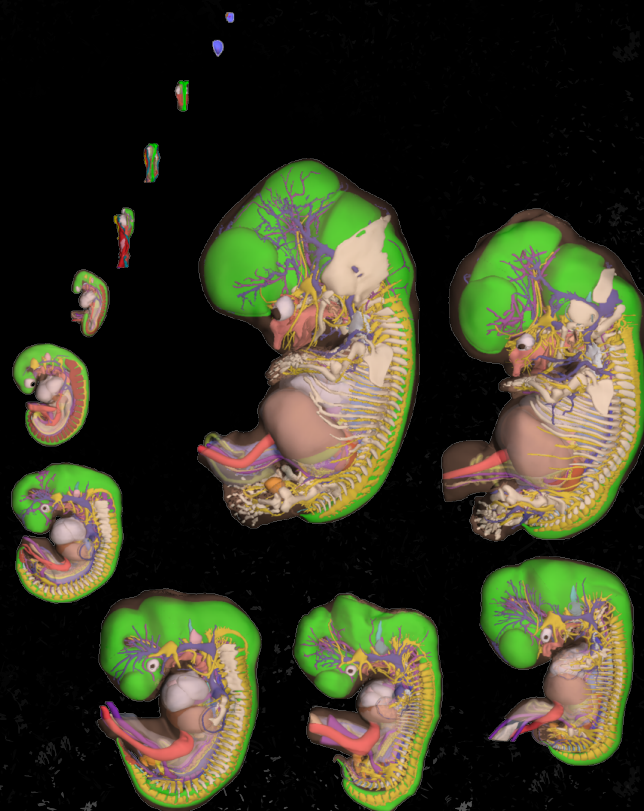
exploration of the complex relations between the different organs and allows researchers to develop an independent view of their spatial relations. The 3D reconstructions enable the measurement of the growth of the individual organs and structures, the assessment of the changing position of organs relative to vertebral segments during development, and the verification of remaining ambiguities in the descriptions of the development of organs.

CONCLUSION: The morphology presented in this atlas is directly connected to the original sections of the embryos in the Carnegie Collection—a connection that was in danger of being lost, with present-day textbook morphology becoming increasingly schematic and deviating from the original substrate. A number of detailed analyses of the development of the kidney, pharyngeal arch cartilages, and notochord show that the current descriptions of the development of these organs are based on comparative animal models rather than on factual observations in human specimens. These examples demonstrate the scientific value of the atlas. This atlas will therefore serve as an educational and reference resource for students, clinicians, and scientists interested in human development and development-related congenital diseases. The 3D-PDFs of the reconstructions, as well as original and labeled images, are freely available (<http://3dembryoatlas.medembryology.com>). ■

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†See this article at B. S. de Bakker et al., *Science* 354, aag0053 (2016). DOI: 10.1126/science.aag0053



Lateral views of a model of a 75-week-old human embryo (16 mm). Left: Skeletal system. Center: Cardiovascular system with transparent heart muscle. Venous system is shown in blue, arterial system in purple, liver vessels in red, and umbilical vein in pink. Right: Reconstructed organs, except skin. Note, for example, the neural tube in green and the nerves in yellow.





The Laryngoscope
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The Development of the Human Hyoid–Larynx Complex Revisited

Bernadette S. de Bakker **ORIGINAL COMMUNICATION**



WILEY

Original Paper

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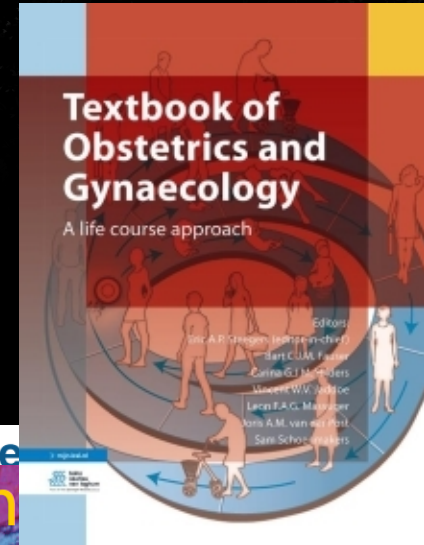
J. Anat. (2017)

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ORIGINAL COMMUNICATION

Single-Site Neural Tube Closure in Human Embryos Revisited

BERNADETTE S. DE BAKKER ,* STAN DRIESSEN, BASTIAAN J.D. BOUKENS,
MAURICE J.B. VAN DEN HOFF, AND ROELOF-JAN OOSTRA



Clinical Anatomy 30:988–999 (2017)



Ongeveer 6.090.000 resultaten (0,64 seconden)

<https://www.amazon.nl> > Just-Atlas-Fetal-Anatomy-Ultras...

Just An Atlas Fetal Anatomy : Ultrasound Handbook Third Edition ...

A perfect pocket ultrasound reference of **fetal anatomy**. The proper ultrasound image for each **fetal** structure is included along with corresponding diagrams.

<https://www.amazon.nl> > Just-Atlas-Fetal-Anatomy-Ultr... ▼

Just an Atlas of Fetal Anatomy: Ultrasound Handbook : Stephenson

...

A perfect pocket ultrasound reference of **fetal anatomy**. The proper ultrasound image for each **fetal** structure is included along with corresponding diagrams.

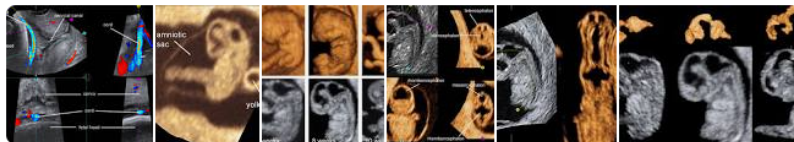
<https://www.bol.com> > ... > Anatomie ▼

Atlas of Fetal Sectional Anatomy (ebook), Glenn Isaacson ... - Bol.com

Atlas of Fetal Sectional Anatomy. The **fetal** period of human growth and development has become an area of intense study in recent years, due in large...

<https://www.glowm.com> > ultrasoun... ▼ [Vertaal deze pagina](#)

Atlas of Obstetric Ultrasound - GLOWM



3D sonography of **fetal** face. Click the image to magnify it. Legend: 3D ultrasound is an ideal tool for the evaluation of the **fetal** face.

[Early pregnancy and...](#) · [Placenta](#) · [The fetal face](#) · [The fetal brain](#)

<https://www.geneeskundeboek.nl> > atlas-of-fetal-imagin... ▼

Advertenties · Nu winkelen



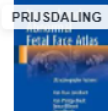
Just an atlas of fetal anatomy:...

€ 40,29

Amazon.nl

+€ 2,49 verz...

Van Google



Normal and Abnormal Fet...

€ 88,72

Was € 135

Wordery

Gratis verz...

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Atlas of Fetal Echocardiogr...

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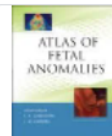
Color Atlas of Human Fetal...

€ 211,44

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Gratis verz...

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Atlas of Fetal Anomalies

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De Slegte

+€ 5,50 verz...

Gebruikt

Van Producth...

Resultaten voor

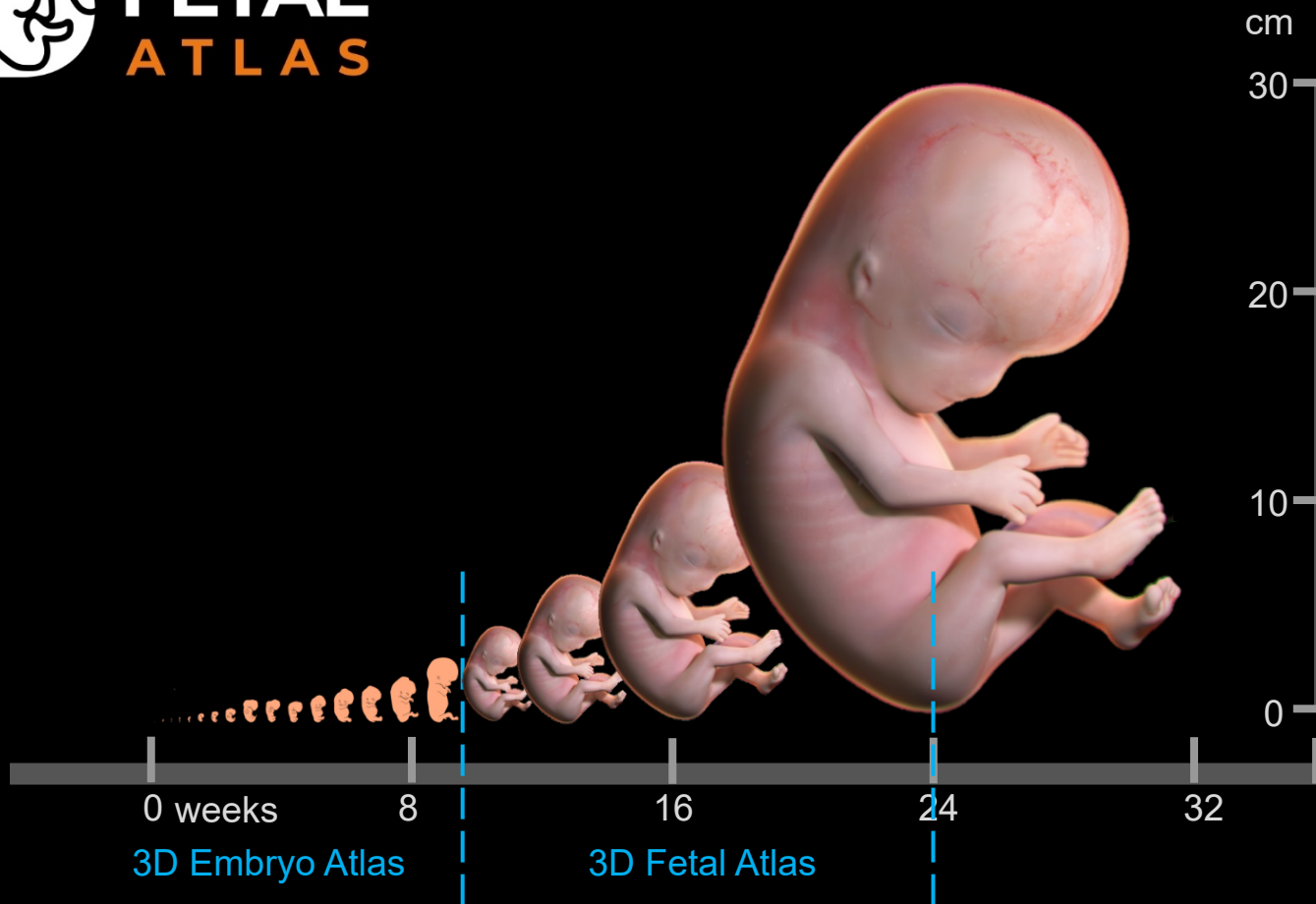


Atlas of Fetal Sectional Anatomy...

Boek van Edmund S. Crelin, Jr.



3D FETAL ATLAS



De Bakker Group



3D Fetal Atlas
Yousif Dawood, MD



3D Ultrasound Atlas
Marieke Buijtendijk, MD



3D Craniofacial Atlas
Karl Jacobs, MSc



3D palate development
Hans Smit, MD

Imaging Human Development



Forensic perinatal radiology
Valérie Niehe, MD



Prenatal Screening
Malou Lugthart, MD



3D tracheal development
Matthijs Fockens, MD



3D orbital development
Özlem Engin, MD



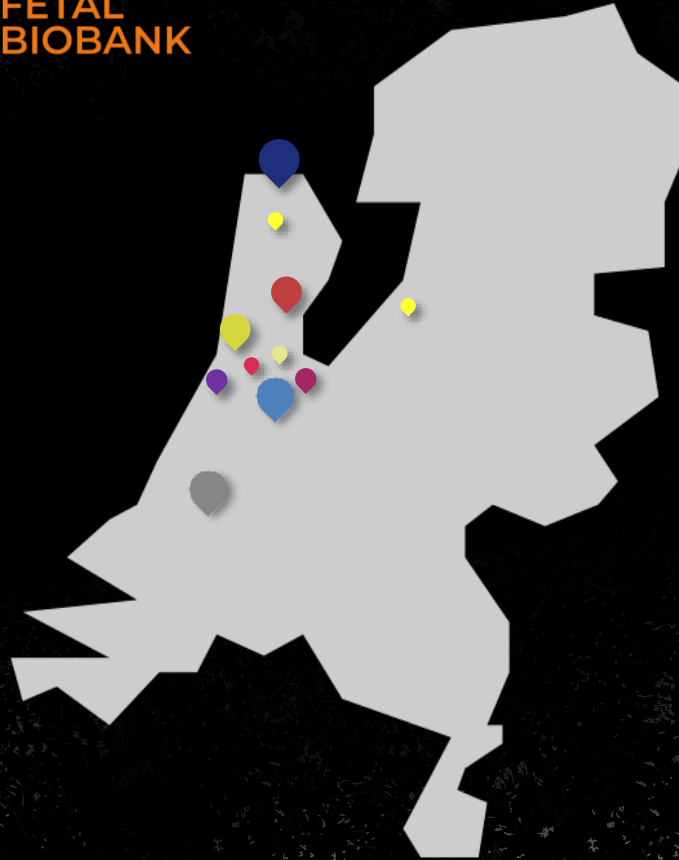
Initiative to make human fetal tissue available for (bio)medical research
Medical ethics committee and Biobank Committee approved protocol

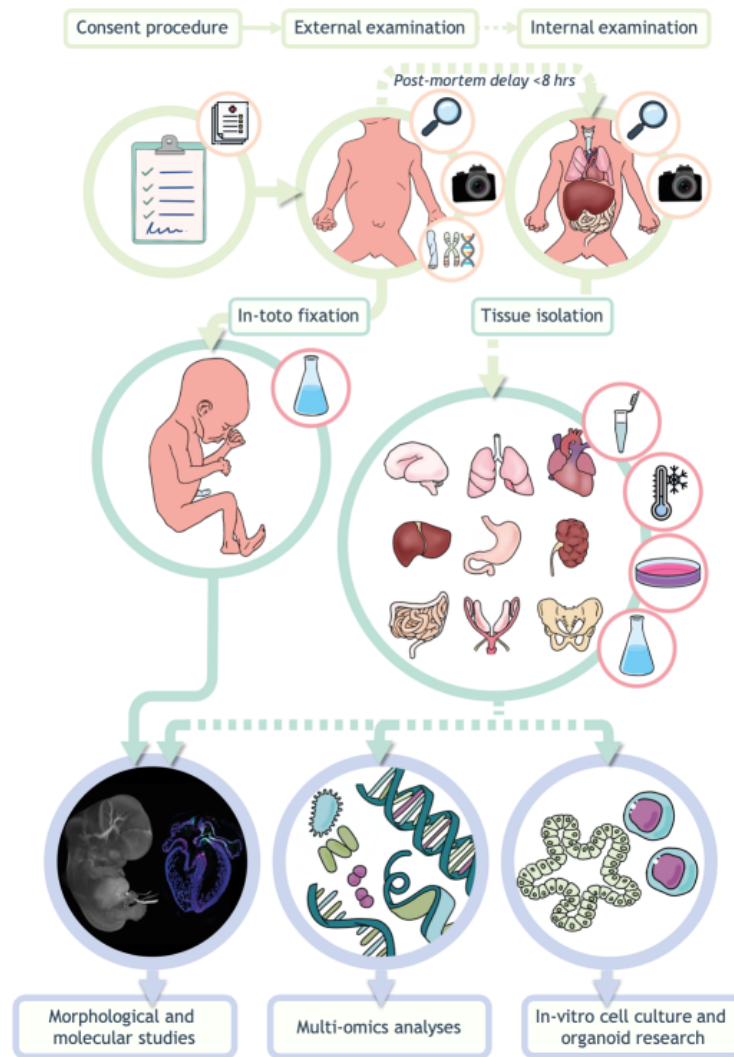
Care and respect



3D-printed fetus

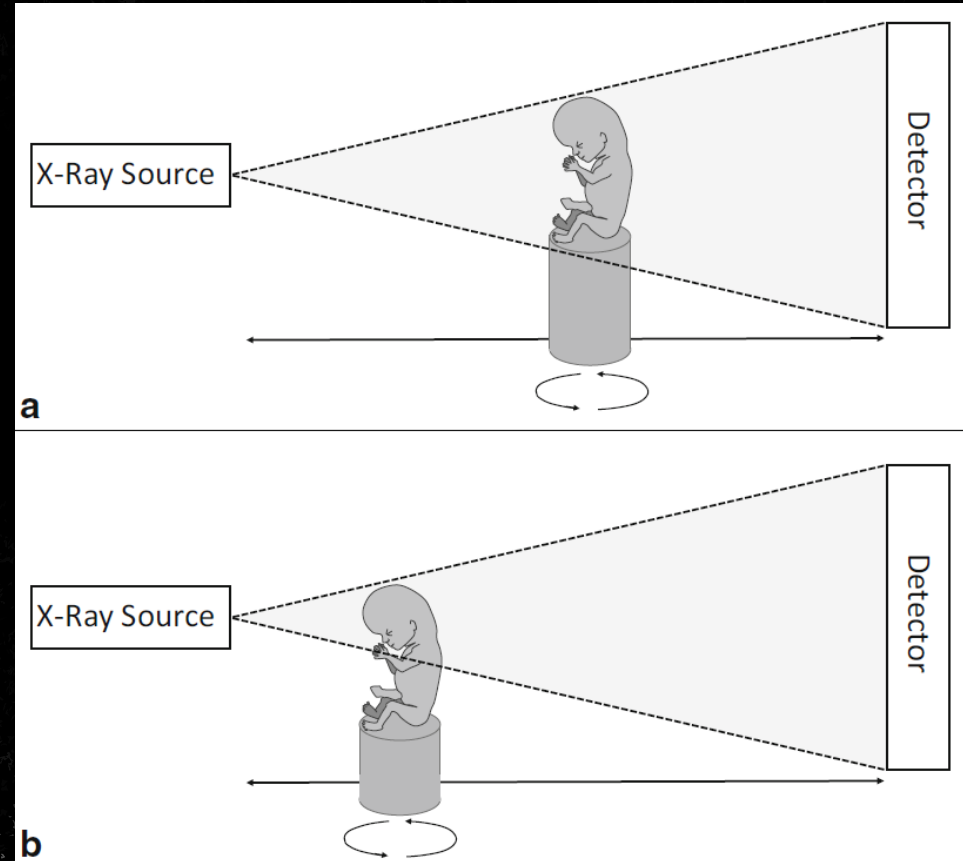






Imaging by Micro-CT

- Voxel size $< 100 \mu\text{m} \sim 1 \mu\text{m}$
- Animal morphology studies

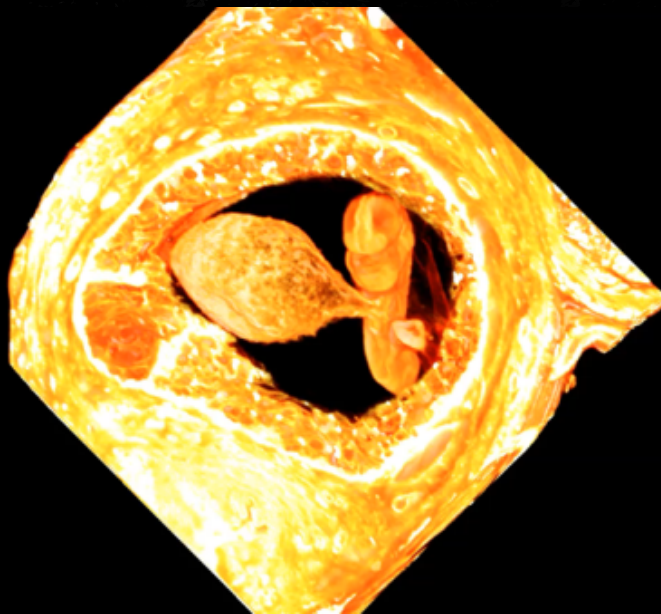


Staining in B-Lugol

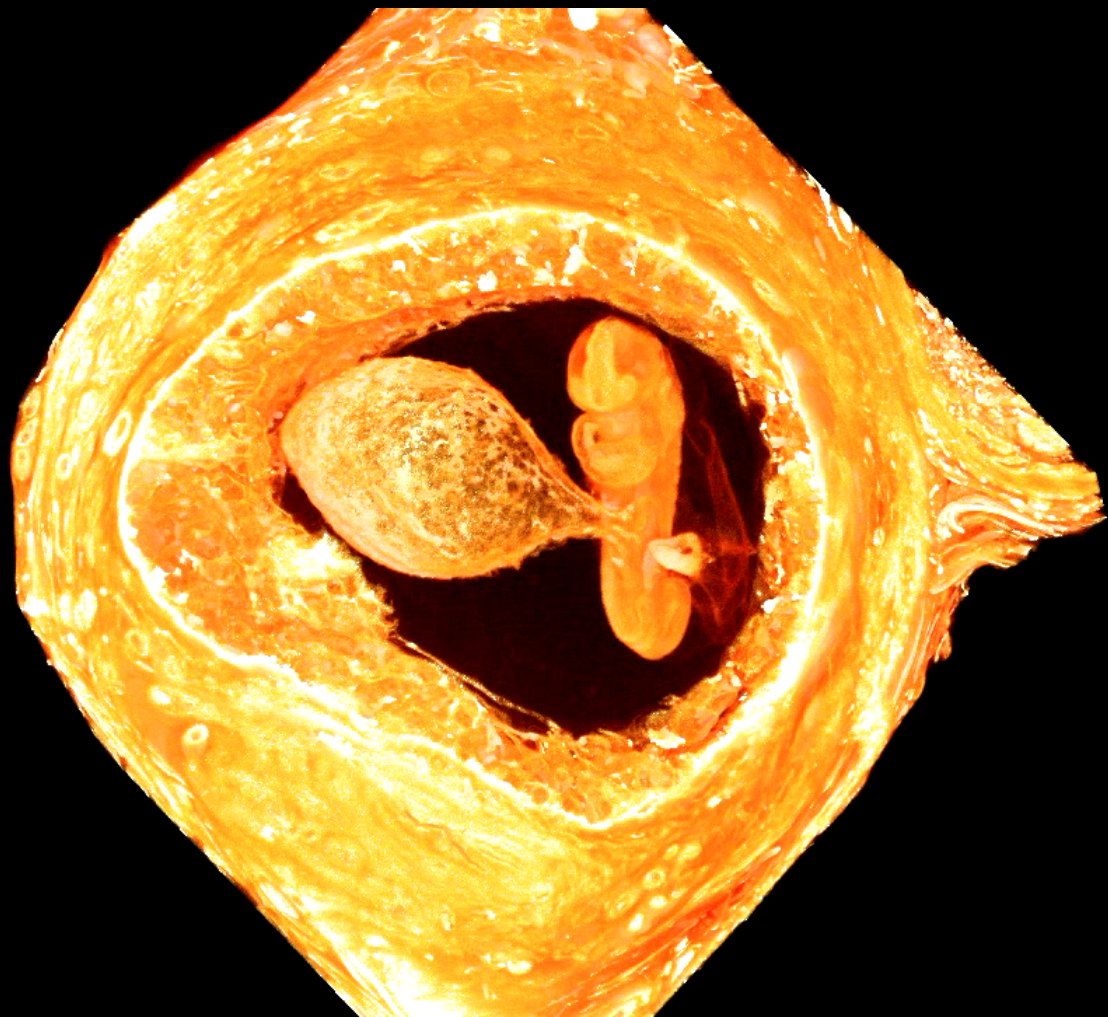




Yousif Dawood, MD
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~6 weeks Ectopic
3 mm CRL
3 micrometer resolution





Membership

Annual Meeting

Journals

Education

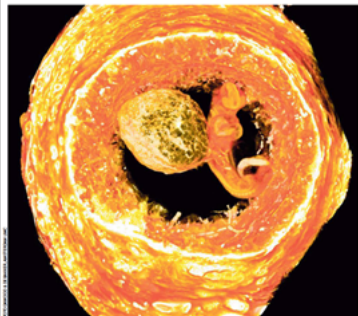
RSNA News

RSNA Radiology Journal Recognizes Its Top Images of 2021

Radiology In Training editors' select the top three images of the year



BEELD VAN DE WEEK



Embryologie
Prl begin van mens
in ruimtelijk detail

Verhogen van een beeld van een menselijke embryo. Een menselijke embryo is een klein, maar zeer complex organisme. Het is een wonder van de natuur, dat in de eerste weken van de zwangerschap al zoveel informatie over de toekomstige ontwikkeling van het kind bevat. Dit beeld toont een menselijk embryo in een vroeg stadium, waarbij de belangrijkste structuren al zichtbaar zijn. Het is een prachtig voorbeeld van de complexiteit van de menselijke ontwikkeling.

Sander Visser

Oudlits



De laatste specifieke
Dit wil je zien: unieke beeld van prl.
Tegels van de mens

MEDISCH CONTACT



Dit beeld toont een menselijk embryo in een vroeg stadium, waarbij de belangrijkste structuren al zichtbaar zijn. Het is een prachtig voorbeeld van de complexiteit van de menselijke ontwikkeling.

Radiology

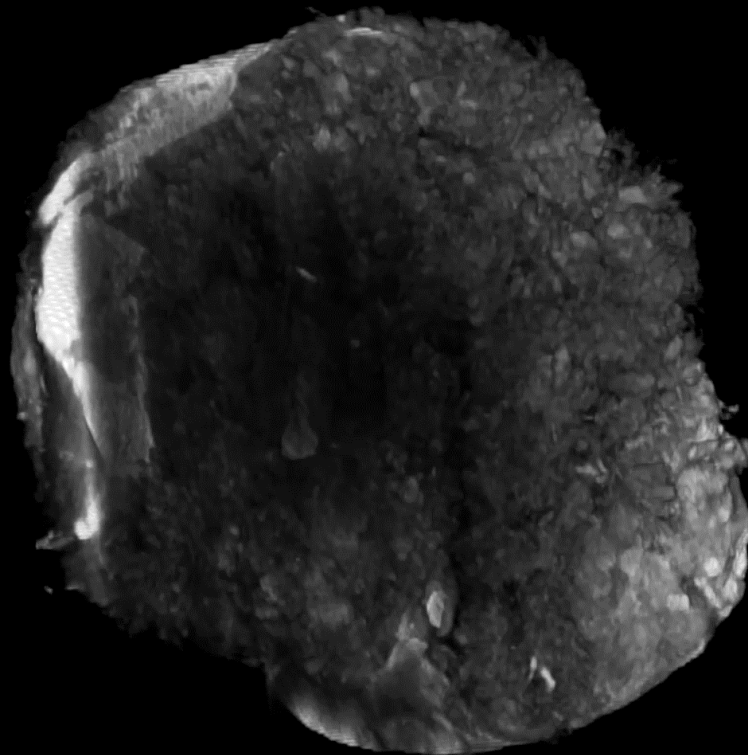


OCTOBER 2020 • VOLUME 297 NUMBER 1 • RADIOLOGY.RSNA.ORG

RSNA
Radiological Society
of North America



8+6 weeks
22 mm CRL
28 micrometer resolution



19+0 weeks
16 cm CRL
56 micrometer resolution







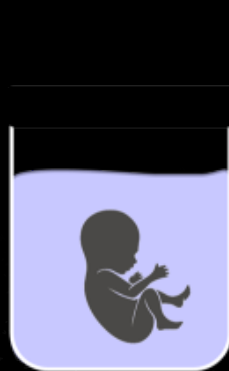
3D  **Ultrasound**
ATLAS







Marieke Buijtendijk, MD
m.f.buijtendijk@amsterdamumc.nl



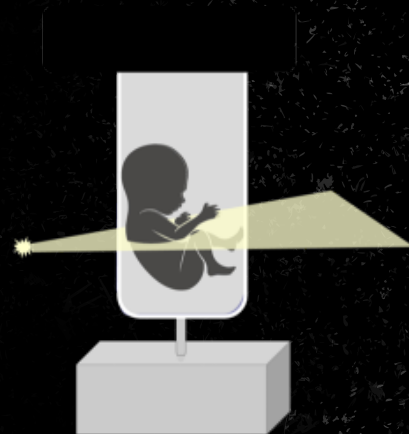
Fixation



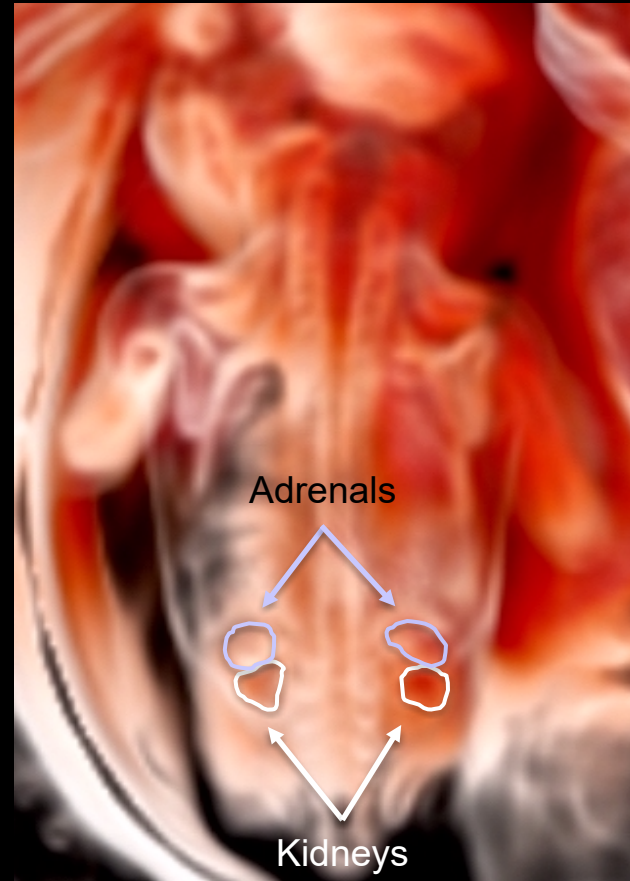
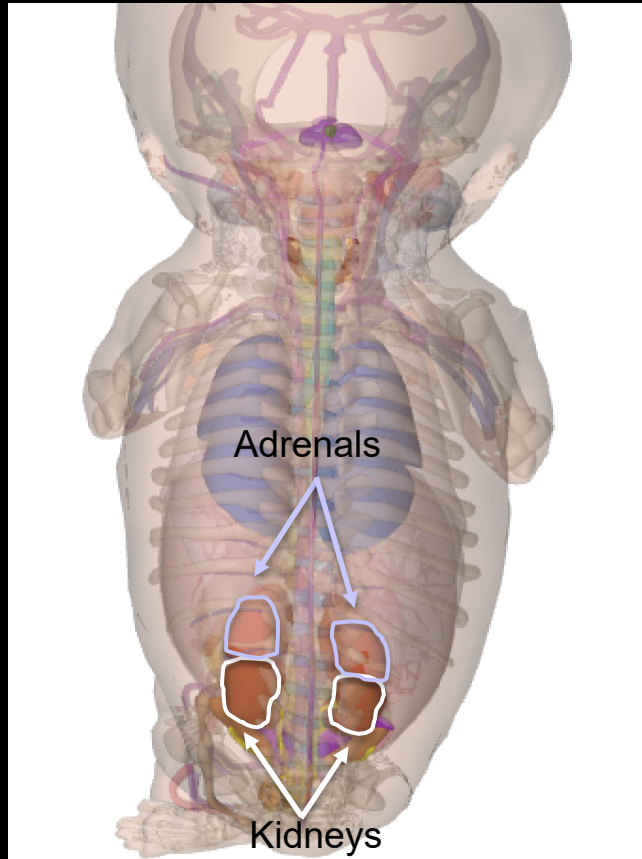
Ultrasound



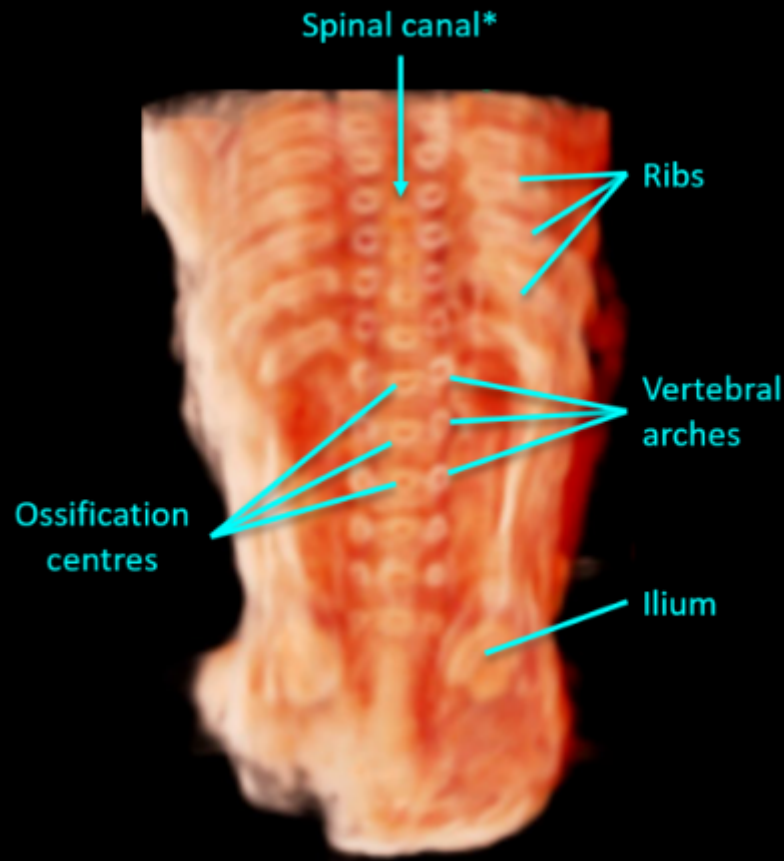
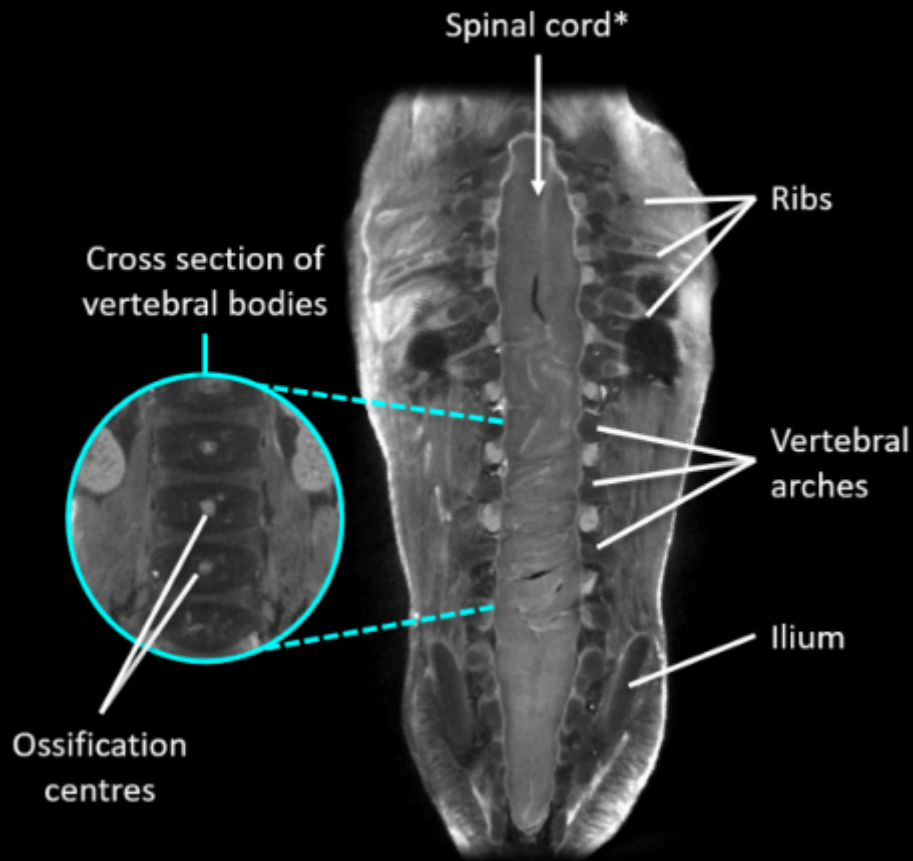
Contrast



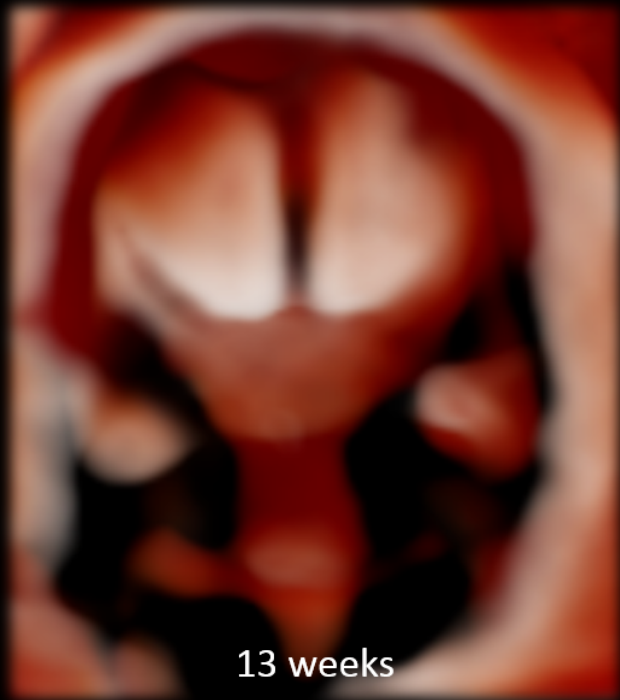
MicroCT



13 weeks



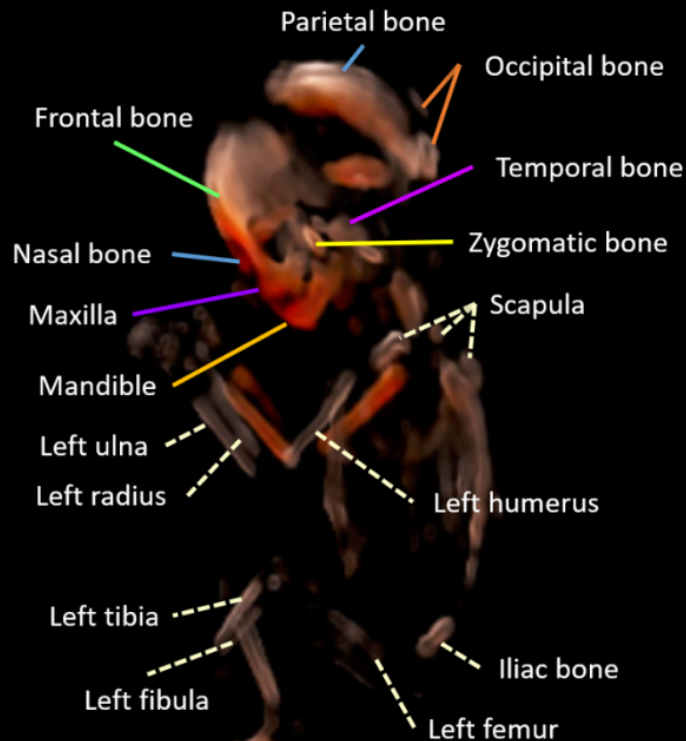
The Ventricular system



13 weeks

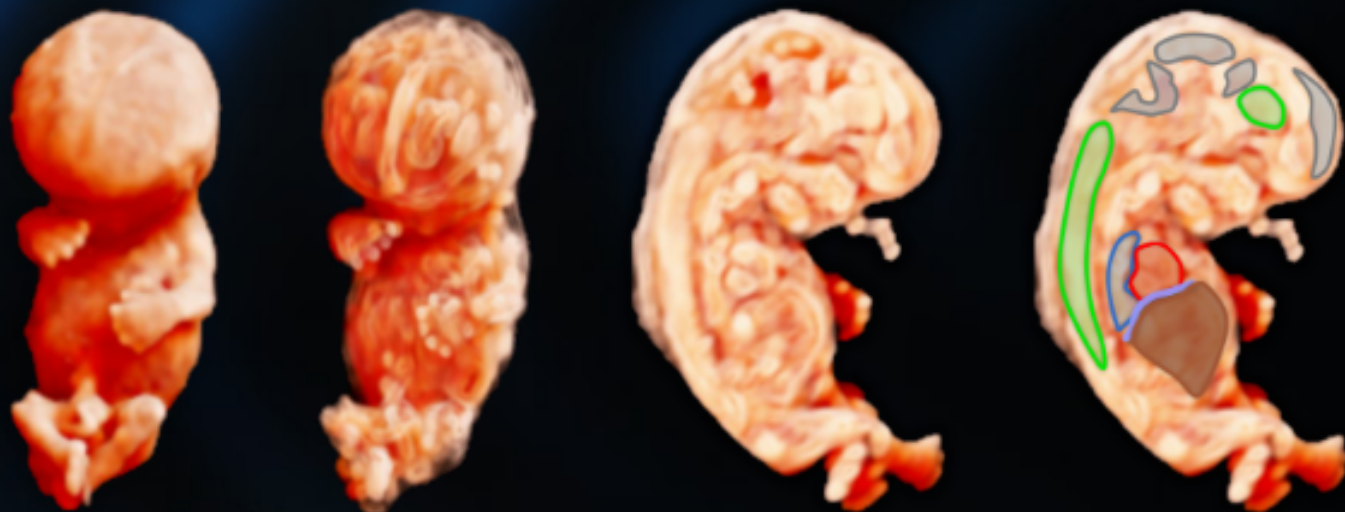


16 weeks



3D Ultrasound Atlas of Fetal Development

Unlocking the potential of state-of-the-art 3D ultrasound technology for fetal anatomy assessment from the first trimester onwards.





Fetal biobank – TOP study

Prof RCM Hennekam
 Prof E Pajkrt
 Prof E Aronica
 Prof RJ Oostra
 Dr C Ris-Stalpers
 Dr MJB van den Hoff
 Dr BS de Bakker
 Y Dawood, MD
 M Buijtendijk, MD
 JA Smit, MD
 P Lauffer, MD
 K Jacobs
 C Klop
 I Sanou
 N Rood
 D Bohly
 J Hagoort
 QD Gunst
 C de Gier-de Vries
 N Lobe

3D Embryology

Prof AFM Moorman
 Prof RJ Oostra
 Prof VM Christoffels
 Dr JM Ruijter
 Dr BS de Bakker
 K de Bree
 KH de Jong
 (Bio)medical students

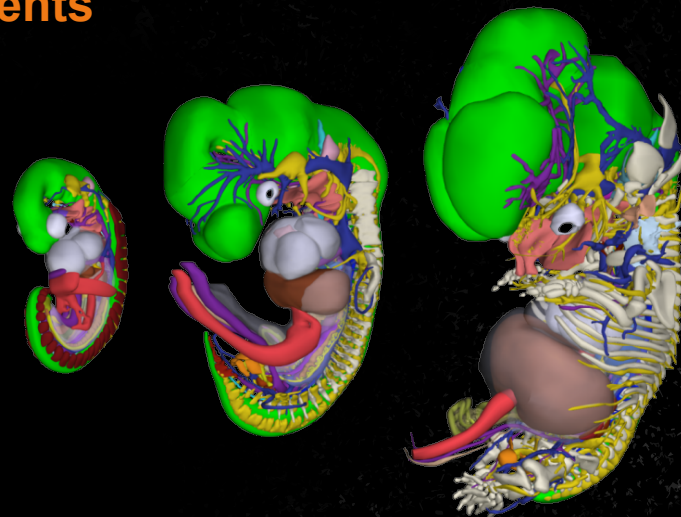
Imperial college London

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Erasmus MC – Paediatric surgery

Prof R Wijnen
 Dr M Schnater

Acknowledgments



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www.medischebiologie.nl/de-bakker-group

