The Rotate-Plus-Shift C–arm Trajectory: Complete Data with Less than 180° Rotation

Ludwig Ritschl[1], Jan Kuntz[2], Marc Kachelrieß[2]

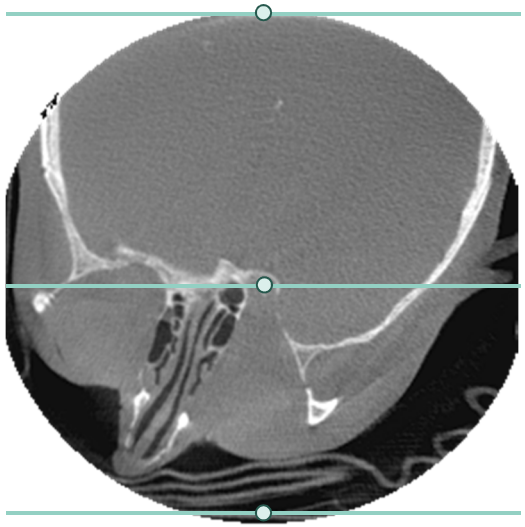
02.12.2014

[1]Ziehm Imaging GmbH, Nürnberg, Germany
[2]German Cancer Research Center, Heidelberg, Germany

Content

> Introduction
  > Theory of the short scan (180° + fan angle)
  > Clinical use of mobile 3D C-arms
> Method
  > The rotate-plus-shift trajectory
  > Implementation on a mobile C-arm
  > Image reconstruction using a filtered backprojection-based approach
> Results
  > Preclinical evaluation
> Discussion

How Much Rotation Range Do I Need in CT?



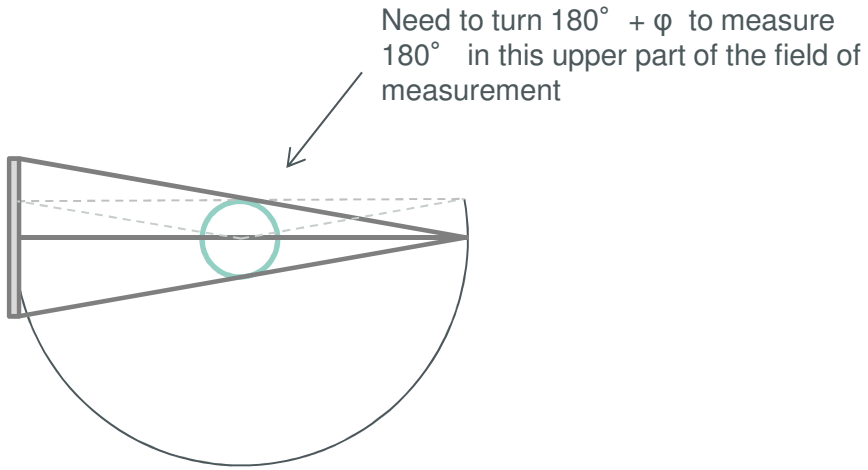
We need to measure every point inside the field of measurement in a 180° range. This is sufficient for accurate reconstruction!

- CT reconstruction bases on 2D Radon transform
- Measure line integrals over 180° for every point inside the field of measurement (FOM).

First EMI CT scanner in 1972 worked this way!

Why Requires the Short Scan 180° + Fan Angle φ?

Today's CT scanners and C-arms are constructed in fan-beam geometry.



The reason for 180° + φ rotation is, that you get 180° in **every** point inside the field of measurement (FOM).

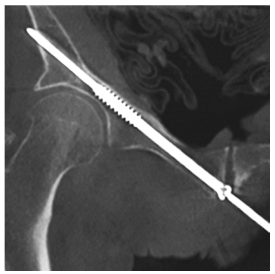
Clinical Use of Mobile 3D C-arms

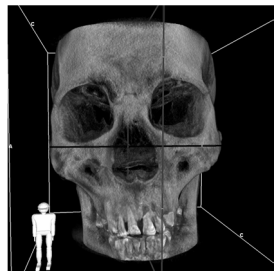
> Mobile C-arms are clinically used since 1954

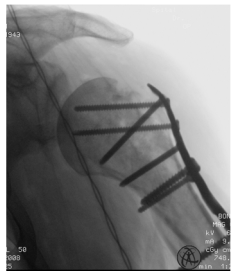
> 3D Imaging on mobile C-arms since 2002.

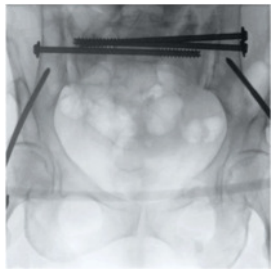
> Main 3D applications: Spine **surgery**, trauma **surgery**, ENT **surgery**

> All applications require a combination of 2D and 3D imaging:
2D usability should be preserved on 3D C-arms.







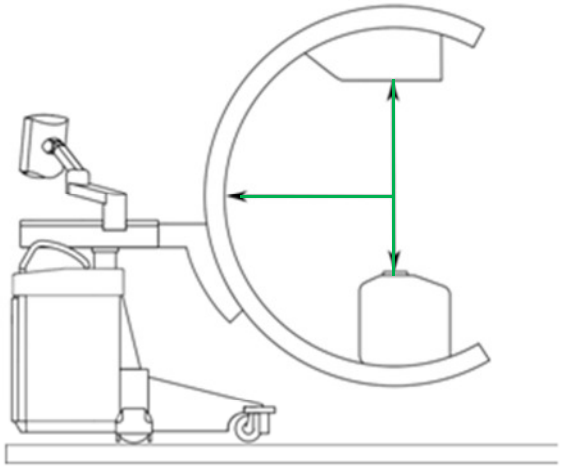


What Are The Geometric Requirements for 2D C-Arms?

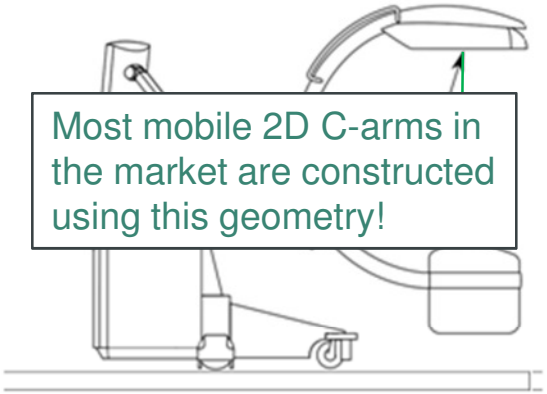
- **We need space:**
  - A **large C opening** in vertical and horizontal direction is needed for patient positioning and patient access.
  - A **small C shape** reduces interference with other equipment in the OR and improves handling.

What Should a Good 2D Mobile C-Arm Look Like?

- **We need space:**
  - A **large C-arm opening** in vertical and horizontal direction is needed for patient access
  - A **small C shape** reduces interference with other equipment in the OR

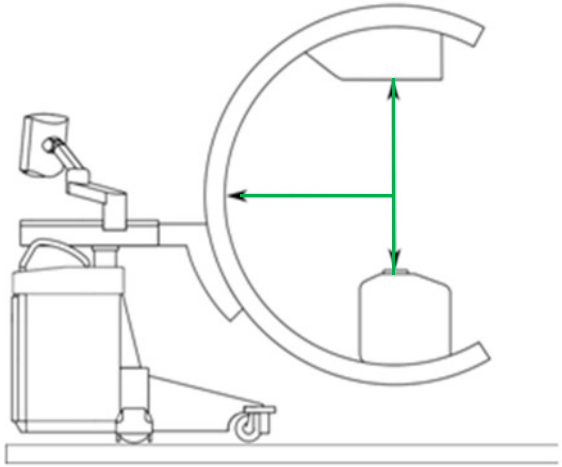


Large Isocentric C
- Large C
- Enough vertical free space
- Large horizontal opening



Small Non-Isocentric C
- Small C
- Enough vertical free space
- Large horizontal opening

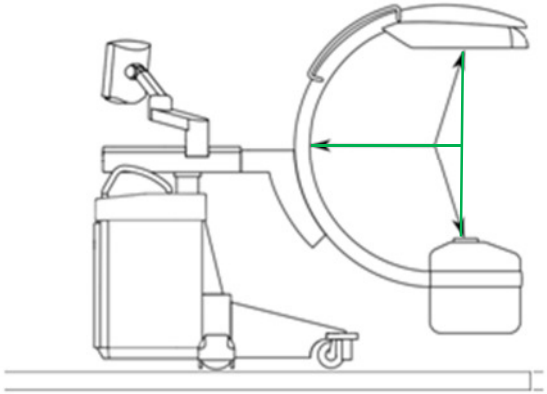
What About 3D Capabilities?



Large Isocentric C
- Large C
- Enough vertical free space
- Large horizontal opening

180° + φ of rotation

~195°



Small Non-Isocentric C
- Small C
- Enough vertical free space
- Large horizontal opening

180° - φ of rotation

~165°

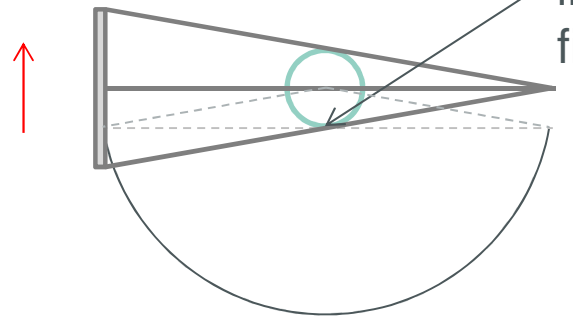
dkfz.

ziehmimaging

Create a way to reach 180° angular coverage in every point of the reconstructed FOM with 180° - φ of rotation!

What Happens at 180° - φ of Rotation?

Idea: Translate these rays to the other side of the field of measurement!

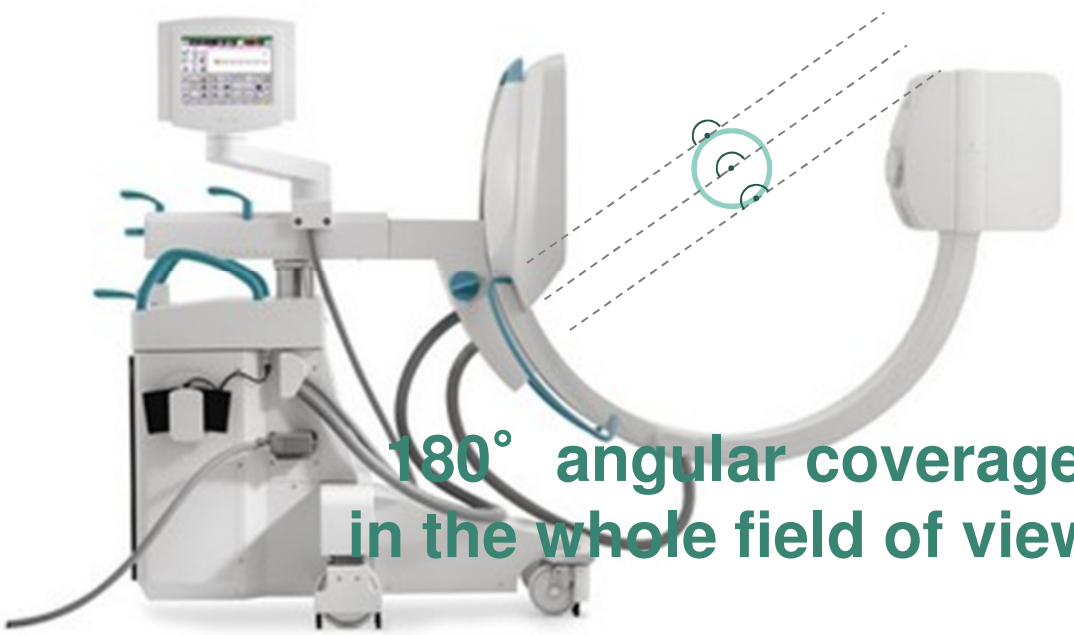


We already get **180°** in this lower part of the field of measurement!

Rotate + Shift Trajectory Using a Mobile C-arm

Scan 1: 180° + Shift

Scan 2: 180° + Shift



180° angular coverage in the whole field of view!

Technical Implementation on a Mobile C-arm

>Requires motorization of the horizontal and vertical axes holding the C

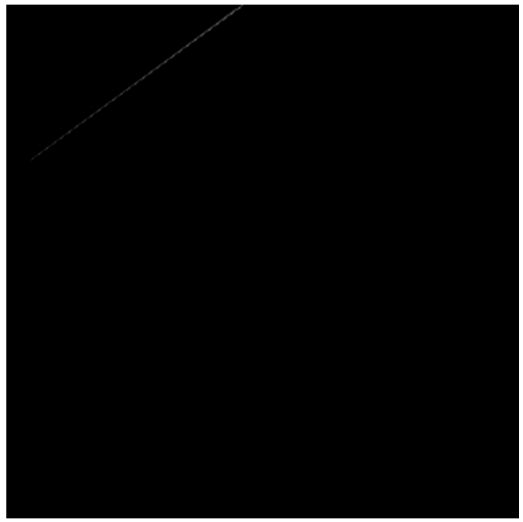
>Use adaptive collimators to collimate rays outside the field of view.

3D Reconstruction using Filtered Backprojection

> Use standard FDK type filtered backprojection for reconstruction

$$f(\boldsymbol{r}) = \int d\alpha \int du \underbrace{w(\alpha, \hat{u}, \hat{v}) \frac{|(\boldsymbol{o}-\boldsymbol{s})\cdot\boldsymbol{u}^{\perp}|}{((\boldsymbol{r}-\boldsymbol{s})\cdot\boldsymbol{u}^{\perp})^2} R_F \cos(\beta)\cos(\gamma)}_{\text{Weighting functions}} \underbrace{p(\alpha, u, \hat{v}(\alpha, \boldsymbol{r}))}_{\text{Raw data}} \underbrace{k(\hat{u}(\boldsymbol{r}, \alpha) - u)}_{\text{Kernel}}.$$

> Define dedicated redundancy weights for the rotate + shift scan.



Results: C-Arm for Preclinical Studies

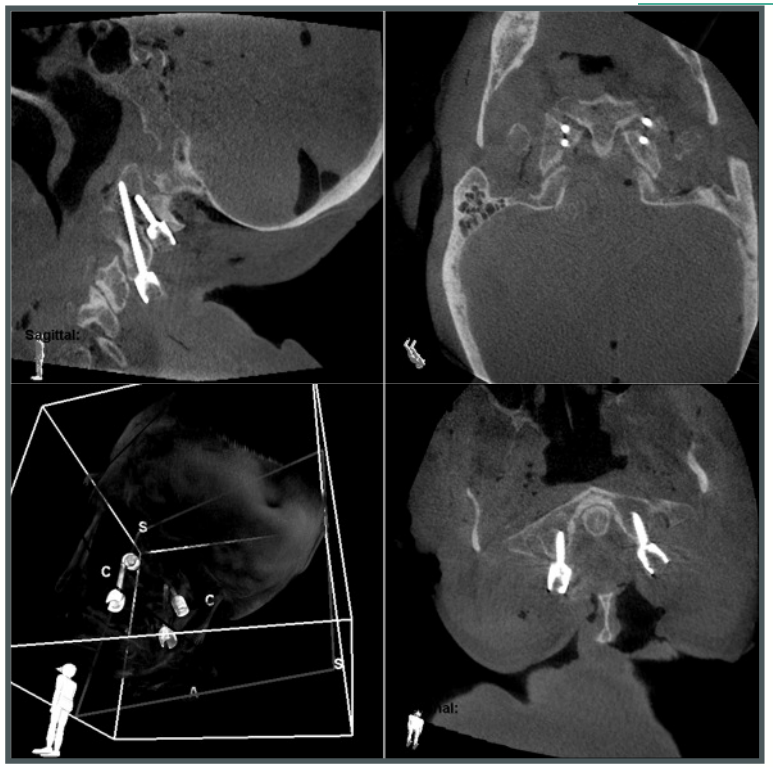
> 165° angular rotation
> 15.8° fan angle
> 25 kW x-ray generator
> 30 cm x 30 cm aSi flat detector

> Volume size 16 cm^3
> ~ 400 projections
> ~ 60-150 nGy detector entrance dose per projection (depending on application)

Results: Preclinical Evaluation

Cervical spine C1-C7

Visualization:
C1 – C2 screwing



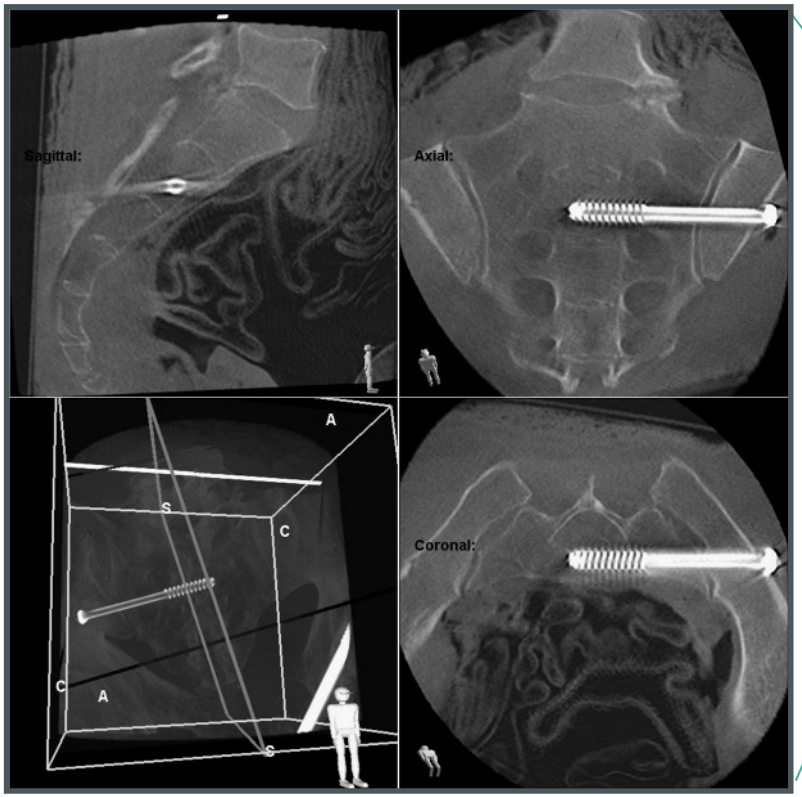
Cadaver: 84 years, male, osteoporotic

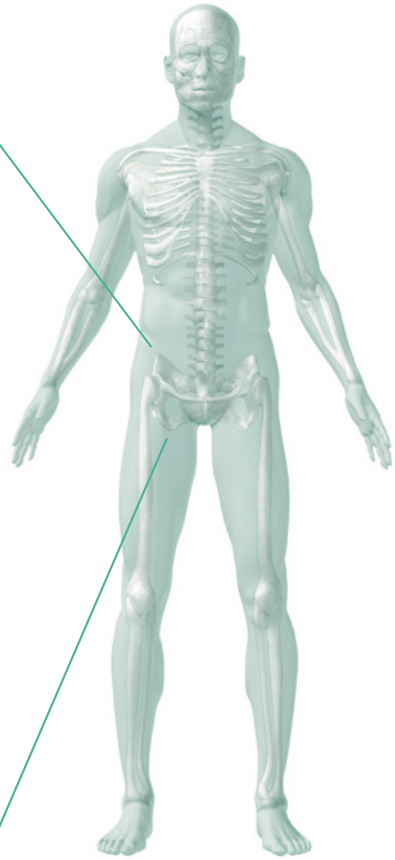
By the courtesy of Weill Cornell Medical College New York

Results: Preclinical Evaluation

Pelvis

Illosacral screw





Fresh cadaver

By the courtesy of University of Texas, Houston

Conclusion

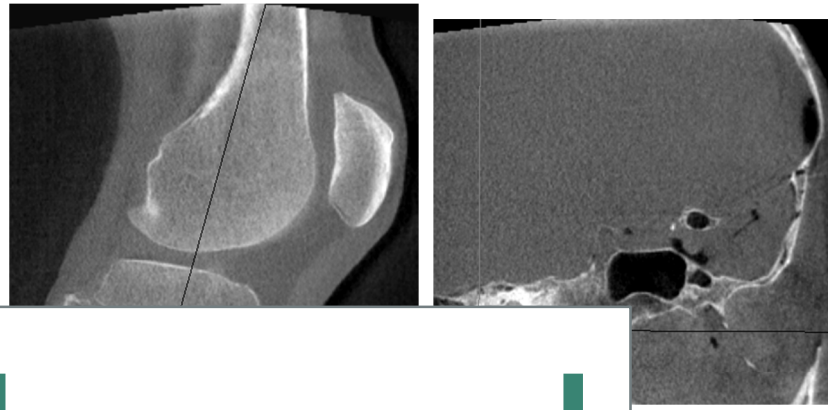
> Proposed new C-arm trajectory that enables for 3D imaging using „classic“ 2D C-arms.

> Technology is driven by clinical needs.

> Technical feasibility on a mobile C-arm was demonstrated.

> First preclinical results show large potential in a wide field of clinical applications.

Thanks to the team!



Christof Fleischmann	Ziehm Imaging GmbH
Eva-Maria Ilg	
Alexander Jooß	
Wolfgang Kränzel	
Stephan Menger	
Dr. Sven Steckmann	
Christina Tille	
Paul Gabriel	
Bryan May	
Ron Villane	Ziehm Imaging Inc.
Prof. Dr. Marc Kachelrieß	DKFZ Heidelberg
Dr. Jan Kuntz	DKFZ Heidelberg

Thank you!

This work was supported by DFG grant KA 1678/11.