An Anthropomorphic Deformable Phantom for Brain Shift Simulation

Siming Bayer[1], Adrian Wydra[2], Zhong Xia[1], Nishant Ravikumar[1], Maddalena Strumia[3], Roman Schaffert[1], Martin Ostermeier[3], Rebecca Fahrig[3], and Andreas Maier[1]

[1]*Pattern Recognition Lab, Department of Computer Science, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany*
[2]*True Phantom Solutions Inc. Windsor, Ontario, Canada*
[3]*Siemens Healthcare GmbH, Forchheim, Germany*

Introduction

- Intraoperative *brain shift* affects the accuracy of neurosurgical guidance significantly
- Conventional image-guided navigation systems do not compensate for soft tissue deformation
- C-Arm computed tomography (CT) is not well studied for *brain shift* compensation [1]
- Due to the lack of clinical data, a physical phantom is necessary

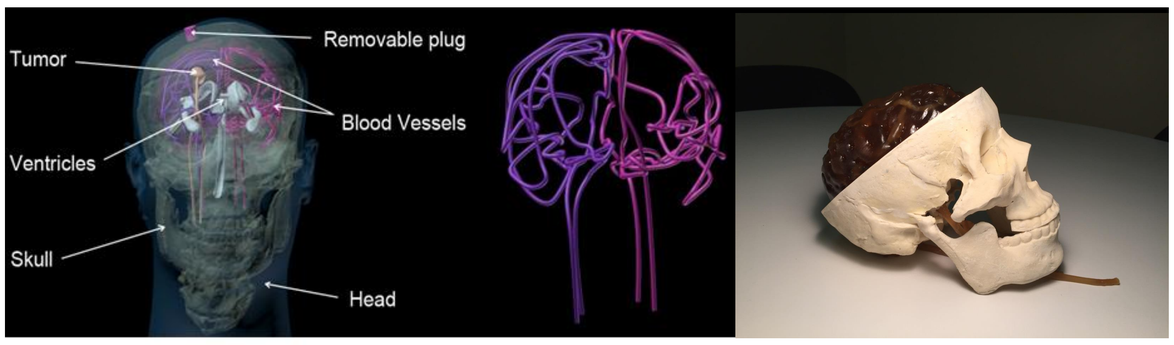
➢ Design and manufacture:
  ✓ an **anthropomorphic deformable brain phantom**
  ✓ visible **both for MRI and contrast enhanced C-Arm CT**

➢ Simulate the brain shift phenomenon
➢ Estimate the magnitude of the simulate brain shift

Phantom design and material properties

Phantom design

1) Skull
   - made out of a unique **ceramic composite bone material** [2]
   - average shape of the skull of an adult
   - an opening with a **removable plug**
2) Brain parenchyma
   - made out of an **ultra soft polyurethane base material**
   - embedded **vasculature** (Fig. 1b), **ventricles** (Fig. 1c) and an **inflatable tumor**



(a) (b) (c)

Figure 1: Front view of the complete design of the phantom (a), the geometry of the vessel (b), and the phantom skull with parenchyma (c).

Material properties

Components	Density [g/cm^3]	Stiffness [kPa]	T_2 [ms]	Hounsfield Unit
Skull	2.31	N.A.	N.A.	1500/600*
Parenchyma	0.99	100	70	-100 -- -15
Skin	1.02	740	45	-130 -- -40

Table 1: Material properties of the phantom. T_2 values are measured with a 3T MRI scanner by the manufacturer.
***** The average HU for the cortical bone and the diploe is 1500 and 600, respectively.

Brain shift simulation

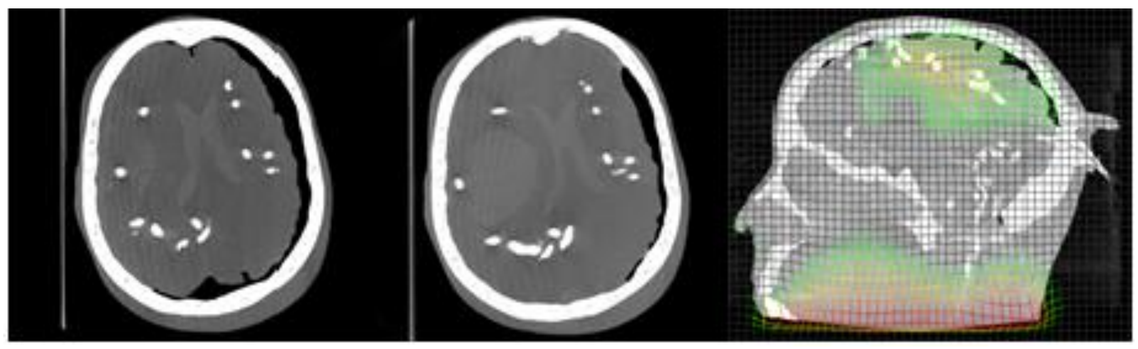
Data acquisition

1) Cone beam CT (CBCT) acquisition (Fig. 4):
   - 10s 3D Head DCT protocol (Siemens Artis Zee)
   - fill the vasculature with iodine-based contrast agent
2) MR acquisition (Fig. 5):
   - 3D flash sag isotropic sequence (Siemens Magnetom Aera)
   - TR = 10ms, TE = 3.25ms

Figure 2: Manufactured phantom

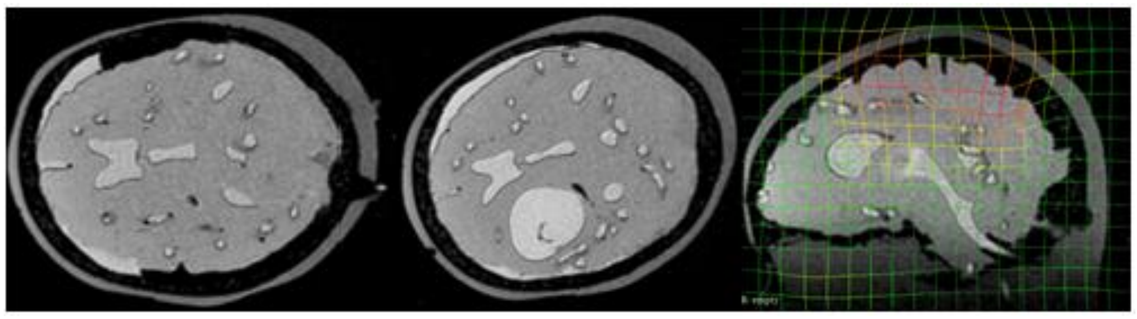
Brain shift estimation

- Perform mono-modal non-rigid registration for CBCT and MRI
- Use **symmetric image normalization (SyN)** [3] within the **Advanced Normalization Tools (ANTs**)
- Max. displacement are 28.1mm (CBCT) and 29.5mm (MRI)
- Results correlates with the clinical observations [4, 5]



(a) (b) (c)

Figure 4: Examples of CBCT (a)-(b) phantom acquisitions. (a) shows the acquisition with maximum deflated tumor, while (b) presents the maximum inflated tumor, (c) shows the estimated displacement field.



(a) (b) (c)

Figure 5: Examples of MR (a)-(b) phantom acquisitions. (a) shows the acquisition with maximum deflated tumor, while (b) presents the maximum inflated tumor, (c) shows the estimated displacement field.

Conclusion

1) Designed and manufactured an anthropomorphic deformable brain phantom:
   - use tissue mimicing materials
   - consists of prominent anatomical structures of brain
2) Simulated brain shift phenomenon on CBCT and MR:
   - estimated the magnitude of the induced deformation
   - results correlate with the clinical findings

References

[1] Bayer S. et al. IJBI. 2017
[2] Wydra A. and Maev B.A. Phys Med Biol. 2013
[3] Avants B. et al. Med Image Anal. 2008
[4] Nimsky C. et al. Neurosurgery. 2000
[5] Gerard I. J. et al. Med Image Anal. 2017

Contact

Siming Bayer
Pattern Recognition Lab, Department of Computer Science, Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany

✉ siming.bayer@fau.de
☎ +49 9131 85 27826

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