First Animal Cadaver Study for Interlocking of Intramedullary Nails under Camera Augmented Mobile C-arm
A Surgical Workflow Based Preclinical Evaluation

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Presented by Lejing Wang
Camera Augmented Mobile C-arm (CamC)

- The Camera Augmented Mobile C-arm (CamC)\textsuperscript{1,2} system augments a regular mobile C-arm by a video camera and mirror construction.

2. Navab et al. IEEE TMI 2010
Camera Augmented Mobile C-arm (CamC)

- Construction concept ¹,²

². Navab et al. IEEE TMI 2010
X-ray and Video Image Overlay

- X-ray images are co-registered with video images without any further calibration or registration during the intervention.

First Applications:
- needle guidance\(^1\)
- Trauma: interlocking of intramedullary nails\(^2\)
- Spine: pedicle screw placement\(^3\)
- Implant/Foreign-body removal
- Joint fractures
- X-ray positioning

CamC is expected to reduce radiation \(^4\)

1. Mitschke et al. MICCAI 00.
2. Heining et al. CAOS 2006
3. Heining et al. IGCARS. 2006
4. Navab et al. IEEE TMI 2010
Previous Work of CamC Evaluation

• Technical system properties
  – Accuracy of the overlay
  – Absorbed and scattered radiation of the mirror

• Pre-clinical study, CamC vs. CT for vertebroplasty using spine phantoms
  – one surgeon and five samples
  – no significant result

• In this work,
  – workflow based comparison method is presented
  – evaluate the clinical impacts of the CamC system

1. Navab et al. IEEE TMI 2010
2. Wang et al. BVM 2009
3. Traub et al. AMIARCS 2008
Evaluation of Image Guided Surgery (IGS) Systems

- Clinical evaluation is an important phase in the development of IGS systems
  - Practicability, efficiency and clinical suitability need to be confirmed

- An assessment framework with six levels from technical system properties to social and legal impacts

- We present a workflow based comparison of a novel IGS solution with a conventional solution, which
  - identifies the advantages and disadvantages on single step
  - easily generalizes results for single workflow steps
  - improves communication between technical researchers and surgeons

Surgical Workflow Based Evaluation

- The workflow based comparison method consists of the following steps

  1. Initializing the assessment objective
     motivation, surgical context, hypothesis, assessment level

  2. Modeling the workflow
     choosing surgical procedures, analyzing the workflow

  3. Defining evaluation criteria
     measurement parameters,

  4. Performing experiments and acquiring measurement parameters
     video or live observations, same setup for novel and conventional solution

  5. Comparing results
     statistical analysis

Interlocking of Intramedullary Nails

- Several computer assisted solutions were developed
  - miniature robot
  - optical tracking

- A clinical study of interlocking: navigation vs. C-arm

- We focus on evaluating the clinical impact of CamC by performing interlocking (not for interlocking)

Because interlocking
- is commonly used in fracture reduction surgery
- uses mobile C-arms
- requires skill and a large number of X-ray shots
- involves various common surgical tasks. e.g. X-ray positioning, targeting, and drilling

1. Yaniv & Joskowicz. IEEE TMI 2005
2. Leloup et al. IEEE TMI 2008
Workflow Model of Interlocking

<table>
<thead>
<tr>
<th>Step</th>
<th>Transition Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray positioning</td>
<td>Nail is placed inside the bone</td>
</tr>
<tr>
<td>Adjustment of hole</td>
<td>The locking hole appears in the X-ray image</td>
</tr>
<tr>
<td>Skin Incision</td>
<td>The hole appears as a circle in the X-ray image</td>
</tr>
<tr>
<td>Center punch</td>
<td>The correct incision position is verified</td>
</tr>
<tr>
<td>Alignment of the tip of the drill</td>
<td>The correct center punching is verified by one X-ray image</td>
</tr>
<tr>
<td>Drilling</td>
<td>The driller tip and the target are aligned, which is verified by one X-ray image</td>
</tr>
<tr>
<td>Locking screw insertion</td>
<td>The success of drilling is confirmed by one X-ray image</td>
</tr>
</tbody>
</table>

Workflow Model

- interlocking of intramedullary nails: drill one hole and put one screw

Assessment objective -> **modeling the workflow** -> defining evaluation criteria -> performing experiments -> comparing results
Defining Evaluation Criteria

- Evaluation criteria
  - The amount of applied radiation exposure
  - The performance of the surgical procedure

- Measurement parameters
  - the number of X-ray shots
  - operation time
  - quality of drilling (assessed by surgeons giving scores 1, 2, 3, or 5) \(^1\)

- Measures of statistics
  - Mean
  - STD
  - P-value (paired t-test)

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1. Suhm et al. Injury 2004
Materials and Experiments

- Foreleg of cow cadaver
- 27 pair cases. i.e. 54 procedures
- Five surgeons
- Parameters are recorded manually

Assessment objective -> modeling the workflow -> defining evaluation criteria -> performing experiments -> comparing results
Comparing Results

<table>
<thead>
<tr>
<th></th>
<th>X-ray Positioning</th>
<th>Adjustment of hole</th>
<th>Skin incision</th>
<th>Center punch</th>
<th>Alignment of the tip of the drill</th>
<th>Drilling</th>
<th>Locking screw insertion</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CamC group</strong></td>
<td>1.04 ± 0.19</td>
<td>2.96 ± 1.56</td>
<td>0.04 ± 0.19</td>
<td>2.56 ± 2.38</td>
<td>1.59 ± 1.34</td>
<td>1.22 ± 0.64</td>
<td>1.00 ± 0.00</td>
<td>10.41 ± 3.59</td>
</tr>
<tr>
<td><strong>C-arm group</strong></td>
<td>1.44 ± 0.70</td>
<td>2.85 ± 1.51</td>
<td>2.67 ± 1.21</td>
<td>4.63 ± 2.62</td>
<td>2.51 ± 1.56</td>
<td>2.89 ± 0.64</td>
<td>1.00 ± 0.00</td>
<td>17.63 ± 4.65</td>
</tr>
<tr>
<td><strong>P-value</strong></td>
<td>0.0052</td>
<td>0.71</td>
<td>&lt; 0.0001</td>
<td>0.00057</td>
<td>0.10</td>
<td>0.0033</td>
<td>1.00</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

**The number of X-ray shots (mean ± STD)**

**Operation time (mean ± STD) in second**

<table>
<thead>
<tr>
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<th>CamC group</th>
<th>C-arm group</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CamC group</strong></td>
<td>21.96 ± 7.16</td>
<td>24.63 ± 18.85</td>
<td>357.67 ± 157.64</td>
</tr>
<tr>
<td><strong>C-arm group</strong></td>
<td>24.85 ± 9.93</td>
<td>21.22 ± 12.94</td>
<td>350.41 ± 108.73</td>
</tr>
<tr>
<td><strong>P-value</strong></td>
<td>0.16</td>
<td>0.40</td>
<td>0.00099</td>
</tr>
</tbody>
</table>

assessment objective -> modeling the workflow -> defining evaluation criteria -> performing experiments -> comparing results
Discussion & Conclusion

- Evaluate the clinical impact of the CamC system
  - surgical workflow based evaluation
  - Interlocking on cow cadaver forelegs

- Surgeons performed surgical tasks more confidently when using CamC

- Overall results
  - significantly less radiation exposure
  - similar operation time and similar drilling quality

- CamC has its main positive impact in the following surgical tasks
  - X-ray positioning, skin incision, center punch, and drilling
  - they are also common in different surgical procedures
Acknowledgement

- Thanks to Trauma Surgery Department, Klinikum Innenstadt, LMU Munich
- Our colleagues at NARVIS lab

Thank you for your attention

- CAMC system has been developed with partial support from Siemens Healthcare
Ongoing...

- Continue pre-clinical study
  - foreign body removal
  - learning curve analysis

- Workflow based comparison for clinical study
  - first 43 surgeries were carried out using CamC
  - complete 43 surgeries using C-arm for matching pairs
Two Clinical Distal Interlocking

- Humerus
- Femur
X-ray Positioning

- Intuitive video-based guidance for moving C-arm
Skin Incision

- Find the target place for skin incision using the guidance of the video with an aligned X-ray image
Center Punch

- Easily identify the location for center punch
Drilling

- The overlay of X-ray and video image can support the control of drilling axis
END OF PRESENTATION