Review of Dynamic Calibration Corridor Making Methods
Back Ground

- So far, two different dynamic calibration test methods (Pendulum Type, Inverse Type) were proposed and then discussed that among the TEG members.
- On the other hands, two different corridor making methods (FTSS-Method, BASt-Method) were also proposed, however, no detailed discussion has not been made among TEG members.
- This study, therefore, reviewed the two different corridor making methods using the published two different dynamic calibration test data.
1. Review of the Two Different Dynamic Calibration Test Methods (Pendulum Type, Inverse Type) and Two Different Corridor Making Methods (FTSS-Method, BASst-Method)
Pendulum Type (Type 2) Dynamic Calibration Test Method and FTSS Corridor Making Method

Dynamic Calibration Test Method

Pendulum Type (Type 2) Dynamic Calibration Test Method
Up side down, Additional Mass 5kg, without Flesh

Corridor Making Method

FTSS-Method

- Average +/- 10% or Average +/- 2 St. Dev (wider one)

Ref.: ESV2009, Paper Number 09-0146

Suspension angle 15 deg.

Tibia

Knee

Femur

Flex-GTR proto

Additional Mass 5kg

Released
(Free fall around the pin joint)
**Inverse Type Dynamic Calibration Test Method and BASt Corridor Making Method**

**Inverse Type Dynamic Calibration Test Method**

**Hanging System**

- Release the FlexPLI within [5] ms after the moving ram impact

**Moving ram**

- Total Mass: 8.1 +/- 0.1 kg
- Impact speed: 11.1 +/- 0.2 m/s

**Impact face**

- 0 +/- 3 mm at impact

**Honeycomb**

- Width: 225 +/- 25 mm
- Height: 160 +/- 2 mm
- Crash strength: 75 psi +/- 10%

**FlexPLI with Flesh**

- (Cross sectional image)

**Knee joint center**

**Corridor Making Method**

**BASt-Method**

- Upper Corridor: Max. x 1.05
- Lower Corridor: Min. / 1.05

Ref.: TEG-094
Already Conducted Analysis

**Pendulum Type**

Test Data obtained from Pendulum Type (Type 2) Dynamic Calibration Test Method

- FTSS-Method
- BASst-Method

Tentative Corridor (FTSS-Method)
For Pendulum Type (Type 2) Dynamic Calibration Test Method

Tentative Corridor (BASst-Method)
For Pendulum Type (Type 2) Dynamic Calibration Test Method

Some test data were excluded

**Inverse Type**

Test Data obtained from Inverse Type Dynamic Calibration Test Method

- FTSS-Method
- BASst-Method

Tentative Corridor (FTSS-Method)
For Inverse Type Dynamic Calibration Test Method

Tentative Corridor (BASst-Method)
For Inverse Type Dynamic Calibration Test Method

All test data were used

Conducted Analysis in This Study

**Pendulum Type**

Test Data obtained from Pendulum Type (Type 2) Dynamic Calibration Test Method

- FTSS-Method
- BASst-Method

Tentative Corridor (FTSS-Method)
For Pendulum Type (Type 2) Dynamic Calibration Test Method

Tentative Corridor (BASst-Method)
For Pendulum Type (Type 2) Dynamic Calibration Test Method

All test data were used

**Inverse Type**

Test Data obtained from Inverse Type Dynamic Calibration Test Method

- FTSS-Method
- BASst-Method

Tentative Corridor (FTSS-Method)
For Inverse Type Dynamic Calibration Test Method

Tentative Corridor (BASst-Method)
For Inverse Type Dynamic Calibration Test Method

All test data were used
2. Making Corridors
2.1 Corridor for Pendulum Test
### Tentative Corridor (FTSS-Method)
for Pendulum Type (Type 2) Dynamic Calibration Test Method

- Test Data: FTSS Nov. 08 Pendulum Type (Type 2) Dynamic Calibration Test Data (TEG-071, all test data were used)
- Corridor Making Method: FTSS-Method

#### Corridor Making Method

**FTSS-Method**

- Average +/- 10% or Average +/- 2 St. Dev (wider one)

Ref.: ESV2009, Paper Number 09-0146

#### Pendulum Test (Type 2) Tentative Corridor

Data: FTSS (TEG-071), Method: FTSS

<table>
<thead>
<tr>
<th>Tibia-1 (Nm)</th>
<th>Tibia-2 (Nm)</th>
<th>Tibia-3 (Nm)</th>
<th>Tibia-4 (Nm)</th>
<th>ACL (mm)</th>
<th>PCL (mm)</th>
<th>MCL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>242.5</td>
<td>201.1</td>
<td>160</td>
<td>108</td>
<td>8.19</td>
<td>4.91</td>
</tr>
<tr>
<td>Max.</td>
<td>248</td>
<td>205</td>
<td>171</td>
<td>111</td>
<td>8.64</td>
<td>5.26</td>
</tr>
<tr>
<td>Min.</td>
<td>235</td>
<td>195</td>
<td>152</td>
<td>106</td>
<td>7.79</td>
<td>4.37</td>
</tr>
<tr>
<td>St.Dev</td>
<td>3.7</td>
<td>3.3</td>
<td>6.8</td>
<td>1.5</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>CV (%)</td>
<td>1.5</td>
<td>1.6</td>
<td>4.3</td>
<td>1.4</td>
<td>3.8</td>
<td>7.0</td>
</tr>
<tr>
<td>Max. Ratio (%)</td>
<td>2.3</td>
<td>1.9</td>
<td>6.9</td>
<td>2.8</td>
<td>5.5</td>
<td>7.1</td>
</tr>
<tr>
<td>Min. Ratio (%)</td>
<td>-3.1</td>
<td>-3.0</td>
<td>-5.0</td>
<td>-1.9</td>
<td>-4.9</td>
<td>-11.0</td>
</tr>
<tr>
<td>Average x 0.1</td>
<td>24.3</td>
<td>20.1</td>
<td>16.0</td>
<td>10.8</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>St.Dev x 2.0</td>
<td>7.4</td>
<td>6.6</td>
<td>13.6</td>
<td>3.0</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Larger value of above</td>
<td>24.3</td>
<td>20.1</td>
<td>16.0</td>
<td>10.8</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Upper Corridor</td>
<td>266.8</td>
<td>221.2</td>
<td>176.0</td>
<td>118.8</td>
<td>9.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Lower Corridor</td>
<td>218.3</td>
<td>181.0</td>
<td>144.0</td>
<td>97.2</td>
<td>7.4</td>
<td>4.3</td>
</tr>
<tr>
<td>Upper Corridor Ratio (%)</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>12.2</td>
</tr>
<tr>
<td>Lower Corridor Ratio (%)</td>
<td>-10.0</td>
<td>-10.0</td>
<td>-10.0</td>
<td>-10.0</td>
<td>-10.0</td>
<td>-12.2</td>
</tr>
</tbody>
</table>

Pendulum Test (Type 2): Up side Down, Additional Mass 5 kg, without Flesh

Max. Ratio: Max. / Average - 1
Min. Ratio: Min. / Average - 1
Upper Corridor Ratio: Upper Corridor / Average - 1
Lower Corridor Ratio: Lower Corridor / Average - 1

- Most of the upper and lower corridors were made by using minimum width of corridor (Average +/- 10%)
Tentative Corridor (FTSS-Method) for Pendulum Type (Type 2) Dynamic Calibration Test Method

• Test Data: FTSS Nov. 08 Pendulum Type (Type 2) Dynamic Calibration Test Data (TEG-071, all test data were used)
• Corridor Making Method: FTSS-Method

- Most of the upper and lower corridors were made by using minimum width of corridor (Average +/- 10%)
**Tentative Corridor (BASt-Method)**

for Pendulum Type (Type 2) Dynamic Calibration Test Method

- Test Data: FTSS Nov.08 Pendulum Type (Type 2) Dynamic Calibration Test Data (TEG-071, all test data were used)
- Corridor Making Method: BASt-Method

---

**Corridor Making Method**

**BASt-Method**

- Upper Corridor: Max. x 1.05
- Lower Corridor: Min. / 1.05

Ref.: TEG-094

---

**Pendulum Test (Type 2) Tentative Corridor**

Data: FTSS (TEG-071), Method: BASt

<table>
<thead>
<tr>
<th></th>
<th>Tibia-1 (Nm)</th>
<th>Tibia-2 (Nm)</th>
<th>Tibia-3 (Nm)</th>
<th>Tibia-4 (Nm)</th>
<th>ACL (mm)</th>
<th>PCL (mm)</th>
<th>MCL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>242.5</td>
<td>201.1</td>
<td>160</td>
<td>108</td>
<td>8.19</td>
<td>4.91</td>
<td>22.4</td>
</tr>
<tr>
<td>Max.</td>
<td>248</td>
<td>205</td>
<td>171</td>
<td>111</td>
<td>8.64</td>
<td>5.26</td>
<td>22.5</td>
</tr>
<tr>
<td>Min.</td>
<td>235</td>
<td>195</td>
<td>152</td>
<td>106</td>
<td>7.79</td>
<td>4.37</td>
<td>22.2</td>
</tr>
<tr>
<td>CV (%)</td>
<td>1.5</td>
<td>1.6</td>
<td>4.3</td>
<td>1.4</td>
<td>0.3</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Max. Ratio (%)</td>
<td>2.3</td>
<td>1.9</td>
<td>6.9</td>
<td>2.8</td>
<td>5.5</td>
<td>7.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Min. Ratio (%)</td>
<td>-3.1</td>
<td>-3.0</td>
<td>-5.0</td>
<td>-1.9</td>
<td>-4.9</td>
<td>-11.0</td>
<td>-0.9</td>
</tr>
</tbody>
</table>

**Upper Corridor**

- Max. x 1.05
- Min. / 1.05

**Lower Corridor**

- Max. x 1.05
- Min. / 1.05

---

**Test Data**

### Summary dynamic calibration

<table>
<thead>
<tr>
<th>FTSS</th>
<th>Log</th>
<th>Tibia-1</th>
<th>Tibia-2</th>
<th>Tibia-3</th>
<th>Tibia-4</th>
<th>ACL</th>
<th>PCL</th>
<th>MCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEST</td>
<td>#1</td>
<td>75.1</td>
<td>177</td>
<td>105.6</td>
<td>102</td>
<td>19</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>TEST</td>
<td>#2</td>
<td>75.1</td>
<td>181</td>
<td>109</td>
<td>103</td>
<td>19</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>TEST</td>
<td>#3</td>
<td>75.1</td>
<td>181</td>
<td>109</td>
<td>103</td>
<td>19</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>TEST</td>
<td>#4</td>
<td>75.1</td>
<td>181</td>
<td>109</td>
<td>103</td>
<td>19</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>TEST</td>
<td>#5</td>
<td>75.1</td>
<td>181</td>
<td>109</td>
<td>103</td>
<td>19</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td>TEST</td>
<td>#6</td>
<td>75.1</td>
<td>181</td>
<td>109</td>
<td>103</td>
<td>19</td>
<td>10</td>
<td>0.5</td>
</tr>
</tbody>
</table>

---

**Pendulum Test (Type 2):**

- Up side Down, Additional Mass 5 kg, without Flesh
- Max. Ratio: Max. / Average - 1
- Min. Ratio: Min. / Average - 1
- Upper Corridor Ratio: Upper Corridor / Average - 1
- Lower Corridor Ratio: Lower Corridor / Average - 1

---

*All of the upper and lower corridors were made by using test data (Max. x 1.05, Min. / 1.05)*
Tentative Corridor (BASt-Method)
for Pendulum Type (Type 2) Dynamic Calibration Test Method

- Test Data: FTSS Nov.08 Pendulum Type (Type 2) Dynamic Calibration Test Data (TEG-071, all test data were used)
- Corridor Making Method: BASt-Method

- All of the upper and lower corridors were made by using test data (Max. x 1.05, Min. / 1.05)
Tentative Corridor (FTSS-Method) for Pendulum Type (Type 2) Dynamic Calibration Test Method

• Most of the upper and lower corridors were made by using minimum width of corridor (Average +/- 10%)

Tentative Corridor (BASt-Method) for Pendulum Type (Type 2) Dynamic Calibration Test Method

• All of the upper and lower corridors were made by using test data (Max. x 1.05, Min. / 1.05)
2.2 Corridor for Inverse Test
**Tentative Corridor (FTSS-Method) for Inverse Type Dynamic Calibration Test Method**

- Test Data: BASl Inverse Type Dynamic Test Data (TEG-094, all test data were used)
- Corridor Making Method: FTSS-Method

**Corridor Making Method**

FTSS-Method

- Average +/- 10% or Average +/- 2 St. Dev (wider one)

Ref.: ESV2009, Paper Number 09-0146

**Inverse Test Tentative Corridor**

Data: BASl (TEG-094), Method: FTSS

<table>
<thead>
<tr>
<th>Tibia-1 (Nm)</th>
<th>Tibia-2 (Nm)</th>
<th>Tibia-3 (Nm)</th>
<th>Tibia-4 (Nm)</th>
<th>ACL (Nm)</th>
<th>PCL (mm)</th>
<th>MCL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>256.6</td>
<td>241.5</td>
<td>194.1</td>
<td>111.7</td>
<td>10.4</td>
<td>5.5</td>
</tr>
<tr>
<td>Max.</td>
<td>262.7</td>
<td>251.3</td>
<td>209</td>
<td>114.5</td>
<td>11.5</td>
<td>6</td>
</tr>
<tr>
<td>Min.</td>
<td>251.4</td>
<td>234.3</td>
<td>184.9</td>
<td>108.9</td>
<td>9.4</td>
<td>5</td>
</tr>
<tr>
<td>St.Dev</td>
<td>3.6</td>
<td>5.3</td>
<td>10.1</td>
<td>1.9</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>CV (%)</td>
<td>1.4</td>
<td>2.2</td>
<td>5.2</td>
<td>1.7</td>
<td>6.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Max. Ratio (%)</td>
<td>2.4</td>
<td>4.1</td>
<td>7.7</td>
<td>2.5</td>
<td>10.6</td>
<td>9.1</td>
</tr>
<tr>
<td>Min. Ratio (%)</td>
<td>-2.0</td>
<td>-3.0</td>
<td>-4.7</td>
<td>-2.5</td>
<td>-9.6</td>
<td>-9.1</td>
</tr>
<tr>
<td>Average x 0.1</td>
<td>25.7</td>
<td>24.2</td>
<td>19.4</td>
<td>11.2</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>St.Dev x 2.0</td>
<td>7.2</td>
<td>10.6</td>
<td>20.2</td>
<td>3.8</td>
<td>1.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Larger value of above</td>
<td>25.7</td>
<td>24.2</td>
<td>19.4</td>
<td>11.2</td>
<td>1.3</td>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Upper Corridor</th>
<th>Lower Corridor</th>
</tr>
</thead>
<tbody>
<tr>
<td>282.3</td>
<td>230.9</td>
</tr>
<tr>
<td>265.7</td>
<td>217.4</td>
</tr>
<tr>
<td>214.3</td>
<td>173.9</td>
</tr>
<tr>
<td>122.9</td>
<td>100.5</td>
</tr>
<tr>
<td>11.7</td>
<td>9.1</td>
</tr>
<tr>
<td>6.1</td>
<td>4.9</td>
</tr>
<tr>
<td>22.8</td>
<td>18.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Upper Corridor Ratio (%)</th>
<th>Lower Corridor Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>-10.0</td>
</tr>
<tr>
<td>10.0</td>
<td>-10.0</td>
</tr>
<tr>
<td>10.4</td>
<td>-10.4</td>
</tr>
<tr>
<td>10.0</td>
<td>-10.0</td>
</tr>
<tr>
<td>12.6</td>
<td>-12.6</td>
</tr>
<tr>
<td>10.6</td>
<td>-10.6</td>
</tr>
<tr>
<td>10.0</td>
<td>-10.0</td>
</tr>
</tbody>
</table>

Max. Ratio: Max. / Average - 1
Min. Ratio: Min. / Average - 1
Upper Corridor Ratio: Upper Corridor / Average - 1
Lower Corridor Ratio: Lower Corridor / Average - 1

- Most of the upper and lower corridors were made by using minimum width of corridor (Average +/- 10%)
Tentative Corridor (FTSS-Method) for Inverse Type Dynamic Calibration Test Method

- Test Data: BASi Inverse Type Dynamic Test Data (TEG-094, all test data were used)
- Corridor Making Method: FTSS-Method

- Most of the upper and lower corridors were made by using minimum width of corridor (Average +/- 10%)
**Inverse Test Tentative Corridor**

**Data:** BAS (TEG-094), **Method:** BAS

<table>
<thead>
<tr>
<th>Tibia-1 (Nm)</th>
<th>Tibia-2 (Nm)</th>
<th>Tibia-3 (Nm)</th>
<th>Tibia-4 (Nm)</th>
<th>ACL (mm)</th>
<th>PCL (mm)</th>
<th>MCL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>256.6</td>
<td>241.5</td>
<td>194.1</td>
<td>111.7</td>
<td>10.4</td>
<td>5.5</td>
</tr>
<tr>
<td>Max.</td>
<td>262.7</td>
<td>251.3</td>
<td>209</td>
<td>114.5</td>
<td>11.5</td>
<td>6</td>
</tr>
<tr>
<td>Min.</td>
<td>251.4</td>
<td>234.3</td>
<td>184.9</td>
<td>108.9</td>
<td>9.4</td>
<td>5</td>
</tr>
<tr>
<td>CV (%)</td>
<td>1.4</td>
<td>2.2</td>
<td>5.2</td>
<td>1.7</td>
<td>6.3</td>
<td>5.3</td>
</tr>
</tbody>
</table>

**Max. Ratio (%)**

- Upper Corridor: 7.5
- Lower Corridor: -6.7

**Min. Ratio (%)**

- Upper Corridor: 9.3
- Lower Corridor: -7.6

• All of the upper and lower corridors were made by using test data (Max. x 1.05, Min. / 1.05)

**Test Data**

**Development of certification corridors**

- Tibia sections:
  - Tibia-1 to Tibia-4
  - ACL, PCL, MCL

**Knee elongations:**

- Tibia sections:
  - Upper Corridor
  - Lower Corridor

**Max. Ratio:**

- Upper Corridor: Max. / Average - 1
- Lower Corridor: Min. / 1.05

**Min. Ratio:**

- Upper Corridor: Min. / Average - 1
- Lower Corridor: Max. x 1.05

**Upper Corridor Ratio (%)**

- 7.5

**Lower Corridor Ratio (%)**

- -6.7
Tentative Corridor (BASt-Method) for Inverse Type Dynamic Calibration Test Method

- Test Data: BASt Jan.09 Inverse Type Dynamic Test Data (TEG-094, all test data were used)
- Corridor Making Method: FTSS-Method

- All of the upper and lower corridors were made by using test data (Max. x 1.05, Min. / 1.05)
Tentative Corridor (FTSS-Method) for Inverse Type Dynamic Calibration Test Method

- Most of the upper and lower corridors were made by using minimum width of corridor (Average +/- 10%)

Tentative Corridor (BASt-Method) for Inverse Type Dynamic Calibration Test Method

- All of the upper and lower corridors were made by using test data (Max. x 1.05, Min. / 1.05)
3. Discussion on the Corridor Making Methods
## Discussion for the Corridor Making Methods

### Corridor Making Method

<table>
<thead>
<tr>
<th>Method</th>
<th>Formula</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTSS-Method</td>
<td>Average +/- 10% or Average +/- 2 St. Dev (wider one)</td>
<td>ESV2009, Paper Number 09-0146</td>
</tr>
</tbody>
</table>
| BASt-Method| Upper Corridor: Max. x 1.05  
|            | Lower Corridor: Min. / 1.05 | TEG-094                       |

### Comment

- Most of the upper and lower corridors were made by using minimum width of corridor (Average +/- 10%).

### Discussion

- Why the minimum width of corridor were made by using Average +/- 10%?
- Can not we use only Average +/- 2 St. Dev. to make all of the corridor?

### JAMA-JARI Opinion

- JAMA-JARI prefer to use the BASt-Method for the corridor making because the BASl-Method always consider the test data (does not automatically set the corridor width as +/- 10% in minimum).
- However, we would like to propose to add a protocol to exclude outliers from the observed test data in order to remove outliers from the test data.

### Comment

- All of the upper and lower corridors were made by using test data (Max. x 1.05, Min. / 1.05)

### Discussion

- This method always taking account of the test data (Max. Min.) to make all of the corridor.
- However, if outliers are involved in the test data (testing error or so), the width of the corridor tend to become very wide.
- So, if we use the method, how about to add a protocol to exclude outliers from the observed test data?