Prevention of suboptimal assembly of glenoidal component in reverse shoulder arthroplasty: development of an intra-operative measurement protocol

Van Tongel A; Leuridan S; Vander Sloten J, Desmet W, Dewilde L, Debeer P

Abstract
Glenosphere disengagement can be a potential serious default in reverse shoulder arthroplasty. Interpositioning of material (bone, soft tissue) between the contact surface of the glenosphere and the baseplate and/or a misalignment, caused by unwanted contact between the glenosphere and the scapula (notching), of the glenosphere relative to the baseplate can result in a suboptimal assembly. It is our belief that a suboptimal assembly can cause glenosphere disengagement. We are developing a measurement protocol to quantify intra-operatively whether the prosthesis is well assembled. This paper describes the promising preliminary results.

Introduction
Glenosphere disengagement can be a potential serious default in reverse shoulder arthroplasty. Initially, the fixation of the sphere on the baseplate was done by use of peripheral threads, but this mechanism had the tendency to unscrew (1,2). In 1996 glenosphere-baseplate fixation was changed to a peripheral Morse taper (3). Molé et al reported on one patient with an implant from 2001 who had disassembly of the glenosphere as a result of improper impaction of the Morse cone. (4) Afterwards Midemacht et al described three total disengagement with this peripheral Morse taper, necessitating revision. Retrospectively radiographic analyses showed partial disengagement between the glenosphere and the baseplate in 1.7 % of Delta IIITM protheses [Depuy International Ltd, Leeds, UK] and in 7.7% of Aequalis prostheses [Tornier, Grenoble, France] (5). It is our belief that the interpositioning of material (bone, soft tissue) between the contact surface of the glenosphere and the baseplate and/or misalignment of the glenosphere relative to the baseplate can cause a suboptimal assembly. This suboptimal assembly can probably give rise to a total displacement. We are developing a measurement protocol to quantify intra-operatively whether the prosthesis is well assembled.

Methods
During surgery, it is very difficult for the surgeon to assess whether his assembly of the glenosphere and baseplate is optimal. At present, no technique is available to assist the surgeon in this assessment. A possible decision tool to assist the surgeon should tick off all of the following requirements; (1) absolute and correct information, (2) feasible during operation, (3) fast, easy-to-use, (4) harmless to the

Figure 1: Test set up for the vibration technique. The left image shows the prosthesis with the accelerometer attached, the right image shows the acquisition system.
Prevention of suboptimal assembly of glenoidal component in reverse shoulder arthroplasty: development of an intra-operative measurement protocol

<table>
<thead>
<tr>
<th>Detection principle</th>
<th>Shift in FRF</th>
<th>Symmetry check</th>
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<td>A change in contact conditions (interpositioning of tissue, ...) will lead to a reduced stiffness of the baseplate–glenosphere assembly. This reduction in stiffness manifest itself as a shift to the left of the resonance peaks in the FRF.</td>
<td>Due to the axisymmetric properties of the prosthesis, the measured FRF should be insensitive to the measurement direction. A change in FRF in a certain direction indicates an asymmetry in the assembly and hence a defect in the contact between baseplate and glenosphere.</td>
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| Advantages | Requires only one measurement | No information about the pristine assembly needs to be known |
| Disadvantages | FRF’s of pristine assembly for the given boundary conditions need to be known | Requires at least two measurements |

Table 1: Measurement protocols FRF-based technique

patient and (5) no damage to the prosthesis. These requirements point to the direction of the development of an non-destructive method which allows to assess whether there is some tissue interpositioned and/or to detect a possible misalignment. Looking at the wide array of techniques that are used in the field of non-destructive testing, four techniques were withheld, of which the results with the vibration-based technique are described in this paper. The basic idea of the vibration-based technique is that a change in the contact conditions (due to interpositioning or misalignment) between the baseplate and the glenosphere will alter the mode shapes of the assembly and thus of the frequency response function (FRF). The test setup (fig.1) consists of an instrumented hammer, an accelerometer attached to the prosthesis with bee wax and an acquisition en data processing instrument. The hammer is used to excite the assembly at the glenosphere. The force cell at the tip of the hammer registers the impact force of the hammer on the test object. The response is measured by the accelerometer. The FRF is computed by taking the Fourier transform of the time signal of the response and the Fourier transform of the excitation and then dividing these two.

When designing a measuring protocol, one has to remember that the protocol should give absolute information about the assembly conditions of the prosthesis and that it should be implementable during an operation. When using an FRF-based technique, two measurement protocols fulfil these requirements. Table 1 summarizes both measurement protocols, their detection principle and their advantages and disadvantages. Experiments are performed with both measuring protocols. To simulate an imperfect assembly, paper of different sizes as well as soft tissue is introduced between the baseplate and glenosphere. The advantage of the paper defects is, that they are easily quantifiable and controllable in both size and thickness. A case of misalignment is also simulated. Table 2 shows the sizes of the different papers that were introduced, as well as the size of the soft tissue defect and the amount of the misalignment. All of the tests were performed with a Delta Xtend prosthesis [Depuy International Ltd, Leeds, UK].

Results
We first performed the test with the shift in FRF principle. Figures 2.a to 2.c show the results. As expected there is a clear
Prevention of suboptimal assembly of glenoidal component in reverse shoulder arthroplasty: development of an intra-operative measurement protocol

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![Figure 2](image)

**Figure 2**: FRF shift measurements; from left to right and top to bottom;

The red curve is the FRF measured in pristine conditions, the green is the FRF measured when the defect is present.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Frequency Shift</th>
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<tbody>
<tr>
<td>2.a</td>
<td>Shows the shift in case of a big defect (large paper)</td>
<td>265 Hz</td>
</tr>
<tr>
<td>2.b</td>
<td>Shows the shift in case of a small defect (small paper)</td>
<td>31 Hz</td>
</tr>
<tr>
<td>2.c</td>
<td>Shows the defect in case of a soft tissue defect</td>
<td>45 Hz</td>
</tr>
</tbody>
</table>

Correlation visible between the size of the defect and the shift in FRF. A smaller defect will lead to a smaller shift in FRF. Although the shift gets smaller for small defects, even for the smallest defect the shift still accounts for 20 times the measurement resolution (1.5 Hz), which is by all means a significant difference. It is important to notice that this technique requires a reference FRF of the prosthesis when it is perfectly assembled.

The results obtained with the symmetry check technique are shown in figure 3 till figure 5. Figure 3 shows that when the assembly is perfect, that the measured FRF is indeed insensitive of the measuring direction.

When a defect is simulated, this symmetric behaviour changes as can be seen in figures 4a till 4d. It is clear that when a defect is present the one dominant-peak behaviour, visible in figure 3 changes and that a second peak becomes visible.

Looking at figure 4a will clarify the measuring principle a bit more. The red and the blue line are measured on a Delta XTEND prosthesis in pristine condition. The difference between the red and the blue line is that they are measured on a different angle relative to each other (the red one was measured in the vertical direction, the blue line in a direction 45 degrees to the red one). As expected they are very similar. The story changes when a defect is present. The light blue dotted and the magenta dotted lines in figure 4a show the measured FRF’s when a piece of paper is present (large paper). The light blue line is measured in the same direction as the red one and shows similar one-peak

<table>
<thead>
<tr>
<th>Wideness (mm)</th>
<th>Small paper</th>
<th>Medium paper</th>
<th>Large paper</th>
<th>Soft tissue</th>
<th>Misalignment</th>
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<tr>
<td>2</td>
<td>3.5</td>
<td>2</td>
<td>3.1</td>
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<table>
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<th>Thickness (mm)</th>
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<th>Large paper</th>
<th>Soft tissue</th>
<th>Misalignment</th>
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<tr>
<td>0.08</td>
<td>0.08</td>
<td>0.12</td>
<td>0.09</td>
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</table>

<table>
<thead>
<tr>
<th>Amount of misalignment (mm)</th>
<th>Small paper</th>
<th>Medium paper</th>
<th>Large paper</th>
<th>Soft tissue</th>
<th>Misalignment</th>
</tr>
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<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
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Table 2: Overview of the different sizes of defects introduced during testing
Prevention of suboptimal assembly of glenoidal component in reverse shoulder arthroplasty: development of an intra-operative measurement protocol

Figure 3 a.: Measured FRF’s on a perfectly assembled Delta XTEND prosthesis when measuring in different directions.
Figure 3 b: The directions of excitation and measuring (top view of the glenosphere)

Figure 4: FRF Symmetry check principle measurements (from left to right and top to bottom)
Figure 4 a. Large paper (Red and blue; pristine) (Dotted magenta and light blue; in case of defect; measured at 45°)
Figure 4 b. Medium paper (Red and blue; pristine) (Dotted magenta and light blue; in case of defect; measured at 39°)
Figure 4 c. Small paper (Light blue and green; in case of defect; FRF’s measured at an angle of 29°)
Figure 4 d. Misalignment (Red and green; in case of defect; FRF’s measured at an angle of 45°)
behaviour like the red one. The only difference between the two is that the light blue graphic is shifted to the left, as is expected. The magenta line is the measured FRF in the same direction as the blue line. The difference between these two is much more however than just a shift of the FRF to the left. Opposite to the one peak-behaviour of the other FRF’s a second peak becomes visible. This is a very clear indication that a defect is present. Furthermore, this principle requires no more reference FRF of the prosthesis in pristine condition. A simple comparison between the magenta and the light blue graphic is more than sufficient, for if the baseplate and the glenosphere would be perfectly assembled, the FRF should be insensitive to the measurement direction, which is clearly not the case. A simple score available to the surgeon based on the calculation of the correlation between the two FRF’s could be a quick and efficient way of quantifying the quality of the assembly during an operation.

As with the measuring principle based on the shift in FRF, the size of the defect plays an important role. The bigger the defect, the more the FRF’s measured in different directions will be different from each other. Figure 4a till 4d show this effect of the defect size. The graphics show the FRF’s measured in two different directions. As can be seen, with decreasing defect size, the two-peak behaviour becomes less prominent, but nevertheless is still very visibly present. A remark should be made that with a decreasing defect size, the zone of sensitivity where the two-peak behaviour is measurable also decreases. This might implicate that more than two measurements should be performed. The big advantage of this symmetry principle is that the appearance of this second peak, how small it may be, will have a deteriorating effect on the correlation and is therefore very easy to quantify. Compared to the shift in FRF technique, it also seems that this technique is more sensitive to small defects. Another advantage is that also a misalignment of the glenosphere to the baseplate (e.g. due to undesired contact of the baseplate with the scapula), is detectable, as can be seen in figure 4d. Since this misalignment also introduces an asymmetric effect, it will also manifest itself in the appearance of a second peak in some measuring directions. Last but not least, the principle is also tested when soft tissue is interpositioned.

The result of this experiment is shown in figure 6. Once again, the red and the green graphic are measured at an angle of 45° relative to each other. Recalling that if the assembly is good, these two FRF’s should be quasi identical, the effect of the presence of soft tissue is crystal clear. To verify these findings a finite element (FE) model was build in MSC Marc. On this model both a harmonic analysis as well as a modal analysis is performed. The harmonic analysis confirms the fact that when no defect is present, the prosthesis shows a one peak dominant behaviour and
Prevention of suboptimal assembly of glenoidal component in reverse shoulder arthroplasty: development of an intra-operative measurement protocol

that the measured FRF is insensitive to the measuring direction. Figure 7 shows the calculated FRF’s from the FE model. For the sake of clarity, the measured results are once again showed next to the calculated FRF’s. This shows that the calculated FRF’s in a good assembly are similar to the measured ones and that the two peak behaviour measured when a defect is present is indeed a anomaly.

Discussion
Glenosphere disengagement can be a potential serious default in reverse shoulder arthroplasty. Our belief is that suboptimal assembly can result in total displacement of the glenoid from his fixation on the baseplate. A suboptimal assembly can be caused by interpositioning of material (bone, soft tissue) between the contact surface of the glenosphere and the baseplate and/or misalignment of the glenosphere relative to the baseplate.

This paper describes the development of a measurement protocol to quantify intraoperatively the glenosphere-baseplate fixation. This would allow to prevent a suboptimal assembly of glenoidal component in reverse shoulder arthroplasty.

A vibration-based technique seems to be a good technique for this purpose. It is a sensitive technique even for small defects. The FRF is dependent on the contact conditions of the baseplate to the glenosphere. Furthermore the technique is able to detect misalignment caused by notching of the glenosphere to the scapula. An important result is the fact that the FE models confirm that the measured differences represent an anomaly in the contact. Since the zone of sensitivity decreases with defect size, an interesting way of measuring might be a sweep around approach.

To conclude, the results show the feasibility of the vibration-based technique as a potentially very useful way to measure suboptimal assembly. The next step is to perform these measurement on cadavers and afterwards during surgery.

References
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