

# Core Set of Radiographic Parameters for Shoulder Arthroplasty Monitoring

## Criteria Defined by an International Delphi Consensus Process

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**Background:** Some unfavorable local events following shoulder arthroplasty occur without the patient experiencing symptoms and yet may be detected on diagnostic imaging, thereby serving as indicators of complications that may require revision. Our aim was to create a standardized protocol for an image-based monitoring process for assessing patients who are asymptomatic following shoulder arthroplasty.

**Methods:** A Delphi exercise was implemented with the participation of an international panel of experienced shoulder surgeons. On the basis of expert opinion from a core steering group, an initial list of imaging parameters for shoulder arthroplasty monitoring of asymptomatic patients was developed and reviewed by panel members. The most appropriate imaging modality was identified. Between each survey, all feedback was considered in order to revise the proposed core set with its definitions and specifications. Consensus was reached upon a two-thirds agreement.

**Results:** Three online surveys were administered, with 98 surgeons responding to the first and/or the second survey. The response rate for the final survey was 74%. Final parameter definitions were organized in 7 categories (implant migration, radiolucency around implant and implant loosening, signs of shoulder displacement, bone resorption and formation, wear of implant articular surfaces, fractures around the implant, and implant breakage and disassembly) and approved with 85% to 100% agreement. Seventy-eight percent of the panel members agreed on a minimum radiographic imaging schedule: standard anteroposterior and axial (alternatively, Y) views made within 6 weeks after implantation and between 3 and 6 months as well as at 12 months post-surgery.

**Conclusions:** Our work presents a monitoring tool developed with international consensus for the assessment of asymptomatic patients after shoulder arthroplasty and including a structured core set of radiographic parameters. Clinical application and scientific evaluation of the monitoring process are needed.

**Clinical Relevance:** This represents a major step toward the standardization of shoulder arthroplasty radiographic monitoring for routine quality controls and research investigations.

Image-based monitoring plays an important role in decision-making processes associated with shoulder arthroplasty and long-term prosthesis survival<sup>1,2</sup>. Shoulder arthroplasty is one of the most successful procedures for treating end-stage arthritis of the glenohumeral joint<sup>3</sup>, among other indications, including rotator cuff arthropathy, trauma, osteonecrosis, and rheumatoid arthritis<sup>4</sup>. However,

some shoulder arthroplasties fail and implant revision is required. The reasons for failure are multifactorial<sup>5</sup> and generally caused by an intrinsic factor, or a combination of factors, associated with the soft tissue, bone, and/or implant<sup>6</sup>. Common types of failure, including loosening, bone loss, or instability, can be diagnosed using standard radiographs.

\*A list of the Shoulder Arthroplasty (SA) Monitoring Steering Group members is included as a note at the end of the article.

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The systematic assessment of radiographs for categorizing shoulder arthroplasty failure type is complicated by a lack of consensus on the most relevant radiographic parameters. Furthermore, a clear and accepted minimum radiographic follow-up procedure including the types and quality of radiographic views and a time schedule is missing. A minimum radiographic monitoring regimen is warranted for assessing the progression of parameters in shoulder arthroplasty and should be applicable to all types of shoulder arthroplasty.

This project was implemented to develop a standardized protocol for an image-based monitoring process in the assessment of patients who are asymptomatic following shoulder arthroplasty, including a defined core set of radiographic parameters as well as minimum requirements governing the radiograph type, views, and schedule. A structured assessment tool was achieved by consensus with the participation of an international panel of experienced shoulder surgeons.

## Materials and Methods

### Delphi Process

For the identification of a core set of imaging parameters for shoulder arthroplasty monitoring, we applied a methodological process<sup>7</sup> used for core outcome set (COS) development. Following a systematic literature review of terms and definitions of shoulder arthroplasty complications, a Delphi technique<sup>8</sup> was implemented after the selection of a consensus panel of experienced surgeons (see Appendix File 1). In short, supported by a steering group with worldwide representation, we conducted 3 successive online surveys using REDCap (Research Electronic Data Capture)<sup>9</sup>. In the first online survey, we asked participants about routinely used imaging technique(s) and timing for monitoring shoulder arthroplasty as well as relevant imaging parameters that may be considered (see Appendix File 2). From the initial responses, the steering group agreed that shoulder arthroplasty monitoring would be performed using radiographs. A second survey was prepared considering 6 groups of radiographic parameters (see Appendix File 3) as well as 4 additional parameters proposed by the

panel members. A minimum set of radiographic views was suggested to be made within the first week and at 3 and 12 months after implantation. Responses from the second survey were reviewed, and amendments were implemented in a revised proposal that was presented to consensus panel members in a third survey (see Appendix File 4).

### Data Analysis and Final Adjudication

Survey data were transferred to Intercooled Stata version 14 (StataCorp) for standard descriptive analyses. Consensus was achieved upon a two-thirds agreement among the respondents. Final amendments and decisions were made by the steering committee following a review of all reported comments.

## Results

Of 182 surgeons who were invited to participate, 98 responded to the first and/or the second survey (Table I; see also Appendix File 5). The response rate to the third and final survey was 74%. The panel had international representation: 74 (76%) of the surgeons were from 13 countries in Europe, 13 were from North America (U.S. and Canada), and 11 other members were from Chile, Brazil, Israel, and Australia.

In the initial survey, 88 respondents unanimously supported radiographs as the standard routine imaging technique for monitoring shoulder status in asymptomatic patients following shoulder arthroplasty (see Appendix File 6). A preliminary list of imaging parameters was agreed on, and respondents provided numerous comments and suggestions for definitions, allowing for the drafting of a consolidated proposal. The parameters “arthritis,” “stress shielding,” and “integrity of the rotator cuff” were excluded from further consideration. Suggested minimum time points for systematic image monitoring within and after the first 5 years were heterogeneous. Radiographic monitoring at 3, 6, and 12 months was supported by 55%, 39%, and 78% of 88 respondents, respectively; 64% agreed on a 5-year check (Table II).

Proposed parameter definitions and their specifications were widely accepted by >90% of the 68 participants in the

TABLE I Consensus Panel Skills\*

	Experience†				Total
	1-5 yr	>5-10 yr	>10-20 yr	>20 yr	
Average no. of SAs/yr‡					
1-20	—	4	5	3	12
>20-50	1	7	14	15	37
>50-100	—	3	16	15	34
>100	—	1	7	7	15
Total	1	15	42	40	98

\*The values are given as the number of surgeon respondents. †Survey question: “How many years of surgical experience do you have in orthopaedics?” ‡Survey question: “On average, how many shoulder arthroplasties (SAs) do you perform annually?”

**TABLE II Suggested Time Points for Radiographic Monitoring After Shoulder Arthroplasty**

Time Point	No. of Respondents	%
<b>≤5 yr</b>		
Never	0	—
3 mo	48	55
6 mo	34	39
12 mo	69	78
2 yr	46	52
3 yr	24	27
4 yr	14	16
5 yr	56	64
Other time points*	5	6
<b>&gt;5 yr</b>		
Never	8	9
Every year	9	11
Every 2 yr	23	27
Every 3 yr	7	8
Every 5 yr	28	33
Every 10 yr	1	1
Other frequency†	9	11

\*Suggestions up to 5 years included: “immediate post-surgery images”; “whenever patients have new symptoms related to the joint or if symptoms change”; and “1 year, then if all is well, more than 2 years—I wonder if it could be next left until 5 years.”  
†Suggestions after 5 years included: “only if clinically indicated or the patient presents with a problem”; “4, 7, 10 years, then every 2”; “on development of new symptoms”; “whenever patients have symptoms related to the joint or if symptoms change”; “only when symptomatic, as decision for intervention not dictated by radiological appearances”; “if patient has symptom about 7 to 8 years, I think it should be every 2 years and then if anything untoward is seen, then more frequently”; and “at 10 then every 10 [years]”.

second survey (see Appendix File 7). Consensus agreement was reached for additional parameters: osteochondral glenoid erosion in hemiarthroplasty (70% agreement), fractures around the implant (humeral or scapular side, 83%), and implant breakage and dissociation (87%). Consensus (75% agreement) was also attained regarding our proposed minimum radiographic view set and schedule, but comments suggested that the 3-month time point be extended to 6 months to offer some flexibility without losing relevance.

During the third survey, 85% to 100% of the respondents agreed to the definitions and specifications of the final radiographic parameters organized into 7 groups (Table III; see also Appendix File 8). The minimum radiographic view set and schedule for monitoring asymptomatic patients following shoulder arthroplasty included a true anteroposterior view in 0° of abduction and neutral position, and an axillary view in 90° of abduction or a Y-view made within 6 weeks, between 3 and 6 months, and at 12 months post-surgery, which was approved with 78% agreement among 64 respondents. Upon final adjudication of all survey-related comments, some minor

amendments were made to the parameter set; for example, we changed the term “signs of shoulder instability” to “signs of shoulder joint displacement.”

## Discussion

Using a Delphi technique<sup>8</sup>, we achieved consensus among an expert panel of specialized shoulder surgeons regarding a standardized core set of parameters for radiographic monitoring after shoulder arthroplasty. The present core set is intended for monitoring asymptomatic patients. This work can be applied for the routine monitoring of all types of shoulder prostheses in clinical practice as well as for registries providing Level-IV data<sup>10</sup>, with a standardized overview regarding the most relevant problems after shoulder arthroplasty. Additional parameters and monitoring time points may be considered, notably in the context of scientific studies requiring more in-depth investigations.

### Implant Migration

Implant migration is relevant in shoulder arthroplasty monitoring, mainly as an indicator of potential implant loosening, which may require subsequent and extended monitoring. However, subtle implant migration without any clinical symptom or restriction of function is not necessarily clinically relevant. Implant migration, whether it occurs in the form of subsidence, tilt, or shift, occurs over a period of time between radiographic examinations. It is not malposition noted directly post-surgery.

Subsequent radiographic examination may produce different patterns of implant migration. Early migration during the first months followed by a stable situation is normal for some implants; uncemented implants are reported to settle before fixation is stable<sup>11</sup>. Continuous migration on subsequent examinations, however, is considered the result of an implant without stable fixation and a risk factor for the progression to loosening<sup>12,13</sup>.

The current and most precise method of detecting implant migration involves radiostereometric analysis<sup>14,15</sup>. On radiographs, the ability to detect migration is highly dependent on the accuracy of measurement and the quality of radiographic images. The panel suggested that migration should be >5 mm in order to be considered “definite.” A tilt of >10° could also be considered migration if radiographs are made in the same plane as in previous views, although the amount of both implant and humeral rotation is generally difficult to assess. Our definition of “implant migration” provides the option to report “definite migration” when an undisputed, noticeable change is detected. Additional examinations should otherwise be considered.

### Radiolucency Around the Implant and Implant Loosening

Radiolucent lines at the bone-implant, bone-cement, or cement-implant interface are a risk factor for implant loosening<sup>16-18</sup>.

Many systems for documenting radiolucent lines exist<sup>19</sup> and are adapted to consider varying implant designs. The presence of radiolucent lines on the humeral side is classically defined by zones<sup>16,20,21</sup>, depending on the stem length or fixation technique; a similar organization exists for glenoid

TABLE III Definitions and Specifications of Postoperative Radiographic Monitoring Parameters

Parameters	Definitions and Specifications	Agreement
Implant migration (subsidence, tilt, shift)	<p>Implant migration is a noticeable change in the position of the implant, relative to the bone it is intended to be fixed to (either cemented or uncemented). Implant migration is documented separately for the humeral and glenoid components</p> <p>- Subsidence: migration of the implant along a linear axis compared with the immediate post-implantation position. Documented as 1 of 3 classes:</p> <p>None = no sign of subsidence</p> <p>Suspicion = subsidence is suspected but with no more than 5 mm of migration</p> <p>Definite = subsidence is noted with &gt;5 mm of migration</p> <p>- Tilt: migration of the implant resulting in an angulation of its main axis compared with the immediate post-implantation position. Documented as 1 of 3 classes:</p> <p>None = no sign of tilt</p> <p>Suspicion = tilt is suspected but with no more than 10° of angulation</p> <p>Definite = tilt is noted with &gt;10° of angulation</p> <p>- Shift: migration as a combination of subsidence and tilt. Shift is suspected when both subsidence and tilt are suspected or 1 is suspected and the other is definite. Shift is definite when both subsidence and tilt are definite</p>	94% (65/69)
Radiolucency around the implant and implant loosening	<p>Radiolucency relates to the occurrence or observation of radiolucent lines (RLLs) at the bone-implant, bone-cement, or cement-implant interface. RLLs are documented according to their presence or absence, location, and thickness, separately for the humeral and glenoid components. The humeral component is further divided into metaphysis and diaphysis according to the surgical neck of the humerus. Within each of these locations (as appropriate for various prosthesis types), the severity of RLL occurrence is graded as follows:</p> <p>Grade 0 = none (no clear sign of RLLs)</p> <p>Grade 1 = incomplete RLLs (radiolucency not all around the implant)</p> <p>a. no line reaching 1.5 mm in width</p> <p>b. at least 1 RLL reaching <math>\geq 1.5</math> mm in width</p> <p>Grade 2 = complete radiolucency around the implant</p> <p>a. not reaching 1.5 mm in width</p> <p>b. reaching <math>\geq 1.5</math> mm in width (loosening)</p> <p>Implant loosening is considered when respective components are identified with Grade-2b lucency or a shift in position (see above parameter) between postoperative radiographs (implant at risk of failure on the basis of radiographic outcome)</p>	99% (67/68)
Signs of shoulder joint displacement	<p>Shoulder joint displacement refers to a loss of alignment of the articulating surface of the humeral component with the articulating surface of its joint partner; not dependent on positioning of the arm</p> <p>- Subluxation: eccentric misalignment of the articulating surfaces with residual contact visible on standard radiographs</p> <p>- Dislocation: complete loss of contact of the articulating surfaces visible on standard radiographs</p> <p>When present, the direction of subluxation or dislocation is noted on the anteroposterior view (superior/inferior) as well as the axillary view or Y-view (anterior/posterior)</p>	85% (57/67)
Bone resorption and formation	<p>Bone resorption: the progressive disappearance of bone from the humerus and/or scapula following shoulder arthroplasty (SA) when compared with the immediate postoperative condition. Bone resorption includes scapular notching and osteochondral erosions (described below)</p> <p>Bone formation: the progressive apposition of bone on or in the humerus and/or scapula following SA when compared with the immediate postoperative condition, more than that required for stable integration of the prosthesis</p>	100% (65/65)

continued

TABLE III (continued)

Parameters	Definitions and Specifications	Agreement
Wear of the implant articular surfaces	<p>- Orthotopic bone formation (ossification): bone formation within the confines of the bone including the periosteum; bone is formed within tissue that is destined to be or become bone under normal healing or loading conditions</p> <p>- Heterotopic bone formation (ossification): a subset of excess bone formation within or between tissues that is not destined to become bone under normal healing or loading conditions</p> <p>Specifications include a bone region-based description of periprosthetic occurrence/extent of bone resorption/formation:</p> <p>- Humeral side: further divided into metaphysis and diaphysis according to the surgical neck of the humerus. When bone resorption is located proximal to the surgical neck, the involvement of the calcar region and/or the tuberosities is documented</p> <p>- Glenoid side (without further division)</p> <p>Heterotopic bone formation is graded according to a modified Brooker classification<sup>28</sup>:</p> <p>Grade 1 = islands of bone within the soft tissues around the shoulder</p> <p>Grade 2 = bone spurs from the proximal humerus or scapula, leaving at least 1 cm between opposing bone surfaces</p> <p>Grade 3 = bone spurs from the proximal humerus or scapula, reducing the space between opposing bone surfaces to &lt;1 cm</p> <p>Grade 4 = apparent osseous ankylosis of the shoulder</p> <p>Scapular notching (specific to reverse SA): bone resorption with disruption of the normal contour (= notch) near the glenoid base plate. Graded according to the Nerot-Sirveaux classification<sup>43,44</sup>:</p> <p>Grade 1 = notch limited to the scapular pillar</p> <p>Grade 2 = notch reaching the inferior screw of the base plate</p> <p>Grade 3 = notch extending beyond the inferior screw of the base plate</p> <p>Grade 4 = notch reaching the central peg of the base plate</p> <p>Osteochondral erosions (as another form of bone resorption): abrasion of bone and/or cartilage caused by friction with a prosthetic component</p> <p>- Glenoid erosion (only for hemiarthroplasty)</p> <p>Eccentric: occurrence of localized glenoid rim erosion</p> <p>Concentric: humeral head centered without localized glenoid rim erosion</p> <p>- Erosion of the acromion (only for anatomical hemi- and total arthroplasty): concave deformity of the acromion undersurface ("acetabularization")</p>	97% (62/64)
Fractures around the implant	<p>Damage, erosion, or loss of the articular surface material over time, identified by a reduction of joint space observed on serial radiographs</p> <p>- Eccentric: the wear location is noted on the anteroposterior view (superior/inferior) as well as the axillary view or Y-view (anterior/posterior)</p> <p>- Concentric</p> <p>Humeral fracture:</p> <p>- Tubercula</p> <p>- Subcapital, at the surgical neck (stemless prosthesis)</p> <p>- Diaphysis spiral/transverse (stemmed shaft prosthesis)</p> <p>- Distal (below the shaft)</p> <p>Scapular fracture<sup>31</sup>:</p> <p>- Body</p> <p>- Processes (spine, acromion, coracoid)</p>	98% (63/64)*

continued

TABLE III (continued)

Parameters	Definitions and Specifications	Agreement
Implant breakage and disassembly	<ul style="list-style-type: none"> <li>- Glenoid neck</li> <li>- Articular (glenoid rim, fossa)</li> </ul> Implant breakage: $\geq 1$ part of the prosthesis is broken Implant disassembly: noticeable change of the relative position of the various parts of a humeral or glenoid implant component Humeral side and scapular side	
*This percentage of agreement applies to both parameter groups "Fractures around the implant" and "Implant breakage and disassembly."		

components<sup>16,22,23</sup>. The differentiation in systems makes it very difficult to compare several designs and studies. Our suggested grading system for radiolucency was simplified for applicability to all shoulder arthroplasty types, fixation techniques, and glenoid components. The presence of radiolucent lines or actual asymptomatic implant loosening does not always lead to a shoulder functional deficit<sup>2,12,24,25</sup>. For clinical practice, we believe that there is no need for a more detailed description of radiolucent lines. In symptomatic cases of radiolucent lines or in a research setting, other imaging examinations, such as computed tomography (CT) scanning<sup>2</sup>, may be performed.

#### Signs of Shoulder Joint Displacement

Shoulder joint displacement can vary in terms of type and severity, and yet a distinction is made between misalignment with residual contact of the articulating surfaces (subluxation) and a complete loss of contact (dislocation) of these surfaces. While dislocation can easily be detected on standard radiographs, subluxation can be more difficult to identify, depending on its severity. Radiographic signs of displacement are documented as a proxy for the occurrence of shoulder instability. Instability in anatomical or reverse shoulder arthroplasty is not uncommon<sup>26,27</sup>, although the presence or absence of symptoms is dependent on the chronicity and the cause of instability. For example, while patients with acute dislocation occurring within a few weeks after shoulder arthroplasty are likely to demonstrate symptoms, patients with some chronic instability caused by soft-tissue deficiency may remain asymptomatic, and the instability is suspected only from signs of joint displacement on postoperative radiographs, requiring further investigation.

The monitoring set of radiographs is appropriate for identifying possible static instability. The misalignment of shoulder arthroplasty components (displacement) is permanent, regardless of arm position. In contrast, dynamic instability refers to a condition in which the components are either aligned or misaligned depending on the arm position; this can be detected using functional imaging by means of fluoroscopy or a series of radiographs with the arm in varying positions. Dynamic instability is therefore an unfavorable event that cannot be monitored through signs of joint displacement when using a minimum set of radiographs required for all patients.

#### Bone Resorption and Formation

Bone resorption and formation may be considered physiological or non-physiological events. An appropriate physiological response may result as a direct effect of loading through the prosthesis or as an indirect effect modulated through usual loading of the related soft tissues. For instance, homotopic bone formation occurs around humeral prostheses following shoulder arthroplasty with uncemented components as a response (via callus) to microfracturing of trabecular bone during implantation. In contrast, an inappropriate bone response may be triggered, for example, following capsular release from the humerus. Bone formation in excess to that required for stable integration of a shoulder arthroplasty prosthesis is usually undesirable.

Resorption, mostly of cortical bone or the periosteal surface, manifests on radiographs as the absence or hypodensity of bone previously present or of normal quality. Bone formation manifests as the appearance of bone that was previously absent. Observations of either resorption or formation should be interpreted with caution, notably with regard to the indication for shoulder arthroplasty as well as the implant design used: different periprosthetic bone behaviors and patterns of bone resorption are exhibited following shoulder arthroplasty performed with uncemented compared with cemented implants. The classification of heterotopic bone formation based on that used for the lower extremity<sup>28</sup> has been applied to shoulder arthroplasty, whether cemented or uncemented, but requires further validation using radiographs.

#### Implant Articular-Surface Wear

Implant wear is defined as the damage, erosion, or loss of surface material of an implant over time, usually due to friction. Implant wear creates biologically active particles generating an inflammatory response that may result in loss of implant fixation, detected indirectly as bone resorption or implant migration. True wear without lysis is more difficult to detect and requires well-aligned serial radiographs made in the same plane to visualize articular joint-space loss. Monitoring for wear enables the early identification of a prosthesis at risk for loosening and (potentially catastrophic) failure or periprosthetic fracture that might increase the complexity of revision surgery.



### *Fractures Around the Implant*

Patients with implant fractures following shoulder arthroplasty usually present with symptoms, but in some cases, the patient can be, or may become, asymptomatic<sup>29</sup>. The consensus panel agreed almost unanimously (98%) to include fractures around the implant in the radiographic monitoring set. Classification systems for periprosthetic fractures have been developed and included in treatment algorithms<sup>30</sup> that are beyond the aim of this monitoring process to primarily document the occurrence of fractures and their localization. For our purposes, we adapted a proposed system for scapular fractures<sup>31</sup>.

### *Implant Breakage and Disassembly*

Implant breakage and, especially, disassembly has been described for several implant designs<sup>32-35</sup>. It was therefore essential to include this parameter in the radiographic monitoring set for both humeral and scapular sides, even if most of these events would be accompanied by symptoms.

### *Radiographic View Set and Schedule*

Adequate imaging is necessary for an accurate preoperative and postoperative assessment of shoulder arthroplasty<sup>1</sup>. For postoperative imaging, radiographs seem to be the standard. Postoperative CT has a greater ability to detect radiolucent lines<sup>36,37</sup> than do radiographs<sup>4</sup>. Magnetic resonance imaging (MRI), with suitable software, or ultrasound would be necessary if the integrity of soft tissue such as the rotator cuff needed examination in symptomatic patients. However, for this postoperative monitoring set for patients who are asymptomatic following shoulder arthroplasty, it became clear after our initial survey that radiographs alone would be appropriate at this current time.

A minimum radiographic view set of at least 2 orthogonal views were widely accepted for monitoring. Shoulder arthroplasty was considered best assessed postoperatively with anteroposterior and axial views of the shoulder<sup>6</sup> or with true anteroposterior views in internal and external rotation and an axial view<sup>4</sup>. These views allow the verification of correct implant positioning and provide reference images for prescribing the subsequent follow-up for the patient: any new entity appearing on follow-up images can be compared with previous images<sup>7</sup>. We acknowledge that some patients may not tolerate holding their shoulder in the required positions to produce the necessary views in the initial postoperative period<sup>6</sup>; therefore, a Y-view (lateral projection) is an accepted alternative. Other radiographic views are considered in a diagnostic context.

There was considerable debate and divergent opinions regarding the monitoring schedule. Our recommendation is to obtain the first set of radiographs within the first 6 weeks after implantation, especially considering the difficulty in obtaining a reproducible series of radiographs shortly after surgery because of pain and the need to protect the reconstructed soft tissue<sup>38</sup>. Furthermore, delayed radiographs would result in substantial cost savings without compromising the quality of patient care, as already seen for noncomplicated primary knee arthroplasty<sup>39,40</sup>. We further recommend that radiograph sets be made between 3 and 6 months and at

12 months post-surgery, to allow the assessment of short-term parameter progression (i.e., migration, bone formation, bone resorption, notching, implant articular-surface wear) and the documentation of implant status as a reference for later examinations. There is no evidence that we are aware of suggesting that long-term radiographic monitoring is more cost-effective than performing clinical and radiographic check-up examinations only for patients reporting symptoms<sup>41</sup>.

### *Application in Practice*

Only widespread application of the present consensus in a documentation system as well as clinical studies will foster scientific comparability and transparency of reporting in shoulder arthroplasty monitoring. We therefore developed a printable form (see Appendix [Supplementary Data 2]) as well as an electronic version available for REDCap<sup>9</sup>. In a first phase of implementation, all parameters should be actively reported without any documentation hierarchy; some parameters (e.g., migration) might have little to no relevance depending on the observations made (e.g., loosening or fracture). However, an option is provided to explain why a parameter cannot be documented in specific circumstances. Finally, although this monitoring system was developed for asymptomatic patients, we recommend its systematic use when investigating the cause of any symptoms that may occur.

### *Strengths and Limitations*

We used a Delphi consensus process that favored the participation of a large international expert panel and achieved a high response rate of 74% for the final survey. Although we had a preconceived idea about which parameters should be considered, the initial survey was implemented mostly with open questions to ensure that important parameters would not be overlooked. Comments and suggestions were evaluated equally without knowing the respondents' identity so as to avoid biased judgments. Steering group members met informally during professional meetings, notably in the context of the International Shoulder Arthroplasty Consortium<sup>42</sup>. Their individual contributions were important to thoroughly address all selected parameters and allow the formulation of a proposal with an increased chance of support by the whole panel. While we cannot exclude that another panel would have selected other parameters or defined them differently, we believe that the present proposal has face validity.


In large national and international registries, defined radiographic parameters may well complement the commonly used outcome of implant revision to identify problematic implants sufficiently early after market introduction. These issues cannot be resolved without wide multicenter application of this monitoring tool and the centralization of standardized data. Field application will almost certainly lead to the continuous evaluation and revision of our tool.

### *Conclusions*

Through international consensus, we developed a radiographic monitoring tool for asymptomatic patients after

shoulder arthroplasty (SA), entitled “SA Radiological Monitoring v1.0,” which includes a structured core set of radiographic parameters. This work represents an important step toward the standardization of documentation and evaluation in shoulder arthroplasty. Clinical application and scientific evaluation of the monitoring process are needed.

## Appendix

 Supporting material provided by the authors is posted with the online version of this article as data supplements at [jbjs.org \(http://links.lww.com/JBJSOA/A119\)](http://links.lww.com/JBJSOA/A119) (<http://links.lww.com/JBJSOA/A120>). ■

NOTE: Shoulder Arthroplasty (SA) Monitoring Steering Group members also include John Sperling, MD, Mayo Clinic, Rochester, Minnesota; and Hans-Kaspar Schwyzer, MD, Shoulder and Elbow Surgery, Schulthess Klinik, Zurich, Switzerland.

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