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Optimizing intraoperative imaging during proximal femoral fracture fixation – a performance improvement program for surgeons

Daniel Rikli[a,1,*], Sabine Goldhahn[b,1], Michael Blauth[c], Samir Mehta[d], Michael Cunningham[e], Alexander Joeris[b], PIP Study group[2]

[a] University Hospital Basel, Clinic for Orthopaedic and Trauma Surgery, Basel, Switzerland
[b] AO Foundation, AO Clinical Investigation and Documentation, Duebendorf, Switzerland
[c] University Hospital Innsbruck, Department of Trauma Surgery, Innsbruck, Austria
[d] Hospital of the University of Pennsylvania, Department Orthopaedic Surgery, Philadelphia, PA, United States
[e] AO Foundation, AO Education Institute, Duebendorf, Switzerland

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ABSTRACT

Introduction: Formal training for surgeons regarding intraoperative imaging is lacking. This project investigated the effect of an educational intervention focusing on obtaining and assessing a standardized lateral view of the proximal femur during intramedullary nailing of a pertrochanteric fracture.
Materials and methods: Anatomical landmarks of the proximal femur that can be identified using intraoperative fluoroscopy and criteria for image quality, i.e. quality of projection were defined in a consensus process, followed by the development of educational materials and a 7-item checklist. Five surgeons from 5 Trauma Centers in 4 countries participated. Each surgeon a) assessed 5 of their own retrospective cases and 5 retrospective cases from 4 colleagues from their clinic, b) viewed an educational video and poster and re-assessed the same cases, and c) assessed the intraoperative images of 5 prospectively collected consecutive cases of their own and of colleagues afterwards.
Results: The percentage of positive ratings for image quality increased from 72% prior to educational intervention to 88% after intervention ($p < 0.001$), and number of “not assessable” images decreased significantly. Percentage agreement between surgeons on the assessments increased from 75% to 87%. The proportion of best possible ratings for fracture reduction and implant position increased from 58% to 72% and from 49% to 66%, respectively. Percentage agreement between surgeons on assessment of reduction and implant position increased.
Discussion and conclusions: A focused educational intervention can improve surgeons’ ability to obtain and assess lateral view intraoperative images of the proximal femur and can improve the quality of reduction and implant positioning.

Introduction

Intraoperative fluoroscopy is universally used during fracture surgery to assess and document reduction of fracture fragments and correct placement of implants. Some specific procedures such as minimal invasive plating and closed nailing rely to a high degree on intraoperative fluoroscopy throughout the procedure. Intra-operative fluoroscopy differs from conventional x-ray in various aspects: First, the quality of the images obtained is inferior, and the area that can be exposed is limited [1,2]. Second, the surgeon can choose the exact view of the area of interest by directing the beam or changing the position of an extremity until the desired view is obtained. It is therefore critical for a surgeon to be able to obtain correct and standardized intraoperative views and to correctly interpret these images. However, systematic investigations on intraoperative imaging and structured teaching is lacking. In a survey among 98 surgeons with the question “have you had structured teaching on intraoperative imaging of the proximal

* Corresponding author: University Hospital Basel, Spitalstrasse 21, 4031 Basel, Switzerland.
E-mail address: daniel.rikli@usb.ch (D. Rikli).
[1] The authors contributed equally to this work.
[2] PIP Study group contributors: Andreas Platz (Triemli Hospital, Zurich, Switzerland), Emanuel Benninger (Cantonal Hospital Winterthur, Switzerland), Franz Seibert (University Hospital Graz, Austria), Brett Crist (University of Missouri Hospital and Clinics, USA), and Matevž Tomaževič (University Medical Centre Ljubljana, Slovenia).

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femur?", the answer was "yes" by 0% of head of departments, 12% of practicing surgeons, and 27% of trainees [3].

Optimal reduction and correct intraoperative views are closely related [4]. If the desired view is not obtained in a standard projection, the probability for an insufficient reduction is high. Moreover, a correct reduction is a prerequisite for optimal implant placement, since the implants are designed to fit to an intact or reduced bony structure. Therefore, imaging, reduction and implant placement have a reciprocal influence on each other: improving imaging improves reduction.

In closed nailing for pertrochanteric fracture fixation there is a considerable incidence of malreduction with 40% of more than 15° internal rotation [5]. Malpositioning of implants due to residual malreduction leads to a higher number of mechanical failures [6–8].

Therefore, a performance improvement program has been designed to improve surgeons' ability to obtain a correct lateral view (also known as axial view) of the proximal femur and to correctly interpret this view during closed nailing. A set of criteria was established on how to obtain an optimal lateral view, and for the assessment of fracture reduction and implant positioning on this optimal lateral view. Specific teaching material was developed to perform a focused educational intervention. We hypothesized that such a focused educational intervention can improve the quality of lateral views as well as the quality of reduction and implant positioning.

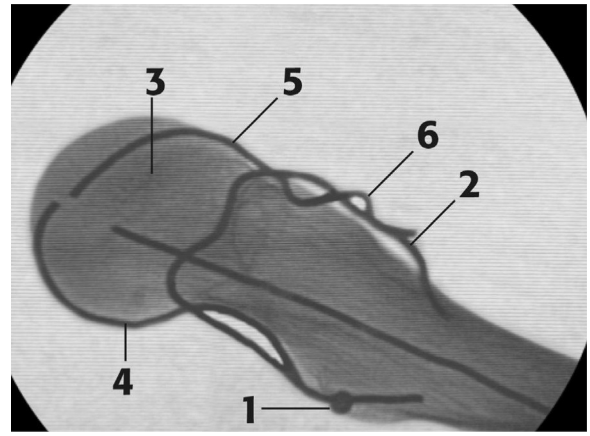

Fig. 1. The following structures must be visible in a good lateral image of a pertrochanteric fracture: the entire femoral head with the joint space, the femoral neck, both trochanters and the proximal portion of the shaft. If the fracture is correctly reduced, these anatomical landmarks can be identified on a lateral view image: 1. Lesser trochanter, 2. Greater trochanter, 3. Femoral head, 4. Posterior line (continuous), 5. Anterior line (continuous), 6. Capsule insertion (crista intertrochanterica).

Materials and methods

In the context of this study, image quality does not focus on physical or radiation-related information but on anatomical landmarks that help to obtain a good reduction and thus, a correct image. Therefore, anatomical landmarks of the proximal femur that can be identified using intraoperative fluoroscopy were defined in cadaver bones using lead markings, and criteria for the desired projection were defined in a consensus process among 5 surgeons. After review of 25 cases, a consensus meeting, and a second review of 50 additional cases, the criteria were finalized. A 21 min educational video and a poster were produced to explain how to achieve a good quality lateral image and good reduction and implant position: [https://www.aointeract.org/#/watch/video/L3YxL3ZpZGVvcy8xOTc=/intraoperative-imaging-of-femur]

1. The patient is placed on a fracture table in supine position. The patella of the fractures side should look upright in a neutral position. The fluoroscope is introduced from distal from the contralateral side at an angle of approximately 30° to the sagittal plane of the operated leg. For the lateral (=axial) view, the C-arm is swung around the leg of the patient until a position of around 20–25° to the horizontal plane to start with. The visible anatomical structures of the image must be centred on the circular screen, they should appear diagonally.
2. The following structures must be visible: the entire femoral head with the joint space, the femoral neck, both trochanters and the proximal portion of the shaft. A true lateral view is achieved if a straight diagonal line can be drawn from the middle of the head, parallel through the neck axis into the shaft ("head/neck and shaft in line"). For this purpose, the optimal position of the fluoroscope should possibly be adjusted; it is usually between 0 and 25° to the horizontal plane, depending on the femoral anteversion angle of the individual patient. Only with a correct positioning of the fluoroscope *and* a good reduction of the fracture a true lateral view can be obtained.
3. In a well reduced fracture on a true lateral view the so-called "anterior" and "posterior line" are continuous (=harmonic) without any opening/gap and/or step off. The "anterior line" is a virtual line anteriorly in the lateral view from the head to the neck to the shaft with an anterior curvature between the latter two corresponding to the crista intertrochanterica (a tuberosity where the anterior capsule attached at the transition between neck and shaft). The "posterior line" can be identified posteriorly from the head to the neck to the shaft (Fig. 1). Any ad latus deformity between the head/neck fragment and the shaft results in an anterior or posterior step off of these lines. Any angulation, opening or gap, either anterior or posterior is a sign of an external rotation/extension deformity or an internal rotation/flexion deformity respectively.
4. The ideal position of the guide wire for the sliding screw is in the center of the head/neck fragment ("center-center-position").

Based on the criteria explained in the educational material, a 7-item questionnaire was developed to assess the intraoperatively obtained lateral images for the respective quality of the views (question [Q]1 and 2), for the landmarks (Q3–Q5), the reduction (Q6), and implant position (Q7) (Table 1).

The performance improvement study (NCT02272972) was conducted at five Trauma Centers in 4 countries (Austria, Slovenia, Switzerland, United States) between August 2014 and November 2016, after local ethics committee approval at each center. Five surgeons and a principal investigator (PI) were recruited at each clinic. Each surgeon a) assessed five own retrospective cases and five retrospective cases from the four colleagues per clinic (pre-educational assessment), b) viewed the educational video and the corresponding poster and re-assessed the same cases (post-educational assessment I). After the educational intervention, each surgeon treated 5 consecutive cases with a pertrochanteric fracture, and c) assessed the intraoperative post-implant images of the own cases and 5 of their colleagues' consecutive prospective cases at each clinic (post-educational assessment II) that were also treated after the educational intervention. Images were included of patients older than 18 years, diagnosed with a pertrochanteric fracture (AO 31-A1, A2, A3) and surgical treatment with either a Proximal Femoral Nail Antirotation (PFNA), a PFNA-II, a Dynamic Hip Screw (DHS), or a Titanium Trochanteric Fixation Nail System (TFN). All images were pseudonymized, and assessed by the individual surgeons using the same 7-item questionnaire at all three assessment time points. The video and poster was viewed and discussed by the surgeons in a 1 h group meeting at each site.

Table 1
Questions (Q) to assess the postimplant lateral view intraoperative images from patients with pertrochanteric fractures.

Part A: Image quality
Q1. Is enough shaft, neck, and head displayed on the lateral image?
Yes/No. In case of a "No" answer, comment (reason):
Q2. Is it a true lateral image?
Yes/No. In case of a "No" answer, comment (reason):
Part B: Quality of reduction and implant position
Q3. Is the angle between the femoral shaft axis and the neck/head axis within the range of 170–190°?
Yes/No [Fracture reduction not correct (it is a true lateral image)]/Not assessable; comment (reason)
Q4. Is the posterior 'harmonic' line (posterior contour of the head-neck-shaft) reduced to an acceptable degree?
Yes/No/Not assessable; comment (reason)
Q5. Is the anterior 'harmonic' line (anterior contour of the head-neck-shaft) reduced to an acceptable degree?
Yes/No/Not assessable; comment (reason)
Q6. Is the fracture reduction
Optimal
Not optimal but acceptable since the implants are already in; it will probably work
Not optimal but acceptable since the implants are already in; increased risk to fail
Not acceptable; needs revision
Not assessable; comment (reason)
Q7. Is the implant position
Optimal
Not optimal but acceptable since the implants are already in; it will probably work
Not optimal but acceptable since the implants are already in; increased risk to fail
Not acceptable; needs revision
Not assessable; comment (reason)

Additionally, the poster was placed close to the operating room for further access.

The primary outcome was the change in percentage of "yes" answers before (retrospective cases) and after the educational intervention (prospective cases) with regard to Q1 and Q2 (quality of projection). We tested the Null hypothesis (H0) that there will be no change in proportion of images rated with "yes" in Q1-Q2 after the Performance Improvement Program. The alternative hypothesis (H1) was that there will be an increase in proportion of images rated with "yes" in Q1-Q2 after the Performance Improvement Program. The collected data were clustered and assessments made by the same surgeon (reader), assessments relating to the same case, as well as assessments on images taken by the same surgeon were correlated. To account for the clustering a mixed effects logistic regression with a random effect for reader, case and the surgeon who took the image and a fixed effect for the time was used for the analysis. P-values less than 0.05 were considered statistically significant.

Inter-rater Kappa and percentage agreement were calculated to assess agreement among raters. For Q3 to Q7 the change in the proportion of "Not assessable" answers from the pre-educational phase to the prospective phase was analyzed with the above mentioned mixed effects logistics regression.

The surgeon's abilities to obtain lateral view images were analyzed by presenting the average number of best possible answers to Q1-Q7. The term "best possible answer" means the answer "yes" for Q1 to Q5 and "optimal" for Q6 and Q7. As no Gold standard for comparison exists, the four rating colleagues per each clinic were regarded as independent standard when assessing the change in average number of best possible answers: For each surgeon the average number of best possible answers *from all assessments concerning the own cases* and *excluding the own assessments* was calculated. Based on this calculation and using a paired *t*-test, the change in the average number of best possible answers were analyzed between the prospective cases (post-educational II) and the retrospective cases after the educational intervention (post-educational I). This time point was chosen for comparison because after the educational intervention, the surgeons were aware of the criteria for a good image and reduction and any change between the mentioned two time points can be assumed to refer to a change in the ability to obtain lateral view images rather than a change in image reading ability. Correlation between the average number of best possible answers and a) years of experience, and b) monthly average of hip fracture surgeries was analyzed using Spearman's rank correlation. The statistical analysis was performed using the software SAS version 9.4 (SAS Institute, Cary NC/USA).

Images from 25 patients per site (total: 125 cases) were assessed in the retrospective phase of this study. The included fracture types according to the AO classification were 46.4% (n = 58), 28.0% (n = 35) and 25.6% (n = 32) for type 31-A2, 31-A1 and 31-A3 fractures, respectively. The majority of patients were treated with a PFNA (68.0%, n = 85). In the prospective phase, 116 patients were subsequently enrolled in the study. 46.6% (n = 54) type AO 31-A2, 42.2% (n = 49) AO 31-A1 and 11.2% (n = 13) AO 31-A3 fracture. The PFNA was the most often used implant to treat these patients (66.4%, n = 77).

The mean age of the image assessing surgeons was 41.7 years (range: 30–58 years, SD 7.7), the majority was male (80%, n = 20). 40% (n = 10) were consultants, 24% (n = 6) were interns, 16% (n = 4) were deputy chief surgeons, 12% (n = 3) were chief surgeons. The investigators had on average 11.4 years of surgical practice (range: 1–25 years, SD 7.6) and operated a mean of 4.6 hip fractures per month (range: 1–15 hip fracture surgeries, SD 3.4).

For the analysis of the primary outcome, the cases of three surgeons had to be excluded due to incomplete data sets: First, the cases of one surgeon had only been assessed by himself and not by the other four raters in the pre-educational phase. Second, two clinics included only 21 and 20 prospective cases each because of respective time constraints for one surgeon and another surgeon's position change.

Results

Statistically significant changes between pre-educational assessments (retrospective cases) and post-educational assessments (prospective cases) were found for the questions Q1 'Is enough shaft, neck, and head displayed on the lateral image?' and Q2 'Is it a true lateral image?' (Table 2). In detail, for Q1 there were 88.1% (n = 467) of positive (=yes) assessments of the prospective images compared to 72.1% (n = 391) before the educational intervention ($p < 0.001$). For Q2 there were 92.3% (n = 489) of

Table 2
Evaluation of image quality, and quality of reduction and surgery (Q1–Q7) by time point of assessment.

	Time point		
Characteristic	Pre-educational assessment N = 542	Post-educational assessment I (retrospect.) N = 550	Post-educational assessment II (prospect.) N = 530
Q1: Is enough shaft, neck, and head displayed on the lateral image?, n (%)	542	550	530
No	151 (27.9)	154 (28.0)	63 (11.9)
Yes	391 (72.1)	396 (72.0)	467 (88.1)
Q2: Is it a true lateral image?, n (%)	542	550	530
No	115 (21.2)	137 (24.9)	41 (7.7)
Yes	427 (78.8)	413 (75.1)	489 (92.3)
Q3: Is the angle between the femoral shaft axis and the neck/head axis within the range of 170-190°?, n (%)	542	550	530
No [Fracture reduction not correct (it is a true lateral image)]	32 (5.9)	31 (5.6)	14 (2.6)
Yes	422 (77.9)	432 (78.5)	486 (91.7)
Not assessable	88 (16.2)	87 (15.8)	30 (5.7)
Q4: Is the posterior harmonic line (posterior contour of the head-neck-shaft) reduced to an acceptable degree?, n (%)	541	550	530
No	62 (11.5)	66 (12.0)	40 (7.5)
Yes	414 (76.5)	388 (70.5)	458 (86.4)
Not assessable	65 (12.0)	96 (17.5)	32 (6.0)
Q5: Is the anterior harmonic line (anterior contour of the head-neck-shaft) reduced to an acceptable degree?, n (%)	542	550	530
No	80 (14.8)	105 (19.1)	46 (8.7)
Yes	393 (72.5)	358 (65.1)	454 (85.7)
Not assessable	69 (12.7)	87 (15.8)	30 (5.7)
Q6: Is the fracture reduction, n (%)	542	550	530
Optimal	312 (57.6)	294 (53.5)	383 (72.3)
Not optimal but acceptable since the implants are already in, it will probably work	125 (23.1)	134 (24.4)	100 (18.9)
Not optimal but acceptable since the implants are already in; increased risk to fail	42 (7.7)	46 (8.4)	28 (5.3)
Not acceptable; needs revision	7 (1.3)	8 (1.5)	4 (0.8)
Not assessable	56 (10.3)	68 (12.4)	15 (2.8)
Q7: Is the implant position, n (%)	542	550	530
Optimal	267 (49.3)	237 (43.1)	348 (65.7)
Not optimal but acceptable since the implants are already in, it will probably work	182 (33.6)	205 (37.3)	140 (26.4)
Not optimal but acceptable since the implants are already in; increased risk to fail	44 (8.1)	49 (8.9)	18 (3.4)
Not acceptable; needs revision	9 (1.7)	7 (1.3)	4 (0.8)
Not assessable	40 (7.4)	52 (9.5)	20 (3.8)

Q: Question, N: Number of assessments.

positive (=yes) assessments of the prospective images compared to 78.8% (n = 427) before the educational intervention ($p < 0.001$). The inter-rater agreement for image quality measured with Kappa was only fair at all time points (Kappa Q1 and Q2: 0.28–0.39). However, the percentage agreement between the surgeons for image quality between the pre-educational assessment and the prospective post-educational assessment increased (Table 3).

For all three criteria assessing reduction-related landmarks (Q3–Q5) the number of 'not assessable' image ratings between the pre-educational (retrospective cases) and post-educational II (prospective cases) assessments was significantly reduced (*p*-values between <0.001 and 0.028). The same result was found for the criteria reduction (Q6, $p < 0.001$) and implant position (Q7, $p = 0.035$). An overview of the assessments for the questions Q3 to Q7 is given in Table 2. The percentage agreement for landmarks, quality of reduction and implant position increased (Table 3).

When focused on the individual surgeon's ability to obtain lateral view images, the average number of best possible ratings by the colleagues increased by 1.2 (range: −0.6–3.1, standard deviation 1.1, $p < 0.001$) between the retrospective image assessments after the education and the assessments of the prospectively recorded images (Table 4). Of the 23 surgeons without missing cases during the prospective phase, 19 had an increase in the average number of best possible assessments by the colleagues, and 4 had a decrease between the two time points post-educational II and post-educational I.

Table 3
Percentage agreement for the questions (Q) regarding image quality, and quality of reduction and surgery (Q1–Q7) by time point of assessment.

	Percentage agreement		
	Pre-education	Post-education I	Post-education II
Q1: Is enough shaft, neck, and head displayed on the lateral image?	74.75%	75.73%	86.55%
Q2: Is it a true lateral image?	78.44%	72.61%	91.81%
Q3: Is the angle between the femoral shaft axis and the neck/head axis within the range of 170–190°?	75.78%	79.09%	87.33%
Q4: Is the posterior harmonic line (posterior contour of the head-neck-shaft) reduced to an acceptable degree?	75.31%	68.11%	82.44%
Q5: Is the anterior harmonic line (anterior contour of the head-neck-shaft) reduced to an acceptable degree?	69.75%	63.15%	80.92%
Q6[a]: Is the fracture reduction . . . ?	55.36%	54.32%	63.85%
Q7[a]: Is the implant position . . . ?	51.56%	52.35%	60.12%

N: Number of assessments.
[a] Q6 and Q7 have 5 answer options that are shown in Table 1.

Table 4
Assessment of surgeon's abilities measured by the change in average number of best possible answers.

	Time point			p-value*
	Post-educational assessment I (retrospective) N = 23	Post-educational assessment II (prospective) N = 23	Change from Post-educational I to Post-educational II N = 23	
Average number of best possible answers (Q1-Q7)				<0.001
n	23	23	23	
Mean (sd)	4.4 (1.0)	5.7 (0.7)	1.2 (1.1)	
Median (Q1;Q3)	4.5 (3.8;5.2)	5.9 (5.4;6.2)	1.1 (0.5;2.2)	
Min;Max	2.7;6.3	3.8;6.8	−0.6;3.1	

* *p*-value from paired *t*-test.

Table 5
Correlation between the average number of best possible answers and experience.[a]

Outcome	Correlation between average number of best possible answers (Q1-Q7)								
	Pre-educational assessment			Post-educational assessment I (retrospective)			Post-educational assessment II (prospective)		
	n	Spearman Rho	p-value	n	Spearman Rho	p-value	n	Spearman Rho	p-value
Years of practice	24	−0.11	0.619	25	0.02	0.910	23	0.00	0.987
Monthly average of surgeries in hip fracture patients (NOT hip replacement/ arthroplasty)	24	−0.20	0.350	25	−0.05	0.816	23	−0.18	0.422

[a] For each surgeon, the average number of best possible answers from all assessments concerning his own cases and excluding his own assessments was calculated per time point. First the average number of best possible answers per case was calculated and afterwards an average over the cases from the respective surgeon was derived. Because of missing data, two surgeons are excluded from the post-educational II assessment and one surgeon is excluded from the pre-educational assessment.

No correlation between the average number of best possible answers and the experience of the surgeons was found (Table 5).

Discussion

Although fluoroscopy is the most important tool to intra-operatively assess reduction and implant position in fracture surgery, it has not been studied systematically in terms of defining standardized views, and formal training is lacking. This study investigated the effect of a formal educational video focusing on obtaining and assessing a true lateral view of the proximal femur during intramedullary nailing of a pertrochanteric fracture, on a) the quality of the intraoperatively obtained image views, b) achieving pre-defined angles and adjustments, c) the quality of reduction, and d) the quality of implant position. The criteria for the assessments were developed and defined during a consensus process and applied in a 7-item questionnaire.

The analysis of the assessments revealed significantly positive effects of the educational intervention on the projection quality. A similar result with improvement of the diagnostic quality of radiographs after a focused educational training using power point teaching, a poster and hands on training using a skeleton has also been shown for shoulder images [9]. Although our approach and the type of images were different, the number of best possible ratings for fracture reduction and implant position increased in our study, and a higher percentage agreement for image quality, landmarks, quality of reduction and surgery was achieved. These findings indicate that better image quality conforms to better abilities to reduce the fracture and place the implant. However, as the assessments from the retrospective pre-educational and the prospective post-educational images are based on different patients, an unambiguous conclusion is not possible. Due to the educational intervention, there may be a change in image taking abilities as well as reading abilities. These two abilities cannot clearly be separated. Although our study is unique, Heetveld et a. also emphasized the importance of correct interpretation of femoral neck radiographs after reduction and dynamic hip screw fixation [10].

There is no accepted Gold standard for intraoperative fluoroscopy in pertrochanteric fractures. Also, no independent expert assessed the images of this study. Therefore, the ratings of a surgeon's own images by the four colleagues were used as independent evaluation in our study. This approach revealed that the average number of best possible ratings of the individual surgeon's images by the colleagues significantly increased.

In the literature, interactive medical education sessions that enhance participant activity and provide the opportunity to practice skills are described to have positive effects on professional practice [9,11]. This is confirmed our study. Neither the years of practice nor the number of monthly hip fracture surgeries influenced the results. We think that the lack of a formalized definition and interpretation of images could be one possible explanation.

The main limitations of this study are the absence of expert assessment of all images and the absence of a control. A separate hospital undergoing the whole study procedures without the educational intervention could have added comparative control data. These limitations should be considered when designing a similar study in the future.

Conclusions

A focused educational intervention using a teaching video and a poster can have a positive effect on overall agreement between surgeons on how to assess intraoperative images as well as on the quality of the obtained views; and on the quality of reduction and implant placement regardless of surgeon experience.

Conflict of interest

No competing interests declared.

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