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Original article

Change in acetabular version after lumbar pedicle subtraction osteotomy to correct post-operative flat back: EOS® measurements of 38 acetabula

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ABSTRACT

Background: Abnormalities in acetabular orientation can promote the development of hip osteoarthritis, femoro-acetabular impingement, or even acetabular cup malposition. The objective of the present study was to determine whether pedicle substraction osteotomy (PSO) to correct sagittal spinal imbalance affected acetabular orientation.
Hypothesis: PSO performed to correct sagittal spinal imbalance affects acetabular orientation by changing the pelvic parameters.
Materials and methods: This was a descriptive study in which two observers measured the acetabular parameters on both sides in 19 patients (38 acetabula) before and after PSO for post-operative flat-back syndrome. Mean time from PSO to post-operative measurements was 19 months. Measurements were taken twice at a 2-week interval, on standing images obtained using the EOS® imaging system and sterEOS® software to obtain 3D reconstructions of synchronised 2D images. Acetabular anteversion and inclination were measured relative to the vertical plane. Mean pre-PSO and post-PSO values were compared using the paired *t*-test, and *P* values lower than 0.05 were considered significant. To assess inter-observer and intra-observer reproducibility, we computed the intra-class correlation coefficients (ICCs).
Results: The measurements showed significant acetabular retroversion after PSO, of 7.6° on the right and 6.5° on the left ($P < 0.001$). Acetabular inclination diminished significantly, by 4.5° on the right and 2.5° on the left ($P < 0.01$). Inclination of the anterior pelvic plane decreased by 8.4° ($P < 0.01$). Pelvic incidence was unchanged, whereas sacral slope increased by 10.5° ($P < 0.001$) and pelvic tilt decreased by 10.9° ($P < 0.001$). The ICC was 0.98 for both inter-observer and intra-observer reproducibility.
Conclusion: Changing the sagittal spinal alignment modifies both the pelvic and the acetabular parameters. PSO significantly increases sacral slope, thus inducing anterior pelvic tilt with significant acetabular retroversion. The measurements obtained using sterEOS® showed good inter-observer and intra-observer reproducibility. To our knowledge, this is the first study of changes in acetabular version after PSO.

1. Introduction

The pelvis constitutes the junction between the torso and the lower limbs, as illustrated by the well-known 'pelvic vertebra' concept introduced by J. Dubousset [1–4]. Loss of lumbar lordosis related to arthrodesis can result in post-operative flat-back syndrome, which is characterised by anterior sagittal imbalance [5] as defined by the sagittal vertical axis (SVA) or C7 plumb line [6].

Postural changes designed to correct the anterior sagittal imbalance consist of posterior pelvic tilt with hip extension and, subsequently, knee flexion. Thus, compensation by the global extension reserve, which is the sum of the extrinsic extension reserve allowed by the lumbo-sacral junction and of the intrinsic extension reserve allowed by the hips [7,8], restores the sagittal balance up to a point [9]. When the global extension reserve is no longer sufficient, sagittal imbalance occurs.

Total hip arthroplasty (THA) with restoration of a good intrinsic extension reserve does not seem to affect the pelvic parameters [10] yet, in some patients, results in relief of low back pain [11]. This fact supports the hip-spine syndrome concept developed by Offierski and MacNab [12].

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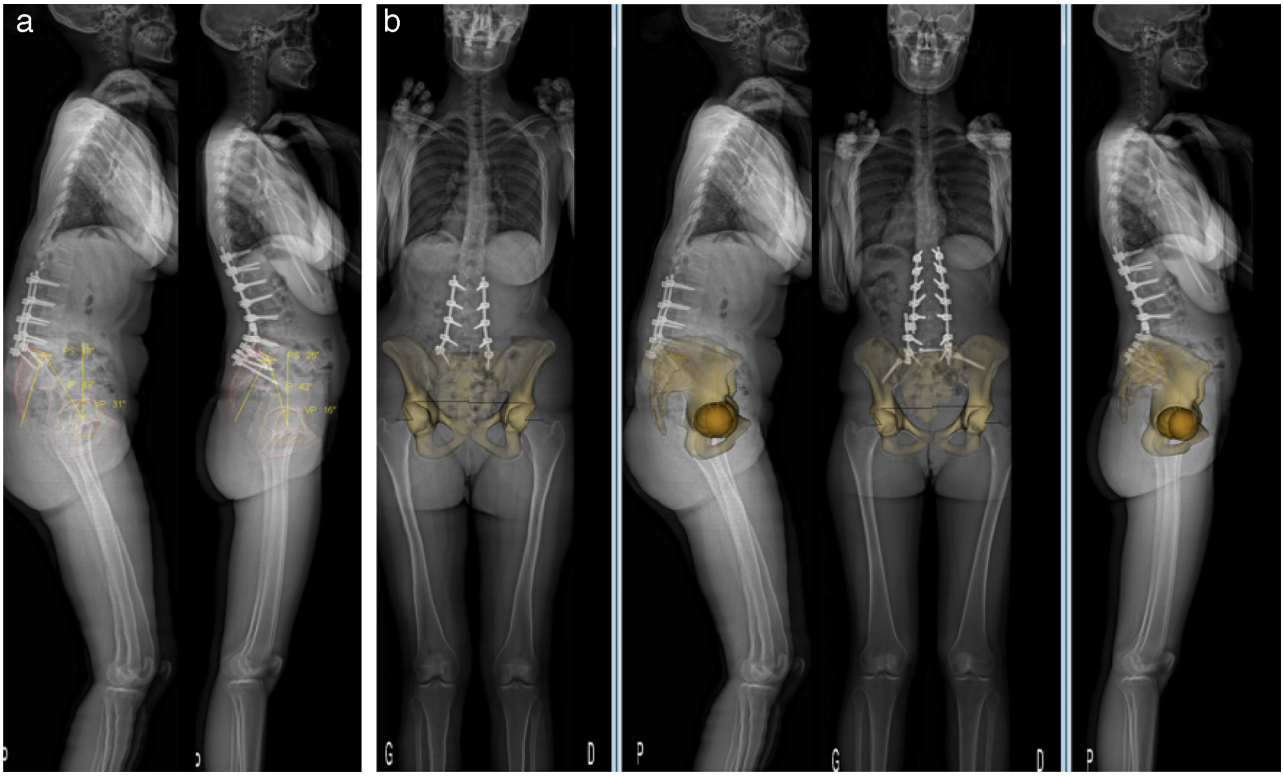

Fig. 1. a: pelvic parameters before and after transpedicular osteotomy. PI: pelvic incidence (°); PT: pelvic tilt (°); SS: sacral slope (°); b: 3D reconstruction.

Close associations linking pelvic parameters to acetabular orientation have been demonstrated [13]. Legaye et al. [14] showed that acetabular inclination depended chiefly on sacral slope and, to a lesser extent, on pelvic incidence.

The development of new imaging tools such as the low-dose EOS® radiographic system (EOS Imaging, Paris, France) has allowed not only a global postural analysis, but also dynamic studies of the femur-pelvis-spine junction [15–19]. When moving from the standing to the seated position, the pelvis tilts posteriorly [20] and changes occur in the acetabular parameters [21,22], including increased acetabular cup anteversion [23,24].

To correct the sagittal imbalance that characterises post-operative flat-back syndrome, one of the treatment options is surgery via the posterior approach with transpedicular closed-wedge resection osteotomy (pedicle subtraction osteotomy, PSO). By inducing anterior pelvic tilt, PSO causes significant changes in the pelvic parameters [25,26]. The magnitude of the change in pelvic orientation depends on the level of the PSO [27]. To our knowledge, no studies have directly investigated the influence of lumbar PSO on acetabular parameters.

The objective of our study was to determine whether lumbar PSO performed to treat post-operative flat-back syndrome induced statistically significant changes in acetabular version. As a preliminary step, we evaluated the repeatability and reproducibility of native-hip acetabular parameter measurements using the sterEOS® system.

2. Material and methods

A retrospective descriptive study of radiographic measurements was performed. Inclusion criteria were age > 18 years, lumbar transpedicular closed-wedge osteotomy to treat post-operative flat-back syndrome, and standing whole-body low-dose EOS® imaging before and after PSO. Exclusion criteria were the presence, in addition to flat-back syndrome, of lumbar or thoracic scoliosis and insufficient visibility of the anatomic structures compromising the ability to determine pelvic and acetabular parameters on the EOS® images.

Two observers measured pelvic and acetabular parameters on both sides in all patients. These measurements were performed twice, at an interval of 2 weeks, using sterEOS® 3D software (Fig. 1a and b), which converts 2D images into a 3D model. The study parameters are described below.

Pelvic parameters:

- pelvic incidence (IPI): angle formed by a perpendicular line through the middle of the sacral endplate and the line connecting the middle of the sacral endplate to the centres of the femoral heads;
- sacral slope (SS): angle formed by the horizontal and a line tangent to the sacral endplate;
- pelvic tilt (PT): angle formed by the vertical and the line connecting the centres of the femoral heads to the middle of the sacral endplate;
- lumbar lordosis (LL): angle formed by the lines tangent to the upper L1 endplate and sacral endplate;
- anterior pelvic plane (APP): plane containing the two antero-superior iliac spines and the pubis;
- APP inclination: angle formed by the vertical and the APP.

Acetabular parameters (Fig. 2a and b):

- acetabular inclination (AI): angle formed by the projection of the horizontal plane corrected by the axis connecting the centres of the acetabula and the projection of the acetabular opening on the coronal plane;
- acetabular anteversion (AA): angle formed by the projection of the sagittal plane corrected by the perpendicular to the axis connecting the centres of the acetabula and the projection of the acetabular opening on the corrected horizontal plane.

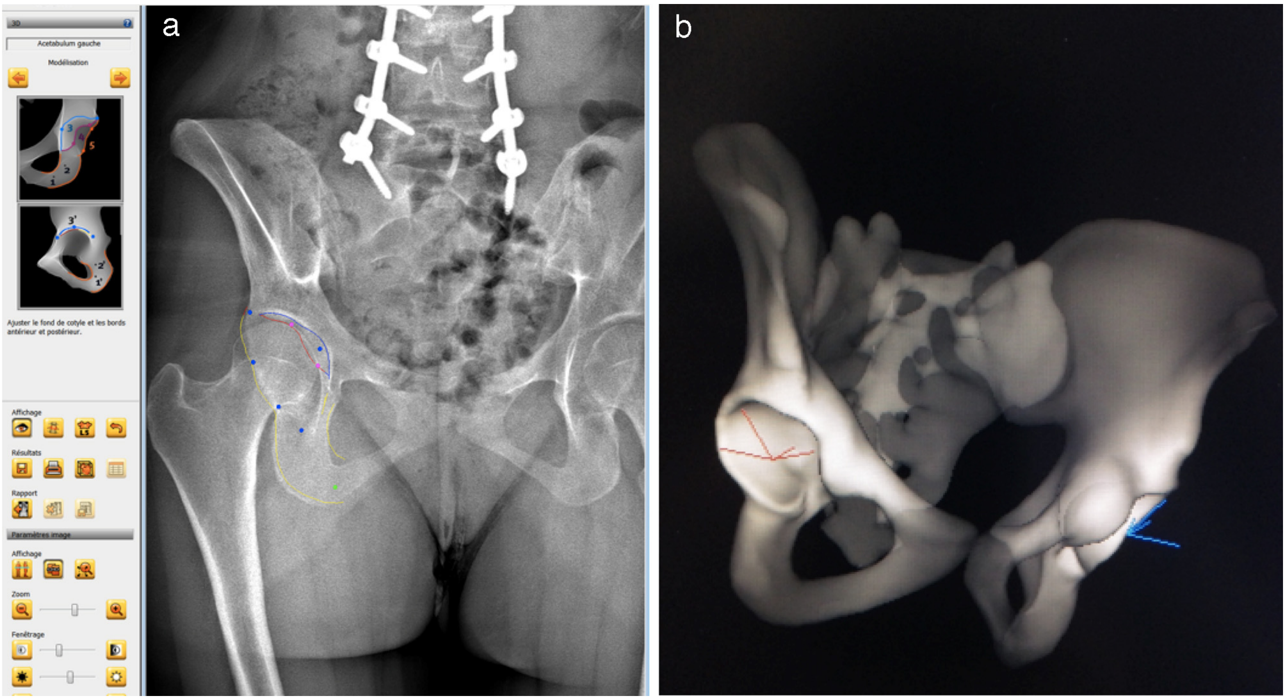

Fig. 2. a: acquisition of the acetabular parameters; b: 3D measurement of acetabular anteversion and acetabular inclination.

The acetabular parameters (AI and AA) and APP were measured relative to the vertical plane, defined as the plane containing the centres of the acetabula (coronal plane).

Statistical analysis: an analysis using the histogram method established that all study variables were normally distributed. The mean pre-operative and post-operative values of each variable were compared using the paired *t*-test. Values of $P < 0.05$ were considered significant. A linear regression model was built using the least-squares method.

Inter-observer and intra-observer reproducibility was assessed by computing the intra-class coefficients (ICCs) [28,29]. Correlations are considered very strong when the ICC is > 0.95 [30].

3. Results

This single-centre study was performed from March 2010 to July 2013. Of the 22 patients included initially, 3 were excluded, including 2 because of poor visibility of the acetabulum, most notably its anterior wall; and 1 because the right iliac wing was outside the acquisition field. This left 19 patients for the study, 13 females and 6 males, with a mean age of 61 years (range, 22–77 years). Thus, 38 acetabula were studied and 76 measurements were obtained by each of the two observers. Mean time from PSO to the post-operative measurements was 19 months (range, 1–35).

Table 1 reports the findings in each patient and Table 2 the comparisons of the mean pre-operative versus post-operative

Table 1
Radiographic variables measured in degrees.

Pre-operative values (°)								Post-operative values (°)							
PI	PT	SS	LL	AA R	AI R	AA L	IA L	PI	PT	SS	LL	AA R	AI R	AA L	AI L
56.9	27.9	27.2	18	27.9	57.1	23.8	58.5	52.4	17.4	34.3	46	22	57.6	22.2	59.9
33.6	20.1	13.7	4	27.4	51.2	21.5	50.2	31.9	5.4	26.3	37	11.5	51.4	14.3	49
47.8	22.7	26.3	23.1	29.6	56.1	23.6	54.6	53	23.7	31.5	41	25.4	54.9	20.1	56.1
66.1	49.1	15.9	27	33.9	64.2	35.6	62.8	68.1	40	25.2	53	27.5	56.1	25	61.5
76.7	55.3	20.7	20	39.9	66.6	36.8	64.8	80.3	44.5	34.5	70	32.2	53.8	28.5	57.6
37.8	42.6	−4.6	−6	36.4	69.5	34.1	67.8	44.1	34.2	10	40	30.1	61.2	29.3	60.6
59.2	36.6	22.3	30.6	34.1	62.5	34.2	62.5	58.6	12.9	46.6	54.8	14.4	52.9	15.7	52.4
48.7	29.4	17.9	12	23.4	60	26.2	60.4	51.7	15.7	35.8	42	15.6	54.4	17.7	56.7
59.8	32	25.1	17	23	60.8	25.8	58.3	61.3	21	42.2	52	20.6	55.1	20	55
40.4	17.6	20.2	15	24.6	54.6	20.7	55.3	39.1	8.3	28.6	50	19.9	53.7	17.7	60.3
56.6	26.3	28.3	41.9	30.2	62.7	26.3	57.4	46.8	11.7	35	67	23.3	56.8	22.1	56.1
57.7	33.7	22.9	30	30.9	58.9	33	60.2	58.5	28.7	29	53	22.5	59.3	24.7	57.1
45.2	7.2	38	15.8	22.7	43.2	31.2	45.5	40.1	−1.7	41.1	48	11.5	42.7	20.9	44.8
65.9	38.4	28.6	35	30.6	60.4	26.6	55.1	68.2	43.2	29.5	56	29.4	60.5	29.8	59.2
52.7	29.5	23	21	30.5	55.9	27.7	55.2	52.5	20.1	31.3	45	25.1	55.9	24.3	53.9
42	32.5	10.1	1	28.7	57.2	25.9	60.2	42.4	13.4	27.2	49	17.1	53.1	17.2	54.7
54	36.1	15.3	11	38.3	54.9	36.1	55.2	49.8	19.7	28.3	52	28.6	49.6	24.2	46.9
69.1	33.7	30.6	14	31.3	68.1	29.1	67.8	61.1	17.9	41.1	57.3	23.3	56.6	24.6	64.6
63.6	46.7	13.6	2.1	29.8	67.4	30.6	67.1	64.8	40.5	26	38	27.9	60	25.9	64.6

PI: pelvic incidence; PT: pelvic tilt; SS: sacral slope; LL: lumbar lordosis; AA R: acetabular anteversion on the right; AI R: acetabular inclination on the right; APPI: anterior pelvic plane inclination.

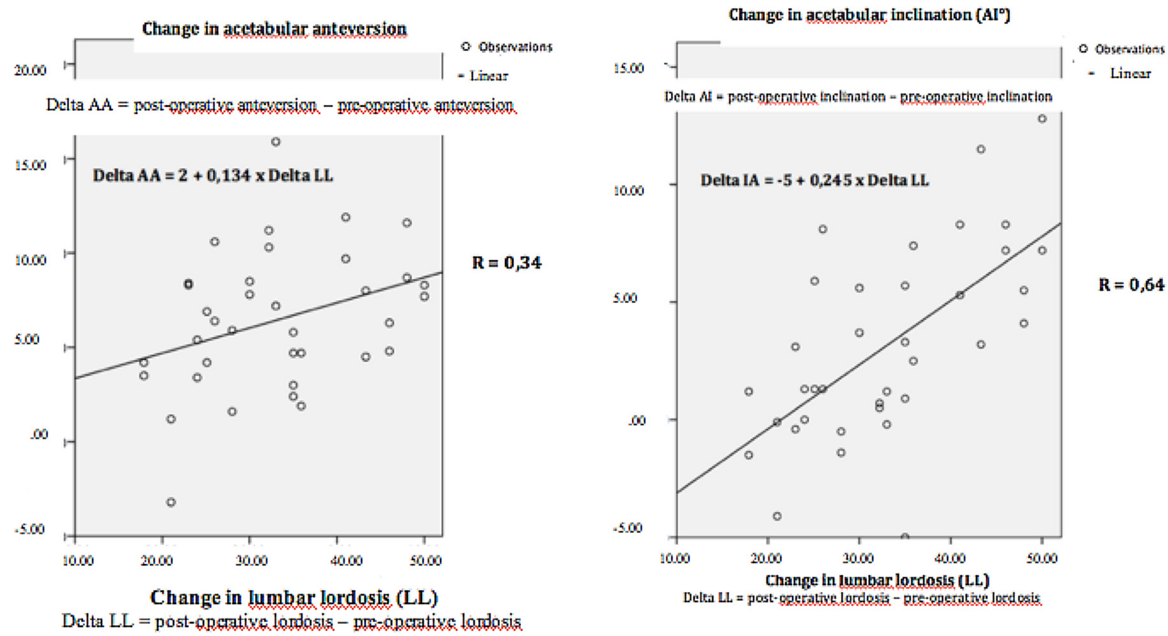

Fig. 3. Linear regression model built using the least-squares method.

Table 2
Radiographic variables measured in degrees (mean ± SD).

Variable	Before PSO (°)	At last follow-up after PSO (°)
PI	54.4 ± 11.4	53.9 ± 11.9
PT	32.4 ± 11.4	21.9 ± 13.3
LL	17.5 ± 12.2	50 ± 8.9
APPI	−15.9 ± 14.4	−7.4 ± 11
AA R	30.1 ± 4.8	22.5 ± 6.2
AA L	28.8 ± 5.0	22.3 ± 4.5
IA R	59.5 ± 6.4	55 ± 4.2
IA L	58.8 ± 5.8	56.3 ± 5.3

PSO: pedicle subtraction osteotomy; PI: pelvic incidence; PT: pelvic tilt; LL: lumbar lordosis; APPI: anterior pelvic plane inclination; AA R: acetabular anteversion on the right; AA L: acetabular anteversion on the left; AI R: acetabular inclination on the right; AI L: acetabular inclination on the left.

Table 3
Differences in mean values in degrees.

Variable	Difference in means before and after PSO (°)	95% confidence interval	*P*-value
PI	0.47	(−1.6; 2.5)	0.63
PT	10.56	(7.4; 13.7)	< 0.01
LL	−32.56	(−37.2; −28)	< 0.01
APPI	−8.48	(−14.3; −2.6)	< 0.01
AA R	7.65	(5.4; 9.9)	< 0.01
AA L	6.56	(1.1; 4.3)	< 0.01
IA R	4.5	(1; 2.4)	< 0.01
IA L	2.5	(0.6; 4.4)	0.013

PSO: pedicle subtraction osteotomy; PI: pelvic incidence; PT: pelvic tilt; LL: lumbar lordosis; APPI: anterior pelvic plane inclination; AA R: acetabular anteversion on the right; AA L: acetabular anteversion on the left; AI R: acetabular inclination on the right; AI L: acetabular inclination on the left.

values of each study variable. Apart from PI, all variables changed significantly between the pre-operative and post-operative measurements (Table 3). From pre-operative to post-operative, the mean change in LL (ΔLL) was 32° and the mean change in acetabular version consisted in retroversion of 7.65° on the right and 6.56° on the left. AI measurements showed a shift towards a more horizontal position of 4.5° on the right and 2.5° on the left.

Changes from pre-operative to post-operative in AA (ΔAA) and AI (ΔAI) correlated significantly ($R \neq 0$) with ΔLL. The linear regression model built using the least-squares method showed simple linear relationships: $\Delta AA = 2 + 0.134 \cdot \Delta LL$; and $\Delta IA = -5 + 0.245 \cdot \Delta LL$. The correlation coefficients were $R_{AA} = 0.34$ and $R_{IA} = 0.64$ (Fig. 3).

For quantitative variables, both the inter-observer ICC and the intra-observer ICC values were 0.98.

4. Discussion

This study demonstrates that spinal surgical procedures aimed at inducing large corrections in sagittal alignment modify the orientation of the acetabula. Thus, PSO performed to treat post-operative flat-back syndrome induces statistically significant acetabular retroversion and horizontalisation.

We selected patients with post-operative flat-back syndrome and we excluded patients with scoliosis in order to focus our study on deformities in the sagittal plane. Although these strict inclusion criteria resulted in limited statistical power, the major effect of PSO in correcting sagittal malalignment allowed us to detect significant changes in our small sample. In all patients, the instrumentation extended down to the pelvis and therefore immobilised the sacro-iliac joints. This fact eliminated all risk of measurement bias related to sacro-iliac joint motion.

Despite the limited statistical power of the study, the measurements made on EOS® images using sterEOS® 3D software showed very good reproducibility and repeatability. Although the changes in acetabular orientation seemed to correlate with the changes in LL, the fairly low correlation coefficients ($R_{AA} = 0.34$ and $R_I = 0.64$) indicate that our results are not sufficiently robust to allow definitive conclusions. A study offering greater statistical power and including the identification of potential confounders would be needed.

In our study, the acetabular parameters were measured relative to the vertical plane and not to the APP. The terms functional inclination and anteversion are therefore appropriate, since these measurements vary with the position of the pelvis [20].

Restoring femoral-pelvic-spinal balance should be among the goals considered when planning THA. Although the frequency of prosthetic hip dislocation has decreased since the introduction of large-diameter femoral heads and dual-mobility acetabular cups

[31], the acetabular retroversion induced by PSO increases the risk of posterior dislocation in patients with THA. Several authors such as Lafage et al. [32] and Boissière et al. [33] developed mathematical formulas designed to predict whether PSO was needed to correct a sagittal imbalance. When a need for PSO is predicted, given the effects of PSO on acetabular version, the hip surgeon should consider these parameters when planning THA and should give preference to a dual-mobility cup in order to minimise the risk of posterior dislocation after PSO. In turn, the spinal surgeon should take the presence of one or two prosthetic hips into account when planning PSO to treat post-operative flat-back syndrome.

Cup orientation based on the safe range defined in the APP by Lewinnek et al. [34] remains unchanged after PSO. The change in acetabular orientation is significant in the vertical (or functional) plane but not in the APP, which is the plane of reference used for navigation during THA. To date, no studies have addressed the clinical consequences (most notably the risk of dislocation) of functional acetabular retroversion induced by PSO in patients with a history of THA.

5. Conclusion

PSO performed to treat post-operative flat-back syndrome induces statistically significant acetabular retroversion and horizontalisation. These changes should be taken into account when planning acetabular cup orientation during THA.

Nevertheless, to date, no proof exists that PSO-induced changes are associated with clinical effects, most notably in patients with a history of THA.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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