Pelvic retroversion: a compensatory mechanism for lumbar stenosis

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OBJECTIVE The flexed posture of the proximal (L1–3) or distal (L4–S1) lumbar spine increases the diameter of the spinal canal and neuroforamina and can relieve symptoms of neurogenic claudication. Distal lumbar flexion can result in pelvic retroversion; therefore, in cases of flexible sagittal imbalance, pelvic retroversion may be compensatory for lumbar stenosis and not solely compensatory for the sagittal imbalance as previously thought. The authors investigate underlying causes for pelvic retroversion in patients with flexible sagittal imbalance.

METHODS One hundred thirty-eight patients with sagittal imbalance who underwent a total of 148 fusion procedures of the thoracolumbar spine were identified from a prospective clinical database. Radiographic parameters were obtained from images preoperatively, intraoperatively, and at 6-month and 2-year follow-up. A cohort of 24 patients with flexible sagittal imbalance was identified and individually matched with a control cohort of 23 patients with fixed deformities. Flexible deformities were defined as a 10° change in lumbar lordosis between weight-bearing and non-weight-bearing images. Pelvic retroversion was quantified as the ratio of pelvic tilt (PT) to pelvic incidence (PI).

RESULTS The average difference between lumbar lordosis on supine MR images and standing radiographs was 15° in the flexible cohort. Sixty-eight percent of the patients in the flexible cohort were diagnosed preoperatively with lumbar stenosis compared with only 22% in the fixed sagittal imbalance cohort ($p = 0.0032$). There was no difference between the flexible and fixed cohorts with regard to C-2 sagittal vertical axis (SVA) ($p = 0.95$) or C-7 SVA ($p = 0.43$). When assessing for postural compensation by pelvic retroversion in the stenotic patients and nonstenotic patients, the PT/PI ratio was found to be significantly greater in the patients with stenosis ($p = 0.019$).

CONCLUSIONS For flexible sagittal imbalance, preoperative attention should be given to the root cause of the sagittal misalignment, which could be compensation for lumbar stenosis. Pelvic retroversion can be compensatory for both the lumbar stenosis as well as for sagittal imbalance.

<https://thejns.org/doi/abs/10.3171/2017.2.SPINE16963>

KEY WORDS flat-back deformity; adult deformity; flexibility; MRI; lumbar spine; lumbar fusion; lumbar lordosis; lumbar stenosis; pelvic retroversion; sagittal imbalance

A PORTION of flexible flat-back deformity is postural, by definition.^{11,12,27,29,30,36,42} Patients with lumbar stenosis are known to have limited lumbar lordosis (LL) because the compensatory flexed posture helps to alleviate pain (Fig. 1).^{11,12,22,27–30,36,42} Flexion of the spine increases the spinal canal diameter and subsequently relieves symptoms of neurogenic claudication.^{25,34,35,41} Distal lumbar flexion (L4–S1) to increase the diameter of the

canal can result in pelvic retroversion (Fig. 2).^{25,34,35,41} Previously, pelvic retroversion in patients with sagittal imbalance was thought to be solely compensatory for the sagittal imbalance.^{5,18,19,20,22,24,26}

A flexible flat-back deformity can result in sagittal imbalance if the patient cannot compensate for the deformity through the hips, knees, and thoracic/cervical spine.^{5,18,24,26} While standing, patients will compensate to improve sta-

ABBREVIATIONS EBL = estimated blood loss; LL = lumbar lordosis; LOS = length of stay; PD-Q = painDETECT questionnaire; PHQ-9 = Patient Health Questionnaire–9; PI = pelvic incidence; PRO = patient-reported outcome; PSO = pedicle subtraction osteotomy; PT = pelvic tilt; SVA = sagittal vertical axis.

SUBMITTED August 13, 2016. **ACCEPTED** February 9, 2017.

INCLUDE WHEN CITING Published online June 9, 2017; DOI: 10.3171/2017.2.SPINE16963.

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bility by grossly flexing the spinal column both proximally and distally, resulting in a reduction of LL that quickly disappears when the patient is supine and gravitational effects are absent.⁹ Sagittal parameters including pelvic incidence (PI), pelvic tilt (PT), LL, and sagittal vertical axis (SVA) can be used to assess the degree of and ability for spinopelvic compensation.^{24,33,40,43}

In a previous study, we identified a cohort of patients with radiographically evident flexible sagittal imbalance from a database of 138 patients undergoing surgery for sagittal imbalance.³⁷ In that study, we determined that flexible sagittal imbalance was a 10° change in LL between weight-bearing and non-weight-bearing images. On further analysis, we found that a significant proportion of the patients with flexible deformities were preoperatively diagnosed with lumbar stenosis when compared with a matched cohort of nonflexible patients from the same patient population (S. Pourtaheri et al: Flexible sagittal imbalance: a compensatory mechanism for lumbar stenosis, presented at the Congress of Neurological Surgeons Annual Meeting, San Diego, 2016). We hypothesize that a portion of the pelvic retroversion for flexible sagittal imbalance is compensatory for coinciding lumbar stenosis.

Methods

We retrospectively reviewed a prospective clinical database (The Knowledge Program, Cleveland Clinic) of all patients who underwent lumbar spinal fusion performed by a single fellowship-trained spine surgeon at a quaternary medical center between 2008 and 2013. Patients undergoing surgery for correction of thoracolumbar spinal deformity with symptomatic sagittal imbalance and neurological deficits were included. Patients with malignancies, infection, and fractures were excluded. All included patients required appropriate preoperative, intraoperative, and 2-year follow-up imaging. Imaging included preoperative and 6-month and 2-year postoperative full-length anteroposterior and lateral standing radiography; preoperative MRI; and intraoperative, localizing lateral lumbar radiography from L-1 to the sacrum. Preoperative lumbar stenosis was defined as significant compression of the thecal sac on axial T2-weighted MRI correlating with symptoms of neurogenic claudication. This was surgically treated via laminectomy.

Interbody fusion was only performed at the L5–S1 level and the L4–5 level because of the risk of pseudarthrosis and to maximize segmental lordosis. Other cases were above and below the pedicle subtraction osteotomy (PSO) level because of the risk of pseudarthrosis. All patients were treated with posterior-only fusion or combined anterior/posterior fusion. The anterior fusion procedure was an anterior lumbar interbody fusion. No lateral interbody fusions or open anterolateral approaches were performed.

The Knowledge Program is a patient-reported outcome (PRO) assessment tool that is partnered with our institutional electronic medical record system. It prospectively compiles self-assessment data obtained at outpatient visits. The PRO metrics used in the current study have been validated to assess patient quality of life after spinal surgery.⁴⁴ The EQ-5D measures and standardizes health

FIG. 1. Diagrams showing that compensatory lumbar flexion due to lumbar stenosis increases C-2 SVA. Figure is available in color online only.

outcomes. Scores are transformed into an index value, between 0 and 1, known as the quality-adjusted life year, where 1 is equivalent to 1 year in perfect health and 0 is patient death.¹⁴ The painDETECT questionnaire (PD-Q), an 11-point (0–10) scale, determines how pain affects a patient's ability to function within 15 categories. It is divided into functional and psychosocial components, which are combined to give a total score (maximum 150; higher scores indicate greater disability).¹⁵ The Patient Health Questionnaire–9 (PHQ-9) screens for depression based on 9 criteria established by the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition*.² Scores between 5 and 10 indicate minor depression, and scores higher than 10 are indicative of major depression.¹⁹ The minimum clinically important differences for the EQ-5D, PD-Q, and PHQ-9 values at 1 year are 0.1, 26, and 5, respectively.³¹ Other data such as age, sex, use of instrumentation during surgery, length of procedure, estimated blood loss (EBL), length of stay (LOS), and complications were also recorded.

A single blinded author (A.S.) performed all radiographic calculations. PI and PT were obtained from full-length standing radiographs. LL was measured using the superior endplates of L-1 and S-1 on both the preoperative standing radiograph and the supine MR image. Flexible deformities were defined as a $\geq 10^\circ$ mismatch between LL measured on supine MRI studies and on standing radiographs.

A control cohort ($n = 23$) comprised patients with fixed sagittal imbalance by matching for age, sex, levels fused, PI, preoperative mismatch between LL and PI, postoperative mismatch between LL and PI, EBL, length of surgery, and LOS for comparison with the flexible sagittal imbalance cases.

FIG. 2. The flexed posture of the proximal (L1–3) or distal (L4–S1) lumbar spine increases the diameter of the spinal canal and neuroforamina and can relieve neurogenic claudication symptoms. Distal lumbar flexion can result in pelvic retroversion; therefore, in cases of flexible sagittal imbalance, pelvic retroversion may be compensatory for lumbar stenosis and not solely compensatory for the sagittal imbalance as previously thought. Arrows indicate proximal and distal regions of flexion within the lumbar spine that provide compensation for lumbar stenosis. Figure is available in color online only.

Two authors (S.P. and A.S.) calculated preoperative global sagittal parameters in both cohorts via the C-2 and C-7 SVAs. The C-2 SVA was obtained from a full-length standing radiograph as the distance between the center point of the femoral heads to the perpendicular dropped from the center of the C-2 vertebral body. The C-7 SVA, also determined using full-length radiographs, was measured from the posterior disc space of L5–S1 to the perpendicular dropped from the center of the C-7 vertebral body. Pelvic retroversion was quantified as the PT/PI ratio.

Interobserver reliability testing was performed by 2 authors (A.S. and S.P.). These authors performed measurements using the same method described above within a 2-day period. Inter- and intraobserver reliability for all measurements were assessed using the intraclass correlation coefficient ($\rho^* > 0.75$).³⁸

Frequency and percentage were used to summarize the categorical variables. The mean and standard deviation were used to summarize the continuous data after a normality assumption was validated. An unpaired Student t-test was used to examine the specific hypothesis. Ordinary least-squares regression was used to determine the association between preoperative presentation and postoperative changes measured by PROs and flexibility, procedural technique, age older than 65 years, sex, and preoperative diagnosis of stenosis with subsequent laminectomy. The model was assessed for multicollinearity and homoscedasticity. A p value of ≤ 0.05 was the threshold for significance. The STATA statistical software (version 14.0, STACorp) was used to perform the analyses.

Results

A total of 138 patients met the inclusion criteria for surgical treatment of sagittal imbalance between 2008 and

2013. From this set of patients, 24 individuals were identified as having a flexible deformity (Table 1). The average difference between LL on supine MR images and standing radiographs was 15° (range 10°–25°), with an improvement of LL on supine MR images compared with standing radiographs.

There were no significant differences between the control cohort (fixed sagittal imbalance) and the flexible sagittal imbalance cohort for any of the chosen control parameters (Tables 1–4). There was no significant difference between the cohorts regarding the preoperative C-2 and C-7 SVAs (Table 2). The C-2 SVA was 6.4 cm in the flexible cohort and 6.5 cm in the fixed cohort ($p = 0.95$). The C-7 SVA was 11.9 cm and 10.4 cm in the flexible and fixed cohorts, respectively ($p = 0.43$). From our previous study,² 67% (16/24) of the patients with flexible sagittal imbalance

TABLE 1. Demographic and clinical information for flexible and nonflexible cohorts

Variable	Flexible	Nonflexible	p Value*
No. of patients (%)	24	23	
Male	8 (33)	8 (35)	0.99
Female	16 (67)	15 (65)	0.99
Mean age at surgery in yrs	63.4 $\pm$ 9.15	61.5 $\pm$ 12.92	0.5632
Mean no. of levels fused	9.96 $\pm$ 2.85	9.39 $\pm$ 3.3	0.5311
Mean EBL (L)	1.87 $\pm$ 1.13	1.88 $\pm$ 1.34	0.9906
Mean length of surgery (mins)	415 $\pm$ 102	403 $\pm$ 84	0.6656
Mean LOS (days)	7.17 $\pm$ 2.73	9 $\pm$ 1.03	0.1190

Mean values are presented as the mean $\pm$ SD.

* The Student t-test was used for continuous variables and the Fisher exact test for categorical variables.

TABLE 2. Radiographic parameters compared between flexible and nonflexible cohorts

Parameter	Flexible	Nonflexible	p Value*
C-2 SVA (cm)	6.4 ± 1.46	6.5 ± 2.94	0.947
C-7 SVA (cm)	11.9 ± 5.67	10.4 ± 3.62	0.430
PI (°)	61.75 ± 16.99	63.32 ± 14.94	0.7412
Preop PI-LL mismatch (°)	48.79 ± 16.14	47.86 ± 22.33	0.8716
Postop PI-LL mismatch (°)	23.82 ± 13.61	19.17 ± 15.62	0.3551

Mean values are presented as the mean ± SD for categorical variables.

* The Student t-test was used to calculate significance.

had lumbar stenosis as opposed to 22% (5/23) of those in the fixed sagittal imbalance cohort ($p = 0.0032$).

Preoperatively, the 2 cohorts (flexible vs fixed) showed no significant difference in terms of PRO on the EQ-5D and PD-Q (Table 5); however, the preoperative PHQ-9 score was significantly greater for the flexible cohort ($p = 0.0459$). There was no significant association between preoperative PRO scores and age or sex. At 12 months, the flexible cohort exhibited pre- to postoperative improvement that was significant for the EQ-5D ($p = 0.0026$), PD-Q ($p = 0.0048$), and PHQ-9 ($p = 0.018$). The fixed cohort showed no statistically significant change in pre- to postoperative PROs at 12 months. The flexible cohort trended toward a statistically significant improvement in PD-Q compared with the nonflexible cohort at 12 months ($p = 0.059$). A preoperative diagnosis of lumbar stenosis was significantly associated with a clinically significant increase of 6.6 points ($p = 0.040$) on the PHQ-9, and a preoperative radiographic diagnosis of flexible deformity was associated with a similar 6-point increase in PHQ-9 scores with a trend toward significance ($p = 0.051$). No other significant associations between change in PRO scores and age older than 65 years, sex, or procedural technique were noted (Table 6).

To assess pelvic compensation, we calculated the preoperative PT/PI ratio for patients from both cohorts with and without LL. The mean PT/PI ratio for the stenotic patients was significantly greater (0.561 ± 0.104), compared with the nonstenotic patients (0.364 ± 0.069) ($p = 0.019$). Figures 3 and 4 depict a clinical example of increased pelvic retroversion in a patient with lumbar stenosis.

Discussion

A large portion of flexible flat-back deformities, with associated sagittal imbalance, is postural.^{1,3–8,29} The study presented herein identified 24 patients with flexible sagittal imbalance. Previously, when comparing these patients to a cohort with fixed sagittal imbalance, we found that a preoperative diagnosis of lumbar spinal stenosis was significantly associated with the flexible deformities (67%) when compared with the nonflexible deformities (22%) ($p = 0.0032$).³ Our findings suggested that the flat-back deformity in these cases was partially postural and compensatory for symptomatic lumbar stenosis. It is well known that a reduction in LL increases the canal diameter^{1,7,11,17} and is usually associated with flexion of the lumbar spine, particularly from L-1 to L-3. However, caudal flexion of

TABLE 3. Surgical techniques for the flexible and nonflexible cohorts

Procedure	No. of Patients		p Value*
	Flexible	Nonflexible	
Type of fusion			
Circumferential	15	14	0.9999
Posterior only	9	9	0.9999
Laminectomy	11	7	0.3715
PSO	6	6	0.9999
Grade 1–3 osteotomy	7	5	0.7400

* Student t-test.

the lumbosacral junction and pelvis also helps to increase the spinal canal diameter.^{17,46} Distal flexion (L4–S1) results in pelvic retroversion and is associated with lumbar stenosis.¹⁷

In patients with sagittal imbalance, retroversion of the pelvis helps bring the hips forward in order to provide sagittal balance.^{8,20,23} However, in patients with concomitant lumbar stenosis and sagittal imbalance, pelvic retroversion compensates for lumbar stenosis. Liu et al. found that patients with lumbar spinal stenosis had a significantly greater incidence of pelvic retroversion compared with patients with degenerative spondylolisthesis, suggesting that pelvic retroversion might help alleviate symptomatic lumbar stenosis.²⁴ In the current study, the patients diagnosed preoperatively with lumbar stenosis had greater pelvic retroversion (PT/PI) despite having an equivalent preoperative C-7 SVA in comparison with the nonstenotic cohort ($p = 0.019$). Therefore, a portion of the pelvic retroversion is compensatory for the lumbar stenosis and not entirely compensation for the global sagittal imbalance.

For both cohorts (flexible and fixed), the C-2 and C-7 SVAs were similar. Therefore, compensatory reduction in LL for lumbar stenosis and resultant sagittal imbalance in the flexible sagittal imbalance cohort appeared to be radiographically equivalent to the fixed sagittal imbalance cohort. In many cases, standing radiographs cannot

TABLE 4. Medical complications present in the flexible and nonflexible patient cohorts

Complication	Flexible	Nonflexible	p Value*
Atrial fibrillation	0	1	0.99
Acute blood loss anemia	5	2	0.4305
Urinary tract infection	2	2	0.99
Metabolic acidosis	1	0	0.99
Respiratory insufficiency/failure	1	1	0.99
Urinary retention	1	0	0.99
Delirium	1	1	0.99
Pulmonary embolism	1	0	0.99
Myocardial infarction	0	1	0.99
Acute kidney injury	0	1	0.99
Deep venous thrombosis	0	1	0.99

* Fisher exact test.

TABLE 5. Patient-reported outcomes*

Metric	Preoperative			12-Mo Follow-Up			
	No. of Patients	Score	p Value†	No. of Patients	Score	p Value†	p Value‡
EQ-5D			0.7927				0.31
Flexible	20	0.441		20	0.658	0.0026	
Nonflexible	18	0.461		17	0.58	0.1785	
PD-Q			0.5797				0.0592
Flexible	12	96.58		18	57.5	0.0048	
Nonflexible	13	90.23		16	81.19	0.4354	
PHQ-9			0.0459				0.5169
Flexible	20	12.9		20	7	0.018	
Nonflexible	18	8.28		18	8.61	0.8852	

Boldface type indicates statistical significance.

* The matched paired t-test was used to determine significance for postoperative values compared with preoperative values. The Student t-test was used to determine significance for differences between flexible and nonflexible cohorts.

† Pre- and postoperative PRO values within the cohorts.

‡ Difference between flexible and nonflexible cohorts.

distinguish postural sagittal imbalance from fixed sagittal imbalance.^{10,21,32}

Clinical differentiation between flexible and fixed deformities is difficult. Standing intolerance is a common complaint in patients with both lumbar stenosis and sagittal imbalance. Symptoms have been attributed to neurogenic claudication in patients with lumbar stenosis,³ and to axial back pain in patients with sagittal imbalance.¹³ Furthermore, axial back pain can also be neurogenic and is associated with lumbar stenosis.^{4,16} The majority of patients with sagittal imbalance present with leg pain due to quadriceps fatigue, and the majority of patients with lumbar stenosis present with leg pain due to neurogenic claudication.^{3,4,16,18} Therefore, the clinical presentations for lumbar stenosis and sagittal imbalance often overlap. From our previous study, recommendations included using preoperative supine MRI studies in relation to the standing radiographs to determine the flexibility of sagittal imbalance. Given the difficulty in differentiating these pathologies both clinically and radiographically, supine imaging modalities can help establish whether the sagittal imbalance is fixed or postural.³⁷

The combination of sagittal imbalance and neurogenic claudication is very disabling in comparison with sagittal imbalance alone. Yabuki et al., in an assessment of Japanese individuals between 40 and 79 years old, found a significant association between lumbar spinal stenosis and the incidence of debilitating comorbidities, including urological disorders and osteoarthritis, as well as severe depressive symptoms.⁴⁹ The authors reported an adjusted odds ratio of severe depressive symptoms to be as high as 3.39. In an assessment of 100 patients with clinically diagnosed lumbar spinal stenosis, Sinikallio et al. found a significantly greater incidence of clinically significant depression (20%) compared with that of the general population.³⁹ In the current study, lumbar stenosis that was treated via laminectomy was associated with a clinically significant improvement in PHQ-9 scores ($p = 0.04$), indicating that identification and treatment of this pathology can significantly improve depressive symptoms for patients.

Patients with flexible sagittal deformities had superior clinical outcomes after surgery compared with the patients with fixed flat-back deformities. The superior outcomes

TABLE 6. Demographic and operative parameters associated with improvement in postoperative PROs

Variable	EQ-5D	p Value*	PD-Q	p Value*	PHQ-9	p Value*
Lumbar stenosis	-0.09	0.44	13	0.53	6.57	0.04
Flexible deformity	-0.08	0.46	27	0.24	5.98	0.05
Age ≥65 yrs	0.07	0.49	4	0.82	-3.043	0.23
Male sex	-0.15		0.44	0.98	2.53	0.38
Operative technique						
Circumferential fusion vs posterior-only fusion	0.02	0.834	4.9	0.8	0	1
Laminectomy	0.2	0.11	-0.53	0.98	-3.21	0.29
PSO	0.05	0.75	-16	0.56	-4.61	0.18
Grade 1–3 osteotomy	0.26	0.07	-22	0.47	-4.91	0.11

Boldface type indicates statistical significance.

* Ordinary least-square regression was used to determine the association between a postoperative improvement or decline in outcomes as measured by the EQ-5D, PD-Q, and PHQ-9 scales.

FIG. 3. Images obtained in a patient with flexible sagittal imbalance. PI (A), C-7 SVA (B), and PT (C) were measured on standing radiographs. The C-7 SVA was found to be 6 cm and PI-LL mismatch was 30°, with a 25° difference between LL on supine MRI (D) and standing radiography (E). Pelvic retroversion (PT/PI ratio) was 0.53 and was increased in patients with lumbar stenosis compared with those with no stenosis. Figure is available in color online only.

could be due to the fact that a significant proportion of the patients with preoperative flexible deformities had lumbar stenosis, while those with fixed deformities did not. Surgical treatment of lumbar stenosis has been shown to be a driving factor for superior outcomes and has a long track record for improvement of quality-of-life metrics.^{6,45,47,48} In SPORT (Spine Patients Outcomes Research Trial), the authors reported that patients with lumbar stenosis experienced significantly greater improvement with surgical treatment, compared with nonsurgical treatment in primary outcomes, including pain and function assessed postopera-

tively at 2 and 4 years.^{47,48} With regular follow-up of more than 8–10 years in the Maine Lumbar Spine Study, Atlas et al. showed that patients with lumbar stenosis who were initially treated surgically reported less severe leg pain and had improved back-specific functional status, compared with patients treated nonsurgically.⁶ Furthermore, we noted that age, sex, and procedural techniques were not significantly associated with significant changes in postoperative outcomes. This further supports the hypothesis that preoperative radiological classification of sagittal imbalance contributes to favorable postoperative surgical outcomes, inde-

FIG. 4. Sagittal (A) and axial (B and C) MR images of lumbar stenosis at L3–5 in the same patient with flexible sagittal imbalance. Figure is available in color online only.

pendently of factors related to sex, senescence, or operative technique.

This study is limited by several factors inherent to the chosen methodological paradigm. This study was a retrospective review of a prospective database, and as such a recall bias and selection bias may be present. Furthermore, sagittal imbalance—and even more—flexible deformity, is a relatively rare pathology, providing a small patient pool from which to draw conclusions. Larger, prospective studies of the dynamic nature of sagittal imbalance are required to fully understand the implications of our findings. Nevertheless, confidence in our findings is reinforced by the fact that our analysis matched methodologies validated in previous studies.^{15,19,31,44}

Conclusions

Flexible sagittal imbalance can be a result of postural changes to alleviate the symptoms of lumbar stenosis. The patients with flexible sagittal imbalance had similar global sagittal parameters as those with fixed sagittal imbalance; furthermore, both patient populations have similar clinical symptoms. Lastly, a portion of the pelvic retroversion can be compensatory for lumbar stenosis as well as for sagittal imbalance.

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Disclosures

The authors report the following. Dr. Savage: consultant for Stryker Spine. Dr. Kalfas: patent holder with Mako Surgical and stock warrants from Paradigm Spine. Dr. Mroz: ownership in Pearl-Diver, and consultant for Stryker and Ceramtech. Dr. Steinmetz: consultant for Biomet Spine and Intelirod; and honoraria from Globus, Stryker Spine, and DePuy.

Author Contributions

Conception and design: all authors. Acquisition of data: Sharma. Analysis and interpretation of data: Pourtaheri, Sharma. Drafting the article: Pourtaheri, Sharma. Critically revising the article: Pourtaheri, Sharma, Savage, Kalfas, Mroz, Steinmetz. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Pourtaheri. Statistical analysis: Sharma, Benzel. Study supervision: Pourtaheri.

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