DOI: 10.4081/aiua.2025.14504

ORIGINAL PAPER

Comparison of dynamic thiol/disulfide homeostasis in Percutaneous Nephrolithotomy and Retrograde Intrarenal Surgery

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Summary

Introduction: Systemic oxidative stress refers to a condition that arises when the production of oxygen-derived free radicals exceeds the capacity of the body's antioxidant defense mechanisms to neutralize them. In recent years, dynamic thiol/disulfide homeostasis has emerged as a sensitive and reversible indicator of oxidative stress. Under oxidative conditions, free thiol groups are converted into disulfide bonds and subsequently reduced back to thiols, reflecting the organism's redox status and antioxidant capacity. Therefore, thiol/disulfide homeostasis parameters are utilized to objectively assess the biochemical effects of surgical stress. In this study, we aimed to compare the effects of two commonly used procedures – Percutaneous Nephrolithotomy (PNL) and Retrograde Intrarenal Surgery (RIRS) – on systemic oxidative stress.

Materials and methods: Eighty patients with renal stones measuring 2-3 cm were prospectively assigned to undergo either PCNL (n = 40) or RIRS (n = 40). Serum levels of total thiol, free thiol (SH), and disulfide (SS) were measured before and after surgery, and the ratios, SS/total thiol, SS/SH and SH/total thiol were calculated.

Results: No significant differences were observed between the groups in demographic characteristics, stone-free rates, procedure times, or complication frequencies ($p > 0.05$). Postoperatively, both total thiol and SH levels decreased significantly, while SS levels and related ratios increased significantly ($p < 0.05$). However, the magnitude of these changes did not differ between PCNL and RIRS ($p > 0.05$). Patients who experienced complications had significantly lower postoperative thiol levels than those without complications ($p < 0.05$).

Conclusions: Despite their different levels of invasiveness, both techniques elicited comparable systemic oxidative stress responses. These findings suggest that dynamic thiol/disulfide homeostasis parameters may serve as reliable biomarkers for monitoring surgery-induced oxidative stress and predicting postoperative complications.

KEY WORDS: *Percutaneous nephrolithotomy; Retrograde Intrarenal surgery; Thiol/disulfide homeostasis; Oxidative stress; Renal calculi.*

Submitted 1 October 2025; Accepted 7 November 2025

INTRODUCTION

This introduction highlights how kidney stone disease (urolithiasis) detrimentally impacts patients' quality of life (1). Advances in technology have driven a shift toward less invasive surgical options that maintain high efficacy while improving patient comfort. Two main techniques dominate current practice: *Retrograde Intrarenal Surgery* (RIRS) and *Percutaneous Nephrolithotomy* (PCNL) (2, 3). The selection between these approaches hinges primarily on stone size and anatomical location. PCNL remains the standard for calculi larger than 2 cm, delivering excellent clearance rates but carrying risks such as parenchymal injury, bleeding, and prolonged hospitalization (2, 4). Conversely, RIRS originally reserved for stones up to 2 cm (5), has gained broader application thanks to improvements in flexible ureteroscopes and accumulated surgical expertise (6). Importantly, RIRS is associated with a lower incidence of major complications, reinforcing its role as a minimally invasive alternative (4).

Surgical procedures provoke not only mechanical tissue injury but also activate inflammatory pathways causing oxidative stress, and perturbations in cellular redox balance (7). In this light, the dynamic interplay between thiols and disulfides has been validated as a robust biomarker of oxidative stress. Under oxidative conditions, free thiol groups reversibly oxidize into disulfide bonds, offering quantifiable measures of systemic redox status. Monitoring this reversible transformation is critical for assessing both oxidant burden and antioxidant defense after surgical trauma (8, 9). Furthermore, documented disruptions in thiol/disulfide homeostasis across various diseases and surgical stress contexts indicate these metrics can objectively compare techniques with different invasiveness profiles (10). Although clinical outcome comparisons of PCNL versus RIRS are plentiful, no study has yet directly evaluated their relative impacts on oxidative stress. Hence, a head-to-head assessment of PCNL and RIRS using thiol/disulfide parameters could guide optimal treatment choice in terms of both clinical efficacy and systemic physiological consequences.

In this study, we compared the impact of two common kidney stone removal techniques (PCNL and RIRS) on systemic oxidative stress by analyzing dynamic thiol/disulfide balance markers. By evaluating both clinical efficacy and biochemical safety parameters together, this design offers a comprehensive assessment of each procedure.

Materials and methods

Patients

This prospective study was conducted from December 2019 to December 2021 following approval by the University Medical Faculty Ethics Committee. A total of 80 adult patients with kidney stones measuring 2-3 cm and *American Society of Anesthesiologists* (ASA) physical status scores of I-II were included in the study; 40 underwent PCNL and 40 underwent RIRS. All patients were thoroughly informed about the advantages and disadvantages of both PCNL and RIRS. Patients were prospectively assigned to undergo either procedure based on stone size, location, and shared decision-making between the surgeon and the patient following detailed preoperative counseling. We recorded sociodemographic characteristics, stone laterality, size and location, operative time, length of hospital stay, and complications. Imaging follow-up included a plain abdominal radiograph on postoperative day 1 and non-contrast CT at three months. Stone-free status was defined as no residual fragments or only asymptomatic fragments < 4 mm. Patients with a solitary kidney, bilateral renal stones, ureteral stones, or other structural urinary tract anomalies such as ureteropelvic or ureterovesical junction obstruction, horseshoe kidney, or duplex collecting system as well as those diagnosed with diabetes mellitus, hypertension, malignancy, rheumatologic disorders, chronic renal failure were excluded from the study.

PCNL technique

Under general anesthesia, patients were placed in the lithotomy position, and the 5-6F ureteral catheter was inserted. The patients were subsequently placed in the prone position. Following fluoroscopic visualization of the opacified renal collecting system, percutaneous renal access was achieved using an 18-gauge needle. After placement and fixation of the guidewire, dilatation was performed up to 28F using Amplatz dilators (*Cook Medical, USA*), and a 28F access sheath was placed. Subsequently, a 26F nephroscope (*Karl Storz, Germany*) was introduced, and the stones were fragmented using pneumatic lithotripsy. Fragments were extracted using forceps and irrigation. A 16-18F nephrostomy tube was placed in the kidney at the conclusion of the procedure in all patients.

RIRS technique

All patients underwent the procedure in the lithotomy position under general anesthesia. To assess potential ureteral anomalies, rigid ureteroscopy was carried out over the guidewire. Afterward, a ureteral access sheath was positioned using fluoroscopic guidance. A flexible 7.5F ureteroscope (*Karl Storz FLEX-X2*) was then introduced into the renal pelvis via this sheath. In every case, stone disintegration was achieved using a Holmium:YAG laser (*Sphinx Xjr, Germany*). The stones were broken down into fragments smaller than 4 mm to facilitate spontaneous elimination. At the conclusion of the operation, a JJ stent was routinely placed in each patient.

Measurement of oxidative thiol-disulfide homeostasis

Peripheral venous blood samples were obtained from all patients preoperatively and postoperatively. After centrifugation at 1500 rpm for 10 minutes, plasma and serum components were separated. Serum aliquots were subsequently preserved at -80 °C until further examination. The assessment of dynamic thiol-disulfide homeostasis was carried out using the automated spectrophotometric technique described by Erel (8). The concentrations of disulfide (SS), native thiol (SH), and total thiol were measured, and ratios such as SS/total thiol, SS/SH, and SH/total thiol were calculated accordingly.

Statistical Evaluation

Descriptive statistics were presented as mean ± standard deviation, ranges (minimum-maximum), medians, and frequency percentages. To evaluate the normality of distribution, both Kolmogorov-Smirnov and Shapiro-Wilk tests were applied. Parametric variables conforming to normal distribution were compared with the independent samples t-test, while non-parametric data were analyzed using the Mann-Whitney U test. Wilcoxon test was used for comparing repeated measures, and categorical variables were analyzed via chi-square test. All statistical procedures were conducted using SPSS version 27.0 (*IBM Corp., Armonk, NY, USA*). A p-value below 0.05 was interpreted as statistically significant.

Results

Eighty patients were included, with a median age of 46 years (45.5 ± 15.5). Baseline parameters; age, gender distribution, *body mass index* (BMI), and stone size were comparable between the PCNL and RIRS groups ($p > 0.05$). No significant differences were observed between the PCNL and RIRS groups regarding stone-free rate, operative time, or complication rate ($p > 0.05$) (Table 1). Preoperative measurements of total thiol, SH, SS, and their ratios (SS/SH %, SS/total thiol %, SH/total thiol %) did not differ significantly between the PCNL and RIRS groups ($p > 0.05$) (Table 2). Postoperative values of these same parameters likewise showed no significant intergroup differences ($p > 0.05$) (Table 2). Both PCNL and RIRS resulted in significant postoperative declines in total thiol and SH levels compared to baseline ($p < 0.05$); the magnitude of those declines was comparable across the two techniques ($p > 0.05$) (Table 2). Preoperative SS levels and the SS/SH and SS/total thiol ratios were similar between groups ($p > 0.05$). After surgery, both methods produced marked increases in SS, SS/SH %, and SS/total thiol % relative to preoperative values ($p < 0.05$); however, the extent of these increases did not differ between PCNL and RIRS ($p > 0.05$) (Table 2). Additionally, both groups experienced a significant postoperative reduction in SH/total thiol % ($p < 0.05$), with the degree of reduction showing no difference between techniques ($p > 0.05$) (Table 2). In the PCNL group, complications included

		PCNL (n: 40)		RIRS (n: 40)		p
		Mean ± sd/n-%	Median	Mean ± sd/n-%	Median	
Age (Years)		44.3 ± 14.5	43.5	46.8 ± 16.6	49.0	0.464 ^{m}
Gender	Female	18 45.0%		17 42.5%		0.822 $^{X^2}$
	Male	22 55.0%		23 57.5%		
BMI (kg/m²)		27.4 ± 4.9	27.0	26.9 ± 3.1	27.8	0.931 ^{m}
Side	Right	23 57.5%		16 40.0%		0.117 $^{X^2}$
	Left	17 42.5%		24 60.0%		
Stone Size (cm)		2.5 ± 0.3	2.4	2.4 ± 0.3	2.4	0.539 ^{m}
Stone free	Yes	37 92.5%		33 82.5%		0.176 $^{X^2}$
	No	3 7.5%		7 17.5%		
Stone Localisation						
Lower Pole		5 12.5%		4 10.0%		0.723 $^{X^2}$
Middle Pole		9 22.5%		8 20.0%		0.785 $^{X^2}$
Pelvis		23 57.5%		22 55.0%		0.822 $^{X^2}$
Upper pole		3 7.5%		6 15.0%		0.288 $^{X^2}$
Operative Time (Minutes)		68.3 ± 8.2	68.5	70.1 ± 10.7	71.0	0.403 ^{t}
Complications	No	35 87.5%		34 85.0%		0.745 $^{X^2}$
	Clavien I	3 7.5%		5 12.5%		
	Clavien II	1 2.5%		1 2.5%		
	Clavien III	1 2.5%		0 0.0%		
Duration of Hospital Stay		3.1 ± 0.8	3.0	1.8 ± 0.7	1.5	0.000 ^{m}

$^{X^2}$: Chi-square test; ^{m}: Mann-whitney u test; ^{t}: Independent Samples t test.

Table 1. *Comparison of the patient groups.*

	PCNL (n: 40)		RIRS (n: 40)		p
	Mean ± sd	Median	Mean ± sd	Median	
Total Thiol					
Preoperative	359.0 ± 69.7	352.6	356.0 ± 59.3	358.4	0.859 ^{m}
Postoperative	286.4 ± 63.4	280.2	303.2 ± 67.3	299.0	0.209 ^{m}
Preoperative/ Postoperative Difference	-72.6 ± 95.1	-67.1	-52.8 ± 95.6	-63.1	0.476 ^{m}
Intra Group Difference p	*0.000 ^{w}*		*0.001 ^{w}*		
Native Thiol (SH)					
Preoperative	326.4 ± 67.7	327.5	323.7 ± 57.5	331.8	0.954 ^{m}
Postoperative	233.9 ± 62.9	232.5	252.4 ± 72.4	255.8	0.224 ^{m}
Preoperative/ Postoperative Difference	-92.5 ± 89.5	-93.2	-71.4 ± 102.2	-79.1	0.447 ^{m}
Intra Group Difference p	*0.000 ^{w}*		*0.000 ^{w}*		
Disulphide (SS)					
Preoperative	16.9 ± 5.7	16.8	15.5 - 6.3	15.4	0.222 ^{m}
Postoperative	26.2 ± 6.9	26.0	25.7 - 7.2	24.9	0.648 ^{m}
Preoperative/ Postoperative Difference	9.3 ± 8.0	9.1	10.2 - 9.8	9.6	0.634 ^{m}
Intra Group Difference p	*0.000 ^{w}*		*0.000 ^{w}*		
SS/SH %					
Preoperative	4.8 ± 2.0	4.6	5.7 ± 3.9	5.2	0.392 ^{m}
Postoperative	12.0 ± 4.4	11.7	11.4 ± 5.5	10.3	0.329 ^{m}
Preoperative/ Postoperative Difference	7.2 ± 4.6	7.2	5.7 ± 7.3	5.3	0.266 ^{m}
Intra Group Difference p	*0.000 ^{w}*		*0.000 ^{w}*		
SS/Total Thiol %					
Preoperative	4.4 ± 1.5	4.2	4.9 ± 2.7	4.7	0.392 ^{m}
Postoperative	9.5 ± 2.9	9.5	8.9 ± 3.6	8.6	0.331 ^{m}
Preoperative/ Postoperative Difference	5.1 ± 3.0	5.3	4.0 ± 4.8	4.2	0.237 ^{m}
Intra Group Difference p	*0.000 ^{w}*		*0.000 ^{w}*		
SH/Total Thiol %					
Preoperative	91.3 ± 3.0	91.6	90.1 ± 5.3	90.6	0.392 ^{m}
Postoperative	81.0 ± 5.7	81.0	81.9 ± 6.9	82.9	0.392 ^{m}
Preoperative/ Postoperative Difference	-10.2 ± 6.0	-10.6	-8.2 ± 9.5	-9.1	0.303 ^{m}
Intra Group Difference p	*0.000 ^{w}*		*0.000 ^{w}*		

^{w}: Wilcoxon test; ^{m}: *Mann-whitney u test.*

Table 2. *Comparison of thiol-disulfide homeostasis parameters between the groups.*

fever (n = 3), bleeding requiring transfusion (n = 1), and JJ stent placement after urine leakage from the nephrostomy tract(n = 1) while in the RIRS group, fever (n = 5) and urinary tract infection (n = 1) were observed. No major complications. Patients with and without complications were comparable in terms of age, sex distribution, BMI, stone size, surgical technique, and procedure duration ($p > 0.05$) (Table 3). Preoperative values of total thiol, SH, SS, SS/SH%, and SS/total thiol% were similar between patients with and without complications ($p > 0.05$) (Table 4) . The postoperative total thiol and SH levels were significantly lower in the complication group than in the complication-free group ($p < 0.05$). The magnitude of the decrease in total thiol and SH levels from the preoperative period to the postoperative period was significantly greater in the complication group than in the complication-free group ($p < 0.05$) (Table 4). However, no significant differences were found between the groups regarding postoperative SS levels, SS/SH%, or SS/total thiol% ($p > 0.05$) (Table 4).

Discussion

Studies in the literature comparing PCNL and RIRS have focused primarily on clinical outcomes, such as success rates, complications, and length of hospital stay. There is no specific study comparing their effects on oxidative stress. This study is a pioneering investigation that compares the systemic levels of oxidative stress effects of PCNL and RIRS using thiol/disulfide homeostasis parameters. In this study, patients with PCNL and RIRS with similar demographic characteristics and stone burden were compared (Table 1). These results demonstrate that both surgical methods lead to significant increases in oxidative stress levels postoperatively, but there is no significant difference in the magnitude of these increases between the two groups. This suggests that both procedures generate similar systemic biochemical effects.

Surgical procedures can induce inflammation and ischemia-reperfusion injury, increasing the production of reactive oxygen species and weakening antioxidant defense mechanisms. This can lead to elevated levels of oxidative stress markers and delayed healing (11). A recently published study showed that as the severity of surgical trauma increases, the oxidative stress response also intensifies. Therefore, to minimize perioperative oxidative stress, patients should receive treatment using the least invasive techniques possible (12). In another study, postoperative delirium was associated with oxidative stress levels. The authors proposed that increased levels of oxidative metabolites after surgery might negatively affect brain function, leading to delirium (13). In recent years, dynamic thiol/disulfide homeostasis has emerged as a reliable biomarker for monitoring oxidative stress (14). Thiol groups are a crucial component of the antioxidant defense system; through reversible conversion to disulfide bonds, they help maintain intracellular redox equilibrium. The biochemical balance can be disrupted by surgical trauma, ischemic injury, and inflammation (14). *Polat et al.* investigated thiol/disulfide homeostasis during laparoscopic cholecystectomy. The total and native thiol levels decreased significantly during the operation (15). One study investigating the effects of urological interventions on thiol-disulfide/homeostasis reported a significant decrease in serum total and native thiol levels after prostate biopsy and concluded that the procedure caused acute oxidative stress (16). In another study, the authors suggested that monitoring oxidative

Table 3. *Comparison of patients according to complication status.*

		Complication (-) (n: 69) Mean ± sd/n-%			Median	Complication (+) (n: 11) Mean ± sd/n-%			Median	p	
Age (Years)		45.7	±	15.3	46.0	44.5	±	17.8	46.0	0.889	m
Gender	Female	29		42.0%		6		54.5%		0.437	X^2
	Male	40		58.0%		5		45.5%			
BMI (kg/m²)		27.3	±	4.2	27.6	26.2	±	3.4	25.9	0.392	t
Side	Right	32		46.4%		7		63.6%		0.288	X^2
	Left	37		53.6%		4		36.4%			
Stone Size (cm)		2.4	±	0.3	2.4	2.6	±	0.4	2.7	0.083	m
Stone free	Yes	63		91.3%		7		63.6%		0.027	X^2
	No	6		8.7%		4		36.4%			
Stone Localisation											
Lower Pole		8		11.6%		1		9.1%		1.000	X^2
Middle Pole		12		17.4%		5		45.5%		0.035	X^2
Pelvis		40		58.0%		5		45.5%		0.437	X^2
Upper Pole		9		13.0%		0		0.0%		0.347	X^2
Type of Surgery	PCNL	35		50.7%		5		45.5%		0.745	X^2
	RIRS	34		49.3%		6		54.5%			
Operative Time (Minutes)		68.4	±	9.0	69.0	73.7	±	11.9	73.0	0.087	t
Duration Of Hospital Stay		2.3	±	0.9	2.0	3.6	±	0.9	3.0	0.000	m

X^2: Chi-square test; ^{m}: Mann-whitney u test; ^{t}: Independent Samples t test.

	Complication (-) (n:69) Mean ± sd	Median	Complication (+) (n:11) Mean ± sd	Median	p
Total Thiol					
Preoperative	354.0 ± 65.2	354.2	379.4 ± 56.3	369.0	0.227 m
Postoperative	303.0 ± 64.0	293.9	243.3 ± 52.0	226.8	0.004 m
Preoperative/ Postoperative Difference	-51.0 ± 93.7	-50.2	-136.1 ± 71.9	-122.9	0.005 m
Intra Group Difference p	*0.000 w*		*0.003 w*		
Native Thiol (SH)					
Preoperative	321.2 ± 63.7	328.3	349.4 ± 49.8	339.1	0.167 m
Postoperative	251.2 ± 66.9	240.4	192.3 ± 53.5	172.8	0.006 m
Preoperative/ Postoperative Difference	-69.9 ± 94.8	-68.9	-157.1 ± 67.6	-154.5	0.004 m
Intra Group Difference p	*0.000 w*		*0.004 w*		
Disulphide (SS)					
Preoperative	16.2 ± 6.0	16.4	16.1 ± 6.3	15.1	0.894 m
Postoperative	26.0 ± 7.0	25.5	25.5 ± 7.4	24.8	0.785 m
Preoperative/ Postoperative Difference	9.8 ± 9.0	9.4	9.5 ± 8.6	5.3	0.610 m
Intra Group Difference p	*0.000 w*		*0.004 w*		
SS/SH %					
Preoperative	5.4 ± 3.3	5.0	4.6 ± 1.5	5.0	0.600 m
Postoperative	11.3 ± 4.8	11.1	14.2 ± 5.6	15.0	0.107 m
Preoperative/ Postoperative Difference	5.9 ± 6.0	6.1	9.7 ± 5.5	10.1	0.073 m
Intra Group Difference p	*0.000 w*		*0.003 w*		
SS/Total Thiol %					
Preoperative	4.7 ± 2.3	4.5	4.1 ± 1.3	4.5	0.600 m
Postoperative	9.0 ± 3.1	9.1	10.8 ± 3.4	11.5	0.107 m
Preoperative/ Postoperative Difference	4.2 ± 4.0	4.7	6.7 ± 3.4	6.7	0.080 m
Intra Group Difference p	*0.000 w*		*0.003 w*		
SH/Total Thiol %					
Preoperative	90.5 ± 4.6	91.0	91.7 ± 2.5	90.9	0.600 m
Postoperative	82.0 ± 6.1	81.8	78.4 ± 6.8	77.0	0.116 m
Preoperative/ Postoperative Difference	-8.6 ± 7.9	-9.6	-13.3 ± 6.9	-13.4	0.092 m
Intra Group Difference p	*0.000 w*		*0.003 w*		

w: Wilcoxon test; m: *Mann-whitney u test.*

Table 4.
Comparison of thiol-disulfide homeostasis parameters according to complication status.

stress during TURP could help reduce complications (17). In the present study, both PCNL and RIRS were associated with decreased total and native thiol values and marked increases in disulfide, SS/SH%, and SS/total thiol% in response to surgical stress.

Studies on the effects of PCNL on oxidative stress suggest that the invasiveness of the surgical procedure and the duration of the operation may affect oxidative stress levels (18, 19). *Söylemez et al.* investigated the impact of PCNL operative time on oxidative stress parameters, and reported that PCNL increased oxidative stress: as the operative time increased, paraoxonase-1 and total antioxidant status levels decreased, while malondialdehyde levels and total oxidant status increased. These changes were particularly pronounced when the operation lasted for more than one hour (18). *Bryniarski et al.* compared classic PCNL with tubeless PCNL in terms of their effects on oxidative stress and observed that patients who underwent tubeless PCNL had lower catalase levels and higher total antioxidant capacity. The authors argued that tubeless PCNL is advantageous in terms of oxidative stress (20). In a study by *Bin Li et al.* evaluating the effects of mini-PCNL on oxidative stress and renal function, patients undergoing mini-PCNL exhibited smaller decreases in superoxide dismutase and glutathione peroxidase levels. These findings suggest that mini-PCNL is advantageous over classic PCNL in terms of oxidative stress (20). High intrarenal pressure and inflammation during RIRS induce oxidative stress by increasing the production of reactive oxygen species (21).

Consequently, as the operative time increases, deterioration in renal function may deteriorate (21, 22). In their study, *Stächele et al.*, 5 of the 12 kidney injury biomarkers showed a significant increase after RIRS (23). In this study, preoperative oxidative stress parameters were similar between the PCNL and RIRS groups. Postoperatively, both methods showed decreases in total and native thiol values and marked increases in disulfide, SS/SH%, and SS/total thiol% due to surgical stress. In each group, the preoperative-to-postoperative changes were statistically significant. However, compared with each other, the preoperative-study to-postoperative changes were similar for both methods (Table 2). This result indicates that despite the consensus that RIRS is less invasive, its biochemical oxidative response is comparable to that of PCNL. This may be related to the potential intrarenal pressure elevation associated with RIRS.

A study conducted in patients undergoing coronary artery bypass grafting demonstrated that the increase in disulfide levels became more pronounced with prolonged ischemia time. During ischemia, decreased native thiol and increased disulfide levels have been reported as potential predictors of postoperative atrial fibrillation (24). In a similar study, it was reported that thiol/disulfide homeostasis in bypass surgery can be monitored during surgery and that appropriate therapeutic strategies can be used for the patient. By doing so, complications can be avoided by preventing cellular damage and excessive inflammatory responses (10). In our subgroup analysis, regardless of the surgical method, patients who developed complications experienced greater postoperative decreases in total and native thiol levels than those without complications (Table 4). Patients with complications exhibited more pronounced redox imbalance, suggesting that the development of complications may be predictable based on biochemical markers. In this context, thiol/disulfide parameters can be potential biomarkers not only for assessing oxidative stress but also for complication prediction.

This study is significant because it is the first study to compare redox homeostasis levels between these two surgical methods in the literature. However, this study has certain limitations. The sample size was relatively small, and although inflammatory, metabolic, and environmental factors that could affect thiol/disulfide homeostasis were excluded, individual variations that could not be controlled may still exist. Additionally, the fact that other oxidative stress markers were not evaluated represents a limitation for a more comprehensive analysis of the oxidative stress response. The inclusion of these parameters in future studies will contribute to a deeper understanding of the redox response.

Declarations

Ethical approval and consent for participate: *All procedures performed in studies involving human participants were in accordance with the ethical standards of our institutional research commitee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all participants prior to their inclusion in the study. Also, the study was approved by the ethical committee of the Harran University's Medical Faculty Ethics Committee (Decision number: HRU/21.08.2019).*

Availability of data and material: *Availability of data andmaterials used in our study are available to access by request.*

Competing interests: *The authors declare that they have no competing interests.*

Funding: *This project was supported by Harran University Scientific Research and Projects Unit, project number: "22209".*

Authors' contributions: *MD: Project development, data collection, operated the cases, manuscript writing. IY: Data collection, manuscript revision. IHA: Data analysis, operated the cases. MNK: Operated the cases, data collection. AŞ: manuscript revision, data analysis. IK: data collection, data analysis. HÇ: Operated the cases, data collection.*

In conclusion, this study demonstrated that PCNL and RIRS exert similar effects on oxidative stress, whereas patients who develop complications exhibit a more pronounced redox imbalance. Further comparative studies assessing systemic biochemical responses in addition to clinical outcomes are necessary. With robust supporting evidence, these parameters may inform treatment selection.

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