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Computed tomography based cross-sectional anatomy of the pelvis predicts surgical outcome after rectal cancer surgery

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Purpose: Narrow pelvis has been considered an adverse factor for postoperative and oncologic outcomes after rectal cancer surgery. The aim of this study was to investigate the validity of using only axial CT scan images to calculate the pelvic cross-sectional area for the prediction of adverse outcomes after rectal cancer surgery.
Methods: The medical records of patients who underwent rectal cancer surgery were reviewed and analyzed retrospectively. Axial images of CT scan were used to measure the pelvic cross-sectional area. Pelvic surgical site infection (SSI), positive resection margin, and early local recurrence were adopted as end-points to analyze the impact of pelvimetry on surgical outcome.
Results: The mean pelvic cross-sectional area was 84.3 ± 10.9 cm^2. Males had significantly smaller pelvic areas than females ($P < 0.001$). Comparing pelvic cross-sectional areas according to the surgical outcomes, the results indicated that patients with pelvic SSI and local failure (positive resection margin or local recurrence within 1 year) have significantly smaller cross-sectional-area than SSI and local failure-free patients ($P = 0.013$ and $P = 0.031$). A calculated cross-sectional area of 88.8 cm^2 was determined as the cutoff value for the prediction of pelvic SSI and/or local failure, which was significant in a validating analysis.
Conclusion: The pelvic cross-sectional area obtained from a routine axial CT scan image was associated with pelvic SSI, positive resection margin, and early local recurrence. It might be an intuitive, feasible, and easily adoptable method for predicting surgical outcomes.
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Key Words: Computed tomography, Outcome, Pelvimetry, Rectal neoplasms, Surgery

INTRODUCTION

The narrow pelvis has been considered a major risk factor for detrimental surgical outcome [1-6]. To perform total mesorectal excision (TME, the standard technique for rectal cancer surgery), within a narrow pelvic cavity can be more technically demanding [7]. For this reason, a narrow pelvis has been suggested as a potential adverse factor for postoperative complications and oncologic outcomes. Recently, various parameters representing geometry of the pelvic cavity such obstetric conjugate, transverse inlet diameter, interspinous distance, sagittal midpelvic diameter, intertuberous distance, and sagittal outlet were calculated and proposed to be associated with surgical outcomes, operative time, early postoperative outcomes, and oncologic parameters such as positive circumferential resection margin or inadequate quality of the mesorectum after TME [5,8-12]. However, pelvimetry has not been a clinical routine because of its time consumption and

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the requirement for additional 3-dimensional reconstruction techniques. In the present study, we adopted a method using only an axial CT scan to calculate the pelvic cross-sectional area and investigated its impact on surgical and oncologic outcomes for rectal cancer surgery.

METHODS

Patients

From January 2011 to December 2016, the medical records of consecutive patients who underwent surgical procedures for rectal cancer at a tertiary medical institution were reviewed retrospectively. All patients with a pathological diagnosis of rectal adenocarcinoma located within 15 cm from the anal verge were included. Of the 271 patients with rectal cancer, patients who underwent an elective low anterior resection (LAR) with colorectal anastomosis using the double-stapling technique under curative intent were included. TME was performed in all cases. A total of 118 patients underwent palliative surgery or surgical procedures other than LAR with double-stapling anastomosis such as local excision, Hartmann operation, and abdominoperineal resection were excluded. In addition, 20 patients underwent synchronous operation for the organs than the rectum were excluded. The study was reviewed and approved by the Institutional Review Board of Ewha Womans University Seoul Hospital (No. SEUMC 2020-03-009). Given the retrospective nature of the study, the Institutional Review Board waived the requirement for written informed consent.

CT-based pelvimetry

CT data were obtained on a 16-channel multidetector CT scanner (SOMATOM Sensation 16; Siemens Medical Solutions, Forchheim, Germany) or a 64-channel multidetector CT scanner (SOMATOM Sensation 64; Siemens Medical Solutions), and CT datasets were processed using a dedicated software of INFINITT picture archiving and communication systems (PACS) ver. 3.0.11.4 (INFINITT Healthcare Co., Ltd., Seoul, Korea). Pelvimetric parameters were obtained using a single axial section of the pelvis presenting the coccygeal tip (Fig. 1). The anteroposterior (AP) pelvic diameter (distance from the posterior border of symphysis pubis to the tip of the coccyx), and transverse pelvic diameter (distance between the inner borders of lateral bony pelvis, perpendicularly bisecting AP pelvic diameter) were measured. The cross-sectional area (marked by the inner area of the ellipse with 2 diameters, AP, and transverse) was calculated automatically using the basic function in INFINITT PACS.

Variables and outcomes

The variables included in the investigation were as follows: age, sex, American Society of Anesthesiologists (ASA) physical status classification grade, body mass index (BMI), modality of surgical approach (open or laparoscopic surgery), location of tumor in rectum, preoperative radiotherapy, fecal diversion, tumor size, pathologic stage, histologic grade, lymphovascular invasion, operation time, estimated blood loss, duration of hospital stay after surgery, pelvic surgical site infection (SSI), and local failure. Rectal cancer was defined as any lesion situated within 15 cm from the anal verge, which was documented by the attending surgeon in the operating room. Tumor location was categorized as upper, middle, and lower rectum according to the distance from the anal verge, which were above 10 cm, between 5 cm and 10 cm, and below 5 cm from the anal verge, respectively. Preoperative radiotherapy was performed for advanced middle and lower rectal cancer (stage greater than T2 and/or presence of metastatic lymph node) as long-course radiotherapy (50.4 Gy radiation/28 fractions/6 weeks) with 2 concurrent cycles of 5-fluorouracil infusion. Fecal diversion was performed as a loop ileostomy at the discretion of the surgeon, with consideration to the patient's age, underlying comorbidity, history of preoperative radiotherapy, and level of anastomosis. Tumor size of the surgical specimen was measured, and the longest diameter was presented. The reported pathologic stage was based on the eighth edition of the American Joint Committee on Cancer TNM system and included both pathologic staging for patients treated without preoperative radiotherapy and postneoadjuvant staging for patients treated with preoperative radiotherapy [13]. Pelvic SSI was defined as any infected fluid collection in the pelvic cavity with or without anastomotic leakage within 30 days after surgery, and diagnosed using CT findings or clinical symptoms

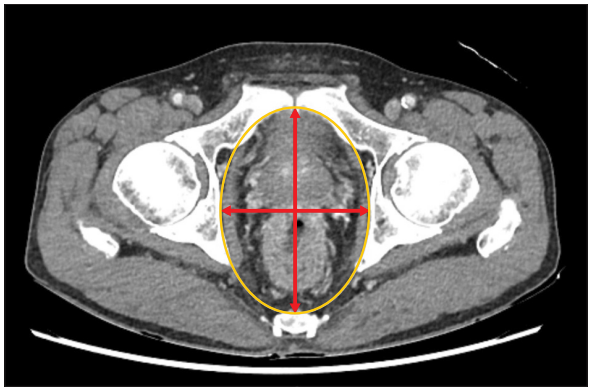

Fig. 1. Measuring pelvimetric parameters. Anteroposterior pelvic diameter (distance from the posterior border of symphysis pubis to the tip of the coccyx, vertical red arrow), transverse pelvic diameter (distance between the inner borders of lateral bony pelvis, perpendicularly bisecting anteroposterior diameter, horizontal red arrow) and cross-sectional area (inner area of ellipse with 2 diameters of anteroposterior and transverse, inner area of orange ellipse) was calculated automatically using the basic function in INFINITT PACS (INFINITT Healthcare Co., Ltd., Seoul, Korea).

and signs, including a change in drainage color and/or fever with peritonitis. Local failure was defined as the presence of tumor cells on the resection margin or local recurrence within 1 year after surgery. Local recurrence was defined as any recurrent tumor growth within the pelvic cavity or perineal area confirmed by clinical, radiological, or pathologic evaluation. The variables of pelvic SSI and local failure were adopted as endpoints to analyze the impact of pelvimetry on surgical outcome.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics ver. 20.0. (IBM Corp., Armonk, NY, USA), except for generating the receiver operating characteristic (ROC) curve and estimating the cutoff value. Descriptive results are presented as means with standard deviation or medians with interquartile ranges (Q1–Q3) for continuous outcomes and as frequencies and percentages for categorical outcomes. We used the 2-sided independent samples t-tests for pelvimetric parameters to identify risk factors of pelvic SSI and local failure. All variables in the risk set were assessed as putative risk factors and a binary logistic regression model was used to identify the risks of pelvic SSI and local failure. ROC curves were used to determine the cutoff values of the pelvimetric parameter to anticipate adverse surgical outcomes of pelvic SSI and/or local failure with the most appropriate values of specificity and sensitivity. To generate the ROC curve and estimate cutoff value, the R package ver. R 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria) was used and analysis was performed using the software "pROC" in R [14]. Based on the ROC curve result, patients were divided into 2 groups and compared regarding surgical outcomes and disease-free survival (DFS). Differences in DFS were estimated using the Kaplan-Meier method and compared using the log-rank test. A P-value of <0.05 was considered statistically significant.

RESULTS

Patient characteristics and surgical outcomes

A total of 133 patients were included in this analysis with a median follow-up period of 38.0 months (range, 19.0–57.5 months). The patients' baseline characteristics are presented in Table 1. Of these, 94 patients (70.7%) were men and 39 (29.3%) were women. Their mean age was 63.2 ± 10.9 years, and mean BMI was 23.4 ± 3.3 kg/m^2. In total, 84 patients (63.2%) underwent open surgery and 49 (36.8%) underwent laparoscopic surgery. For tumor location in the rectum, patients were relatively evenly distributed: 46 patients (34.6%), 52 patients (39.1%), and 35 patients (26.3%) had tumors in the upper, middle, and low rectum, respectively. The mean tumor size was 3.8 cm. For pathologic staging, the number of patients with stage I, II, and III were 40 (30.1%), 37 (27.8%), and 50 (37.6%), respectively. Six patients (4.5%) achieved a pathologic complete response. Thirty-seven patients (27.8%) underwent preoperative radiotherapy, and 96 patients (72.2%) did not. Fecal diversion was performed in 42 patients (31.6%). For overall surgical outcomes, mean operation time, estimated blood loss, and duration of hospital stay after surgery were 197.3 ± 59.4 minutes, 256.1 ± 233.7 mL, and 13.4 ± 11.5 days, respectively. Pelvic SSI was present in 22 patients (16.5%) and local failure occurred in 9 patients (6.8%) (Table 2). In 22 patients with pelvic SSI, anastomotic leakage was definite in 8 patients and 5 patients underwent surgical procedures under general anesthesia. For local failure, 5 patients underwent

Table 1. Patient characteristics (n = 133)

Characteristic	Value
Age (yr)	63.2 ± 10.9
Sex	
Male	94 (70.7)
Female	39 (29.3)
Body mass index (kg/m^2)	23.4 ± 3.3
ASA PS classification	
1	25 (18.8)
2	100 (75.2)
3	8 (6.0)
Surgical approach	
Open surgery	84 (63.2)
Laparoscopic surgery	49 (36.8)
Tumor location in rectum	
Upper	46 (34.6)
Middle	52 (39.1)
Low	35 (26.3)
Tumor size (cm)	3.8 ± 2.7
Pathologic stage	
0 (pCR after radiotherapy)	6 (4.5)
I	40 (30.1)
II	37 (27.8)
III	50 (37.6)
Histology	
Well differentiation	21 (15.8)
Moderate differentiation	96 (72.2)
Poor/mucinous/signet	16 (12.0)
Lymphovascular invasion	
Present	40 (30.1)
Absent	93 (69.9)
Preoperative radiotherapy	
Present	37 (27.8)
Absent	96 (72.2)
Fecal diversion	
Present	42 (31.6)
Absent	91 (68.4)

Values are presented as mean ± standard deviation or number (%).
ASA, American Society of Anesthesiologists; PS, physical status; pCR, pathologic complete response.

Table 2. Overall surgical outcomes (n = 133)

Variable	Value
Operation time (min)	197.3 ± 59.4
Estimated blood loss (mL)	256.1 ± 233.7
Duration of hospital stay (day)	13.4 ± 11.5
Pelvic surgical site infection	
Present	22 (16.5)
Absent	111 (83.5)
Local failure[a]	
Present	9 (6.8)
Absent	124 (93.2)

Values are presented as mean ± standard deviation or number (%).
[a]Positive resection margin and/or local recurrence within 1 year after surgery.

Table 3. Multivariate risk analysis for pelvic surgical site infection

Variable	Odds ratio (95% CI)	P-value
Cross-sectional area	0.933 (0.883–0.986)	0.013
Surgical approach	0.487 (0.123–1.923)	0.305
Operation time	0.991 (0.979–1.003)	0.153
Estimated blood loss	1.001 (0.999–1.004)	0.346
Age	1.019 (0.969–1.072)	0.457
ASA PS classification	1.037 (0.263–4.094)	0.959
Body mass index	1.118 (0.937–1.334)	0.217
Preoperative radiotherapy	1.231 (0.286–5.308)	0.780
Tumor location in rectum	1.510 (0.716–3.186)	0.279
pT stage	0.855 (0.429–1.705)	0.657
pN stage	0.866 (0.380–1.972)	0.731
Tumor size	1.063 (0.827–1.365)	0.634
Fecal diversion	2.103 (0.580–7.625)	0.258

CI, confidence interval; ASA, American Society of Anesthesiologists; PS, physical status; pT stage, pathologic stage of primary tumor infiltration; pN stage, pathologic stage of regional lymph node metastasis.

local recurrence within 1 year after surgery and 6 patients presented tumor involvement on resection margin (4 patients on circumferential resection margin and 2 patients on distal resection margin). Two patients showed both early local recurrence and positive resection margin.

Pelvimetric results

Regarding pelvimetric parameters, mean AP pelvic diameter and transverse pelvic diameter were 11.1 ± 0.9 cm and 10.4 ± 6.8 cm, respectively. The mean cross-sectional area, calculated with these 2 diameters (AP and transverse), was 84.3 ± 10.9 cm^2. Comparing pelvimetric parameters in men and women, the AP (11.1 ± 0.8 cm in men *vs.* 11.1 ± 1.2 cm in women) and transverse pelvic diameter (10.4 ± 8.1 cm in men *vs.*10.4 ± 0.7 cm in women) did not show any significant differences (P = 0.993 and P = 0.982, respectively). However, for the pelvic cross-sectional area, the area was significantly smaller in men than in women (81.9 ± 9.6 cm^2 in men *vs.* 90.2 ± 11.7 cm^2 in women, P < 0.001).

Table 4. Multivariate risk analysis for local failure[a]

Variable	Odds ratio (95% CI)	P-value
Cross-sectional area	0.803 (0.658–0.980)	0.031
Surgical approach	0.022 (0.000–4.421)	0.159
Operation time	0.987 (0.959–1.015)	0.348
Estimated blood loss	0.999 (0.0.993–1.005)	0.815
ASA PS classification	3.673 (0.068–197.199)	0.959
Body mass index	1.571 (0.882–2.797)	0.125
Preoperative radiotherapy	266.620 (2.261–31,437.345)	0.022
Tumor location in rectum	5.743 (0.838–39.384)	0.075
pT stage	2.825 (0.369–21.645)	0.318
pN stage	23.473 (1.387–397.15)	0.029
Tumor size	1.279 (0.758–2.159)	0.356
Histology	0.323 (0.023–4.495)	0.400
Lymphovascular invasion	0.342 (0.016–7.519)	0.496

CI, confidence interval; ASA, American Society of Anesthesiologists; PS, physical status; pT stage, pathologic stage of primary tumor infiltration; pN stage, pathologic stage of regional lymph node metastasis.
[a]Positive resection margin and/or local recurrence within 1 year after surgery.

Comparing pelvimetric parameters according to the surgical outcomes of pelvic SSI and local failure, the cross-sectional area was significantly smaller in patients with pelvic SSI and local failure than in patients without them in the univariate and multivariate analyses (Tables 3, 4). The cross-sectional area was 79.8 ± 10.6 cm^2 in patients with pelvic SSI, and 85.3 ± 10.8 cm^2 in patients without SSI, which was statistically significant in the univariate analysis (P = 0.030). In contrast, the AP and transverse pelvic diameters did not show the difference according to the presence of pelvic SSI (P = 0.507 and P = 0.479, respectively). In the multivariate analysis including potential confounders for SSI, the cross-sectional area was significantly associated with pelvic SSI (odds ratio [OR], 0.933; 95% confidence interval [CI], 0.883–0.986; P = 0.013). In terms of local failure, the cross-sectional area was 75.6 ± 7.7 cm^2 in patients with local failure and 85.0 ± 10.8 cm^2 in patients without local failure, which was statistically significant in the univariate analysis (P = 0.012). Similar to pelvic SSI, the AP and transverse pelvic diameters were not different according to the occurrence of local failure (P = 0.236 and P = 0.639, respectively). In the multivariate analysis including potential confounders for local failure, the cross-sectional area was significantly associated with local failure (OR, 0.803; 95% CI, 0.658–0.980; P = 0.031).

Table 5. Comparison of surgical outcomes according to the cutoff value

Variable	Cross-sectional area		P-value
	<88.8 cm^2	≥88.8 cm^2	
Operation time (min)	201.5 ± 62.5	187.7 ± 51.2	0.216
Estimated blood loss (mL)	263.2 ± 246.3	240.4 ± 204.6	0.605
Duration of hospital stay (day)	14.5 ± 13.4	11.0 ± 4.4	0.028
Pelvic surgical site infection			0.056
Present	19 (20.7)	3 (7.3)	
Absent	73 (79.3)	38 (92.7)	
Local failure[a]			0.038
Present	9 (9.8)	0 (0)	
Absent	83 (90.2)	41 (100)	

Values are presented as mean ± standard deviation or number (%).
[a]Positive resection margin and/or local recurrence within 1 year after surgery.

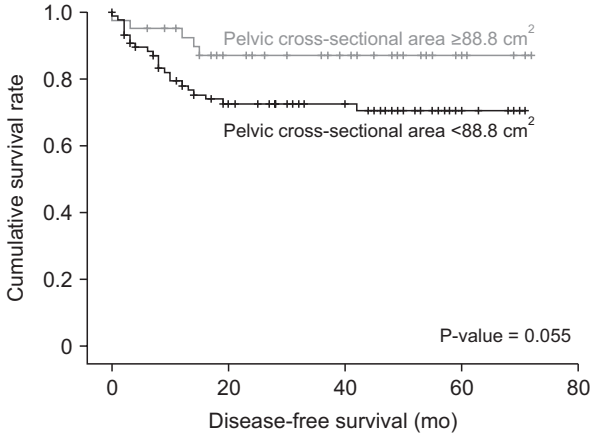

Fig. 2. Kaplan-Meier curve for disease-free survival in patients with pelvic cross-sectional area below 88.8 cm^2 (black line) and above 88.8 cm^2 (gray line), which showed marginal significance of P-value 0.055.

Estimation of the pelvimetric cutoff value predicting adverse surgical outcomes

ROC analysis was performed to obtain an appropriate cutoff value for the cross-sectional area predicting adverse surgical outcomes of pelvic SSI and local failure. A cross-sectional area of 88.8 cm^2 was calculated as the cutoff value, with a sensitivity of 88.9% and specificity of 35.8%. For its low area under curve of 0.650, this analysis was only used for calculating the cutting point. Several significant differences were observed when surgical outcomes were compared between patients who had pelvic cross-sectional areas below and above 88.8 cm^2 (Table 5). Patients with cross-sectional areas below 88.8 cm^2 showed significantly longer duration of hospital stay after surgery and more local failure than patients with cross-sectional areas above 88.8 cm^2 (P = 0.028 and P = 0.038, respectively). Even though it was not statistically significant, there was a trend for more pelvic SSI in the patients with cross-sectional areas below 88.8 cm^2 (P = 0.056). Comparing survival outcomes, patients with cross-sectional areas below 88.8 cm^2 showed lower survival rate (72.5% of 3-year DFS) than patients with cross-sectional areas above 88.8 cm^2 (87.2% of 3-year DFS), with marginal significance (P = 0.055) (Fig. 2).

DISCUSSION

The results of our study showed that pelvic cross-sectional area calculated using only axial CT images scan could be a predictor for surgical and oncologic outcomes. The cross-sectional area was associated with the incidence of pelvic SSI, including anastomotic leakage. Furthermore, it was associated with the indices of oncologic outcomes such as tumor involvement of resection margin and early local recurrence, which were defined as local failure in this study.

Similar to the present study, previous studies demonstrated the association of pelvimetric parameters with surgical outcomes. Based on the pelvimetry using CT scan, Zur Hausen et al. [8] suggested that a smaller obstetric conjugate and larger sagittal mid-pelvic diameter were associated with a higher rate of incomplete mesorectal excision, which might affect oncologic outcomes. In another study on CT-based pelvimetry, distance from the symphysis pubis to the coccygeal tip, and angle of symphysis pubis to the sacral promontory were associated with the operating time of laparoscopic rectal cancer surgery [11]. In addition, MRI-based pelvimetric analysis was performed. Baik et al. [9] reported that obstetric conjugate and interspinous distance in MRI-based pelvimetry were predictive factors for the quality of TME, and short interspinous distance was a predictive factor for a positive circumferential resection margin. Although detailed results were not identical in these previous studies due to differences in study design and cohort size, they demonstrated a significant correlation between several pelvimetric parameters and surgical outcomes.

Most previous studies required 3-dimensional reconstruction of CT scan imaging or MRI, which has been taken in addition to clinical routine and/or has been time consuming [5,8-11,15]. Furthermore, MRI-based pelvimetry requires experienced technicians to perform accurate planning of the sequences and image interpretation [16,17]. In the present study, only 2 measurements of the AP pelvic diameter (distance from the posterior border of the symphysis pubis to the tip of the coccyx) and transverse pelvic diameter (the shortest distance between the inner borders of the lateral bony pelvis) in the axial image of the CT scan were used for automatic calculation of the pelvic cross-sectional area in PACS. CT was a part of routine examination before rectal cancer surgery, and measurement of pelvimetric parameters could be performed by the clinicians

themselves without the aid of radiologists or radiologic technicians. Furthermore, we attempted to reveal the cutoff value to predict adverse outcomes with this simple pelvimetric parameter, and a significant pelvic cross-sectional area around 90 cm^2 was calculated. Although its predictive value was limited by its small cohort size and the retrospective nature of the study, this result showed the validity of anatomy-based prognostic markers using CT scans, which have been routinely performed for rectal cancer.

In the present study, men showed significantly smaller pelvic cross-sectional areas than women. This result may provide an objective explanation for previous studies dealing with risk factors relating to poor surgical outcomes after rectal cancer surgery. Multiple studies have suggested that the male gender is an independent risk factor for poor surgical outcomes, including anastomotic leakage [18-23]. This gender-specific difference might be explained by the gender-specific geometry of the pelvis with a wide pelvis in the female and a narrower pelvis in the male. In addition, the narrower pelvis, a smaller pelvic cross-sectional area in this study, was associated with poor surgical outcomes of pelvic SSI, positive resection margin, and early local recurrence. From this point of view, we excluded gender from the risk set for the multivariate analysis to identify risk factors for adverse surgical outcomes and pelvic cross-sectional area was an independent risk factor in the present study.

This study has some limitations. First, several variables were not included in the multivariate analysis, which may have affected surgical outcomes. For example, we did not include technical variables such as cartilage length and the number of cartilage used to transect the rectum, and the use of a pelvic drain or rectal tube, which have been shown to affect surgical outcomes such as anastomotic leakage in previous studies. Also, other variables which might affect the occurrence of SSI such as patients' underlying morbidity, pre/postoperative medication, transfusion, and bowel preparation were not included in the analysis, neither. Second, this was a retrospective study with a small population in a single center. Despite the limitations of this study, the results provided a possible predictive parameter with a cutoff value to estimate surgical and oncologic outcomes. Certainly, further prospective studies with a larger population are needed to confirm that this simple pelvimetry is feasible to predict the adverse outcome for rectal cancer surgery to better help in the management of such patients.

In conclusion, this study suggests that the pelvic cross-sectional area obtained from a routine axial CT image was associated with pelvic SSI including anastomotic leakage, positive resection margin, and early local recurrence. It may be useful as an intuitive, feasible, and easily adoptable method to predict surgical outcomes.

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Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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