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Magnetic resonance (MR) pelvimetry as a predictor of difficulty in laparoscopic operations for rectal cancer

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Laparoscopic surgery for rectal cancer is now well established. Recent studies have shown no difference in survival or oncologic outcomes when laparoscopic surgery is compared to open procedures [1, 2]. The laparoscopic approach does, however, present the surgeon with inherent challenges. Previous abdominal surgery, tumours closer to the anal verge, high body mass index (BMI), and preoperative radiotherapy have been shown to increase the difficulty of laparoscopic procedures in the pelvis [3–6].

It is often assumed that laparoscopic resections for rectal cancer are also complicated by a deep, narrow pelvis in which access and vision are both restricted by pelvic anatomy. Although a majority of patients undergo preoperative pelvic magnetic resonance (MR) staging, radiological measurement of the bony pelvis—pelvimetry—has not been fully assessed as a predictor of difficult laparoscopic operations.

Male sex has been shown to correlate with surgeons' perceived difficulty of laparoscopic resections, although more objective evidence of increased difficulty, in the form of longer operating times or more frequent involvement of the circumferential resection margin (CRM), is sparse [6]. Indeed, while some authors have demonstrated significant differences in pelvic measurements between the sexes [7, 8], others have shown considerable overlap [9], suggesting that the measurements themselves may be a more useful predictor of difficulty than sex alone.

MR pelvimetry has been evaluated for potential application in predicting the technical difficulty and outcomes of open rectal resection and prostatectomy [3, 4, 7, 10]. Various dimensions of the bony pelvis thought to be of importance during surgery were studied; all studies used a combination of anteroposterior (AP) measurements in the mid-sagittal plane and some form of transverse measurement to describe the breadth and depth of the pelvis. Some authors measured angles and dimensions on the mid-sagittal slices to define the acuity of the sacral curve and the other boundaries of the pelvis [3, 7, 10]. One author went further, developing a synthetic measurement designed to better describe the pelvic depth observed by the surgeon performing open radical prostatectomy—the apical depth of the pelvis divided by the transverse interspinous distance [11]. None of these measurements were shown to significantly predict any objective or subjective measure of operative difficulty and pelvimetry seems to have been abandoned as a predictor in open resections.

It is reasonable to expect that pelvic anatomy may be more important in laparoscopic resections. A prominent sacral promontory, an acutely curved sacrum, or a pelvis particularly narrow in the transverse plane could conceivably represent anatomical bottlenecks, impeding vision, access, and space in which instruments can be manipulated. Indeed, initial research has shown correlations between longer operating times and a larger pelvic outlet [4] and a smaller lower pelvis diameter [5] and between CRM involvement and shorter transverse interspinous distances [12]. Further ascertainment of the influence of pelvic

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anatomy may assist laparoscopic surgeons in identifying potentially difficult resections and plan accordingly. This study aims to further clarify the role pelvimetry has in predicting difficult laparoscopic resections for rectal cancer.

Materials and methods

In this retrospective observational study, we identified all patients who underwent preoperative pelvic MR staging prior to an anterior resection (AR) or abdominoperineal resection (APR) for rectal cancer in our centre. Patients were operated on laparoscopically by one of two experienced consultant laparoscopic colorectal surgeons following discussion at our multidisciplinary team meeting. Operative time was used as a measurement of operative difficulty. Accurate, contemporaneously documented knife-to-skin and end-of-surgery times were recorded and length of surgery calculated. Operating time was chosen as the primary measure of difficulty as it is objective, validated in the literature as an indicator of operative difficulty, and is well suited to a relatively small sample size in which some postoperative complications may not occur.

The resected specimen was examined by a pathologist and minimum distance of the tumour from the circumferential resection margin (CRM) was measured. The CRM was involved when the tumour was found at or within 1 mm of the CRM.

On a picture archiving and communications system (PACS) workstation, key dimensions of the bony pelvis were retrospectively measured on the patient's staging MRI scans by one of our team (TK), blinded to the clinical and histological outcome of the cases studied. We chose a number of measurements in the mid-sagittal and transverse

Fig. 1 Sagittal MR image demonstrating the five measured pelvic dimensions and angles

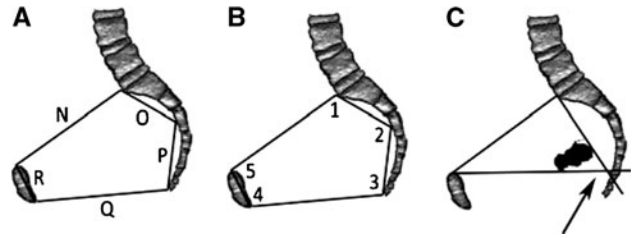

Fig. 2 Sagittal midline views of bony pelvis showing pelvimetry distances (**A**), pelvimetry angles (**B**), and calculated tumour angle (**C**, *arrow*)

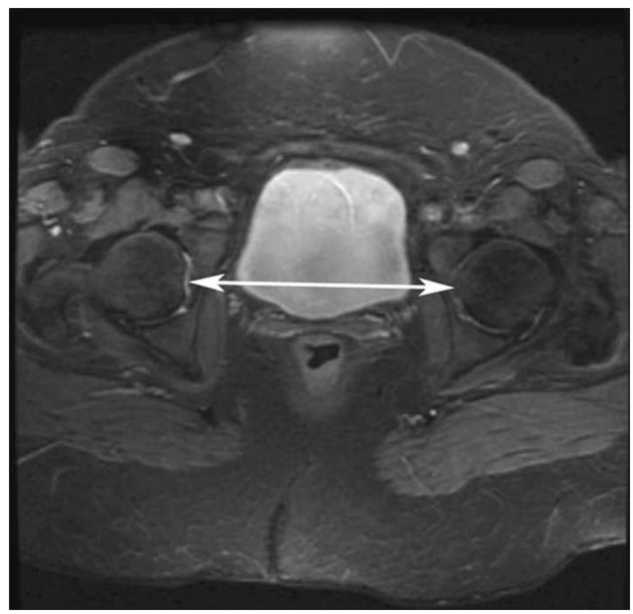

Fig. 3 Transverse MR image demonstrating the interacetabular distance

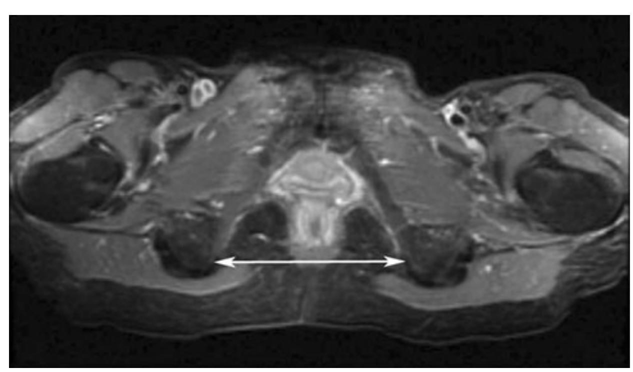

Fig. 4 Transverse MR image demonstrating the intertuberous distance

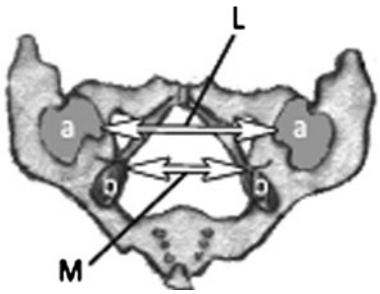

Fig. 5 Inferior view of bony pelvis showing the acetabulae (**a**) and ischial tuberosities (**b**) with interacetabular (*L*) and intertuberous (*M*) distances

planes (see Figs. 1, 2, 3, 4, and 5). These were the intertuberous distance (between the ischial tuberosities in the transverse plane); the interacetabular distance (between the most medial aspects of the femoral head in the transverse plane); and five measurements in the sagittal plane forming a pentagon consisting of the pelvic inlet, the promontory—mid-S3 distance, the mid-S3—coccygeal tip, the pelvic outlet, the pubic bone; and, finally, the pubic bone—sacral promontory distance. The five angles formed at the intersections of these sagittal dimensions were also recorded (Table 1). To better understand the relationships between the angles and distances recorded in our sample, correlations between pelvimetry parameters were sought using Spearman's rank correlation coefficient (Table 2).

A number of ratios were calculated from the raw pelvimetry measurements. The formulae selected related various aspects of pelvic anatomy to other attributes in either the same or a different plane. These ratios describe three-dimensional properties of the pelvis that we felt may be important in laparoscopic procedures in the lower pelvis (Table 3).

A subset of ten patients' scans were randomly selected and reassessed independently by TK and another researcher (ZD) 12 weeks later to determine intra- and interobserver reliability.

To assess whether the combination of information about the tumour and pelvic measurements might be a more useful predictor of difficulty, we also developed a synthetic measurement that we called the tumour angle (Fig. 2). This was an angle measured in the mid-sagittal using a projection of maximum craniocaudal dimension of the rectal tumour demonstrated in any sagittal plane. The tumour angle was formed between two lines drawn tangentially from the sacral promontory and the anterosuperior tip of the pubis to the superior and inferior edges of the tumour. The angle formed by the intersection of these lines would be more acute in large tumours distant to the pelvic inlet and more obtuse in smaller tumours closer to the inlet. The tumour angle was measured by an experienced consultant radiologist (ZD), also blinded to operating times, CRM status, and clinical outcomes.

Table 1 Description of pelvimetry angles

Angle number	Description
Angle 1	Superior anterior pubis—sacrovertebral angle—mid S3
Angle 2	Sacrovertebral angle—mid S3—coccyx
Angle 3	Mid S3—coccyx—inferoposterior pubis
Angle 4	Coccyx—inferoposterior pubis—superior anterior pubis
Angle 5	Inferioposterior pubis—superior anterior pubis—sacrovertebral angle

Table 2 Correlations between pelvimetry measurements/angles

	Correlation	*p* value
Angle 2/angle 3	−0.65	0.001
Pelvic outlet/angle 2	0.66	0.001
Pelvic outlet/angle 3	−0.6	0.002
Pelvic outlet/(angle 2/angle 3)	0.62	0.002

Results

All pelvic measurements and angles were normally distributed (Shapiro–Wilk test). When operating times for APR and AP were considered together, Spearman's rank correlation coefficient was used to determine any correlations between pelvimetry measurements and operating time. Pearson's product-moment coefficient was used to determine relationships between the (normally distributed) operating times for anterior resections and pelvic parameters as well as between the pelvic measurements themselves. Unpaired t tests were used to assess the relationship between sex, age, CRM status, and type of operation with operating time.

The MR scans and operative records of 25 patients (10 men, mean (±SD) age = 68.9 ± 11.7 years) were retrospectively analysed. Seventeen underwent AR while eight had an APR. Mean duration of surgery was 252 ± 65 min, with APRs taking significantly longer (294 ± 64 min) than ARs (232 ± 58 min) ($p = 0.04$). Inter- and intraobserver variabilities were calculated (0.85 and 0.97, respectively, intraclass correlation coefficient) and showed the pelvic measurements to be reproducible between and within observers. Strong correlations were found between the transverse dimension of the pelvic outlet and both Angle 2 (positive) and Angle 3 (negative). Five pelvimetry measurements were shown to have a significant association with operating time. A larger pelvic outlet (0.47; $p = 0.02$)

Table 3 Associations of demographic and pelvimetry variables with operating time and CRM status

Variable	Correlation with operating time				Circumferential resection margin (CRM)					
					Comparison of means for each variable					
	All operations ($n = 25$)		AR only ($n = 17$)		CRM ≤1 mm	CRM >1 mm	p	CRM ≤5 mm	CRM >5 mm	p
Age (years)	−0.05	ns	−0.36	ns	72.6	67.3	ns	66.9	68.7	ns
Transverse measurements										
Interacetabular distance (L)	0.02	ns	0.01	ns	116 mm	122 mm	ns	122 mm	121 mm	ns
Intertuberous distance (M)	−0.33	ns	−0.10	ns	122 mm	121 mm	ns	123 mm	120 mm	ns
Sagittal measurements										
Pelvic inlet (N)	0.19	ns	0.17	ns	109 mm	111 mm	ns	109 mm	111 mm	ns
Inlet to S3 (O)	0.22	ns	0.39	ns	78 mm	76 mm	ns	75 mm	77 mm	ns
S3 to coccyx (P)	0.09	ns	0.21	ns	73 mm	73 mm	ns	74 mm	73 mm	ns
Pelvic outlet (Q)	0.47	0.02	0.31	ns	85 mm	85 mm	ns	84 mm	85 mm	ns
Pub. tubercle (R)	−0.13	ns	−0.40	ns	54 mm	49 mm	ns	49 mm	50 mm	ns
Angles										
Angle 1	0.13	ns	−0.27	ns	95°	93°	ns	96°	91°	ns
Angle 2	0.46	0.02	0.23	ns	114°	115°	ns	112°	117°	ns
Angle 3	−0.41	0.05	−0.28	ns	107°	106°	ns	107°	106°	ns
Angle 4	0.37	ns	0.01	ns	126°	124°	ns	126°	124°	ns
Angle 5	−0.16	ns	0.20	ns	97°	101°	ns	98°	103°	ns
Derived measurements										
(N + Q)/(O + P)	0.19	ns	0.02	ns	1.29	1.32	ns	1.31	1.32	ns
(L + N)/(O + P)	0.03	ns	−0.16	ns	1.50	1.56	ns	1.56	1.55	ns
(O + P)/angle 2	−0.15	ns	0.04	ns	1.34	1.31	ns	1.33	1.29	ns
Q/Angle 2	−0.45	0.02	0.31	ns	0.74	0.73	ns	0.75	0.73	ns
Q/angle 3	0.52	0.01	0.30	ns	0.81	0.80	ns	0.79	0.81	ns
Angle 3/Angle 2	0.45	0.03	−0.32	ns	0.95	0.93	ns	0.96	0.91	ns
N/L	0.06	ns	0.13	ns	0.94	0.92	ns	0.91	0.93	ns
N/M	0.42	0.04	0.22	ns	0.91	0.95	ns	0.92	0.96	ns
Q/L	0.25	Ns	0.27	ns	0.73	0.70	ns	0.45	0.46	ns
Q/M	0.56	0.006	0.38	ns	0.72	0.72	ns	0.92	0.96	ns
Q/N	0.28	ns	0.20	ns	0.78	0.77	ns	0.77	0.77	ns
Calculated tumour angle	−0.12	ns	0.01	ns	41°	49°	ns	45°	40°	ns

and a larger Angle 3 (between the promontory, S3, and the coccygeal tip) (0.46; $p = 0.02$) were associated with longer operations. Conversely, a larger Angle 3 (between S3, the coccygeal tip, and the pubis) (−0.41; $p = 0.05$) was associated with shorter operations. A higher sagittal pelvic inlet:intertuberous distance ratio (0.42; $p = 0.04$) and a higher sagittal pelvic outlet:intertuberous distance ratio (0.56; $p = 0.006$) were both related to longer operations. The pelvic outlet:Angle 2 (−0.45; $p = 0.02$) and pelvic outlet:Angle 3 (0.52; $p = 0.01$) indices showed a significant correlation with decreased and increased operating time, respectively.

Sex, age, CRM status, and tumour angle showed no association with operating time. CRM status was not significantly related to any of the pelvimetry measurements, angles, or derived measures. CRM was more likely to be involved in specimens resected during APR than during AR (0 vs. 38%; $p = 0.04$).

Discussion

The sacral curve and pelvic outlet

Of the sagittal pelvic dimensions measured, only the pelvic outlet was independently correlated with operating time. This corroborates the recent findings of Akiyoshi et al. [4] who also demonstrated a link between a larger pelvic outlet, increased operating time, and the risk of anastomotic leakage.

While we anticipated that an acutely curved sacrum would pose problems for the surgeon, this study has shown that it is a more obtuse, shallow sacral curve that is associated with longer operations. In our sample, acuity of the sacral curve was closely related to pelvic outlet. It is therefore not surprising that a combined measure of both factors is a strong predictor of longer operations, with a pelvic outlet rendered narrow by an impinging coccyx more closely associated with shorter operating times. This anatomical arrangement may facilitate rectal excision through more favourable presentation of the rectum and mesorectum.

Transverse and sagittal ratios

Considered alone, neither of the transverse measurements correlated significantly with operating time, although the intertuberous distance approached significance ($p = 0.08$). However, when combined with significant predictors in the sagittal plane, the intertuberous distance reveals itself as an important modifier—showing a synergistic effect on the strength of other variables' correlation with operating time. The strongest correlation with longer operations was seen in patients with a large sagittal pelvic outlet coupled with a narrow transverse intertuberous distance. These patients lacked the favourable anatomical arrangement associated with a narrower pelvic outlet while presenting the surgeon with the additional problem of reduced lateral space in which to work.

Circumferential resection margin

Involvement of tumour in the CRM (≤1 mm; Table 4) was apparent in three resected specimens, all of which were from AP resections and, importantly, were predicted preoperatively to have an involved margin. Other than type of operation (AR vs. APR), no other factors were associated with CRM involvement. CRM status showed no association with any of the pelvic measurements, angles, or derived measures.

Tumour angle

We attempted to simplify prediction of difficulty by combining a pelvimetry measurement with tumour factors known to influence ease of resection, namely, tumour height and tumour bulk, into one index. It is likely that this approach failed due to its dependence on the pelvic inlet as the anatomical variable, a factor shown in this study and others to be of little independent significance in predicting difficulty.

Limitations

Many factors are recognised as contributing to the difficulty of completing laparoscopic procedures in the lower pelvis. Because of the small number of patients in this pilot study, we made no attempt to control for parameters already known to be important, such as BMI, previous abdominal surgery, or specific tumour factors. Unfortunately, such data were not available for all patients in the study, but we have no reason to expect our sample to be systematically biased in such a way as to invalidate the overall results.

Inclusion of APR data reflects the feeling among the investigating team that pelvic anatomy similarly influences the difficulty of both operations. One advantage of a retrospective study is the removal of bias stemming from the surgeon's knowledge that her performance is being recorded. As the duration of different components of operations is not routinely recorded, it was not possible to establish the proportion of the duration of APR spent working laparoscopically in the pelvis. While conceivable that this introduces problematic bias, this is rendered less likely by the

Table 4 CRM status and demographic variables

Variable	Sex		AR vs. APR		Age		CRM			
	Male ($n = 15$)	Female ($n = 10$)	AR ($n = 17$)	APR ($n = 8$)	≤70 ($n = 16$)	>70 ($n = 9$)	≤1 mm ($n = 3$)	>1 mm ($n = 22$)	≤5 mm ($n = 10$)	>5 mm ($n = 15$)
Mean operating time (min)*	257	245	232	294	240	274	312	244	272	239
	$p =$ ns		$p = 0.04$		$p =$ ns		$p =$ ns		$p =$ ns	
CRM ≤1 mm†	$n = 3$ (20%)	$n = 0$ (0%)	$n = 0$ (0%)	$n = 3$ (38%)	$n = 1$ (6%)	$n = 2$ (13%)				
	$p =$ ns		$p = 0.02$		$p =$ ns					
CRM ≤5 mm†	$n = 7$ (46%)	$n = 3$ (30%)	$n = 5$ (29%)	$n = 5$ (63%)	$n = 6$ (38%)	$n = 4$ (25%)				
	$p =$ ns		$p =$ ns		$p =$ ns					

* Unpaired t test; † Fisher's exact test

fact that when the data presented in Table 3 are consulted, it is clear that the pelvimetry measures which reach significance for both operations also approach significance (for 15 d.f., $p \leq 0.05$, where Pearson $r \geq 0.482$) for AR only.

The two consultant surgeons who performed the operations are experienced laparoscopists and it is unlikely that learning curve factors were a source of bias in this sample. The positive results published here indicate that preoperative MR pelvimetry does predict operative difficulty, although larger, prospective studies that include other patient and tumour factors will be necessary to better define this role.

The absence of unexpectedly involved CRM margins in our sample means that the inconclusive CRM data presented here neither supports nor refutes the conclusions drawn from the positive associations of pelvimetry with operating time.

Implications for the laparoscopic colorectal surgeon

MR pelvimetry is simple and cheap and utilises anatomical information gathered noninvasively prior to operations. Knowledge of the findings presented here, which begin to shed light on the true nature of the "hostile" and "benign" pelvis, will be of use to the surgeon anticipating operating laparoscopically within them. As part of an assessment of the patient prior to surgery and in combination with other known risk factors, patients with quantifiably challenging pelvic anatomy can may be informed, consented, and scheduled accordingly.

Scoring systems for predicting the difficulty of laparoscopic resections for rectal cancer have been proposed [6], often with the rationale that surgical trainees could gradually be exposed to more difficult cases as they progress along their learning curve, minimising poor outcomes associated with inexperience [13]. One such system uses male sex as a proxy indicator for "difficult pelvis," an assumption that may be imprecise [6]. This study suggests that the routine collection of MR pelvimetry data may help in refining and perfecting such a scoring system for laparoscopic rectal resections.

Conclusion

This study establishes several preoperative pelvic factors as important predictors of difficulty in laparoscopic resections for rectal cancer. A less acutely curved sacrum and a larger sagittal pelvic outlet are significantly correlated with longer operations, especially in a pelvis with a narrow intertuberous distance. Multivariate analysis of the effect of these measurements, along with other patient and tumour factors, could form the basis of a prospective validation of these findings with a larger sample size. If positive, MR pelvimetry could then be assessed as part of a preoperative scoring system to predict difficulty in these operations, allow surgeons to plan accordingly, and permit the judicious selection of cases by laparoscopic surgical trainees.

Disclosures Drs. Killeen and Dabbagh, Mr. Banerjee, Mr. Warren, Mr. Francis, and Mrs. Vijay have no conflicts of interest or financial ties to disclose.

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