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RESEARCH ARTICLE

Posterior Rectus Sheath: A Prospective Study of Laparoscopic Live Surgical Anatomy during Total Extraperitoneal Preperitoneal Hernioplasty

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ABSTRACT

Aim: Posterior rectus sheath (PRS) recently assumed great importance during laparoscopic total extraperitoneal preperitoneal (TEPP) hernioplasty. However, literature is scanty and cadaveric. Novel observations on live PRS anatomy are reported here.

Materials and methods: Totally, 60 male patients with primary inguinal hernia underwent 68 TEPP hernioplasties. Standard 3-midline-port technique was used with telescopic dissection. Data were analyzed as mean ± standard deviation (SD).

Results: All patients were male with mean age and body mass index of 50.1 ± 17.2 years (18–80) and 22.6 ± 2.0 kg/m^2 (19.5–31.2) respectively. The classically described PRS (normal-length whole tendinous) was found in only 46% of the cases, while in the remaining 54%, the PRS was found as variant types, which included short whole-tendinous (4.4%), long whole tendinous (LWT) (4.4%), complete-length whole tendinous (8.8%), normal-length partly tendinous (NPT) (11.8%), long partly tendinous (LPT) (10.3%), normal-length thinned-out (NTO) (1.5%), complete-length thinned-out (4.4%), normal-length grossly attenuated (1.5%), complete-length grossly attenuated (4.4%), complete-length partly tendinous (CPT) (1.5%), and complete-length musculo-tendinous (CMT) (1.5%). Additionally, anatomy of the PRS was not a mirror image on the two sides of the body in 75% of patients with bilateral hernias. No hernia recurrence occurred in mean follow-up of 33 months.

Conclusion: Posterior rectus sheath varied markedly in its extent and morphology, resulting in its categorization of 12 types. Truly new visions of the structures known for centuries are realized under excellent perspective and magnification of laparoscopy, and, therefore, continued anatomic research is strongly recommended.

Clinical significance: Crisp, precise knowledge of preperitoneal anatomy is of paramount importance for timely identification of its variations in order to perform a seamless laparoscopic hernia repair with better outcome.

Keywords: Clinical research, Laparoscopic live surgical anatomy, Posterior rectus canal, Posterior rectus sheath, Preperitoneal anatomy, Total extraperitoneal preperitoneal access anatomy, Total extraperitoneal preperitoneal anatomy.

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INTRODUCTION

The oversimplified traditional description of the inguinal anatomy is still taught in our anatomy classrooms, leading to a fixed mindset that often proves counterproductive for instant recognition and precise dissection of the anatomical structures required during the laparoscopic surgery.[1] This seems true not only for the upcoming young surgeons, but also the seasoned senior surgeons. Inadequate understanding and improper dissection of the preperitoneal anatomy is now regarded as the main cause of difficulties during the TEPP hernioplasty, especially in presence of the wide anatomic variations reported from time-to-time over the last several decades,[2-6] which received little/no attention of the anatomists and the practicing surgeons alike.[1] In view of the sparse/scanty research work on the laparoscopic live surgical anatomy available in the literature, especially in relation to the TEPP access anatomy,[1,7] a prospective first-of-its-kind laparoscopic study of the PRS was undertaken and its partial observations were published as the interim result by the author[8] in order to create a general awareness among the surgical fraternity, especially the upcoming young hernia surgeons, and to get feedback from them to make the present study more illuminating and fruitful at completion, which is presented herein. Laparoscopic live surgical anatomy (morphology and extent) of the PRS is primarily addressed here with its possible clinical significance.

MATERIALS AND METHODS

A prospective study was conducted in the form of a doctoral research for award of doctorate in surgery. Infraumbilical PRS was carefully studied under the excellent perspective and magnification of the preperitoneal laparoscopy. Laparoscopic TEPP was performed in the Department of Surgery, Jawaharlal Nehru Medical

College, Aligarh Muslim University, Aligarh, Uttar Pradesh, India, during a period w.e.f. April 2010 to November 2015. All patients with inguinal hernia were operated under the ethical clearance of our Institutional Ethics Committee and written informed consent.

Selection Criteria for Recruitment in the Study

- Patient's choice under the informed consent.
- Patient's good financial status: The existing financial circumstances of the patients including patients' ability to expend extra money for the laparoscopic procedure (our institution charges double for the laparoscopic hernioplasty as compared with the open hernioplasty).
- Preoperative feasibility of laparoscopic hernioplasty based on the preanesthetic check-up (PAC) in outpatient department.
- Availability of functioning laparoscopic equipment and instruments.
- Availability of the expertise (laparoscopic surgeon).

Inclusion Criteria of the Study

- Patients with age more than 18 years
- Patients with uncomplicated fully reducible primary inguinal hernia
- Patients with American Society of Anesthesiologists (ASA) grades I to II only
- Written informed consent for laparoscopic repair of inguinal hernia

Exclusion Criteria of the Study

- Patient's refusal for laparoscopic repair
- Patients with age less than 18 years
- Patients with severe comorbid disease (ASA grades III–V)
- Patients with recurrent inguinal hernia
- Patients with complicated inguinal hernia (irreducible/inflamed/obstructed/strangulated)
- Patients with femoral and other groin hernia
- Patients with history of lower abdominal surgery

Surgical Technique

Under general anesthesia with patient supine, the distance between the umbilicus and the upper border of the pubic symphysis was first measured and, thereafter, the laparoscopic TEPP hernioplasty was performed with the standard 3-midline port technique as reported earlier by the author.[9,10] Access to the posterior rectus canal was obtained by open method through a 2 cm infraumbilical incision in skin and anterior rectus sheath ipsilateral to the side of inguinal hernia. After placement and fixation of an 11-mm optical trocar, the initial dissection in posterior rectus canal was performed with unhurried to-and-fro movements of the 0° 10-mm laparoscope with careful observation and documentation of PRS extent and morphology. Two 5-mm working ports were placed in the midline lower down for further dissection (Fig. 1) in the retropubic and inguinal regions for mesh placement.

As per the traditional teaching through major anatomy textbooks,[11] the anterior rectus sheath is considered as complete as it is covering the whole length of the rectus abdominis muscle, while the PRS is considered incomplete, as it covers the undersurface of only the upper two-thirds of the rectus abdominis muscle and ends short of the pubic symphysis with formation of an Arcuate line (of Douglas). Based on two factors, viz., firstly, our present understanding based on current literature[11-13] that the Arcuate line is generally present at about one-thirds of the distance from umbilicus to the pubic symphysis (U-PS), and secondly, the maximum U-PS of 18.0 cm recorded in the present study, the infraumbilical incomplete PRS (IC-PRS) was arbitrarily divided into three categories for further reference and discussion: (1) The classical normal-length PRS (U-AL 3–6 cm), (2) the short PRS (U-AL <3 cm), and (1) the long PRS (U-AL >6 cm), where U-AL represents the distance from umbilicus to the arcuate line. The PRS extending up to the pubic symphysis with/without formation of an arcuate line was considered as the complete PRS (C-PRS) in the present study.

The demographic data of age, weight (measured without footwear), height, and occupation of the patients were recorded. Body mass index (BMI) was calculated by the formula of weight in kilogram divided by the square of the height in meters as recommended in 1991

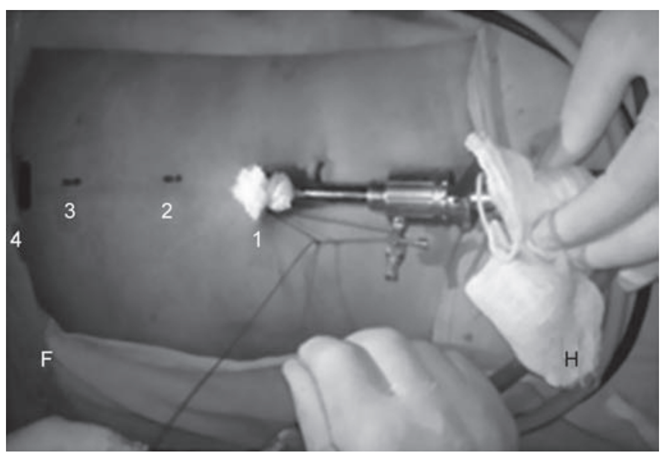


Fig. 1: Port placement for laparoscopic TEPP hernioplasty for right inguinal hernia: F, foot end of patient; H, head end of patient; 1, infraumbilical site with optical port (11 mm) *in situ*; 2 and 3, site for working ports (5 mm); 4, marking for upper border of pubic symphysis

by Deurenberg et al.[14] The PRS was observed in terms of its extent, morphology, layer, and symmetry in all the patients who underwent the laparoscopic TEPP hernioplasty for the inguinal hernia. The Statistical Package for Social Sciences version 21 was used for the statistical analysis. All data were computed as mean ± SD.

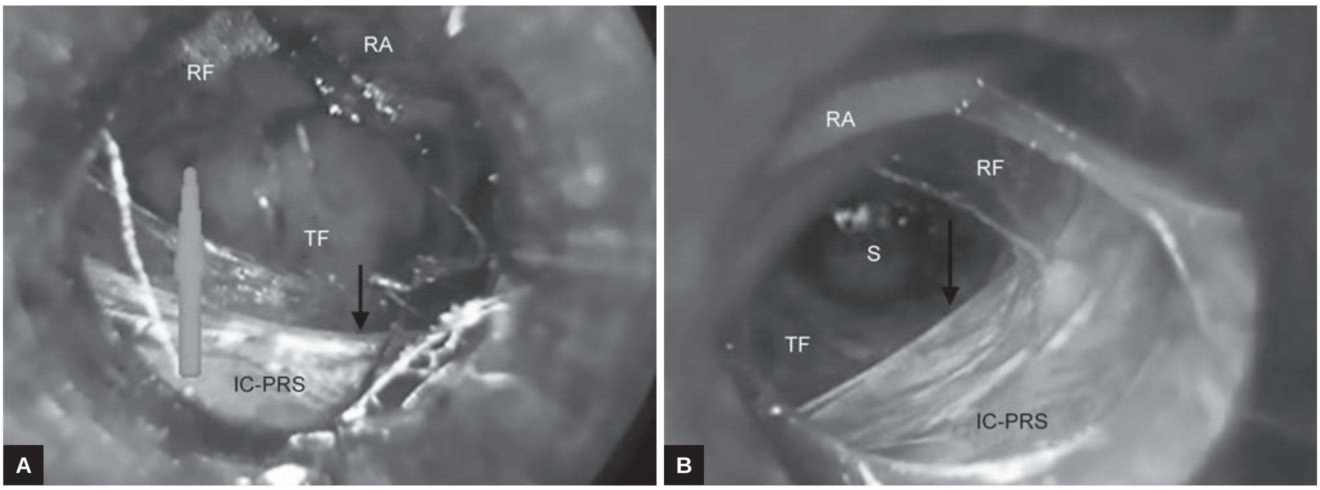
RESULTS

Demographic Characteristics of Patients

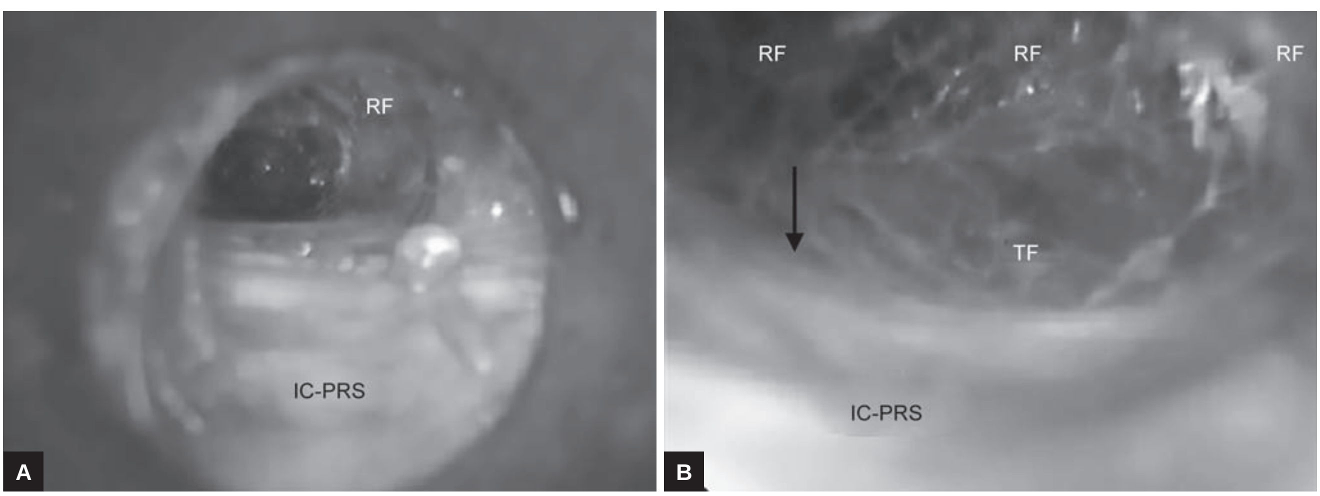
Sixty out of 63 adult male patients with primary inguinal hernia successfully underwent a total of 68 TEPP hernioplasties [unilateral 52 (left side 35; right side17), and bilateral 8]. Three patients were excluded due to early forced conversion before sufficient observations were made of the PRS; and the reasons for exclusion included early peritoneal injury by the first blunt trocar secondary to short PRS as detected on conversion to TAPP (1), early inadvertent injury to the deep inferior epigastric vessels (1), and early anesthetic problem secondary to excessive CO_2 retention (1). Three female patients with inguinal hernia presenting in the study period were not recruited for the laparoscopic hernia repair due to one or more exclusion criteria. Mean age and BMI of the 60 patients studied were 50.1 ± 17.2 years (18–80) and 22.6 ± 2.0 kg/m^2 (19.5–31.2) respectively. Totally, 49 out of 60 patients were in the ASA grade I, while 11 patients were in ASA grade II. By occupation, patients were manual laborers (n = 24), retired persons (n = 9), office workers (n = 8), students (n = 7), farmers (n = 6), and field workers (n = 6).

Extent of PRS

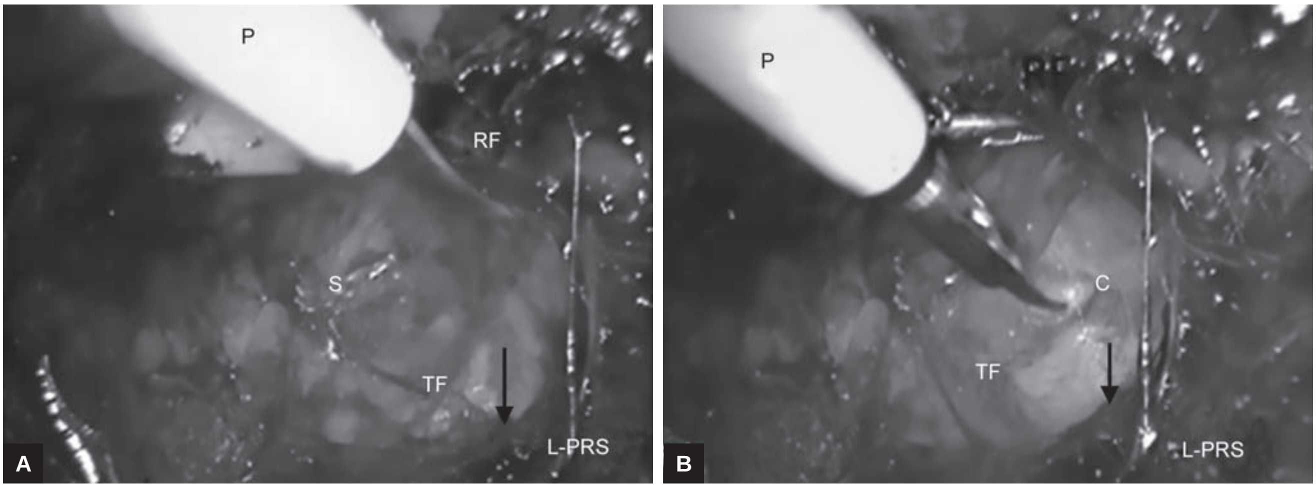
The PRS was found incomplete in 79.4% of cases (Figs 2 to 4) and the PRS was complete in 20.6% of cases (Figs 5 to 8),



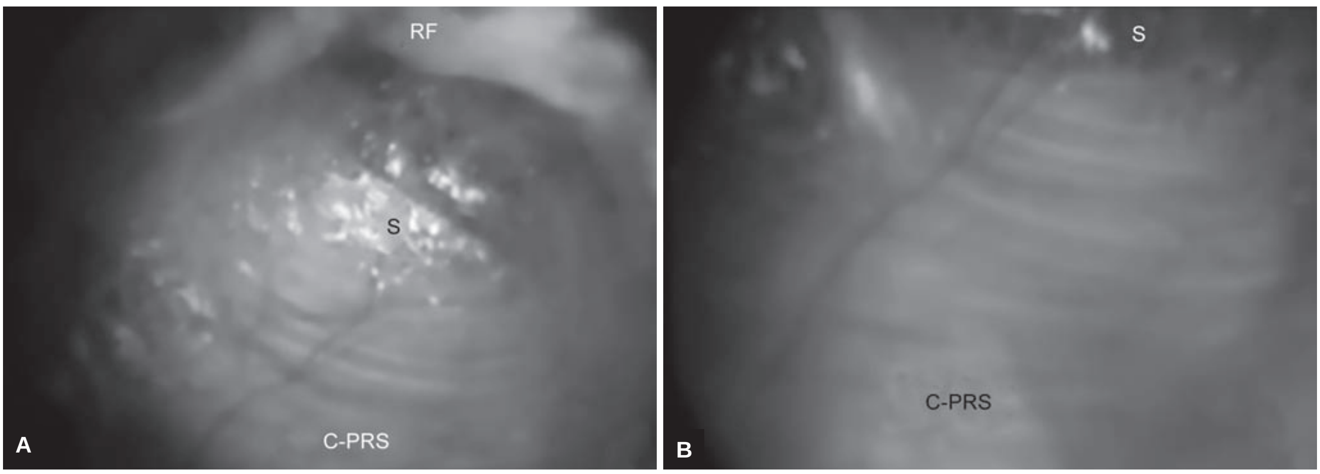
Figs 2A and B: Dissection in posterior rectus canal showing incomplete PRS (whole tendinous): (A) An IC-PRS which is tendinous in nature throughout with formation of a well-defined arcuate line (black arrow); green arrow indicates the gradual opening of the posterior rectus canal with the to-and-fro movement of the telescope; (B) an IC-PRS which is tendinous in nature throughout with formation of a well-defined arcuate line (black arrow) in another patient; S: Sign of lighthouse seen in the depth; RA: Rectus abdominis muscle; RF: Posterior epimysium (rectusial fascia) of rectus abdominis muscle



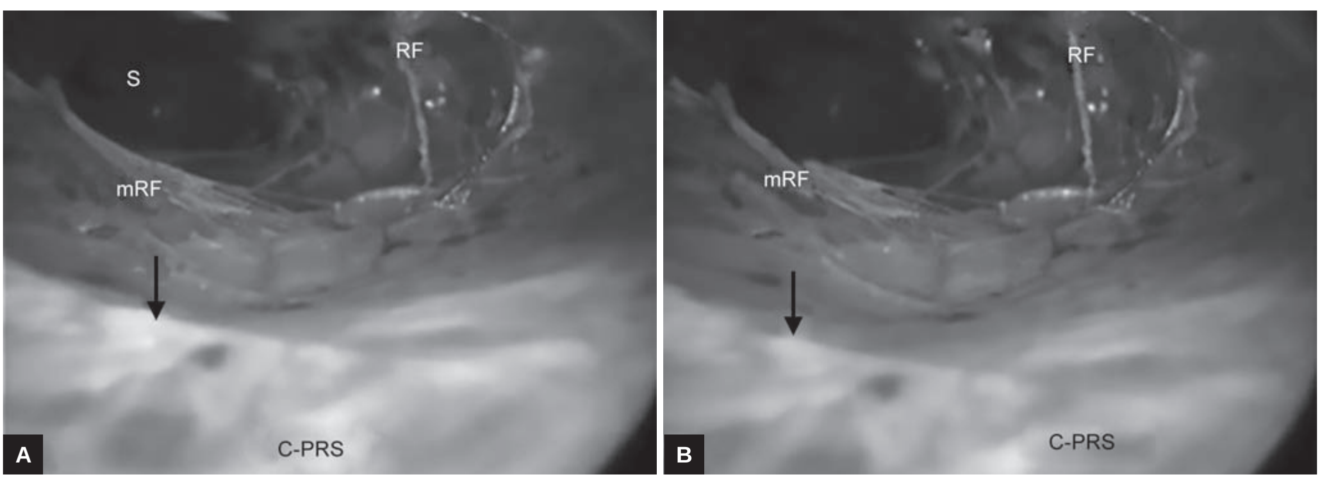
Figs 3A and B: Dissection in posterior rectus canal showing incomplete PRS (partly thinned out): (A) an IC-PRS, which is tendinous in its upper part; (B) an IC-PRS, which is gradually thinned out in its lower part with formation of a rather ill-defined arcuate line (arrow) in the same patient; TF: Transversalis fascia; RF: Posterior epimysium (rectusial fascia) of rectus abdominis muscle



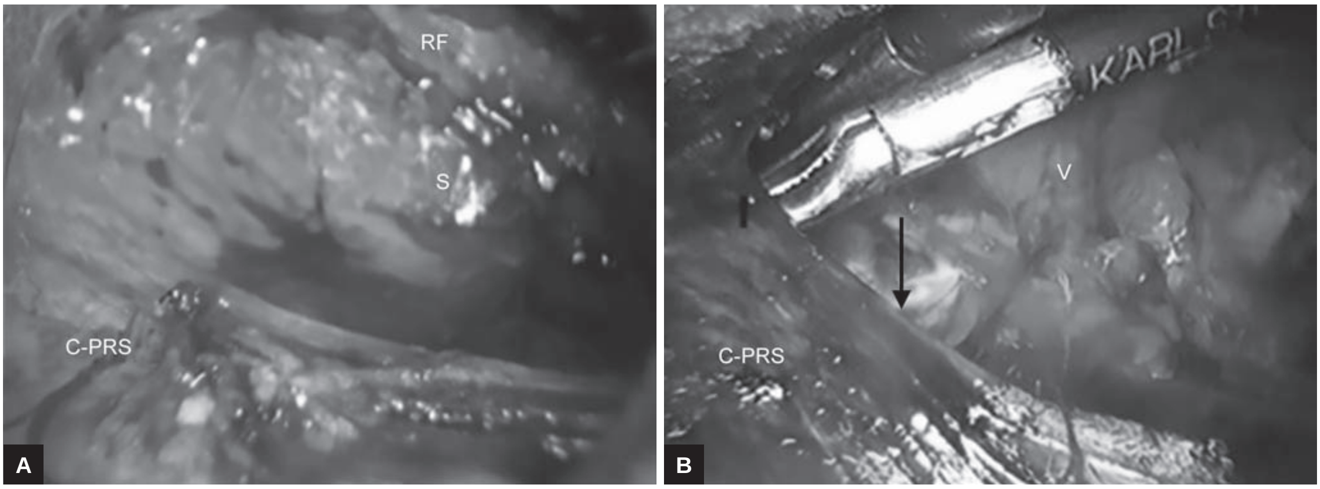
Figs 4A and B: Dissection in posterior rectus canal showing incomplete PRS (long tendinous): (A) long tendinous incomplete PRS (L-PRS) extending up to just short of pubic bone and pectineal ligament; (B) more clearly defined low arcuate line (arrow), which is seen situated just above the pectineal ligament covered by corona mortis (c) after the transversalis fascia is dissected off; TF: Transversalis fascia; RF: Posterior epimysium (rectusial fascia) of rectus abdominis muscle; S: Sign of lighthouse; P: Plastic working port



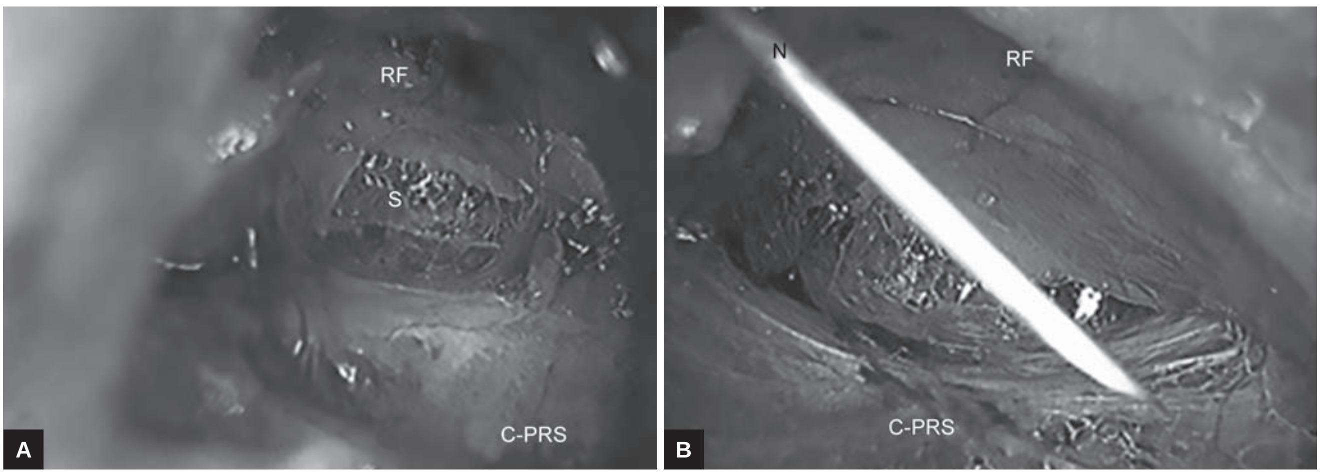
Figs 5A and B: Dissection in posterior rectus canal showing complete PRS (whole tendinous): (A) A C-PRS, which is tendinous in nature throughout and extending up to the pubic symphysis without formation of an arcuate line; S: Sign of lighthouse seen in the depth; RF: Posterior epimysium (rectusial fascia) of rectus abdominis muscle



Figs 6A and B: Dissection in posterior rectus canal showing complete PRS (partly thinned out): (A and B) a C-PRS which was tendinous in its upper part with formation of a partial arcuate line (arrow), but which was continued down in a thinned-out membranous fashion in its lower part (extending up to the pubic symphysis found on further dissection); S: Sign of lighthouse seen in the depth; RF: Posterior epimysium (rectusial fascia) of rectus abdominis muscle; mRF: Medial part of the rectusial fascia, which was inadvertently taken down along with the PRS during the telescopic dissection



Figs 7A and B: Dissection in posterior rectus canal showing complete PRS (whole thinned out): (A) A C-PRS, which is thinned-out membranous in nature throughout and extending up to the pubic symphysis without formation of an arcuate line; (B) thinned-out membranous C-PRS across which blades of the instruments are visible after the C-PRS was opened up about half-way with creation of an artificial arcuate line (arrow) in the same patient; S: Sign of lighthouse seen in the depth; RF: Posterior epimysium (rectusial fascia) of rectus abdominis muscle; V: Deep inferior epigastric vessels visible across the thin C-PRS and transversalis fascia



Figs 8A and B: Dissection in posterior rectus canal showing complete PRS (grossly attenuated): (A) A C-PRS, which is grossly attenuated with loosely arranged fibers and extending up to the pubic symphysis without formation of an arcuate line; (B) grossly attenuated C-PRS with formation of tendinous band in-between in the same patient; S: Sign of lighthouse seen in the depth; RF: Posterior epimysium (rectusial fascia) of rectus abdominis muscle; N: Needle confirmation before placement of working port

and mean age and BMI of the patients were not significantly different ($p > 0.05$) between the two groups (Tables 1 and 2). In other words, the occurrence of the complete and incomplete PRS was independent of the age or BMI of the patients.

Based on our criteria (*vide supra*), three types of the incomplete PRS (n = 54) were documented in the present study, namely, (1) the normal-length incomplete PRS (NIC) in 60.3%, (2) the long incomplete PRS (LIC) in 14.7% (Fig. 4), and the short incomplete PRS (SIC) in 4.4% (Table 1).

The occurrence of the three subgroups of the incomplete PRS (NIC, LIC, and SIC) did not vary significantly ($p > 0.05$) with respect to the age of the patients (Table 1). However, the BMI of patients with the short incomplete (SIC) PRS was statistically much higher ($p < 0.001$) in comparison with not only the other two subgroups (NIC and LIC) of the incomplete PRS, but also the complete PRS (Table 2). In other words, the overweight/obese patients, albeit limited in number, tend to have the short type of the incomplete PRS.

Morphology of PRS

The present study documented 5 morphology types of the PRS: (1) whole tendinous (WT) in 43 cases (Fig. 5), (2) musculo-tendinous (MT) in 1 case, (3) partly tendinous (upper part tendinous and then gradually attenuated below) (PT) in 16 cases (Fig. 6), (4) thinned-out membranous/fascia-like throughout (TO) in 4 cases (Fig. 7), and (5) grossly attenuated lattice like with/without tendinous bands (GA) in 4 cases (Fig. 8) (Tables 3 to 5).

There was no significant difference ($p > 0.05$) in the mean age and BMI among the patients with the four types

Table 1: Age distribution of patients with different types of PRS according to its extent

PRS type	Hernias n	Hernias %	Patients n	Patients %	Age, mean ± SD (range) Years	CID	t- or f-value	Sig. (2-tailed)	p-value
IC-PRS	54	79.4	47	78.3	51.64 ± 16.42 (18–80)	−3.508 to 17.868	t = 1.3447	0.184	>0.05
C-PRS	14	20.6	13	21.7	44.46 ± 19.23 (19–72)				
Total	68	100	60	100					
IC-PRS types									
NIC	41	75.9	35	74.5	50.51 ± 17.86 (18–80)	–	$F_{2\ 44}$ = 0.318	0.729	>0.05
LIC	10	18.5	9	19.1	55.22 ± 11.63 (40–72)				
SIC	3	5.6	3	6.4	54 ± 12.17 (40–62)				
C *vs* NIC *vs* LIC *vs* SIC	–	–	–	–	–	–	$F_{3\ 56}$ = 0.785	0.507	>0.05
Total	54	100	47	100					

CID: 95% confidence interval of difference; t: independent-sample t-test value; F: one-way analysis of variance value; p > 0.05: insignificant

Table 2: The BMI distribution of patients with different types of PRS according to its extent

PRS type	Hernia n	Hernia %	Patient n	Patient %	BMI, mean ± SD (range) kg/m^2 Years	CID	t- or f-value	Sig. (2-tailed)	p-value
IC-PRS	54	79.4	47	78.3	22.54 ± 2.22 (19.3–31.2)	−1.471 to 1.0914	t = 0.2968	0.7677	>0.05
C-PRS	14	20.6	13	21.7	22.73 ± 1.13 (20.9–24.3)				
Total	68	100	60	100					
IC-PRS types									
NIC	41	75.9	35	58.3	22.20 ± 1.65 (19.3–27.5)	–	$F_{2\ 44}$ = 23.303	0	<0.001
LIC	10	18.5	9	15.0	21.81 ± 0.71 (20.9–23.2)				
SIC	3	5.6	3	5.0	28.63 ± 2.38 (26.5–31.2)				
C *vs* NIC *vs* LIC *vs* SIC	–	–	–	–	–	–	$F_{3\ 56}$ = 17.314	0	<0.001
Total	54	100	47	100					

CID: 95% confidence interval of difference; t: independent-sample t-test value; F: one-way analysis of analysis value; p > 0.05: insignificant

Table 3: Age distribution of the patients with various morphological types of PRS

PRS type	Hernias n	Hernias %	Patients n	Patients %	Age, mean ± SD (range) kg/m^2 Years	f-value	Sig. (2-tailed)	p-value
WT + MT	44	64.71	39	65.00	44.18 ± 17.51 (18–80)	$F_{3\ 56}$ = 0.895	0.449	>0.05
PT	16	23.53	14	23.33	52.64 ± 15.66 (21–80)			
TO	4	5.88	4	6.67	51.00 ± 26.41 (20–80)			
GA	4	5.88	3	5.00	48.67 ± 12.20 (35–58)			
Total	68	100	60	100				

WT also includes 1 case of MT PRS to avoid invalidation of statistical analysis due to n less than 2 in any group; F: one-way analysis of variance value; Sig.: Significance value; p > 0.05: not significant

Table 4: The BMI distribution of the patients with different types of PRS according to its morphology

PRS type	Hernias n	Hernias %	Patients n	Patients %	BMI, mean ± SD (Range) kg/m^2 Years	f-value	Sig. (2-tailed)	p-value
WT + MT	44	64.71	39	65.00	22.85 ± 2.34 (19.3–31.2)	$F_{3\ 56}$ = 0.716	0.547	>0.05
PT	16	23.53	14	23.33	21.96 ± 1.22 (19.5–23.8)			
TO	4	5.88	4	6.67	22.15 ± 1.39 (20.9–23.5)			
GA	4	5.88	3	5.00	22.47 ± 0.84 (21.5–23.00)			
Total	68	100	60	100				

WT also includes 1 case of MT PRS to avoid invalidation of statistical analysis due to n less than 2 in any group; F: one-way analysis of analysis value; Sig.: Significance value; p > 0.05: not significant

(WT + MT, PT, TO, and GA) of the PRS morphology (Tables 3 and 4). In other words, the PRS morphology was independent of the changes in the age or BMI of the patients.

The normal-length whole-tendinous (NWT) incomplete PRS is traditionally known as the classical type as compared with the other types, which are called the variant types (Tables 5 and 6). The classical morphology (NWT) of the PRS was seen in 31 out of 68 cases, while variant PRS was observed in 37 instances. The classical and variant groups of the PRS were not significantly

Table 5: Age distribution of various subtypes of PRS according to the combined features of its morphology and extent

	Hernias		Patients		Age, mean ± SD (range)				
PRS type	*n*	*%*	*n*	*%*	*Years*	*CID*	*t- or f-value*	*Sig. (2-tailed)*	*p-value*
NWT	31	45.6	27	45.00	49.67 ± 17.48 (18–80)	−9.7357 to 8.2357	t = 0.1671	0.8679	>0.05
V-PRS	37	54.4	33	55.00	50.42 ± 17.15 (19–80)				
Total	68	100	60	100					
V-PRS type									
SWT	3	8.1	3	9.1	54 ± 12.17 (40–62)				
LWT	3	8.1	2	6.1	53.5 ± 4.95 (50–57)				
CWT	6	16.2	6	18.2	48.17 ± 21.74 (20–72)				
CMT	1	2.7	1	3.0	19.00 ± 0.00 (–)				
NPT	8	21.6	7	21.2	49.57 ± 18.28 (21–80)				
LPT	7	18.9	7	21.2	55.71 ± 13.23 (40–72)	–	$F_{10\ 26}$ = 1.088	0.407	>0.05
CPT	1	2.7	OS	–	35.00 ± 0.00 (–)				
NTO	1	2.7	1	3.0	80.00 ± 0.00 (–)				
CTO	3	8.1	3	9.1	41.33 ± 22.03 (20–64)				
NGA	1	2.7	OS	–	72.00 ± 0.00 (–)				
CGA	3	8.1	3	9.1	48.67 ± 12.20 (35–58)				
Total	37	100	33	100					

OS: Opposite side; t: independent-sample t-test value; F: one-way analysis of analysis value; Sig.: Significance value; p > 0.05: not significant

Table 6: The BMI distribution of patients with various subtypes of PRS according to the combined features of its morphology and extent

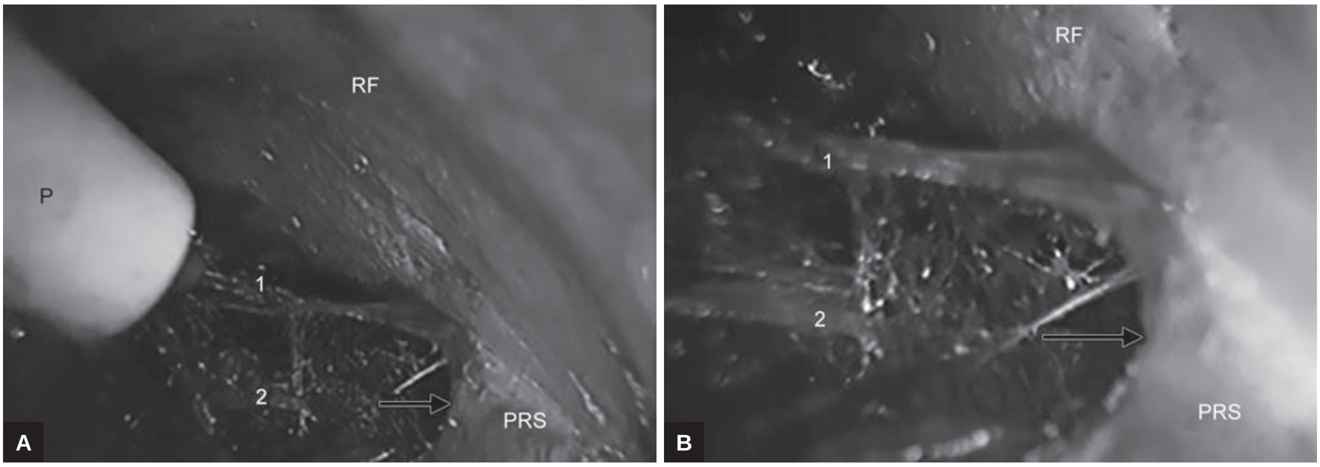
	Hernias		Patients		BMI, mean ± SD (range)				
PRS type	*n*	*%*	*n*	*%*	*years*	*CID*	*t- or f-value*	*Sig. (2-tailed)*	*p-value*
NWT	31	45.6	27	45.00	22.29 ± 1.70 (19.3–27.5)	−1.5867 to 0.5267	t = 1.004	0.3196	>0.05
V-PRS	37	54.4	33	55.00	22.82 ± 2.27 (19.5–31.2)				
Total	68		60						
SWT	3	8.1	3	9.1	28.63 ± 2.38 (26.5–31.2)				
NPT	8	21.6	7	21.2	22.03 ± 1.60 (19.5–23.8)				
LPT	7	18.9	7	21.2	21.89 ± 0.80 (20.9–23.2)				
LWT	3	8.1	2	6.1	21.55 ± 0.07 (21.5–21.6)				
NTO	1	2.7	1	3.0	21.00 ± 0.00 (–)	–	$F_{10\ 26}$ = 7.616	0	<0.001
CTO	3	8.1	3	9.1	22.53 ± 1.42 (20.9–23.5)				
CGA	3	8.1	3	9.1	22.47 ± 0.84 (21.5–23.0)				
CMT	1	2.7	1	3.0	23.90 ± 0.00 (–)				
CWT	6	16.2	6	18.2	22.77 ± 1.29 (21.1–24.3)				
CPT	1	2.7	OS	–	23.00 ± 0.00 (–)				
NGA	1	2.7	OS	–	21.50 ± 0.00 (–)				
Total	37	100	33	100					

OS: Opposite side; CID: Confidence interval of difference; t: independent-sample t-test value; F: one-way analysis of analysis value; Sig.: Significance value; p > 0.05: not significant

different ($p > 0.05$) with respect to the mean age and BMI of the patients (Tables 5 and 6). In other words, the PRS morphology was not affected by the variations in the age or BMI of the individuals.

The five morphological groups (WT, MT, PT, TO, and GA) of the variant PRS were categorized into further 11 subgroups according to the extent of the PRS (Tables 5 and 6). The different morphological subtypes of the variant PRS (n = 37) included short whole tendinous (SWT) in 3 cases, LWT in 3 (Fig. 8), complete-length whole tendinous (CWT) in 6, NPT in 8, LPT in 7, NTO in 1, complete-length thinned out (CTO) in 3, normal-length grossly attenuated (NGA) in 1, complete-length grossly attenuated (CGA) in 3, CPT in 1, and complete-length musculo-tendinous (CMT) in 1 case of a young student accustomed to regular gymnasium exercises (Tables 5 and 6).

The 11 subgroups of the variant PRS morphology (SWT, LWT, NPT, LPT, NTO, NGA, CWT, CTO, CGA, CPT, and CMT) were not different significantly ($p > 0.05$) with respect to the age of the patients (Table 5). However, they were different very significantly ($p < 0.001$) with respect to the BMI of the patients. The patients' mean BMI (28.63 ± 2.38 kg/m^2) in the short whole (SWT) variant subgroup was much higher as compared with the patients' mean BMI (21.00 ± 0.00 kg/m^2 to 23.90 ± 0.00 kg/m^2) in the other



Figs 9A and B: Dissection in posterior rectus canal showing double-layered complete PRS (double PRS): (A and B) Double-layered PRS (D-PRS) is seen clearly after creation of an artificial arcuate line (arrow) about half-way surgically in a patient with complete PRS; 1: First layer of PRS; 2: Second layer of PRS

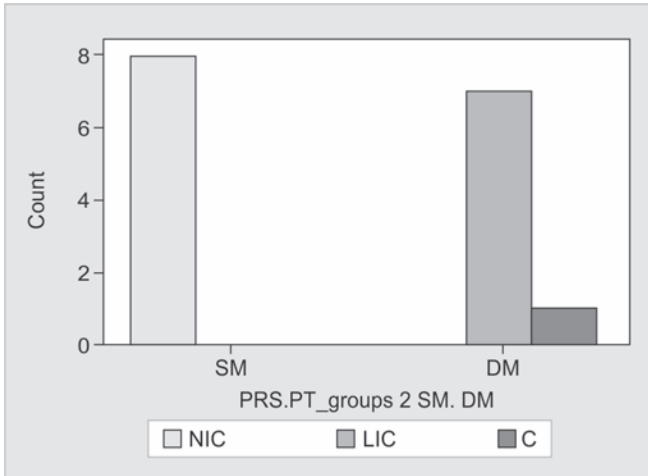
10 subgroups of the variant PRS morphology and the difference was highly significant statistically ($p < 0.001$) (Table 6). In other words, the PRS tends to be well-defined and shorter in the overweight/obese persons.

Layers of PRS

In all patients with the 4 categories of WT, MT, TO, and GA, the PRS consisted of a single layer (SM) only. However, the PRS in the PT category was found as a double membranous layer (DM) in 8 out of 16 cases (Fig. 9) and as a single membranous layer (SM) in the remaining eight patients, i.e., in the PT category, the PRS was found consisting of single layer (SM) in only 50% of the cases but consisted of double layer (DM) in the remaining 50% of PT-PRS group, especially in the patients with long PRS (n = 7) and complete PRS (n = 1) (Fig. 9).

There was no significant difference in the mean age, BMI, and ASA grade of the patients between the SM and DM groups. However, there was a highly significant correlation between the PRS types and the PRS extent ($p < 0.001$); the likelihood ratio was very highly significant ($p < 0.001$), and the linear-by-linear association was also highly significant ($p < 0.01$) (Graph 1).

It is of interest to acknowledge that during the initial telescopic dissection in the posterior rectus canal, the laparoscope used to enter the cave of Retzius readily and smoothly in an avascular fashion in all our patients, suggesting that the posterior rectus space/canal directly communicated with the retropubic space of Retzius. However, the pubic bones were not seen bare due to the regular presence of a fascia in direct continuity of the rectusial epimysium/fascia (Figs 2 to 8) as reported earlier.[10] In this situation, the retropubic space was found bounded posteriorly by the transversalis fascia alone or by both the complete PRS (if present, *vide supra*) and the transversalis fascia.



Graph 1: Correlation between the PRS-PT types and the PRS extent. SM: Single membranous; DM: Double membranous; NIC: Classical incomplete; LIC: Long incomplete; C: Complete; Pearson CHISQ CC: R = 16.000, df 2, Sig. 0.000, $p < 0.001$; Likelihood Ratio: R = 22.181, df 2, Sig. 0.000, $p < 0.001$; Linear-by-Linear Association: R = 9.615, df 2, Sig. 0.002, $p < 0.01$

Bilateral Anatomy of PRS

In patients undergoing the bilateral TEPP hernioplasty (n = 8), the PRS on the left side was long incomplete (LIC) in 7 cases and complete in 1 case. However, the PRS extent on the right side was found complete in 3 cases, and incomplete in 5 cases; and the incomplete PRS was of the classical extent (3–6 cm) in 3 cases (NIC) and long (>6 cm) in 2 cases (LIC) (Table 7). Ratio of incomplete and complete PRS was 1.6:1 and 7:1 on the right and left sides respectively, i.e., complete PRS tend to occur more commonly on the right side. The types of the incomplete PRS (NIC *vs* LIC) were also found variable on the two sides of the body (Table 7). The PRS extent was a mirror image in only 4 out of 8 cases (bilateral classical incomplete in 3 cases and bilateral complete in 1 case), while it was not mirror image in the remaining 4 cases (complete *vs*

Table 7: Anatomy of PRS in the consecutive bilateral inguinal hernias (n = 8) in patients who underwent TEPP hernioplasty

PRS extent		*PRS extent subtypes*		*PRS morphology*		*PRS extent and morphology*	
Right side	*Left side*	*Right side*	*Left side*	*Right side*	*Left side*	*Right side*	*Left side*
IC	IC	NIC	NIC	PT	PT	NPT	NPT
IC	1C	NIC	NIC	WT	WT	NWT	NWT
C	C	C	C	GA	PT*	CGA	CPT*
C	IC*	C	NIC*	WT	WT	CWT	NWT*
C	IC*	C	NIC*	WT	GA*	CWT	NGA*
IC	IC*	LIC	NIC*	WT	WT	LWT	NWT*
IC	IC	NIC	NIC	PT	WT*	NPT	NWT*
IC	IC	LIC	NIC*	WT	WT	LWT	NWT*

*Different PRS type on contralateral side

Table 8: Age of patients with mirror and nonmirror anatomy of PRS on two sides of the body in patients with bilateral hernias

Anatomy	*Type*	*n*	*%*	*Age, mean ± SD (range) years*	*CID*	*t-value*	*Sig. (2-tailed)*	*p-value*
PRS extent	Mirror	4	50	47.5 ± 10.40 (35–60)	−24.925 to 7.9253	1.2663	0.2524	>0.05
	Nonmirror	4	50	56.00 ± 8.49 (45–65)				
PRS morphology	Mirror	5	62.5	56.00 ± 8.49 (45–65)	−22.754 to 23.4139	0.0350	0.9732	>0.05
	Nonmirror	3	37.5	55.67 ± 18.88 (35–72)				
PRS extent and morphology	Mirror	7	87.5	53.57 ± 10.83 (35–65)	NA	NA	NA	NA
	Nonmirror	1	12.5	72				

NA: t-test not applicable due to n<2 in one group; CID: Confidence interval of difference; t: independent-sample t-test value; Sig.: Significance value; p>0.05: not significant

Table 9: The BMI of patients with mirror and nonmirror anatomy of PRS on two sides of the body in patients with bilateral hernias

Anatomy	*Type*	*n*	*%*	*BMI, mean ± SD (range) kg/m²*	*CID*	*t- value*	*Sig. (2-tailed)*	*p-value*
PRS extent	Mirror	4	50	21.38 ± 0.80 (20.5–22.4)	−3.285 to 1.4453	0.9517	0.3780	>0.05
	Nonmirror	4	50	22.30 ± 1.76 (202–24.4)				
PRS morphology	Mirror	5	62.5	21.88 ± 1.74 (20.2–24.4)	−2.550 to 2.7701	0.1012	0.9227	>0.05
	Nonmirror	3	37.5	21.77 ± 0.77 (21.1–22.4)				
PRS extent and morphology	Mirror	7	87.5	21.77 ± 0.65 (21.1–22.4)	NA	NA	NA	NA
	Nonmirror	1	12.5	21.84				

NA: t-test not applicable due to n<2 in one group; CID: Confidence interval of difference; t: independent-sample t-test value; Sig.: Significance value; p>0.05: not significant

classical incomplete (NIC) in 2 cases, and long incomplete (LIC) *vs* classical incomplete (NIC) in 2 cases) (Table 7).

In only 5 out of 8 cases, the PRS morphology was mirror image on the two sides of the body (WT both sides in 4 cases, and PT in 1 case), and in the remaining 3 cases, the PRS morphology was not mirror image (GA *vs* PA in 1 case; tendinous *vs* GA in 1 case; and PA *vs* WT in 1 case) (Table 7).

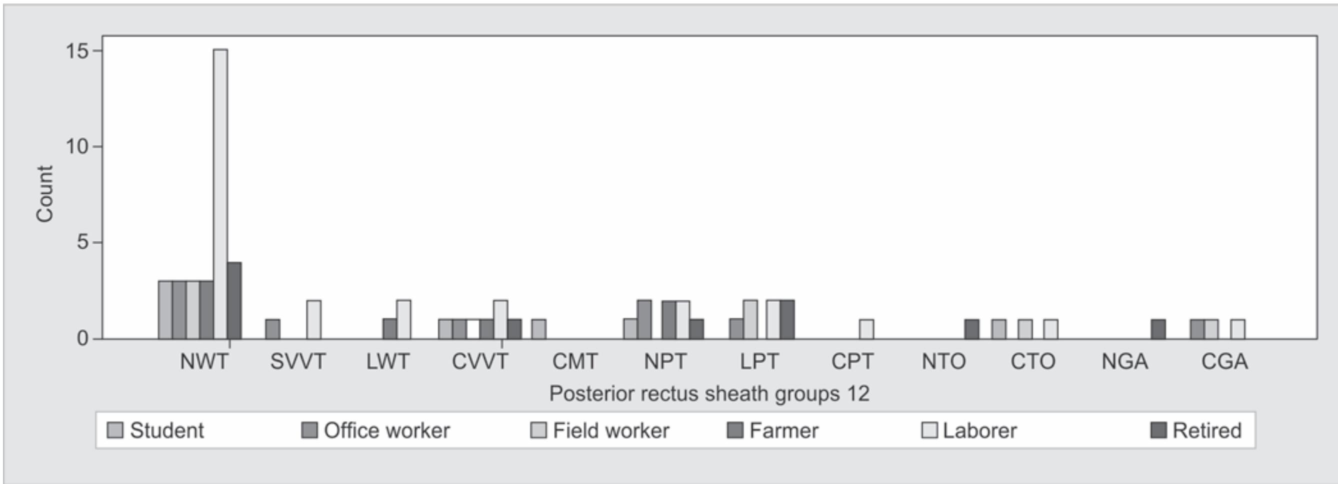
In terms of both the PRS extent and morphology, the mean age and BMI of patients did not differ significantly ($p > 0.05$) between the two subgroups of the mirror and nonmirror anatomy (Tables 8 and 9). In other words, the PRS anatomy did not tend to differ on the two sides of the body with respect to the age or BMI of the individuals.

In patients undergoing bilateral TEPP hernioplasty, asymmetry of both the PRS extent and morphology was seen in only one case of a 72-year-old retired person with BMI of 21.8 kg/m^2. The patient with twin asymmetry of PRS extent and morphology was much older than the age (mean age 53.57 ± SD 10.83; 35–65 years), although his BMI was comparable with mean BMI (21.77 ± SD 0.65; 21.1–22.4 kg/m^2) (Tables 8 and 9).

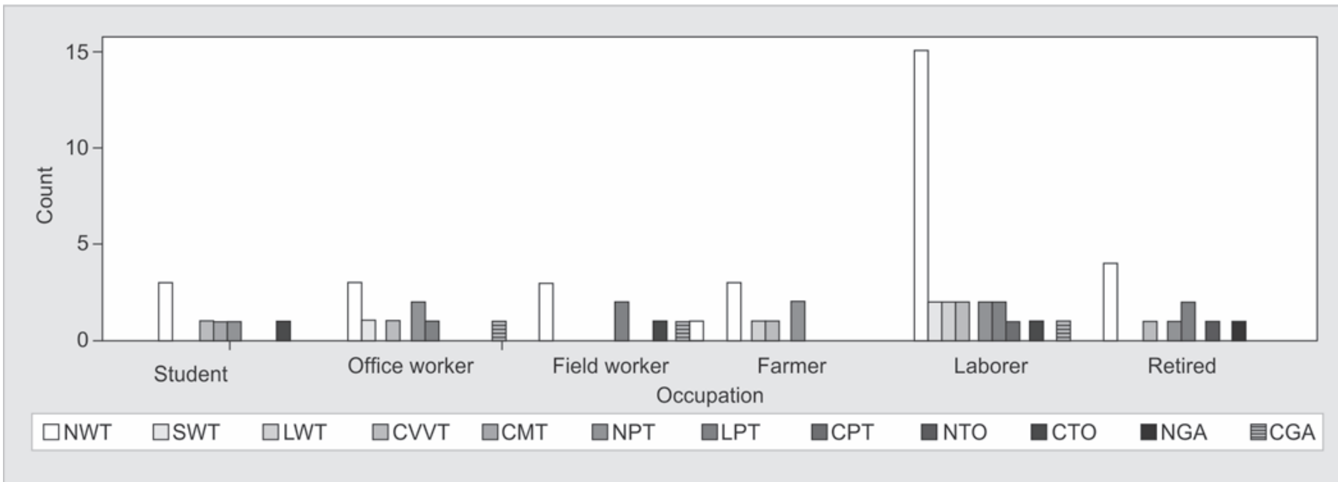
Relation of PRS Anatomy with Profession

Distribution of various types of the PRS among the different kinds of professional workers is shown in the Graph 2. Pearson Chi-squared analysis did not reveal any significant correlation between the classical/variant PRS and the nature of work (R = 3.466, df 5, Sig. 0.629, $p > 0.05$). Further, Pearson chi-squared analysis also did not reveal any significant correlation between the 12 PRS subtypes (the classical 1, and the variant 11) and the nature of patients' work (R = 46.685, df 55, Sig. 0.780, $p > 0.05$) (Graph 3).

Moreover, the likelihood ratio and linear-by-linear association were also found statistically insignificant among the 12 subtypes of the PRS with respect to the patients' occupation (likelihood ratio: R = 42.283, df 55, Sig. 0.895, $p > 0.05$; linear-by-linear association: R = 0.330, df 1, Sig. 0.566, $p > 0.05$) (Graph 3).



Graph 2: Distribution of the classical and 11 variant subtypes of PRS-morphology. Observed during TEPP hernioplasty (n = 68) in the different workers (n = 60); NWT: Normal-length whole-tendinous; SWT: Short whole-tendinous; LWT: Long whole-tendinous; CWT: Complete whole-tendinous; CMT: Complete musculo-tendinous; NPT: Normal-length partly tendinous; LPT: Long partly-tendinous; CPT: Complete partly-tendinous; NTO: Normal-length thinned-out; CTO: Complete thinned-out; NGA: Normal-length grossly attenuated; CGA: Complete grossly attenuated;



Graph 3: Correlation between PRS types and occupation; NWT: Normal-length whole-tendinous; SWT: Short whole-tendinous; LWT: Long whole-tendinous; CWT: Complete whole-tendinous; CMT: Complete musculo-tendinous; NPT: Normal-length partly tendinous; LPT: Long partly-tendinous; CPT: Complete partly-tendinous; NTO: Normal-length thinned-out; CTO: Complete thinned-out; NGA: Normal-length grossly attenuated; CGA: Complete grossly attenuated

Clinical Outcome

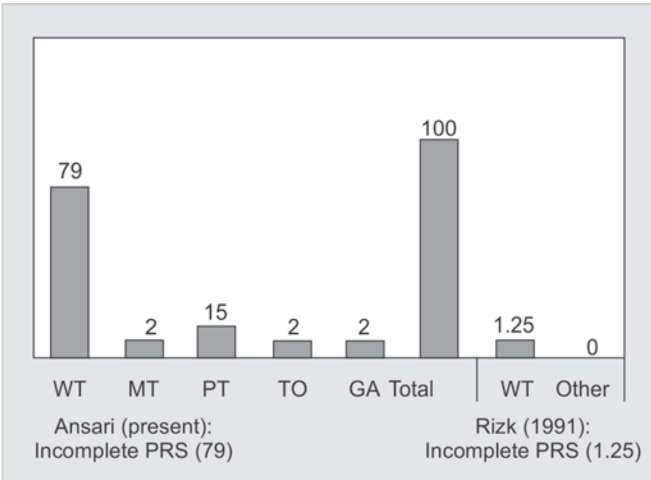
All 60 patients successfully underwent 68 TEPP hernioplasties (unilateral TEPP 54; bilateral TEPP 8). There was no conversion due to the difficult dissection secondary to the so-called adhesions or inflammatory reactions. There was no recurrence of inguinal hernia after TEPP hernioplasty in the mean follow-up period of 33 ± 17 months (5–61 months).

DISCUSSION

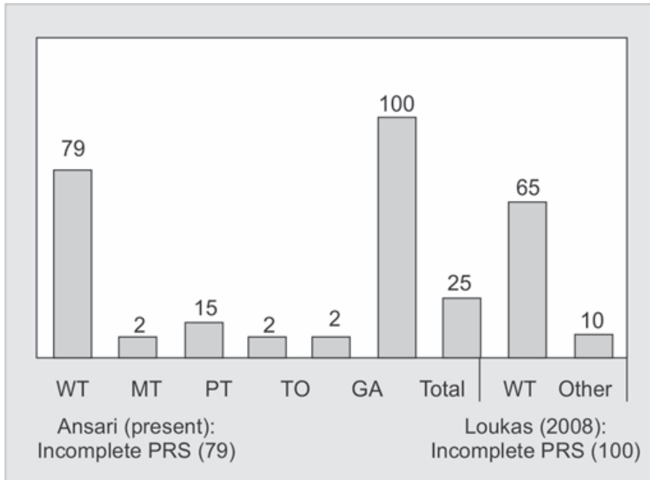
Wide anatomic variations observed in the present study are in tune with the several previous reports of gross cadaveric dissections.[3-6,15-18] No report on the live surgical anatomy of the rectus sheath was available in the English literature to the best of the author's knowledge. It is interesting to recall that in 1960, Anson et al[17] in their classic publication on 500 groin dissections documented 43 variations in defects and musculoaponeurotic insertions of the internal oblique and transversus abdominis in the inguinal region.

The PRS in the present study was found neither closely applied nor attached/adherent to the undersurface of the rectus abdominis muscle. Our observations were in full agreement with those of other authors.[19-21] This anatomic feature really facilitates the technical feasibility of not only the rectus sheath technique of the TEPP hernioplasty, but also the smooth avascular telescopic dissection, obviating the need of the specialized dissecting balloon.

Classical teaching describes the PRS as incomplete with formation of the Arcuate line of Douglas at its lower end.[19-21] However, this anatomic disposition is often lacking,[17,18] and wide variations in the rectus sheath formation have been reported from time-to-time.[2] Twelve subtypes of the PRS were documented in various proportions in the



Graph 4: Comparative morphology of the incomplete PRS: Ansari *vs* Rizk: WT: Whole-tendinous; MT: Musculo-tendinous; PT: Partly tendinous (upper part tendinous and lower part fascia-like thinned-out); TO: Thinned out throughout; GA: Grossly attenuated with tendinous bands (numbers indicate percentage)



Graph 5: Comparative morphology of incomplete PRS: Ansari *vs* Loukas; WT: Whole-tendinous; MT: Musculo-tendinous; PT: Partly tendinous (upper part tendinous and lower part fascia-like thinned-out; TO: Thinned-out throughout; GA: Grossly attenuated with tendinous bands (numbers indicate percentage)

present study (NWT, SWT, LWT, CWT, NPT, LPT, CPT, NTO, CTO, NGA, CGA, and CMT) based on its twin anatomic features of morphology and extent (Tables 5 and 6, *vide supra*).

Way back in 1940, McVay and Anson[16] reported the occurrence of the classical PRS, i.e., incomplete tendinous PRS with a single sharp well-defined arcuate line (SWD-AL) in only 2 out of their 56 specimens (3.6%). Rizk[4] also observed the classical PRS with SWD-AL in only 1.25% in a study of 80 cadaver sides (Graph 4). Arregui[1] described that the PRS is of variable thickness and almost always continues below the arcuate line, if one is present, albeit in an attenuated form up to the symphysis pubis.

The incomplete PRS was recently documented in only 80% of human cadavers by Mwachaka et al.[6] This was confirmed by the present observation of 79% incidence of the incomplete PRS in patients undergoing TEPP hernioplasty. These observations are in sharp contrast to the other previous cadaveric studies.

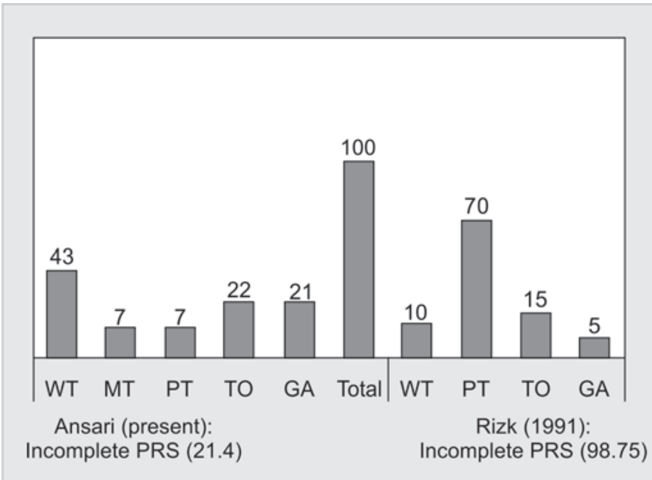
Loukas et al[12] observed three distinct types of the incomplete PRS in a study of 100 cadavers, viz., (1) gradual thinning with absent arcuate line (65%), (2) tendinous with well-defined arcuate line (25%), and (3) attenuated with thickened tendinous bands and double arcuate lines (10%). The present study showed a reverse phenomenon in the PRS anatomy, i.e., the incomplete PRS was tendinous in a high percentage of 68% and variably attenuated in the remaining 32% of the cases (Graph 5).

Anson et al[17] documented that "occasionally … the medial margin of the Linea Semicircularis is attached to the pubic crest, not to the linea alba", i.e., the PRS was often found complete extending up to the pubic symphysis in their study. McVay[18] supported Anson's observations. In 2001, Spitz and Arregui[22] has pointed out that "Much of the confusion regarding the preperitoneal fascia, the posterior rectus fascia, and the transversalis fascia may stem from the erroneous anatomical preoccupation that all fibres of the rectus sheath pass anterior to the rectus muscle below the arcuate line."

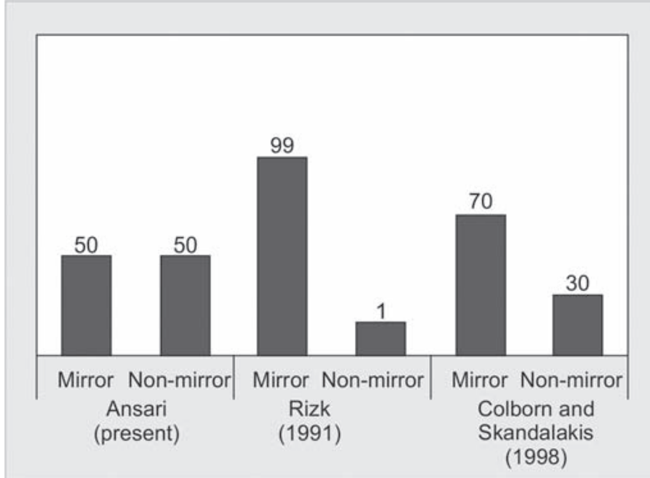
Rizk[4] reported presence of the complete PRS in 98.75% of the human cadavers (80 sides), and his observations were supported by Arregui.[1] However, the present study documented the complete PRS in only 21% during the laparoscopic TEPP hernia repair, which is in full agreement with its incidence of 20% in the cadavers studied by Mwachaka et al.[6]

In terms of the morphology of the complete PRS, Arregui[1] observed in 1997 that the PRS was generally complete, being partly tendinous above the arcuate line and partly attenuated fascia-like below the arcuate line. Present study documented five morphology types of complete PRS, and this was in tune with four types of morphology of the complete PRS reported by Rizk[4] (Graph 6). However, the complete PRS was whole-tendinous/musculo-tendinous PRS in only 50% of our cases and variably attenuated PRS in the remaining 50%, while Rizk[4] documented the normal thickness (tendinous) of the complete PRS and its variable attenuation in 90 and 10% of cases respectively (Graph 6).

Our observation of the musculo-aponeurotic complete PRS in only 1.5% of hernia repair is at variance with its much higher incidence of 11.5 and 57.5% in cadaveric studies reported by Mwachaka et al[5] and Monkhouse and Khalique[3] respectively. The musculo-tendinous PRS in the present study was seen in a young student accustomed to regular gymnasium exercises. This is easily understandable, but may not be necessarily true. It is unfortunate that other two investigators reporting its higher incidence did not elaborate any correlation between the PRS nature and the profession of the individuals.



Graph 6: Comparative morphology of the complete PRS: Ansari *vs* Rizk; WT: Whole-tendinous; MT: Musculo-tendinous; PT: Partly tendinous (upper part tendinous and lower part fascia-like thinned-out); TO: Thinned out throughout; GA: Grossly attenuated with tendinous bands; (Numbers indicate percentage)



Graph 7: Comparative distribution of mirror and nonmirror anatomy of the PRS on the two sides of the body (Numbers indicate percentage)

It is being increasingly recognized that the termination of the PRS is usually gradual, but may occasionally be abrupt with formation of a well-defined arcuate line.[1,11,22] Cunningham et al[23] reported a gradual thinning of the PRS with absence of the arcuate line in 10% of the human cadavers (n = 19). The present study documented this phenomenon of attenuation in only 1.5% of the hernia repairs (n = 68) or 7% of all complete PRS cases (Graph 6).

In a classic first laparoscopic study, Arregui[1] observed in 1997 that "In many dissections, we have also noticed that this posterior fascial sheet is made up of more than one layer further supporting the idea that this is a continuation of the attenuated PRS…". Later in 2001, Spitz and Arregui[22] observed that "with the improved optics and magnification afforded by the laparoscope, we have seen, as mentioned earlier, that the PRS continues in a variably attenuated fashion below the arcuate line. We are also able to see that the PRS is comprised of more than one layer below the arcuate line." Their observations supported the findings of Anson et al.[17] In the present study, a double-layered PRS was seen in 50% of the PT category (n = 16) of the PRS only, resulting in its overall incidence of 11.8%.

Colborn and Skandalakis[24] reported nonmirror anatomy of the PRS in about 30% of the cadaveric dissections. Present study documented nonmirror morphology of the PRS in 37.5% of the hernia repairs, which is in tune with that of the Colborn and Skandalakis[24]; however, the PRS extent in our study was nonmirror in a much higher percentage of 50% (Graph 7). Rizk[4] reported nonmirror anatomy of the PRS in only 2.5% of cadavers, especially in terms of the PRS extent and the PRS morphology was found similar on the two sides of the body even in these cases.

The extent and/or morphology of the PRS did not vary significantly with respect to the age or profession of the patients in the present study. With respect to the BMI of the patients, the PRS extent was found to vary significantly and the short PRS tended to occur mainly in the overweight/obese patients. To the best of our knowledge, there is no clinical report cited in the literature in this regard for our comparative assessment. Therefore, this phenomenon (occurrence of shorter PRS in overweight/obese individuals) needs, in view of the very small number of patients in this group, validation by a larger laparoscopic study.

Recurrence after TEPP hernioplasty for the primary inguinal hernia has come down markedly to 0.1 to 0.5% in recent years.[25,26] However, some recent studies have reported even 0% recurrence rate after primary laparoscopic repair through the TEPP approach.[27-29] Present study also did not record any instance of hernia recurrence in the mean follow-up period of 33 months. Presently zero-recurrence rate is cherished by many TEPP surgeons, especially in surgical forums and live operative workshops. As it is evident also in the present study, identification of the variability of the structures is really important for the success of the seamless laparoscopic hernia repair with better outcomes.[1,30] We agree with Faure et al[25] that "the requirement for a flawless knowledge of preperitoneal anatomy and its variations" is essential for performing the well-organized preperitoneal repair with ease and safety. Moreover, we now believe the prophetic Words of Spitz and Arregui[22] that "As comprehensive knowledge of the preperitoneal fascial anatomy becomes more widespread, there likely will be a broader application of the laparoscopic preperitoneal hernia repair."

The present study has rather two limitations—one, the sample size is rather small, and second, there is absence of female patients in the study, because inguinal hernia is one of the commonest surgical procedures in general surgery and that the inguinal hernia is known to occur in both sexes albeit rarely in females.

CONCLUSION

The PRS varies markedly in its extent and morphology. The present study documented the occurrence of the classically described PRS in only 46% of the laparoscopic TEPP hernia repairs, while in the remaining 54% of the cases, the PRS was found variant in extent and/or morphology. Variant PRS included SWT (4.4%), LWT (4.4%), CWT (8.8%), NPT (11.8%), LPT (10.3%), NTO (1.5%), CTO (4.4%), NGA (1.5%), CGA (4.4%), CPT (1.5%), and CMT (1.5%). Moreover, the PRS anatomy did not have mirror image on the two sides of the body in 75% of the bilateral hernias. Early conversion secondary to unforeseen anatomic variation was seen in 1.6%, but there was no conversion secondary to the so-called difficult dissection. There was no recurrence of hernia.

CLINICAL SIGNIFICANCE

Truly new visions of the structures known for centuries are realized under excellent perspective and magnification of laparoscopy,[7] and therefore, continued research in the laparoscopic live surgical anatomy cannot be overemphasized in the current era of the newer laparoscopic approaches as had been rightly recommended by Arregui[1] and Avisse et al.[7] The requirement for a crisp, precise knowledge of preperitoneal anatomy and the timely identification of its variations for performing the seamless laparoscopic hernia repair with better outcomes cannot be overemphasized,[1,25,30] as is also evident from the present study.

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