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Penile Revascularization in Improving Erectile Function After Radical Prostatectomy: An Alternative Therapeutic Approach for Penile Rehabilitation

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What's known on the subject? and What does the study add?

Erectile dysfunction is a common complication after radical prostatectomy due to neurovascular damage. When oral and intracavernosal treatments are insufficient for penile rehabilitation, penile prosthesis implantation is typically performed. This study demonstrates that penile revascularization surgery can be an effective treatment option for vascular-origin erectile dysfunction following radical prostatectomy, offering a more physiological and less invasive alternative to penile prosthesis implantation. It emphasizes the potential to improve erectile function before resorting to penile prosthesis implantation. Careful patient selection and long-term follow-up are crucial for treatment success.

Abstract

Objective: The aim of this study is to evaluate the therapeutic effects of penile revascularization, applied as a penile rehabilitation method, on erectile function in the treatment of vascular-origin erectile dysfunction that develops after radical prostatectomy.

Materials and Methods: A total of 21 cases who underwent radical prostatectomy due to localized prostate cancer between 2017 and 2024 and were diagnosed with postoperative erectile dysfunction were treated with penile revascularization surgery. All patients had undergone bilateral neurovascular bundle-sparing radical prostatectomy. All patients underwent penile color Doppler ultrasonography, corpus cavernosum electromyography, cavernosometry tests, the International Index of Erectile Function (IIEF) 5-15, and erectile hardness score questionnaires before penile revascularization and at the third, sixth, and twelfth postoperative months,

Results: The average age of the operated patients was found to be 59.05±3.05 years. The preoperative scores of the IIEF-5 and 15 were 8.57±1.16 and 21.33±1.60, respectively. In the postoperative final follow-up, these scores were 14.67±0.69 and 35.43±2.21. On penile color Doppler ultrasonography, the peak systolic velocity, end-diastolic velocity, and resistive index values were 16.68±1.85, 7.23±1.34, and 0.56±0.06, respectively, in the preoperative period. In the postoperative period, these values were 28.79±6.18, 3.76±1.02, and 0.87±0.06, respectively.

Conclusion: Penile revascularization surgery in cases of vascular-origin erectile dysfunction following radical prostatectomy can significantly contribute to the rehabilitation of erectile function by increasing penile blood flow. This procedure should be recommended to patients as an option prior to more invasive interventions, such as penile prosthesis implantation.

Keywords: Radical prostatectomy, erectile dysfunction, penile rehabilitation, penile revascularization

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Introduction

Prostate cancer is one of the most common malignancies in men, and its prevalence has been steadily increasing over time. Radical prostatectomy is a widely used surgical approach for the treatment of localized prostate cancer. Despite advances in the understanding of prostate anatomy and the use of minimally invasive techniques, postoperative erectile dysfunction (ED) remains a significant factor contributing to a decline in patients' quality of life (1). ED observed after radical prostatectomy may result from damage to the neurovascular bundle, mechanical manipulation, thermal injury, ischemic effects, local inflammation, or injury to the accessory pudendal artery (2). Even the use of neurovascular bundle-sparing techniques is insufficient to completely eliminate this complication (3). When the physiology of penile erection is disrupted, penile rehabilitation plays a key role in understanding the mechanisms leading to ED and in supporting the recovery of erectile function. In this context, treatment methods such as phosphodiesterase type 5 inhibitors, vacuum devices, intracavernosal injection therapy, and penile prosthesis implantation are commonly employed during the postoperative period (4). In this study, we evaluated the efficacy and safety of penile revascularization surgery in patients who developed vascular-origin ED after radical prostatectomy, and did not respond to oral or intracavernosal treatments during penile rehabilitation. The aim was to offer a more physiological treatment alternative prior to penile prosthesis implantation, which is considered an irreversible and final option.

Materials and Methods

This retrospectively designed study was conducted at a tertiary healthcare institution and received approval from the Ankara Bilkent City Hospital Ethics Committee (approval number: TABED 1-25-908, date: 12.03.2025). All procedures were carried out in accordance with the principles of the Declaration of Helsinki. The interventional and surgical procedures performed were part of the routine clinical evaluation and treatment processes of patients who had undergone radical prostatectomy and presented with complaints of ED. Although current clinical guidelines do not explicitly recommend penile revascularization for iatrogenic ED following radical prostatectomy, these procedures were performed based on our clinical experience and judgment, with the patients' best interests in mind. A total of 21 patients who underwent penile revascularization surgery for vascular-origin ED diagnosed after radical prostatectomy in our clinic between 2017 and 2023 were included in this study. At baseline, a detailed medical history was obtained for each patient, including age, duration of ED, comorbidities potentially contributing to ED, history of trauma, prior medical or surgical treatments, and lifestyle factors. After physical examination of all patients, the International Index of Erectile Function (IIEF) 5 and 15, and the erectile hardness score (EHS) questionnaires were completed. Penile color Doppler ultrasonography (PCDU), corpus cavernosum electromyography (CC-EMG), and cavernosometry tests were performed for all patients during the preoperative period. Total testosterone levels were measured in all patients. Phosphodiesterase type 5 inhibitors were routinely administered for 3 months before surgery, and intracavernosal alprostadil injections were recommended for patients who did not benefit from oral pharmacotherapy. Patients who did not benefit from these methods and had a regular sexual partner were included in the study. Additionally, patients were questioned about diabetes, hyperlipidemia, hypertension, and smoking, and their body mass indices were calculated. Patients were interviewed face-to-face at the 3rd, 6th, and 12th postoperative months. During these follow-ups, patients were re-evaluated using the IIEF-5 and IIEF-15, and EHS questionnaires; and PCDU was performed.

PCDU Technique

The PCDU was performed in a quiet and comfortable room to ensure the patients' comfort. To diagnose arterial insufficiency or veno-occlusive disease, PCDU (B-K Medical, Herlev, Denmark) was performed with the patient lying in the supine position. First, gray-scale imaging of the flaccid penile shaft in transverse and sagittal planes was performed to exclude intracavernosal fibrosis and calcifications. Subsequently, 60 mg of papaverine hydrochloride (Papaverine HCl®, Galen Medical Industry, Turkiye) was injected laterally into one of the corpora cavernosa using a 22-gauge needle. Twenty minutes after the papaverine hydrochloride injection, PCDU was performed using an 8 MHz linear probe at an angle of approximately 45 degrees. Peak systolic velocity (PSV) and end-diastolic velocity (EDV) values were measured and resistive index (RI) values of both cavernosal arteries were calculated using the measurements. In addition, the patency of the anastomosis was evaluated. Measurements were repeated at 5-minute intervals and continued for 30 minutes. Cases with PSV <25 cm/s were evaluated as having arterial insufficiency, whereas cases with PSV >25 cm/s, EDV >5 cm/s, and RI <0.80 were interpreted as having veno-occlusive disease. The RI was calculated using the formula: RI = (PSV-EDV)/PSV. Patients were informed about the risk of priapism following papaverine hydrochloride injection and were advised to consult the clinic immediately if an erection persisted for more than four hours.

CC-EMG Technique

Penile cavernous electrical activity (CEA) was recorded using a high-speed EMG module equipped with a computer (Medical Measurement Systems, Enschede, the Netherlands). The sampling frequency was 200 Hz, and a band-pass filter with a

cut-off frequency of 0.1-20 Hz was used. During the CC-EMG recordings, a monopolar needle electrode was used to measure CEA. A grounding electrode was placed on the patient's foot to avoid electrical activity originating simultaneously from non-penile areas, as such activity appears as a single line in the EMG recording. CC-EMG recordings were started after patients rested for 10 minutes in a quiet and dim room. CEA potentials were recorded for 10 minutes. Later, the CEA potentials of the penile cavernous nerves were assessed by detecting the peak-to-peak amplitudes. Ten minutes later, papaverine hydrochloride (60 mg) was injected into a single corpus cavernosum to avoid the pattern of discoordination, which is manifested by an increase or no change in the CEA recording and suggests neurogenic ED. A total of 29 cases showing a discoordination pattern on CC-EMG, indicating the vascular component of ED, were excluded from this study. The relaxation degree (RD) was calculated using the formula: RD = [(pre-injection CEA - post-injection CEA)/pre-injection CEA] × 100, as previously described (5).

Cavernosometry

The cavernosometry test was applied as an important part of our clinical evaluation protocol to objectively detect caverno-occlusive dysfunction and to perform a detailed hemodynamic analysis of vascular pathology. After the CC-EMG recordings were completed, cavernosometry was performed using the same device. A diagnosis of caverno-occlusive dysfunction was made based on the following criteria.

1. Requires a maintenance flow rate greater than 5 mL/min after revealed an intracavernous pressure of 150 mmHg with the artificial erection test.

2. The intracavernous pressure decreased by a minimum of 45 mmHg within 30 s following the termination of infusion.

Surgical Technique

The operations were conducted using the Furlow–Fisher procedure or the Virag-V technique (6). In contrast to the Furlow-Fisher procedure, the modified approach preserved the circumflex collaterals and did not disrupt the deep dorsal venous valves using a stripper. After the inferior epigastric artery was brought to the penile root through a subcutaneous tunnel, an end-to-side anastomosis was performed with the proximal part of the deep dorsal vein. A 7-0 polypropylene suture was used according to standard microsurgical technique. After the anastomosis, the deep dorsal vein was ligated proximal to the arteriovenous anastomosis (Figure 1). The procedure was performed under optical magnification (×2.5) to prevent damage to the neurovascular bundle. In the postoperative period, intravenous heparin (5000 IU/day) was administered for 3 days, and patients received 75 mg/day dipyridamole and 300 mg/day acetylsalicylic acid for three months. Patients were advised to abstain from sexual intercourse for 2 months following the surgery.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 21.0 (IBM Corp., Armonk, NY, USA). All patients completed the IIEF-5, IIEF-15, and EHS questionnaires during the preoperative period and throughout the postoperative follow-up. At the final postoperative evaluation, the outcomes were considered successful if there was an increase of at least five points in the IIEF-5 score compared to the preoperative period, a RI value above 0.80, an IIEF-15 score ≥26, and an EHS score ≥3. The normal distribution of continuous variables was assessed using the Shapiro-Wilk test. Descriptive statistics for normally distributed data were presented as mean ± standard deviation. The significance levels of normally distributed continuous variables were compared using the repeated measures ANOVA test. In cases where the ANOVA test revealed a significant difference, the Bonferroni post-hoc test was used to determine the specific time points between which the differences occurred. Statistically significant increases were observed in RI, IIEF-5, and IIEF-15 scores at all evaluation points over time ($p<0.05$). Post-hoc analyses showed that the improvements were particularly pronounced at the third and sixth months compared to the preoperative period. Moreover, a significant but more limited improvement was detected in IIEF-5 ($p=0.012$) and IIEF-15 ($p=0.004$) scores between the 6th and 12th months. For the comparison of categorical variables such as EHS, Fisher's exact test was applied. Categorical data were presented as numbers and percentages (%). Significant improvements were observed at the 3rd, 6th, and 12th postoperative months compared to the preoperative period ($p=0.015$, $p=0.0023$, and $p=0.0014$, respectively). However, no significant difference was found between the postoperative periods: 3rd vs. 6th month, 3rd vs. 12th month, and 6th vs. 12th month ($p>0.05$). A p-value of less than 0.05 was considered statistically significant.

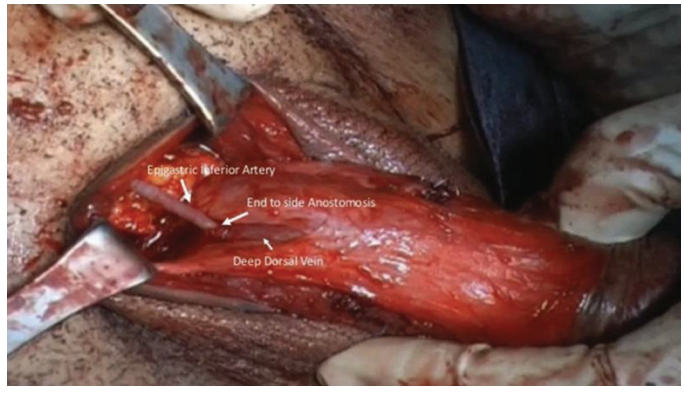

Figure 1. Epigastric artery and deep dorsal vein anastomosis

Results

At the time of surgery, the mean age of the patients was 59.05±3.05 (52-64) years. The demographic characteristics of the patients are shown in Table 1. According to preoperative PCDU, 11 patients had arterial insufficiency and 10 patients had both arterial and venous insufficiency. The mean IIEF-5 and 15 scores were found to be 8.57±1.16 and 21.33±1.60, respectively, before surgery. In the postoperative third, sixth and twelfth months, IIEF-5 scores were found to be 12.05±1.04, 13.71±0.86, 14.67±20.69, respectively. In the postoperative third, sixth, and twelfth months, IIEF-15 scores were found to be 30.43±3.17, 32.19±2.49, 35.43±2.21, respectively. The mean right and left cavernosal artery RI was 0.55±0.04, 0.57±0.03, respectively, before surgery. In the postoperative third, sixth, and twelfth months, right cavernozal artery RI was found to be 0.61±0.06, 0.72±0.04, 0.85±0.09, respectively. In the postoperative third, sixth, and twelfth months, left cavernozal artery RI was found to be 0.63±0.04, 0.73±0.02, 0.86±0.04 respectively. In the postoperative third, sixth, and twelfth months, anastomosis region RI was found to be 0.61±0.08, 0.78±0.09, 0.85±0.07, respectively. In 12 of the 21 operated cases, a significant increase of 5 points or more was observed in IIEF-5 scores; RI values were determined to be above 0.80. In the remaining 9 cases, no sufficient increase was detected in IIEF-5 and RI values, in the PCDU performed during postoperative controls, it was observed that the anastomosis in these cases was obliterated or thrombosed. According to the EHS questionnaire, no patients exhibited penile erection (EHS <3) in the preoperative period. However, at the 3rd postoperative month, 7 patients (33.3%) had; at the 6th month, 8 patients (38.1%) had; and at the 12th month, 10 patients (47.6%) had an EHS score of 3 or higher. Analysis showed that when comparing the preoperative period with any postoperative time point, statistically significant increases indicating surgical success were observed in all parameters (Table 1 and 2).

Discussion

In parallel with advancements in diagnosis and treatment, the likelihood of detecting localized prostate cancer at younger ages has increased. Radical prostatectomy is the preferred method for treating localized prostate cancer. While this approach provides favorable outcomes in terms of cancer control, it can significantly impair patients' quality of life in the postoperative period, particularly regarding erectile function. Tal et al. (7), in

Table 1. Demographic characteristics, RI, IIEF-5, IIEF-15 and EHS results of the patients

Number of patients	21				
Age (year)	59.05±3.05 (52-64)				
Comorbidity					
Diabetes mellitus	4				
Smoking	3				
Obesity (body mass index >26)	4				
Hypertension or cardiovascular disease	4				
Hyperlipidemia	3				
Type of ED					
Aretial insufficiency (n)	11				
Both arterial and venous insufficiency (n)	10				
	Preoperative	**Postoperative 3rd month**	**Postoperative 6th month**	**Postoperative 12th month**	**p-value**
RI					<0.05
Right cavernosal artery	0.55±0.04	0.61±0.06	0.72±0.04	0.85±0.05	
Left cavernosal artery	0.57±0.03	0.63±0.04	0.73±0.02	0.86±0.04	
Anastomotic region	-	0.60±0.12	0.79±0.16	0.85±0.26	
IIEF-5	8.57±1.16	12.05±1.04	13.71±0.86	14.67±0.69	
IIEF-15	21.33±1.60	30.43±3.17	32.19±2.49	35.43±2.21	
EHS (n, %)					
<3	21 (100%)	14 (66.7%)	13 (61.9%)	11 (52.4%)	
≥3	- (0%)	7 (33.3%)	8 (38.1%)	10 (47.6%)	

Statistical analysis: The normality of continuous variables was assessed using the Shapiro-Wilk test. Descriptive statistics for normally distributed data were presented as mean ± standard deviation. The significance levels of normally distributed continuous variables were compared using the Repeated Measures ANOVA test. Fisher's exact test was applied for the comparison of categorical variables. Categorical data were expressed as numbers and percentages (%). A p-value of less than 0.05 was considered statistically significant. ED: Erectile dysfunction, RI: Resistive index, IIEF: International Index of Erectile Function, EHS: Erectile hardnes score

Table 2. The p-values of pairwise comparisons between parameters at different time points (pre-treatment and post-treatment at 3rd, 6th, and 12th months) are presented

	RCA-RI	LCA-RI	Anastomosis-RI	IIEF-5	IIEF-15	EHS
Preop vs. 3rd postop month	p<0.001	p<0.001	-	p<0.001	p<0.001	0.015
Preop vs. 6th postop month	p<0.001	p<0.001	-	p<0.001	p<0.001	0.002
Preop vs. 12th postop month	p<0.001	p<0.001	-	p<0.001	p<0.001	0.001
3rd month vs. 6th postop month	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	0.420
3rd month vs. 12th postop month	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	0.162
6th month vs. 12th postop month	p<0.001	p<0.001	p=0.036	p=0.012	p=0.004	0.798

Since the data showed a normal distribution, the repeated measures ANOVA test was used to analyze changes over time. Pairwise comparisons were performed with Bonferroni correction as a post-hoc analysis. A p-value of less than 0.05 was considered statistically significant. RCA-RI: Right cavernosal artery resistive index, LCA-RI: Left cavernosal artery resistive index, IIEF: International Index of Erectile Function, EHS: Erectile hardness score

their meta-analysis, reported that the incidence of postoperative ED following radical prostatectomy varies between 14% and 90%. Haglind et al. (8) prospectively followed 2,625 patients who underwent robotic and open radical prostatectomy for twelve months. They reported ED rates of 70.4% in the robotic group and 74.7% in the open surgery group. The cause of postoperative ED is multifactorial; however, the primary mechanism is damage to the neurovascular bundle during surgery. Neuropraxia, ischemic and hypoxic injuries, fibrosis, and remodeling all contribute to ED (9). The cavernous nerves travel very close to the prostate capsule alongside vascular structures, forming the neurovascular bundle, as described by Walsh (10). Parasympathetic innervation carried by the cavernous nerves relaxes arterial and cavernosal smooth muscles, increasing penile blood flow and resulting in an erection (11). In the postoperative period, neuropraxia of the neurovascular bundle, followed by Wallerian degeneration, disrupts penile erection. This reduces penile blood flow, leading to cavernosal hypoxia (12). While cavernous nerve damage is a significant factor in the development of postoperative ED, it is not the only mechanism. Additionally, injury to the accessory pudendal arteries during surgery, which occurs in up to 75% of patients, leads to penile hypoxia. These arteries play a key role in maintaining the integrity and function of erectile tissue by providing penile blood flow and cavernous oxygenation (13). Penile hypoxia has been shown to result in collagen accumulation, smooth muscle apoptosis, and cavernous fibrosis (14).

The penile arterial blood supply is primarily provided by the internal pudendal artery and, in some cases, the accessory pudendal artery. The significance of the accessory pudendal artery in supplying blood to the cavernous tissue has been demonstrated in cadaveric studies. The accessory pudendal artery most commonly originates from the obturator artery, the inferior vesical artery, or the external pudendal artery, and it courses parallel to the dorsal venous complex in the periprostatic region. After traversing the pelvic floor muscles, approximately 70% of the branches of the accessory pudendal artery enter the cavernous tissue. In a study by Gray et al. (15), the presence of accessory pudendal arteries was demonstrated in 14% of cases unilaterally and 7% bilaterally. In a study by Rosen et al. (16), the presence of accessory pudendal arteries was identified in 7% of cases. Additionally, these arteries were reported to be the primary structures responsible for supplying blood flow to the penile artery. Damage to the accessory pudendal artery has been shown to have a negative impact on postoperative erectile function (17). In a study comparing surgical techniques with and without preservation of the accessory pudendal artery, a statistically significant improvement in postoperative erectile function was observed in the group in which the artery was preserved (18). In contrast, Box et al. (19) reported no postoperative deterioration in erectile function in cases where the accessory pudendal artery was damaged.

Understanding the mechanisms that cause ED following radical prostatectomy, as well as the penile rehabilitation efforts aimed at improving these mechanisms, is of great importance. Penile rehabilitation is considered a standard component of postoperative care for patients undergoing radical prostatectomy. However, the evidence regarding the efficacy of phosphodiesterase inhibitors, which are commonly used as first-line therapy for this purpose, remains controversial. As second-line therapy, drugs administered via intracavernosal injection are somewhat more effective but still insufficient for achieving natural erections. Moreover, their injectable form requires a high level of patient compliance. Penile prostheses, on the other hand, are mechanical devices used as a last-resort treatment option. However, the need for patient compliance, potential complications, and the inability of these techniques to restore natural erections are considered negative factors (20). In addition, methods such as extracorporeal shock wave therapy, stem cell therapy, platelet-rich plasma, gene therapy, and nerve grafts have been explored in various studies. It has been reported that these methods may face issues related to surgical techniques, have limited data on efficacy and safety, and are based on studies with short follow-up periods -highlighting the need for long-term and larger-scale research (21).

Both arterial and venous insufficiency can occur following radical prostatectomy. Arterial insufficiency has been reported to be associated with injury to the accessory pudendal artery during the procedure. Early erectile loss due to neuroapraxia leads to impaired cavernosal oxygenation and smooth muscle apoptosis. The resulting damage to the cavernous tissue is suggested to be the cause of venous insufficiency (13). Penile revascularization increases blood flow to the cavernous tissues, thereby enhancing intracavernosal oxygenation. This approach aims to prevent cavernous smooth muscle damage and improve erectile function. Penile revascularization can contribute to the improvement of erections, particularly in cases with arterial insufficiency due to trauma. Goldstein reported an 80% success rate in young patients with ED due to internal pudendal or penile artery injuries resulting from pelvic trauma, following penile revascularization surgery (22). In another study, end-to-end anastomosis was performed between the inferior epigastric artery and the deep dorsal vein, with normal erections observed in 49% of patients and improvement in 20% of patients (23). Kayıgil et al. (24) reported an 81% success rate in the long-term follow-up of 110 patients who underwent penile revascularization.

In this study, penile revascularization surgery was performed for the treatment of vascular-origin ED that developed after radical prostatectomy. In 1989, Hauri et al. (25) performed penile revascularization surgery on two cases for penile rehabilitation after radical prostatectomy, reporting unsuccessful outcomes in both cases. However, the reporting of only two cases in that study indicates an insufficient sample size to evaluate the effectiveness of the method. In our study, a larger sample size was used, microsurgical techniques were applied, and a multidisciplinary approach was adopted. In our study, successful outcomes were achieved in 12 out of 21 patients who underwent penile revascularization, while failure was observed in the other 9. The literature generally recommends penile prosthesis implantation for patients in whom oral and intracavernous treatments are unsuccessful. However, contrary to classical treatment approaches, we recommend performing penile revascularization surgery before resorting to highly invasive and irreversible procedures, such as penile prosthesis implantation. Our study demonstrates that successful outcomes can be achieved in cases of vascular-origin ED detected after radical prostatectomy. In conclusion, we believe that this study highlights the effectiveness of penile revascularization in selected cases and makes a significant contribution to the literature in this field. Patient selection based on specific criteria, the use of objective and comprehensive methods for diagnosis and treatment, and long-term follow-ups enhance the reliability of our results.

Study Limitations

However, its limitations include a single-center study, a retrospective design, and a limited number of patients.

Conclusion

Penile revascularization is considered an effective treatment option for penile rehabilitation following radical prostatectomy. The results indicate that penile revascularization shows promise in improving erectile function, especially in cases of vascular-origin ED. These findings support considering penile revascularization as an option before resorting to more invasive procedures, such as penile prosthesis implantation.

Ethics

Ethics Committee Approval: This retrospectively designed study was conducted at a tertiary healthcare institution and received approval from the Ankara Bilkent City Hospital Ethics Committee (approval number: TABED 1-25-908, date: 12.03.2025).

Informed Consent: Retrospective study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: F.A., Ö.K., Concept: F.A., Ö.K., Design: F.A., Ö.K., Data Collection or Processing: F.A., Ö.K., Analysis or Interpretation: F.A., Ö.K., Literature Search: F.A., Ö.K., Writing: F.A., Ö.K.

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