**Background:** Currently, there is no ideal agent to prevent adhesion formation. We have shown that sildenafil, a phosphodiesterase-5 (PDE-5) inhibitor, reduces post-operative adhesion formation by vasodilation and increases fibrinolytic activity. Here, we evaluated whether tadalafil, a long-acting PDE-5 inhibitor, decreases post-operative adhesion reformation in rats.

**Materials and Methods:** Standardized lesions were created in Wistar albino rats by cauterization of uterine horns and abrasion of adjacent peritoneum. The extent and severity of adhesions were scored on the 14th post-operative day and adhesiolysis was performed at the second laparotomy. Animals were then assigned randomly into two groups. The study group \( (n = 11) \) received 10 mg/kg oral tadalafil by gavage 60 min before the second laparotomy and daily for 14 days afterwards. Controls \( (n = 11) \) received the same volume of tap water for 14 days by gavage. Animals were killed 15 days after adhesiolysis and adhesions were scored blind during the third laparotomy.

**Results:** Basal adhesion scores at the time of the second laparotomy were comparable in the study and control groups. Scores for the extent of adhesion reformation in the study and control groups did not differ \( \text{median 1 (range 0–3) versus median 2 (range 1–3); } P: 0.81 \) but tadalafil reduced the respective severity scores \( \text{median 0.5 (range 0–1) versus median 1 (range 0.5–1); } P: 0.02 \) and total scores \( \text{median 2 (range 0–4) versus median 2.5 (range 1.5–4); } P: 0.042 \).

**Conclusions:** Oral administration of tadalafil during the perioperative period reduces intra-abdominal adhesion reformation in rats.

**Key words:** adhesion reformation / tadalafil / rat / phosphodiesterase-5 inhibitor / post-operative adhesions

**Introduction:** Adhesion formation is one of the most common and troublesome complication of pelvic and abdominal surgery that affects 55–94% of patients having open surgery \( (Drollette and Badawy, 1992) \), and responsible for 50% of hospital readmissions \( (Parker et al., 2001) \). It can also cause late complications, such as female infertility and chronic pelvic pain. Additionally, adhesion formation is the leading factor for the occurrence of intra-operative complications, including organ injury, in subsequent surgery \( (Dijkstra et al., 2000) \). Adhesion-related conditions are common and difficult to treat, and the financial burden of adhesiolysis is very high on healthcare systems \( (Ray et al., 1998) \). Therefore, these facts have led to an acceleration of the description of studies trying to prevent adhesion formation. The methods suggested as means for preventing adhesions vary from meticulous surgical handling of tissues and mechanical barriers to intraperitoneal (i.p.) application of profibrinolytic substances and virus-mediated gene transfection \( (Rodgers et al., 1996; Basbug et al., 1998; Johns et al., 2001; Ozc¸elik et al., 2003; Gutt et al., 2004; Atta et al., 2009) \). Unfortunately, the elusive nature of adhesion genesis and individual differences regarding tissue repair and fibrosis frustrate efforts to find a universally applicable means to prevent adhesion formation.

Adhesion formation can be defined as a tissue reaction to inciting stimuli, causing mesothelial injury and tissue ischemia that ultimately leads to the formation of fibrous bands and connections that distort normal anatomy. It starts as a normal protective physiological mechanism to contain inciting stimuli and to repair tissue injury, and culminates in pathological wound healing and fibrosis. It is thought that the disturbed balance between procoagulant and fibrinolytic activity is an important factor determining the outcome of the wound-healing process \( (Ellis, 1971; Reijnen et al., 2003) \). At the critical period of inflammation and wound healing, local tissue oxygenation mediated by local hormones and growth factors determines whether adhesion formation occurs.

Experimental studies showed that agents that increase local tissue perfusion, such as nitric oxide (NO), and those enhancing its biological

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activity decrease adhesion formation (Kaleli et al., 1998; Ozden et al., 1999). NO is generated by certain NO synthases as a by-product of conversion of L-arginine to L-citruline. NO plays multiple roles in the initiation, maintenance and modification of inflammatory response. At least some of the biological actions of NO are mediated through the stimulation of guanylate cyclase. Subsequent formation of cyclic guanosine monophosphate (cGMP) leads to the activation of protein kinase G (PKG) which is thought to play a central role in NO effect. NO is produced constitutively by endothelial cells and plays an important role in the maintenance of local perfusion owing to its inhibiting effect on platelet adhesion, mast cell degranulation and free oxygen radical production by leukocytes (Kubes et al., 1991; Rodeberg et al., 1995; Lugnier et al., 1999). Aside from its effect on the inflammatory component of tissue injury, it was recently shown that inhibition of phosphodiesterase-5 (PDE-5), which catalyses the breakdown of cGMP, reduces collagen synthesis and induces apoptosis of fibroblasts and myoblasts (Chiche et al., 1998; Sirotkin et al., 2000). The beneficial role played by cGMP against adhesion formation is further supported by the experimental study of Batukan et al. (2007) which showed that the administration of oral sildenafil, a PDE-5 inhibitor, can inhibit adhesion formation in a rat modified uterine horn model (Batukan et al., 2007).

Once formed, adhesions can only be eliminated by operative adhesiolysis and there is a high rate of reformation (Gutt et al., 2004). There is no satisfying hypothesis for how adhesion reformation occurs and which factors determine its occurrence. Whether adhesion reformation goes through the same route as the initial formation and is governed by the same mediators, such NO is yet to be determined. Although adhesion formation is a somewhat well-studied process, data about the prevention of adhesion reformation are limited. On the basis of these facts, the aim of this experimental study was to evaluate whether tadalafil (Cialis®, Lilly, USA), a long-acting PDE-5 inhibitor, can decrease post-operative adhesion reformation in rats.

On the 14th post-operative day, the rats were randomly assigned into two groups (Study and Control groups) and a second surgery was performed using the same protocol for entering the abdominal cavity. The first and second surgeries and adhesiolysis were performed by the same operator (M.T.O.) who was unaware of the animal allocation. After the first and second surgeries, the extent and severity of adhesions in the operation field were evaluated by the same observer (C.B.), who was blinded to the treatment regimen. The severity of adhesions were graded modifying the classification of Knightly et al. (1962): Grade 0, no adhesion; Grade 1, thin filmy adhesions, easy to separate without tension or injury of the involved tissues; Grade 2, dense adhesion, which requires tension to divide them; Grade 3, dense adhesion, which leads to serosal injury during lysis or needs to be divided with scissors; Grade 4 adhesion, where other intra-abdominal organs were involved and a conglomerate was formed. The extent of adhesions across the uterine horn was defined according to the criteria of Leach et al. (1998): 0, no adhesion; 1, 1–25% involvement; 2, 26–50% involvement; 3, 51–75% involvement; 4, 76–100% involvement. The sum of both parameters was used as the overall (total) score for each uterine horn.

Tables containing 20 mg tadalafil were crushed and suspended in tap water to yield a concentration of 2 mg/ml. The animals in the study group (n = 12) were administered 10 mg/kg tadalafil by gavage 60 min prior to the second laparotomy, and daily for 14 days thereafter; the same volume of tap water was administered daily for 14 days by gavage to the control group.

The animals were killed 15 days after adhesiolysis and adhesions were determined and scored by a blinded examiner, according to the aforementioned criteria, during the third laparotomy. Data are expressed as median (min.–max.) and mean ± SD. Comparison of adhesion scores between the groups was made using the Mann–Whitney U-test. Statistical significance was set at P < 0.05. All analyses were performed with the statistical package for social science (SPSS) (version 15.0, Chicago, IL, USA).

**Materials and Methods**

Twenty-two, 4-month-old female Wistar albino rats weighing 170–210 g were used in this study. During the whole study period, the animals were kept under controlled conditions of temperature (21–24°C), humidity (40–60%) and light (12-h light/12-h dark regime) and fed ad libitum on rat cubes and tap water. All procedures contained in the study were approved by the Animal Care Laboratory of Erciyes University, Turkey, and approval was obtained from the Institutional Review Board before the study.

The study protocol used was adopted from Batukan et al. (2007). Ketamine (10 mg/kg i.p.; Ketalar, Eczacibasi, Istanbul, Turkey) and xylazine (3 mg/kg; Rompun 2%, Bayer, Germany) were used to anesthetize the rats. The lower abdomen was shaved and prepared with povidone iodine solution. Laparotomy was carried out through a lower midline incision, 3–4 cm in length. A modified rat uterine horn adhesion model was used to induce intra-abdominal adhesion formation. The peritoneal sidewalls were scraped and care was taken not to harm the retroperitoneal structures. Unipolar electrocautery was used to traumatize the antimesenteric surface of the ipsilateral uterine horn at 8–10 spots. The scraped peritoneal sidewalls and the uterine horn were then approximated from the proximal and distal ends with 4/0 polypropylene (Prolene, Ethicon, Inc.) sutures. The midline incision was closed with two layers of 4/0 prolene sutures. The abdominal wall scar was examined for 2 days post-operatively. Antibiotic prophylaxis was not administered during or after surgery.

**Discussion**

PDEs are a specific family of serine proteases that lyse cGMP and thus inhibit the pathway through which NO operates (Michel and Feron, 1997). Sildenafil (Viagra®, Pfizer, USA), a specific PDE-5 inhibitor
Phosphodiesterase inhibitor-5 reduces adhesions

that augments NO activity by the way of PDE-5 inhibition has been approved for the treatment of male erectile dysfunction (Goldstein et al., 2002). After demonstration of its clinical efficacy in erectile dysfunction, Sildenafil has emerged as the most popular subject of studies in the area of vascular diseases, including pulmonary hypertension (Galie, 2005), diabetes (Desouza et al., 2002) and cerebrovascular disease (Royl et al., 2009).

Following the discovery of a role of insufficient local perfusion in adhesion formation, Batukan et al. (2007) studied sildenafil, an NO enhancer, as a potential adhesion preventing agent in an experimental animal model. In their study, they used a modified uterine horn model. Results of the study showed that sildenafil, when given orally at 15 mg/kg doses, significantly decreases de novo adhesion formation, whereas lower doses were not effective.

The effect of NO in modifying the inflammatory response and adhesiogenesis is known to be correlated with intra-cellular concentration of cGMP. Short-acting nitrate derivatives may not elevate cGMP levels long enough to allow a sufficient effect to occur (Bult et al., 2000). After the discovery of an adhesion preventing the effect of the orally administered sildenafil by Batukan et al. (2007), we aimed to study the effect of a longer acting PDE-5 inhibitor in the adhesion reformation process. For this purpose, we used tadalafil with a half life of 17.5 h, which is three times longer than that of sildenafil (Carson, 2006).

In order to create a proper experimental model to examine the adhesion reformation process, firstly, the kinetics of adhesion formation should be comprehended. Recently, an increasing body of evidence recently suggests that, besides platelets and leukocytes, fibroblasts also contain PDE-5 (Redondo et al., 2003). Experimental studies have shown that exogenous cGMP analogues can induce apoptosis and inhibit collagen synthesis (Lee et al., 1997; Redondo et al., 1998; Sirokin et al., 2000). It is likely that the apoptotic effect of NO might be mediated through the action of intra-cellular cGMP-PKG. Intensifying the activity of these downstream compounds in the NO–cGMP cascade by certain PDEs may be important for elimination of the adhesion fibroblasts during adhesion reformation. Given the relatively ischemic and fibrotic nature of adhesion tissue, a direct effect of NO on fibroblast receptor may be a determining factor in the prevention of adhesion reformation. It was also shown that PDE-5 inhibitors reverse fibrotic change in cell cultures induced by transforming growth factor-B1 (Valente et al., 2003). Within this theoretical frame, based on our results, we suggest that after the formation of adhesion tissue, long-acting PDE-5 inhibitors reduce the tenacity of readhesions but whether this effect results from administering a longer acting agent, or from a longer duration of application, is yet to be determined.

We conclude that oral administration of tadalafil during the peri-operative period attenuates adhesion reformation in a rat uterine horn model. Further studies are required to reach a definitive conclusion regarding the value of tadalafil in reducing adhesion reformation.

Table I: The effect of tadalafil on intra-abdominal adhesion reformation in rats, measured 15 days after adhesiolysis.

<table>
<thead>
<tr>
<th>Uterine horn (n)</th>
<th>Adhesion scores</th>
<th>Severity (median; min.–max.), $\bar{x} \pm SD$</th>
<th>Total score (extent + severity) (median; min.–max.), $\bar{x} \pm SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study group (10 mg/kg/day tadalafil, for 14 days)</td>
<td>22 (1; 0–3), 1.29 $\pm$ 0.85</td>
<td>(0.5; 0–1), 0.57 $\pm$ 0.36</td>
<td>(2; 0–4), 1.86 $\pm$ 1.14</td>
</tr>
<tr>
<td>Control group</td>
<td>22 (2; 1–3), 1.72 $\pm$ 0.63</td>
<td>(1; 0.5–1), 0.82 $\pm$ 0.25</td>
<td>(2.5; 1.5–4), 2.55 $\pm$ 0.71</td>
</tr>
<tr>
<td>P-value*</td>
<td>0.810</td>
<td>0.020</td>
<td>0.042</td>
</tr>
</tbody>
</table>

*N=Mann–Whitney U-test.
Authors’ roles
M.S.K. helped design the study, prepared the manuscript and approved the final version. M.T.O. and C.B. helped design the study, participated in surgeries, edited the manuscript and approved the final version. B.O. helped design the study, edited the manuscript and approved the final version. M.B. helped design the study, reviewed the manuscript and approved the final version. A.O. helped design the study, performed all the statistical analysis, reviewed the manuscript and approved the final version.

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Conflict of interest
None declared.

References


Valente EG, Vernet D, Ferrini MG, Qian A, Rajfer J, Gonzalez-Cadavid NF. L-arginine and phosphodiesterase (PDE) inhibitors counteract fibrosis in the Peyronie’s fibrotic plaque and related fibroblast cultures. *Nitric Oxide* 2003;9:229–244.