Scientific Research Publishing

Open Journal of Obstetrics and Gynecology, 2024, 14, 535-546
https://www.scirp.org/journal/ojog
ISSN Online: 2160-8806
ISSN Print: 2160-8792

Effects of β-Glucan Supplementation on Repairing of Phenol-Induced Vaginal Mucosal Epithelium Damage in Rats

Song Fei[1], Weidong Wu[1*], Ying Wang[2], Dan Li[1], Bo Jin[1]

[1]Department of Thoracic and Cardiovascular Surgery, Guangzhou Red Cross Hospital of Jinan University, Guangzhou, China
[2]Guangzhou Xiaomanyao Medical Equipment Co., Ltd., Guangzhou, China
Email: william0406@163.com

How to cite this paper: Fei, S., Wu, W.D., Wang, Y., Li, D. and Jin, B. (2024) Effects of β-Glucan Supplementation on Repairing of Phenol-Induced Vaginal Mucosal Epithelium Damage in Rats. *Open Journal of Obstetrics and Gynecology*, **14**, 535-546.
https://doi.org/10.4236/ojog.2024.144047

Received: March 25, 2024
Accepted: April 19, 2024
Published: April 22, 2024

Abstract

Objective: To investigate the effects of different concentrations of β-glucan on the repair of damaged vaginal mucosa, the expression of vascular endothelial growth factor (VEGF), and the inflammatory factor-6 (IL-6) in vaginal tissues. **Methods:** Thirty-six adult female specific pathogen free (SPF)-grade Wistar rats were randomly divided into 3 phase groups with 12 rats each. Vaginal inflammation rat models were established by injecting phenol gel into the vagina of each rat at a dose of 0.1 ml/100g body weight. After modeling, rats were divided into 4 groups based on different concentrations of the test agent. The control group was injected with 0.5 ml of saline, experimental group A was injected with 0.375 ml saline + 0.125 ml β-glucan, experimental group B was injected with 0.25 ml saline + 0.25 ml β-glucan, and experimental group C was injected with 0.50 ml β-glucan. The injection sites were selected at the 3 o'clock and 9 o'clock positions of the vagina. Rats were sacrificed at 7-, 14-, and 28-days post-injection, and tissue samples were collected from the injection sites and prepared for histological analysis. New blood vessels and fibroblast numbers in the tissues were observed after Hematoxylin-eosin (HE) staining. The expression levels of VEGF and IL-6 in the tissues were measured using quantificational reverse transcription polymerase chain reaction (qRT-PCR). **Results:** Histological examination of vaginal tissue specimens at 7-, 14-, and 28-days post-injection showed that on day 7, there were no significant changes in the experimental groups compared to the control group. However, on days 14 and 28, the experimental groups showed more new blood vessels, macrophages, and fibroblasts with increased activity compared to the control group. The expression levels of VEGF in vaginal tissues were elevated on days 14 and 28 in the experimental groups. The com-

parison of IL-6 levels in vaginal tissues on day 28 showed that serum IL-6 levels returned to normal, and there was no statistically significant difference between the experimental and control groups. **Conclusion:** In the 3 experimental phases, the increase in VEGF levels in vaginal tissues on day 14 post-injection was more pronounced with higher concentrations of β-glucan, and IL-6 levels returned to normal on day 28. β-Glucan can enhance VEGF levels in damaged vaginal tissues, promote the repair of damaged vaginal tissues, and higher concentrations of β-glucan have a better effect.

Keywords

β-Glucan, Vaginal Mucosa, Damage Repair

1. Introduction

The human vaginal mucosal epithelial cells are mainly composed of glandular epithelial cells and squamous epithelial cells. In various gynecological and vaginal intimate plastic surgery procedures, the vaginal mucosal epithelium is often damaged. For middle-aged and elderly women, once the vaginal mucosa is damaged, recovery is often difficult due to the decrease in estrogen levels in the body, and the side effects of estrogen therapy are difficult to avoid [1] [2]. Therefore, there is a need to develop better treatment methods and drugs for repairing damaged vaginal mucosa. It has been found that β-glucan promotes the migration of macrophages and fibroblasts and stimulates the secretion and release of tissue enzymes and related metalloproteinases by some cytokines, achieving the purpose of skin wound repair and intestinal mucosal repair [3] [4] [5]. However, there is limited research on the reparative effects of β-glucan on damaged vaginal mucosa. This study aims to investigate whether different concentrations of β-glucan have similar reparative effects in damaged vaginal mucosa and explore the impact of β-glucan on the repair of damaged vaginal mucosa.

2. Materials and Methods the Animal Experiment

2.1. Experimental Animals

Thirty-six SPF-grade female Wistar rats, aged 6 weeks, weighing 200 ± 20 g, were purchased from a reputable domestic animal research institute. The animal experiments were conducted in accordance with animal experimental code of ethics approved by the Animal Ethical and Welfare Committee (AEWC) of Guangzhou Miles Biosciences Application (NO. IACUC. MIS20230038). The experiment was carried out following the guidelines of the "Guide for the Care and Use of Laboratory Animals" by the National Institutes of Health. The rats were housed in cages at a temperature of (25 ± 2)˚C, relative humidity of (50 ± 5)%, and a 12-hour light-dark cycle, with ad libitum access to food and water. The rats were acclimated for 7 days.

2.2. Reagents and Instruments

β-glucan (Guangzhou Xiaomanyao Medical Equipment Co., Ltd.); anhydrous ethanol (China National Pharmaceutical Group Chemical Reagent Co., Ltd.); phenol, glycerol (Shengong Biotechnology Co., Ltd.); Western blotting reagent (purchased from JD.com); Trizol-RNA extraction reagent, Evo M-MLV RT Kit with gDNA Clean for qPCR (Aike Ray Biotechnology Co., Ltd.); 75% anhydrous ethanol, isopropanol (Tianjin Damao Biotechnology Co., Ltd.); real-time fluorescence quantitative PCR instrument (BIO-RAD Biotechnology Co., Ltd.), ChamQ SYBR qPCR Master Mix (Vazyme Biotechnology Co., Ltd.); xylene (Tianjin Fuyu Fine Chemical Co., Ltd.); eosin staining solution, hematoxylin staining solution, and neutral gum (Google Biotechnology Co., Ltd.); microscope (Nikon Biotechnology Co., Ltd.); slide warmer (Anlishin Biotechnology Co., Ltd.); dehydrator, embedding machine (Wuhan Junjie Electronics Co., Ltd.); benchtop high-speed refrigerated centrifuge (Tianmei Biotechnology Co., Ltd.).

2.3. Experimental Grouping

Following the methods as described by previous studies, a vaginal inflammation model was established using phenol gel for 3 consecutive days. After one week of acclimation, phenol gel was administered for 3 days (0.1 mL/100g body weight injected into the vagina). The day following the phenol gel administration was defined as day 1. On day 1, treatment with polypeptides was administered at the 3 o'clock and 9 o'clock positions within the vagina, with an area of approximately 1.5 cm around the injection site marked. A dose of 0.5 ml was injected at a single site. The injection regimens were the same as the cell groups, as shown in Table 1.

2.4. Methods

2.4.1. Reagent Injection

36 rats were fasted for 12 hours and water-deprived for 4 hours before the surgery. After weighing the rats, a single intraperitoneal injection of 1.5% pentobarbital sodium (5 ml/kg) was administered for anesthesia. Following appropriate anesthesia, the perineal skin of the rats was prepared, and after disinfection, experimental groups A, B, and C were treated by injecting polypeptides at the 3 o'clock and 9 o'clock positions within the vagina (using a 30G * 25 mm sharp

Table 1. Treatment Groups.

Group	Saline	*β*-glucan	Total dose
Control	0.50 ml	0	0.50 ml
Group A	0.375 ml	0.125 ml	0.50 ml
Group B	0.25 ml	0.25 ml	0.50 ml
Group C	0	0.50 ml	0.50 ml

needle and 1 ml/5ml luer-lock syringe). The needle was inserted at a 15˚ angle to the submucosal layer, approximately 4 mm in depth, and injection was performed after blood-free aspiration and slight resistance during injection. The injection site was marked around a range of approximately 1.5 cm from the injection point. A 0.5 ml dose was injected at a single site, resulting in the immediate appearance of a clear small wheal. The control group was injected with an equal amount of saline. After injection, light massage was applied to ensure even distribution of the reagent. The rats were maintained under standard conditions and euthanized by carbon dioxide (CO_2) asphyxiation at 7, 14, and 28 days according to the experimental period. The vaginal tissues of the rats were excised, and the injected sites were transversely sectioned. Half of the tissue was fixed in 4% paraformaldehyde (for HE staining), while the other half was stored at -80˚C (for qPCR). Assessment of the degree of redness and swelling at the vaginal opening of rats was scored as follows: severe 3 points, moderate 2 points, mild 1 point, and none 0 points.

2.4.2. Hematoxylin-Eosin Staining

After fixing the vaginal tissue of the rats at the injection site in 4% paraformaldehyde for 48 hours, the tissue was rinsed with running water for 4-8 hours to remove paraformaldehyde. The tissue was then embedded in a net bag and placed in 70% ethanol overnight. The following day, the tissue was sequentially immersed in 80%, 90%, 100% A, and 100% B ethanol for 1 hour each. It was then immersed in xylene A and xylene B for 30 minutes until the tissue block appeared light brown or dark red and transparent. The tissue block was incubated in paraffin baths A, B, and C for 1.5 hours each at 60˚C. After embedding, the tissue block and embedding molds were placed in the embedding instrument for at least 30 minutes, and the water bath was closed after embedding. The tissue was sectioned using a Leica microtome at a thickness of 4μm, with sectioning at 45˚C, followed by baking in a slide warmer at 75˚C for 60 minutes. The paraffin sections were placed in a slide warmer at 60˚C for 30 minutes, then transferred to a staining dish for 5 minutes each in xylene A, xylene B, and xylene C to deparaffinize the sections completely. The sections were rehydrated in a gradient of ethanol (100%, 90%, 80%, 70%), followed by two washes in distilled water for 5 minutes each. The sections were then stained in hematoxylin for 3 - 5 minutes, differentiated for 1 - 3 seconds, rinsed in tap water, counterstained in eosin, and washed thoroughly in running water. Dehydration and eosin (alcohol-soluble) staining: The sections were dehydrated in 85% and 95% ethanol for 5 minutes each, then stained in eosin (alcohol-soluble) for 5 minutes. Dehydration and clearing: The sections were dehydrated in absolute ethanol three times for 5 minutes each, followed by immersion in xylene for transparency. The specimens were removed from xylene, slightly dried, and mounted with neutral gum. The target area was identified under a light microscope and photographed. The formation of new blood vessel cells and the infiltration of inflammatory cells

in the surrounding tissue were observed in the specimen.

2.4.3. qRT-PCR Detection of VEGF Expression in Vaginal Tissues

Total RNA was extracted from the tissues using Trizol reagent, and RNA concentration and purity were determined using NanoDrop. qRT-PCR was performed to measure the levels of VEGF and IL-6. The reverse transcription system included: gDNA Clean Reaction Mix Ver.2: 2 μL, total RNA: 0.5 - 1 μg, RNase-free ddH_2O up to 10 μL, incubated at 42˚C for 2 minutes. Then, 5× Evo M-MLV RT Reaction Mix Ver.2: 4 μL was added, and RNase-free ddH2O was added to a total volume of 20 μL. The mixture was incubated at 37˚C for 15 minutes, followed by denaturation at 85˚C for 5 seconds, and termination at 12˚C. The cDNA was stored at −20˚C for further use. The reaction conditions were as follows: pre-denaturation at 95˚C for 10 minutes; denaturation at 95˚C for 10 seconds, annealing at 60˚C for 30 seconds, extension at 72˚C for 20 seconds, repeated for 40 cycles. The fluorescence signal was collected during the melting curve analysis from 68 to 95˚C. The relative expression levels of VEGF were normalized to GADPH, with the forward primer (F: P11249): GGACAGACAGACAGACACCG, reverse primer (R: P11250): TTCTCCCCTCTCTTCTCGGG. The relative expression levels of IL-6 were normalized to GADPH, with the forward primer (F: P11251): TCCTTCCTACCCCAACTTCCA, reverse primer (R: P11252): AGGTTTGCCGAGTAGACCTCA. GADPH was used as the internal reference gene with the forward primer (F: P63): TGCCACTCAGAAGACTGTGG, reverse primer (R: P64): TTCAGCTCTGGGATGACCTT. The 2-ΔΔCt method was used for relative quantification analysis of VEGF and IL-6 expression levels in the cells. The experiment was repeated three times.

2.5. Statistical Analysis

The data in this study were analyzed using SPSS 25.0 statistical software. Continuous data are presented as mean ± standard deviation (x ± s). Group comparisons were performed using one-way analysis of variance (ANOVA), with statistical significance set at $P < 0.05$. Graphs were generated using GraphPad Prism 8.2.1 software (GraphPad Software, USA).

3. Results

3.1. Macroscopic Observation of Rat Vaginas

On the 3rd day post-modeling (day 1 of the experiment), the vaginal openings of the 36 rats appeared swollen, some with purulent discharge, and this condition persisted until the 10th day of the experiment (day 7). By the 14th day of the experiment, rats in the experimental group showed reduced vaginal swelling compared to the control group, and there was no purulent discharge. By the 28th day of the experiment, the vaginal condition of the rats in the experimental group had returned to normal, while the vaginas of the control group rats remained slightly swollen. Refer to **Figure 1** and **Table 2**.

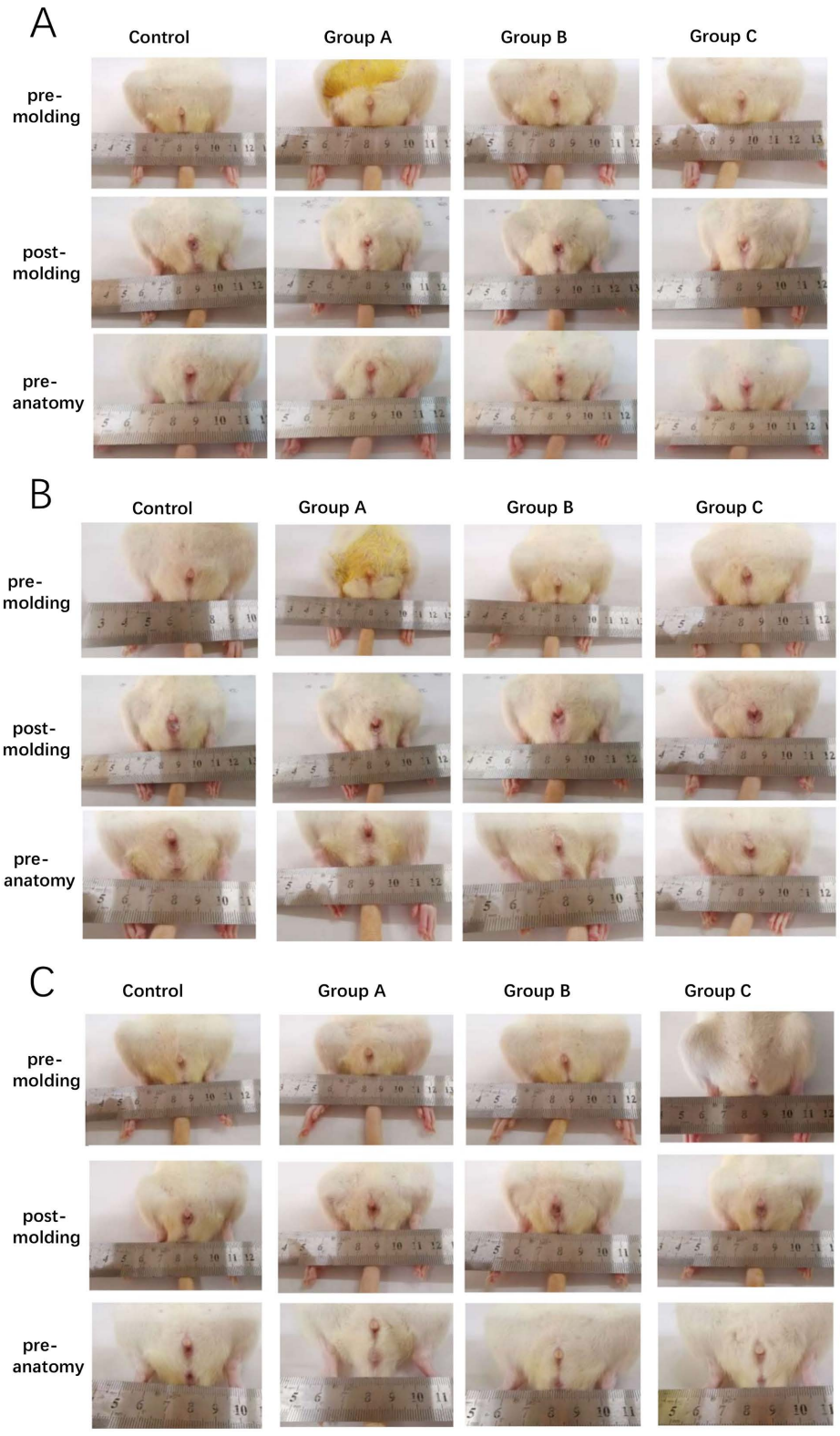

Figure 1. Macroscopic observation of rat vaginas before and after modeling, and before dissection in rats from the three phases. Note: (A) Macroscopic appearance of rat vaginas on day 7 of the first phase of the experiment; (B) Macroscopic appearance of rat vaginas on day 14 of the second phase of the experiment; (C) Macroscopic appearance of rat vaginas on day 28 of the third phase of the experiment.

Table 2. The degree of redness and swelling at the vaginal opening of rats.

Group	n	7 day	14 day	28 day
Control	3	3.00 ± 0.47	3.00 ± 00	2.33 ± 0.47
Group A	3	2.67 ± 0.47	2.33 ± 0.47	1.33 ± 0.00
Group B	3	2.33 ± 0.47	1.67 ± 0.47	0.67 ± 0.47
Group C	3	2.00 ± 0.81	1.00 ± 0.81	0.33 ± 0.47
F		0.61	5.33	7.00
P		0.62	0.02	0.01

3.2. Histological Results of Rat Vaginal Tissue HE Staining

On the 7th day of the experiment, there were no significant changes observed in the experimental groups compared to the control group. By the 14th and 28th days, the experimental groups showed infiltration of macrophages and fibroblasts, increased collagen fiber proliferation, and formation of new blood vessels. Refer to **Figure 2**.

3.3. Comparison of VEGF Levels in Rat Tissues among Groups

To avoid errors caused by selecting slices under the microscope, this study assessed the expression levels of VEGF in rat vaginal tissues. Apart from the control group, the VEGF expression levels in each experimental group showed an increasing trend. On day 7, there was no significant difference in VEGF expression levels among the groups ($P > 0.05$). On days 14 and 28, the VEGF expression levels in each experimental group were higher than those in the control group, with the highest expression level observed in experimental group C, and the difference was statistically significant ($P < 0.05$). Refer to **Figure 3**.

3.4. Expression Levels of IL-6 in Vaginal Tissues on Day 28

RT-PCR results showed that on day 28 of the experiment, the expression levels of IL-6 were low in all experimental groups compared to the control group, and the difference was not statistically significant ($P > 0.05$, $F = 0.2235$). Refer to **Figure 4**.

4. Discussion

The incidence of vaginal mucosal injuries has been increasing in recent years, especially as women age and experience a decline in estrogen levels, making self-repair of vaginal mucosal injuries more challenging. Additionally, with the improvement in living standards, women are increasingly concerned about intimate aesthetics. Medical-induced vaginal mucosal injuries during intimate procedures are often difficult to avoid. When vaginal mucosal injuries, or even cervical tissue injuries, occur, the risk of HPV infection significantly increases [6]. Statistics show that at least 70% - 80% of sexually active women will have at least one HPV infection in their lifetime [7] [8]. Persistent HPV infection can

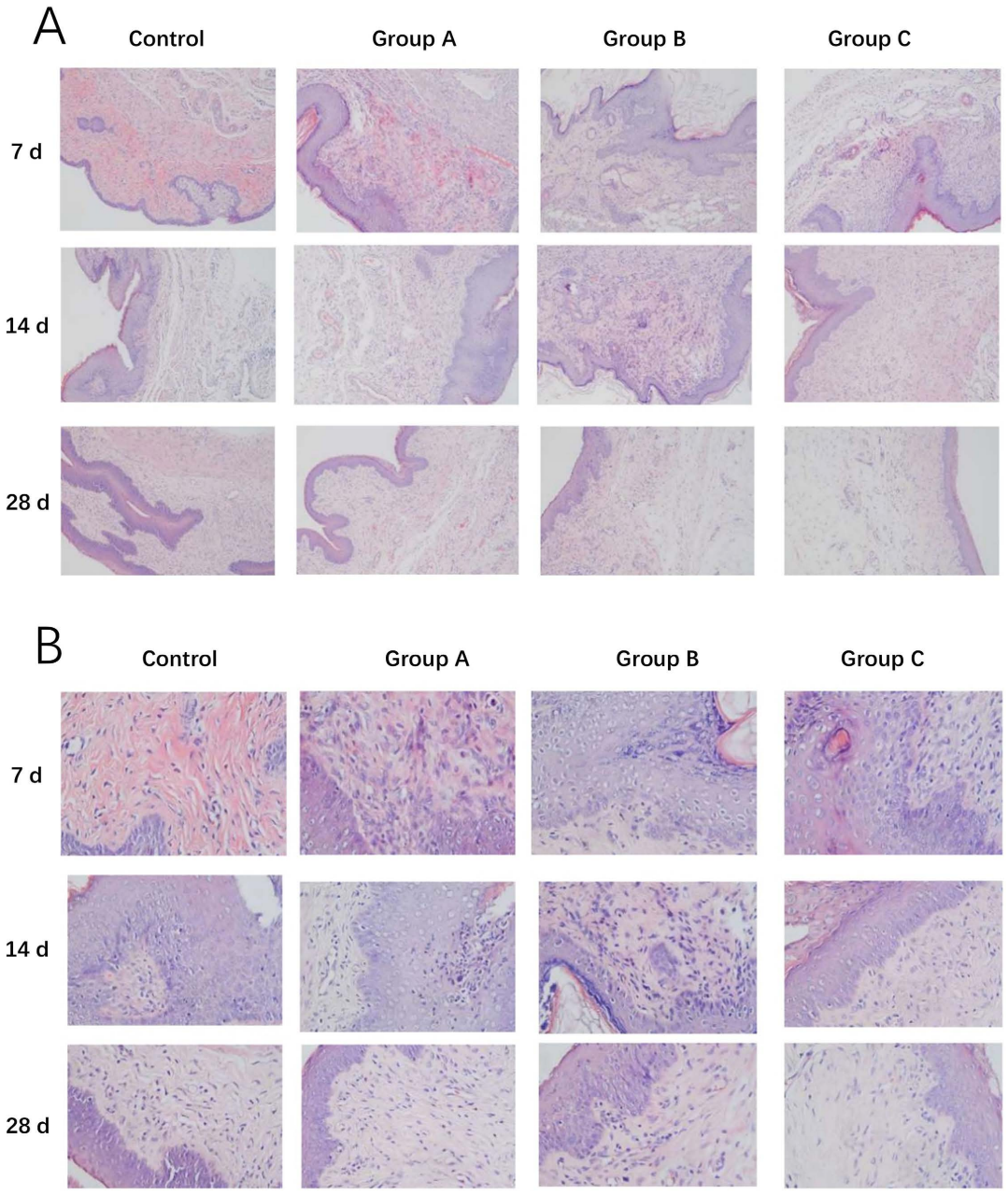

Figure 2. Histological results of rat vaginal tissue HE staining from the three phases. Note: (A) Histological section of rat vaginal tissue HE staining (100× magnification); (B) Histological section of rat vaginal tissue HE staining (400× magnification).

lead to the integration of HPV DNA with human DNA, which is a major cause of cervical cancer. The World Health Organization declared HPV as the primary factor leading to cervical cancer as early as 1992. Every two minutes, a woman dies from cervical cancer worldwide [7]. The incidence and mortality rates of cervical cancer in China are very high, making it one of the most serious tumors [8]. However, there is currently no universally recognized effective treatment for HPV infection on a global scale. Therefore, early repair of damaged vaginal tissues is crucial for preventing HPV infections.

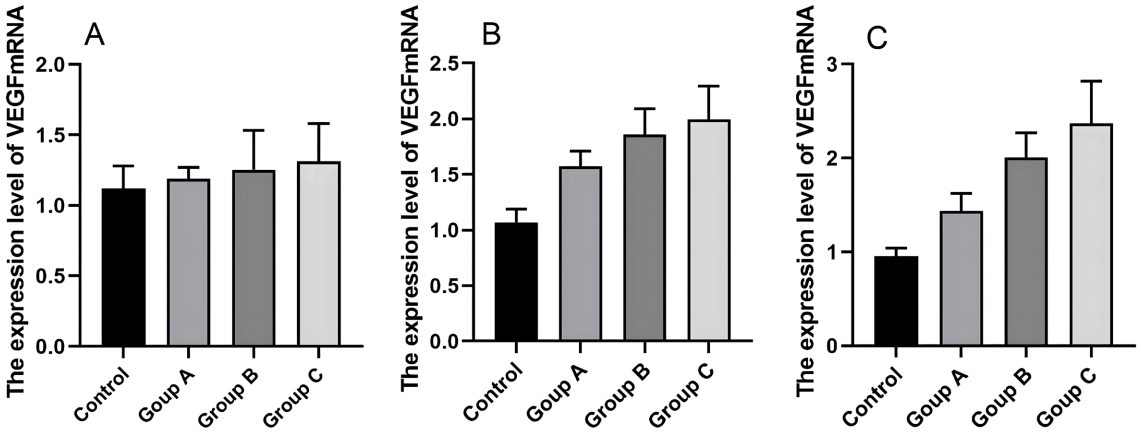

Figure 3. The effect of β-glucan on the VEGF mRNA expression levels in rat vaginal tissues. Note: (A) Relative expression levels of VEGF mRNA in each group on day 7, $F = 0.4541$, $P > 0.05$; (B) Relative expression levels of VEGF mRNA in each group on day 14, $F = 11.46$, $P < 0.05$; (C) Relative expression levels of VEGF mRNA in each group on day 28, $F = 14.71$, $P < 0.05$.

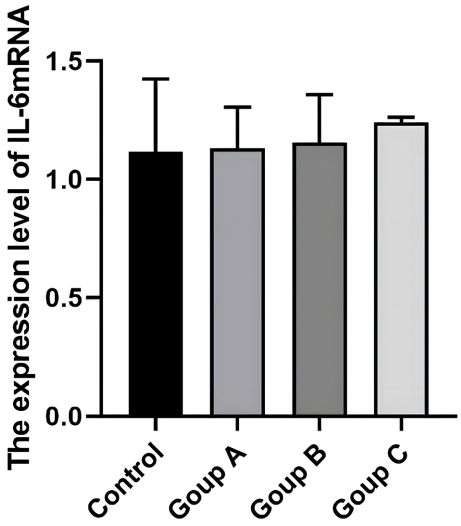

Figure 4. RT-PCR results showing the expression of IL-6 mRNA in various injection sites of vaginal tissues.

β-glucan itself possesses a powerful triple helical structure, forming a cylindrical triple helix structure in aqueous solutions with significant rigidity and structural stability, allowing it to remain stable in subcutaneous tissues. Due to its non-toxic, good biocompatibility, and biodegradability, β-glucan is widely used in various industries such as food, cosmetics, and pharmaceuticals [9]. Studies have shown that β-glucan has potential clinical applications in the treatment of HPV infection and vaginal and cervical inflammation due to its physical and biological characteristics [10]. Clinical trials conducted by the Drug Research Laboratory of the Institute of Dermatology, Chinese Academy of Medical Sciences, in collaboration with the Affiliated Hospital of Changchun University of Traditional Chinese Medicine and Jilin Provincial Institute of Traditional Chinese Medicine, have shown the effectiveness of β-glucan in treating vaginal and cer-

vical epithelial injuries caused by HPV infection [11].

In intestinal mucosal repair, it has been demonstrated that β-glucan can reduce damage to the intestinal mucosa caused by pathogenic bacteria, enhance the body's immune response, exhibit antioxidant properties, and regulate the intestinal flora. β-glucan can specifically bind to monocytes, macrophages, neutrophils, and natural killer cells, thereby enhancing humoral and cellular immunity [12] [13] [14] [15]. In promoting tissue regeneration, β-glucan accelerates wound healing by promoting the migration of macrophages near the wound site, inducing the secretion of cytokines such as TNF-α, IL-6, VEGF, and IL-10, and inducing the transformation of M0 and M2 macrophages into M1 macrophages, enhancing their role in wound repair [4]. Studies have shown that human fibroblasts have a β-glucan receptor on their surface, which, upon binding with the corresponding β-glucan ligand, can stimulate the activation of transcription factors activating protein 21 (AP 21) and specificity protein 1 (SP1). β-glucan can also stimulate the secretion of neurotrophic factor 3 (NTF-3), platelet-derived growth factor PDGF-2A, and PDGF-2B, which play crucial roles in promoting wound repair [5].

In this experiment, we observed an increase in the number of new blood vessels, fibroblasts, collagen density, and macrophage activity near the injured vaginal mucosal epithelium in rabbits treated with β-glucan. The number and activity of macrophages near the injured vaginal mucosal epithelium were significantly higher in the experimental group than in the control group, indicating that β-glucan stimulated the activity of macrophages and fibroblasts. This finding is consistent with the results of cell experiments conducted by Qiu and Fusté N P. Similar to previous studies, our experiment found that on day 28, the expression of the inflammatory factor IL-6 in vaginal tissues of the experimental group was significantly different from that in the normal control group, indicating that β-glucan itself did not cause significant inflammation or rejection reactions.

5. Conclusion

In conclusion, β-glucan has a role in promoting the repair of damaged vaginal mucosa. Despite the numerous benefits of β-glucan, its poor solubility, determined by its physical properties, not only limits its application but also hinders its physiological functions in the body. Current research focuses on enhancing its physiological effects in the body through various modifications [16] [17]. This study only investigated the reparative effect of pure β-glucan in rat vaginal tissue. The limitation of this experiment lies in the investigation of only one concentration and one molecular weight of β-glucan. Different molecular weights and concentrations of β-glucan exhibit varied physicochemical properties and effects [16] [17]. Previous studies in intestinal mucosal repair have shown that different molar concentrations of β-glucan have diverse effects on wound healing [18]. Future research should further explore the specific effects of

β-glucan of different molecular weights and concentrations on vaginal mucosal repair. Furthermore, studies conducted domestically and internationally have indicated that *β*-glucan has a good reparative effect on vaginal and cervical injuries and associated vaginal inflammation caused by HPV infection. This study did not conduct relevant validation, and further verification is needed in the future.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Authors' Contributions

Song Fei contributed in protocol development, data collection and management, and manuscript writing. Weidong Wu contributed in data collection and analysis and manuscript revisiting. Ying Wang contributed in protocol development, data management and analysis, and manuscript writing. Dan Li contributed in manuscript revisiting. Bo Jin contributed in manuscript editing and revisiting.

Conflicts of Interest

The authors declare that there is no conflict of interest.

References

[1] Peng, H.F., Yan, X.N. and Xu, C.L. (2020) Menopausal Hormone Therapy and Osteoporosis. *Chinese Journal of Practical Gynecology and Obstetrics*, **36**, 230-233.

[2] Lou, C.H., Lan, Y.B., Ma, L.J., *et al.* (2020) Application and Research Progress of Local Estrogen in Postmenopausal Vaginal Atrophy. *Chinese Journal of Maternal and Child Health Research*, **31**, 1562-1567.

[3] Renke, G., Baesso, T., Paes, R., *et al.* (2022) *B*-Glucan "Trained Immunity" Immunomodulatory Properties Potentiate Tissue Wound Management and Accelerate Fitness Recover. *Immunotargets and Therapy*, **11**, 67-73. https://doi.org/10.2147/ITT.S381145

[4] Qiu, M., Li, B., Geng, D., *et al.* (2022) Aminated *B*-Glucan with Immunostimulating Activities and Collagen Composite Sponge for Wound Repair. *International Journal of Biological Macromolecules*, **221**, 193-203. https://doi.org/10.1016/j.ijbiomac.2022.08.202

[5] FustÉ, N.P., Guasch, M., Guillen, P., *et al.* (2019) Barley *B*-Glucan Accelerates Wound Healing by Favoring Migration versus Proliferation of Human Dermal Fibroblasts. *Carbohydrate Polymers*, **210**, 389-398. https://doi.org/10.1016/j.carbpol.2019.01.090

[6] Stanley, M. (2010) Pathology and Epidemiology of HPV Infection in Females. *Gynecologic Oncology*, **117**, S5-10. https://doi.org/10.1016/j.ygyno.2010.01.024

[7] Sung, H., Ferlay, J., Siegel R, L., *et al.* (2021) Global Cancer Statistics 2020: Globocan Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. *Ca*: *A Cancer Journal for Clinicians*, **71**, 209-249. https://doi.org/10.3322/caac.21660

[8] Wang, Z., Guo, E., Yang, B., *et al.* (2017) Trends and Age-Period-Cohort Effects on Mortality of the Three Major Gynecologic Cancers in China from 1990 to 2019: Cervical, Ovarian and Uterine Cancer. *Gynecologic Oncology*, **163**, 358-363. https://doi.org/10.1016/j.ygyno.2021.08.029

[9] Bashir, K.M.I. and Choi, J.S. (2017) Clinical and Physiological Perspectives of *B*-Glucans: The Past, Present, and Future. *International Journal of Molecular Sciences*, **18**, E1906. https://doi.org/10.3390/ijms18091906

[10] Yu, J., Liu, L., Chen, X.S., *et al.* (2019) Clinical Study on the Use of Anti-HPV*B*-Pectin Dressings in the Treatment of Chronic Cervicitis Complicated with HPV Infection. *Practical Journal of Gynecological Endocrinology*, **6**, 4-6.

[11] Lavitola, G., Della Corte, L., De Rosa, N., *et al.* (2020) Effects on Vaginal Microbiota Restoration and Cervical Epithelialization in Positive HPV Patients Undergoing Vaginal Treatment with Carboxy-Methyl-Beta-Glucan. *Biomed Research International*, **2020**, 5476389. https://doi.org/10.1155/2020/5476389

[12] Xie, Y., Shao, F., *et al.* (2023) Whole *B*-Glucan Particle Attenuates Aom/Dss-Induced Colorectal Tumorigenesis in Mice via Inhibition of Intestinal Inflammation. *Frontiers in Pharmacology*, **14**, 1017475. https://doi.org/10.3389/fphar.2023.1017475

[13] Han, X., Luo, R., Ye, N., *et al.* (2022) Research Progress on Natural *B*-Glucan In intestinal Diseases. *International Journal of Biological Macromolecules*, **219**, 1244-1260. https://doi.org/10.1016/j.ijbiomac.2022.08.173

[14] Kopiasz, Ł., Dziendzikowska, K., Gajewska, M., *et al.* (2021) Effects of Dietary Oat Beta-Glucans on Colon Apoptosis and Autophagy Through TLRS and Dectin-1 Signaling Pathways-Crohn's Disease Model Study. *Nutrients*, **13**, 321. https://doi.org/10.3390/nu13020321

[15] Huang, H.H., Lee, Y.C. and Chen, C.Y. (2018) Effects of Burns on Gut Motor and Mucosa Functions. *Neuropeptides*, **72**, 47-57. https://doi.org/10.1016/j.npep.2018.09.004

[16] Du, B., Meenu, M., Liu, H., *et al.* (2019) A Concise Review on the Molecular Structure and Function Relationship of *B*-Glucan. *International Journal of Molecular Sciences*, **20**, E4032. https://doi.org/10.3390/ijms20164032

[17] Yuan, H., Lan, P., He, Y., *et al.* (2019) Effect of The Modifications on the Physicochemical and Biological Properties of *B*-Glucan-A Critical Review. *Molecules*, **25**, E57. https://doi.org/10.3390/molecules25010057

[18] Abo Ghanima, M.M., Abd El-Aziz, A.H., *et al.* (2020) *B*-Glucan Administration Improves Growth Performance and Gut Health in New Zealand White and APRI Rabbits with Different Breed Responses. *PLOS ONE*, **15**, E0234076. https://doi.org/10.1371/journal.pone.0234076