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Article

Tanshinone IIA Pretreatment Renders Free Flaps against Hypoxic Injury through Activating Wnt Signaling and Upregulating Stem Cell-Related Biomarkers

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Abstract: Partial or total flap necrosis after flap transplantation is sometimes clinically encountered in reconstructive surgery, often as a result of a period of hypoxia that exceeds the tolerance of the flap tissue. In this study, we determine whether tanshinone IIA (TSA) pretreatment can protect flap tissue against hypoxic injury and improve its viability. Primary epithelial cells isolated from the dorsal skin of mice were pretreated with TSA for two weeks. Cell counting kit-8 and Trypan Blue assays were carried out to examine the proliferation of TSA-pretreated cells after exposure to cobalt chloride. Then, Polymerase chain reaction and Western blot analysis were used to determine the expression of β -catenin, GSK-3 β , SOX2, and OCT4 in TSA-treated cells. *In vivo*, after mice were pretreated with TSA for two weeks, a reproducible ischemic flap model was implemented,

and the area of surviving tissue in the transplanted flaps was measured. Immunohistochemistry was also conducted to examine the related biomarkers mentioned above. Results show that epidermal cells, pretreated with TSA, showed enhanced resistance to hypoxia. Activation of the Wnt signaling pathway in TSA-pretreated cells was characterized by the upregulation of β -catenin and the downregulation of GSK-3 β . The expression of SOX2 and OCT4 controlled by Wnt signaling were also found higher in TSA pretreated epithelial cells. In the reproducible ischaemic flap model, pretreatment with TSA enhanced resistance to hypoxia and increased the area of surviving tissue in transplanted flaps. The expression of Wnt signaling pathway components, stem-cell related biomarkers, and CD34, which are involved in the regeneration of blood vessels, was also upregulated in TSA-pretreated flap tissue. The results show that TSA pretreatment protects free flaps against hypoxic injury and increases the area of surviving tissue by activating Wnt signaling and upregulating stem cell-related biomarkers.

Keywords: free flap; epithelial cell; traditional Chinese medicine; Wnt; stem cell

1. Introduction

In plastic surgery, flaps are routinely used for coverage of tissue defects resulting from trauma, ablative surgery, or congenital malformation. While a large number of medical professions are clinically confronted with the effect of partially or totally flap necrosis after flap operation [1,2]. As flap transplantation is becoming more widely used in reconstructive surgery, it is important to understand the mechanism of flap necrosis so that it can be prevented.

Ischemia occurs when there is inadequate blood flow to a specific tissue area after flap reconstruction, and it is an underlying cause of tissue hypoxia and flap loss [3,4]. When hypoxia exceeds the tolerance level of epithelial cells, necrosis or scarring of flap tissue occurs. Although not all epithelial skin cells exhibit the same resilience to hypoxia, they are a promising source of stem cells that are resistant to noxious surroundings, exhibit anti-apoptotic characteristics, and possess enhanced DNA repair machinery, which are essential properties for cell regeneration and repair [5]. Stem cells are defined by their capacity for self-renewal and their resistance to maladaptive microenvironments, including hypoxia, and there is now compelling evidence that multipotent stem cells contribute to recovery from hypoxia and epidermal repair [6,7].

Nowadays, understanding of the epithelial stem cells, together with the exploration of stem cell related signaling pathways that control the reconstruction of skin, open a new door to the flap surgery. Wnt signaling, which is required for tissue repair and regeneration, is involved in the growth of various cell types, and plays a critical role in stem cell maintenance and differentiation [8,9]. SOX2 and OCT4, which are regulated by Wnt signaling, are markers of somatic cell stemness [10]. Takahashi *et al.*, [11] induced pluripotent stem cells by transducing adult human dermal fibroblasts with defined factors, such as OCT4 and SOX2. When Wnt signaling is reduced, its associated biomarkers, such as OCT4, SOX2, and β -catenin, are downregulated, and cell resistance to hypoxia and capacity for regeneration

are also impaired [12,13]. For instance, in zebrafish eye, the inhibition of Wnt signaling results in an abrupt cessation of the normally continuous regeneration of the retina [14]. Additionally, inhibition of Wnt signaling during skin wounding in mice prevents the formation of epithelial appendages, including hair and sweat glands, which results in prominent scarring of the epidermis [15]. By contrast, elevating Wnt signaling within the wound site promotes the growth of adult skin [15]. Several studies also show that increasing Wnt signaling stimulates healing of many different injuries, including bone fractures, retinal damage, skin wounding, and myocardial infarction [16]. If Wnt signaling is required for tissue regeneration, can we find a convenient and effective way to elevate Wnt signaling in epithelial skin cells with limited regenerative capacity to improve the healing response?

Tanshinone IIA (TSA) is the most abundant diterpene quinone isolated from Danshen (*Salvia miltiorrhiza*) and has been used to treat cardiovascular diseases for more than 2000 years in China. Over the last decade, interest in the mechanism of its versatile protective effects in neurodegenerative diseases, metabolic abnormalities, and ischemic damage has been growing [17–23]. For instance, Zhang *et al.*, demonstrated that TSA enhances cell resistance to hypoxic insult by upregulating miR-133 expression through activation of the mitogen-activated protein kinase (MAPK)/extracellular signal-related kinase (ERK) pathway in neonatal cardiomyocytes [24]. Chen *et al.*, showed that TSA has neuroprotective effects against ischemia/reperfusion (I/R) injury through the inhibition of macrophage migration inhibitory factor (MIF) and the release of tumor necrosis factor- α and interleukin-6 in rats [17]. Furthermore, Zhu *et al.*, found that TSA protects rat primary hepatocytes against carbon tetrachloride toxicity via inhibiting mitochondria permeability transition [25].

In the present study, we investigated whether TSA could protect free flaps against hypoxia-induced necrosis and improve tissue viability in the hypoxic zone. Next, we examined the regulation of the Wnt signaling pathway and stem cell-related biomarkers in epithelial cells and tissue. Finally, we tested whether TSA therapy activates the Wnt signaling pathway and upregulates stem cell-related biomarkers in epithelial cells.

2. Results

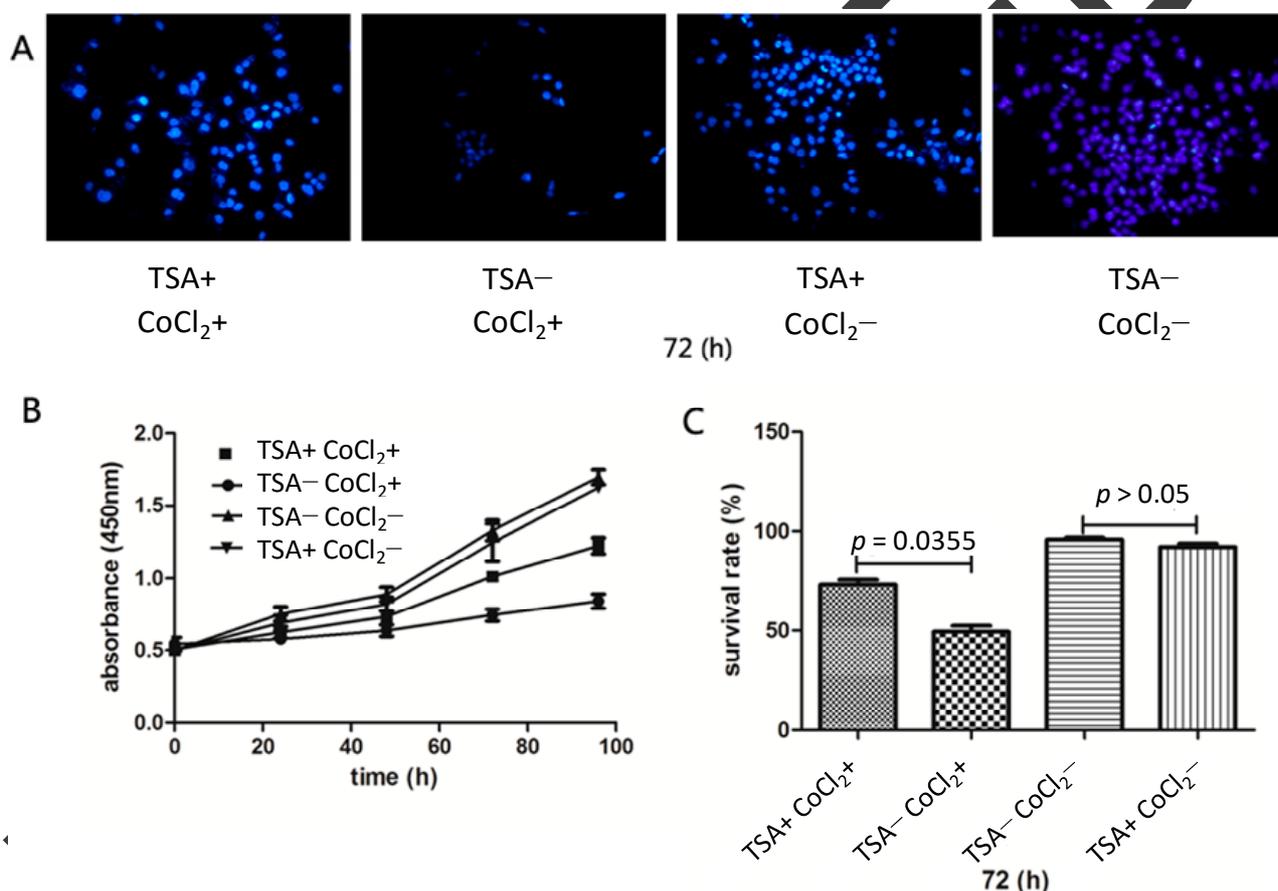
2.1. Epithelial Skin Cells Showed Enhanced Resistance to Hypoxia after Tanshinone IIA (TSA) Pretreatment

The results are presented in Figure 1. Isolated epithelial cells that were pretreated by TSA (2 mg/L) for two weeks demonstrated enhanced resistance to CoCl₂ which was used for mimic hypoxia *in vitro*.

4'-6-diamidino-2-phenylindole (DAPI) staining showed that isolated epithelial skin cells that were pretreated with TSA (2 mg/L) for two weeks exhibited enhanced resistance to CoCl₂. That is, the viability of control epithelial cells declined after 72 h of treatment with CoCl₂, whereas epithelial cells pretreated with TSA showed higher viability. As to epithelial cells pretreated with TSA, no phenomenon of accelerated proliferation manifested (Figure 1A). A CCK-8 assay showed enhanced proliferation of TSA-pretreated cells after CoCl₂ treatment compared with control cells for 72 h (0.74 ± 0.02 vs. 1.01 ± 0.31 , $p = 0.0313$; Figure 1B). Using a Trypan Blue assay, we determined the

exact proportion of viable epithelial cells after treatment with CoCl_2 and found that the survival rate of TSA-pretreated epithelial cells was higher than that of control cells after treatment with CoCl_2 for 72 h ($49.33\% \pm 7.29\%$ vs. $73.17\% \pm 6.05\%$, $p = 0.0355$; Figure 1C).

Figure 1. Isolated epidermal cells that were pretreated with tanshinone IIA (TSA) for two weeks showed enhanced resistance to CoCl_2 , which was used to mimic hypoxia *in vitro*. After exposure to CoCl_2 for 72 h, nuclear 4'-6-diamidino-2-phenylindole (DAPI) staining revealed larger number of TSA-pretreated cells than control cells (A); A CCK-8 assay demonstrated that TSA-pretreated cells showed more proliferation than control cells after exposure to CoCl_2 for 96 h (B); A Trypan Blue assay showed that the survival rate of TSA-pretreated cells was higher than that of control cells after treatment with CoCl_2 in the 72 h time point (C).

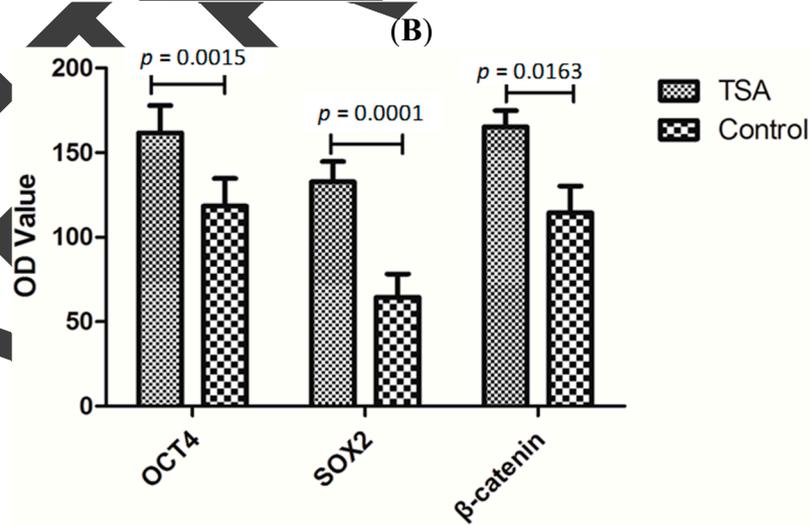
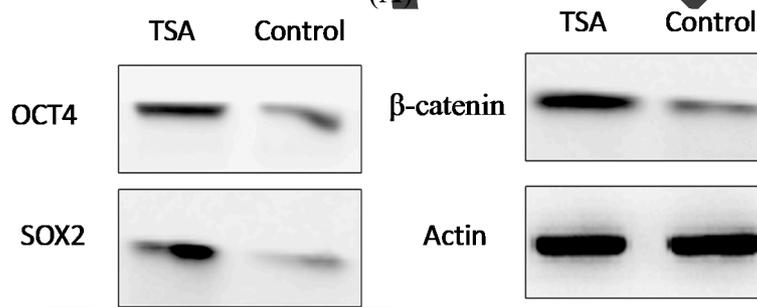
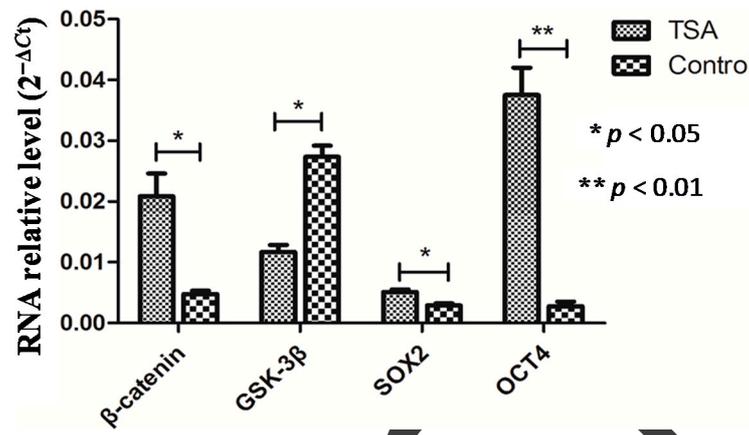


2.2. Epithelial Cells Showed Upregulated Wnt Signaling and Increased Expression of Stem Cell Related Biomarkers after TSA Pretreatment

The results are presented in Figure 2. The Wnt signaling pathway is characterized by the expression of several biomarkers, such as GSK-3 β and β -catenin, which are regarded as being critical for stem cell regulation. qRT-PCR revealed an upregulation of β -catenin (0.0048 ± 0.0005 vs. 0.0200 ± 0.0037 , $p = 0.014$) and a downregulation of GSK-3 β (0.0273 ± 0.0018 vs. 0.0117 ± 0.0012 , $p = 0.012$) in TSA-pretreated epithelial cells compared with control cells (Figure 2A). The expression of stem cell markers SOX2 (0.0029 ± 0.0003 vs. 0.0051 ± 0.0004 , $p = 0.032$), and OCT4 (0.0027 ± 0.0008 vs.

0.0375 ± 0.0045, $p = 0.002$) was higher in TSA-pretreated cells than in control cells. Similar results were found using Western blot analysis (Figure 2B).

Figure 2. Epidermal cells showed activated Wnt signaling and enhanced stemness after pretreatment with TSA. qRT-PCR showed upregulation of β -catenin, SOX2, OCT4 and downregulation of GSK-3 β in TSA-pretreated epithelial cells compared with control cells (A); Similar results were obtained using Western blot analysis (B,C).

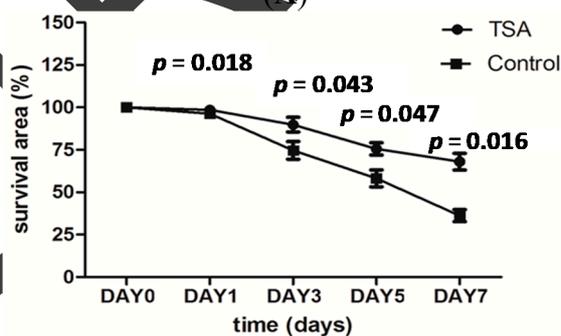
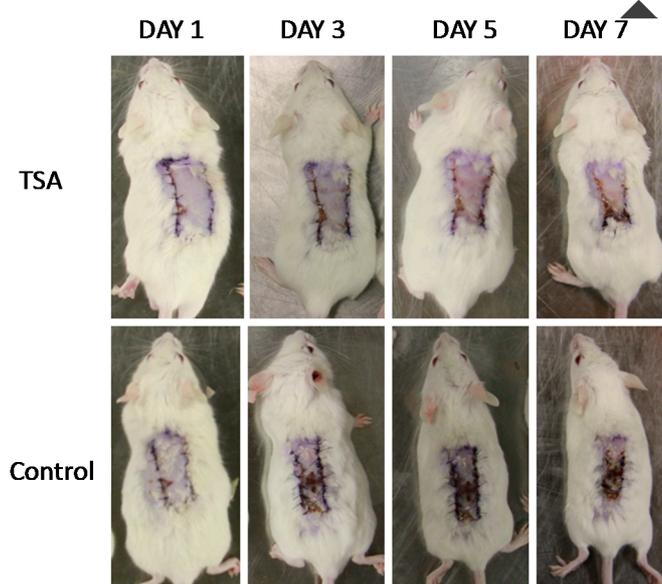


2.3. TSA Pretreatment Resulted in Reduced Flap Necrosis in an Ischaemic Flap Model

The results are presented in Figure 3. Pretreatment with TSA (10 mg/kg/day) enhanced tissue resistance to hypoxia and increased tissue survival area in an ischemic flap model (Figure 3A). That is, on the first day after surgery, there was no significant difference between TSA pretreatment and control

groups in the area of surviving tissue ($96.34\% \pm 2.19\%$ vs. $98.56\% \pm 1.69\%$, $p = 0.183$; Figure 3B). On the third day, however, the ischemic flaps in the control group began to undergo necrosis, whereas the flaps in the TSA pretreatment group showed an enhanced resistance to hypoxia as evidenced by a greater tissue survival area ($73.72\% \pm 6.09\%$ vs. $89.82\% \pm 7.48\%$, $p = 0.043$). On the fifth day after surgery, flap necrosis in TSA-pretreated mice advanced more slowly than control mice ($58.14\% \pm 8.67\%$ vs. $75.54\% \pm 6.20\%$, $p = 0.047$). Finally, on the seventh day, flaps in TSA-pretreated mice showed a greater survival area than control mice ($35.91\% \pm 10.22\%$ vs. $68.02\% \pm 8.89\%$, $p = 0.016$).

Figure 3. Pretreatment with TSA enhanced resistance to hypoxia (A) and resulted in larger areas of surviving tissue (B) in an ischemic flap model.

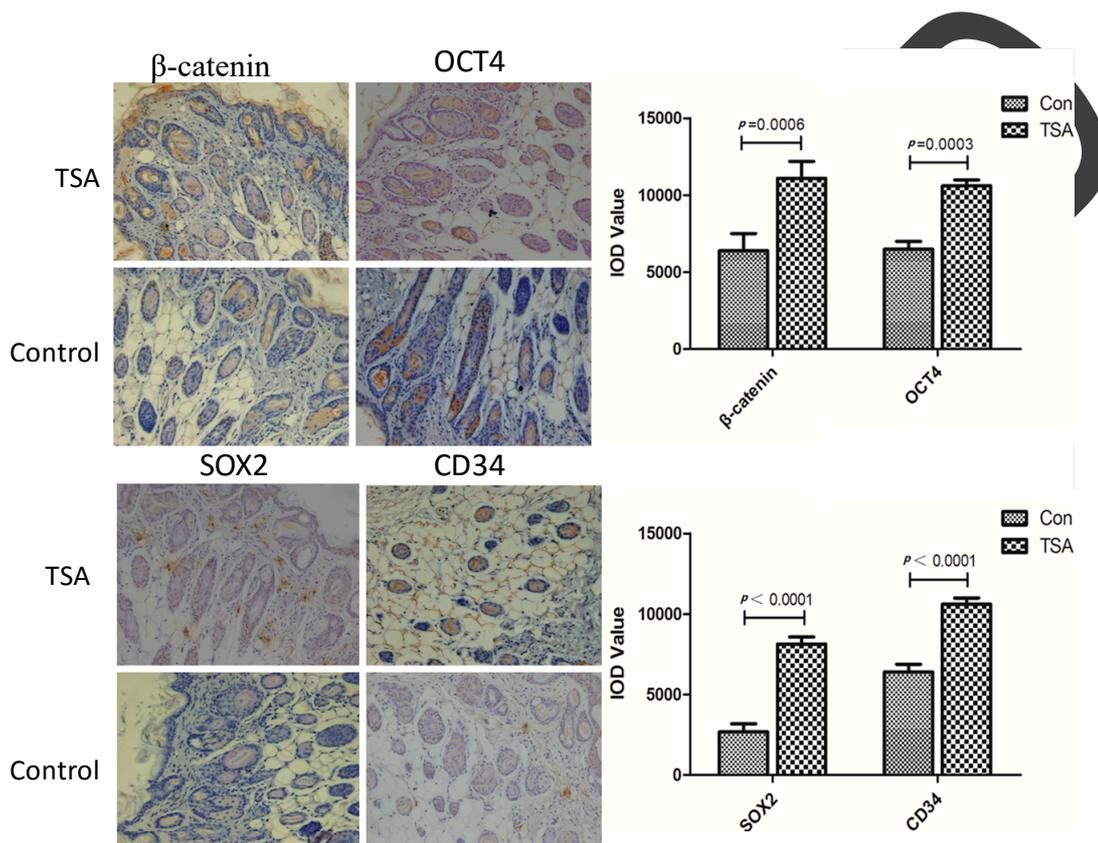


2.4. TSA Treatment Upregulated Wnt Signaling and Increased the Expression of Stem Cell-Related Markers in Epithelial Skin Tissue

The results are presented in Figure 4. To investigate the mechanism by which TSA protects against ischemia-induced flap necrosis, we examined components of the Wnt signaling pathway and stem cell-related biomarkers in epithelial skin tissue using immunohistochemistry. We observed a significantly increased expression of β -catenin in epithelial skin tissues after pretreatment with TSA for two weeks ($11,094 \pm 2698$ vs. 6399 ± 2740 , $p = 0.0006$). The stemness related biomarkers, such as SOX2 (7508 ± 2298 vs. 3102 ± 1644 , $p < 0.0001$), and OCT4 ($10,939 \pm 1698$ vs. 6488 ± 1244 , $p = 0.0003$),

were upregulated significantly after pretreated by TSA with the same trend of activated Wnt signaling. CD34 ($11,795 \pm 1398$ vs. 5988 ± 1544 , $p < 0.0001$), which is represented the microvessel density (MVD) was also raised after pretreatment with TSA.

Figure 4. TSA pretreatment showed the up-regulated of β -catenin and the increased expression of stemness related markers, such as OCT4 and SOX2 in epithelial skin tissues. CD34 which is represented the microvessel density (MVD) was also raised after pretreatment with TSA.



3. Discussion

Human skin forms a large and important physical barrier between the body and its environment. In plastic surgery, tissue defects resulting from trauma, ablative surgery, or congenital malformation are frequently encountered, therefore flap transplantation is routinely used for re-establishing the epithelial barrier after injury. However, delayed healing or necrosis sometimes occurs when a free flap is transplanted from one area to another, which can increase the risk of infection and scar tissue formation or even lead to patient morbidity. Therefore, it is important for surgeons, who perform flap surgery, to have more knowledge of flap necrosis and how it can be prevented.

Ischemia is a condition of inadequate blood flow to a specific tissue area, which can lead to tissue hypoxia [3,4]. When the period of hypoxia exceeds the tolerance of transplanted free flap tissue, necrosis will occur. Whereas common epithelial skin cells show poor survivability of hypoxia, epithelial stem cells show a powerful resistance to maladaptive microenvironments [26]. In most organ systems, stem cells are thought to be the source of undifferentiated cells needed to maintain tissue

homeostasis and to repair injury. One of the critical signaling pathways that regulates stem cell properties and plays an important role in skin organogenesis and regeneration is Wnt signaling, with several studies showing that Wnt signaling plays a critical role in tissue injury repair [14–16]. Phase I/II clinical trials demonstrate that enhancing Wnt signaling via antibody-mediated repression of Dkk1 is an effective means of stimulating new bone formation [27]. In addition, in states of debilitating chronic injury, transiently elevating Wnt signaling is beneficial for tissue regeneration [28]. In the present experiment, we found that isolated epidermal cells that were pretreated with TSA showed upregulated Wnt signaling and enhanced resistance to hypoxia *in vitro*. We also found less necrosis and upregulated Wnt signaling in flap tissue after TSA pretreatment *in vivo*. Thus, although endogenous Wnt signaling is a prerequisite for tissue repair, there are obvious caveats to this general conclusion because of limited Wnt signaling activation in epithelial cells [16,29,30]. Therefore, finding an effective and convenient way to pre-generate a sufficient amount of Wnt signaling activation may be important for injury restoration in hypoxic flaps.

Traditional Chinese medicine, a type of alternative and complementary medicine, is commonly used in Asian countries to treat cancer, as well as cardiovascular, cerebrovascular, metabolic, and neurodegenerative diseases. TSA, which is isolated from Danshen (*Salvia miltiorrhiza*), has multiple targets including transcription factors, scavenger receptors, ion channels, kinases, pro- and anti-apoptotic proteins, growth factors, inflammatory mediators, and microRNA [31]. For instance, Tang *et al.*, showed that the neuroprotective role of TSA monotherapy is mediated by the PI3K/AKT signaling pathway [32]. Chen *et al.*, found that TSA alleviates the proinflammatory responses associated with I/R-induced injury by downregulating MIF expression [17]. In addition, Zhang *et al.*, showed that TSA enhances cell resistance to hypoxic insult by upregulating miR-133 expression through activation of MAPK-ERK1/2 [24]. In the present study, we found that epithelial skin cells, pretreated with, TSA showed greater viability than control cells after CoCl₂ treatment *in vitro*. We also found that pretreatment with TSA enhanced tissue resistance to hypoxia and resulted in larger areas of surviving tissue in an *in vivo* ischemic flap model. Furthermore, we demonstrated that activation of the Wnt signaling pathway and increased expression of stem cell-related markers such as SOX2 and OCT4 are involved in the effect of TSA on epithelial cells and tissue.

In summary, we provide experimental evidence that TSA pretreatment protects against necrosis of transplanted flap tissue in mice, suggesting that TSA pretreatment might be a potential way to improve the success of free flap surgery in humans. However, several fundamental questions remain concerning the ability of TSA to increase the stemness of epithelial skin cells. Therefore, additional animal models of ischemia should be utilized to further investigate the relationship between TSA and stemness, and future studies could also determine whether TSA can be clinically useful for treating human ischemic tissues and organs.

4. Experimental Section

4.1. Regents and Antibodies

TSA injection (sulfotanshinone sodium injection, 5 mg/mL; First Biochemical Pharmaceutical Co., Ltd., Shanghai, China) was used in the *in vivo* experiments. TSA monomer (Sigma, St. Louis, MO,

USA), a lyophilized powder (99.99% purity), which was first dissolved in dimethyl sulfoxide, and then diluted with phosphate-buffered saline (PBS) to the required concentration, was used in the *in vitro* experiments. Antibodies used for immunoblotting and/or immunohistochemistry were as follows: mouse anti-human monoclonal β -catenin (Abcam, Cambridge, MA, USA), rabbit anti-human polyclonal glycogen synthase kinase-3 β (GSK-3 β ; Epitomics, Burlingame, CA, USA), rabbit anti-human polyclonal SOX2 (Epitomics, Burlingame, CA, USA), mouse anti-human monoclonal OCT4 (Abcam, Cambridge, MA, USA), mouse anti-human monoclonal CD34 (Abcam, Cambridge, MA, USA), and mouse anti-human monoclonal actin (Beyotime, Shanghai, China).

4.2. Isolation and Preparation of Epidermal Cells

To obtain epithelial cells of high purity, the dorsal skin of male BALB/C mice was processed as previously described with slight modifications [33]. Immediately after mice were killed by cervical dislocation, the shaved dorsal skin was treated for 5 min with a depilatory agent, rinsed under running water, excised, and placed in ice-cold Dulbecco's Modified Eagle's Medium (DMEM, Gibco, Gaithersburg, MD, USA). The subcutis was removed by scraping with a razor blade. The skin, consisting of dermis and epidermis, was minced with scissors, and the pieces were washed once with DMEM. The pieces of skin were excised and cut into smaller pieces in collagenase buffer containing 0.05% collagenase IV (Sigma, St. Louis, MO, USA) and 0.25% trypsin (Sigma, St. Louis, MO, USA) for 2 h. The digestion solution was filtered through nylon gauze, and the filtrate was sedimented twice by centrifugation at $70\times g$ for 5 min at 4 °C. Finally, cells were collected, counted, and resuspended with DMEM containing 10% fetal bovine serum at a concentration of 5×10^5 in T₂₅ flasks. Two days later, cells were digested with 0.25% trypsin and washed gently with PBS to remove fibroblasts resulting from the strong adhesion of epithelial cells. Finally, cells were digested and passaged by repeating the above steps three times to obtain epithelial cells with high purity.

4.3. Cell Proliferation Assay

Primary epithelial cells were pretreated with TSA (2 mg/L) for 2 weeks and transferred to glass cover slips and grown to 50% confluence. Cells were exposed to cobalt chloride (CoCl₂ 50 μ mol/L) *in vitro* for 72 h to mimic hypoxia, fixed, permeabilized, and stained with 4'-6-diamidino-2-phenylindole (DAPI, Beyotime, Shanghai, China) to visualize cell nuclei using fluorescence microscopy (Olympus, Tokyo, Japan).

Other primary epithelial cells were pretreated with TSA (2 mg/L) for 2 weeks, and then exposed to CoCl₂ (50 μ mol/L) *in vitro* for 24, 48, 72, or 96 h. Cell proliferation was assessed using the Cell counting kit-8 (CCK-8; Dojindo Molecular Technologies, Inc., Kumamoto, Japan). Results are expressed as the absorbance of each well at 450 nm (OD₄₅₀). The half maximal inhibitory concentration (IC₅₀) of CoCl₂ was 179 μ mol/L for a 72 h treatment time (data not shown). Almost half of the primary epithelial cells died and floated in the culture flasks at this concentration. After several preliminary experiments, a concentration of 50 μ mol/L, which is far below the IC₅₀, was selected to mimic hypoxia.

4.4. Trypan Blue Assay

Primary epithelial cells were pretreated with TSA for 2 weeks and exposed to CoCl₂ (50 μmol/L) for 72 h. Cells were digested and suspended in PBS. Cell suspension solution (0.5 mL) and 0.4% Trypan Blue solution (0.5 mL) were added to a test tube and mixed thoroughly for 5 min to stain non-viable cells blue. Separate counting of viable and non-viable cells was performed, and cell viability (%) was calculated as (viable cells/(viable cells + non-viable cells)) × 100%.

4.5. Quantitative Real-Time Polymerase Chain Reaction

Total RNA was extracted from TSA-treated primary epithelial cells and their parental cell lines using Trizol reagent (Invitrogen, Grand Island, NY, USA). Total RNA was reversely transcribed using a Prime Script RT reagent kit (TaKaRa, Biotechnology, Inc., Dalian, China). mRNA expression was determined by qRT-PCR using SYBR Premix Ex Taq II (TaKaRa). The primers used for the amplification of target genes were as follows: β-catenin forward primer 5'-ATGGCTACTCAAGCTGAC-3' and reverse primer 5'-CAGCACTTTCAGCACTCTGC-3'; GSK-3β forward primer 5'-GTTGTGGAAATAATAAAGG-3' and reverse primer 5'-AAGTTGAAGAGGGCAGGT-3'; SOX2 forward primer 5'-GTGGTGGTACGGGAAATCAC-3' and reverse primer 5'-TAGCCAGGTTTCGAGAATCCA-3'; OCT4 forward primer 5'-CTGGGTTGATCCTCGGACCT-3' and reverse primer 5'-CACAGAACTCATAACGGCGGG-3'; β-actin forward primer 5'-CAATGTGCCGAGGACTTTG-3' and reverse primer 5'-CATTCTCCTTAGAGAGAAGTGG-3'.

4.6. Western Blot

Expression of β-catenin, SOX2, OCT4 in TSA-treated epithelial cells was detected by Western blot analysis as previously described with slight modifications [34]. The primary antibodies were diluted according to the manufacturer's instructions. The concentration of protein extracted from epithelial cells was determined using the BCA Protein assay kit (Beyotime).

4.7. Animals and Ethics Statement

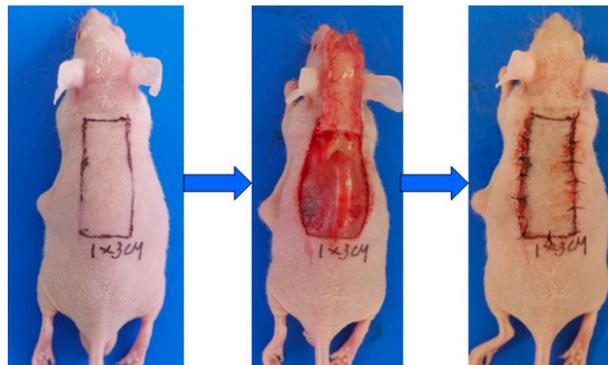
BALB/c mice (aged 4–6 weeks and weighing approximately 20 g) were obtained from the Chinese Academy of Science and maintained under standard pathogen-free conditions. The experimental protocol was approved by the Shanghai Medical Experimental Animal Care Commission. All surgery was performed under sodium pentobarbital anesthesia, and all efforts were made to minimize suffering.

4.8. In Vivo Evaluation of Free Flap Survival

Twelve BALB/c mice were selected and randomly divided into TSA group and control group. TSA group mice were treated intraperitoneally (i.p.) with 0.1 mL TSA (10 mg/kg/day) for 28 days which was diluted by 5% glucose solution (5% GS). And control group mice were just treated with 0.1 mL 5% GS. The reproducible ischaemic flap model was established, as previously described, with slight modifications [35] (showed in Figure 5). The dorsal skin area of BALB/c mice was depilated

and cleansed. The dorsal random pattern flaps measuring 1 cm × 3 cm were constructed. After the flap was elevated, 1 cm × 0.2 cm epithelial skin tissues in the distal end of the flap were excised for immunohistochemistry, and the main vessels in the flap were coagulated by cautery. Finally, the flap was repositioned and sutured. The percentage of flap survival area was calculated with standard grid paper 7 days after surgery.

Figure 5. The reproducible ischaemic flap models were established in 3 cm length and 1 cm width with the main vessels coagulated by cautery in the flap.



4.9. Immunohistochemistry

Epithelial skin tissues were fixed, embedded, and sliced into 5 μm thick sections. Immunohistochemical staining of β -catenin, GSK-3 β , SOX2, OCT4, and CD34 was carried out using a standard protocol with slight modifications [36]. And integrated optical density values (IOD) were obtained for immunohistochemistry quantification by Image Pro Plus software (Media Cybernetics, Rockville, MD, USA).

4.10. Statistical Analysis

Data are expressed as mean \pm standard error of the mean (SEM). Student's *t*-tests were used to compare groups. Statistical analysis was performed using SPSS 17.0 software for Windows (SPSS Inc., Chicago, IL, USA). $p < 0.05$ was considered statistically significant.

5. Conclusions

TSA pretreatment renders free flaps against hypoxic injury and increases the area of surviving tissue in transplanted flaps by activating Wnt signaling and upregulating stem cell-related biomarkers in epithelial skin cells.

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Author Contributions

Zihan Xu, Lijun Wu, Yaowen Sun, Yadong Guo, Gaoping Qin, Shengzhi Mu, Ronghui Fan, Benfeng Wang, Wenjie Gao, and Zhenxin Zhang. contributed to the study design, analysis, and interpretation of data; Zhenxin Zhang conceived the study; Zihan Xu and Lijun Wu performed the experiments; Yaowen Sun, Gaoping Qin, Shengzhi Mu and Ronghui Fan participated in the isolation of primary epithelial cells; Wenjie Gao participated in statistical analysis; Zihan Xu drafted the manuscript; Zhenxin Zhang carried out the revision and provided important suggestions. All authors approved the final manuscript.

Abbreviations

TSA, Tanshinone IIA; I/R, ischemia/reperfusion; MIF, macrophage migration inhibitory factor; DAPI, 4'-6-diamidino-2-phenylindole; FBS, fetal bovine serum; CoCl₂, cobalt chloride; TCM, traditional Chinese medicines; MVD, microvessel density.

Conflicts of Interest

The authors declare no conflict of interest.

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