Acupuncture and Herbal Medicine

Formulations of traditional Chinese medicine for the prevention and treatment of radiation-induced injury

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Abstract

The likelihood of radiation-induced injury (RII) has increased. Currently, the chemical drugs used to prevent and control radiation damage have some drawbacks, such as high toxicity, which can also have other side effects on the body. However, many traditional Chinese medicine (TCM) monomers, single TCM, and compound TCM preparations have shown good therapeutic effects against radiation damage with increased safety and minimal adverse reactions. Therefore, new anti-RII TCMs must be explored and developed. This study reviewed the TCM preparations for the prevention and treatment of RII and their mechanisms of action to provide a better theoretical basis for research on the prevention and treatment of RII. TCM is an efficient, safe, and convenient strategy for the prevention and treatment of RII.

Keywords: Formulations, Prevention and treatment, Radiation-induced injury, Traditional Chinese medicine

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Introduction

The current environment increases the risk of radiation exposure through several sources: the potential leakage of nuclear power plants; the increase in human space activities; the wide application of clinical, radiological diagnostic, and therapeutic equipment; and the persistent terrorist threat of nuclear weapons. Therefore, radiation exposure has become an inevitable part of daily life, posing a potential health threat[1].

Although existing radioprotectants are highly effective, their widespread clinical use is hindered by toxicity and side effects. Amifostine is the only radioprotectant approved by the Food and Drug Administration to improve the adverse effects of radiation therapy[2]. However, amifostine has limited clinical application owing to its inevitable side effects such as vomiting, nausea, and hypotension[3]. This necessitates the development of drugs that inhibit or repair radiation-induced injury (RII).

In recent years, herbs and other natural compounds have played a significant role in anti-radiation therapy. The active ingredients in Chinese herbal medicine and compound traditional Chinese medicine (TCM) preparations have demonstrated considerable efficacy in reducing oxidative stress and promoting deoxyribonucleic acid (DNA) repair. TCM is thus considered a promising radiation-protective agent[4]. This review summarized the recent studies on the active ingredients of TCM, single TCM, and compound TCM preparations for the prevention and treatment of RII (Figure 1). This study aimed to provide an efficient, safe, and convenient strategy for the prevention and treatment of RII.

Mechanisms of RII

RII is a complex signaling network that can lead to apoptosis, cell cycle arrest, DNA damage, and cancer. In severe cases, RII can cause systemic reactions affecting several organs and systems, with the most pronounced damage observed in the digestive, nervous, and hematopoietic organs. The mechanisms of action of RII include oxidative stress, DNA damage, inflammation, and mitochondrial dysfunction (Figure 2).

Oxidative stress

The human body is composed of approximately 80% water. Ionizing radiation (IR) ionizes water to produce large amounts of highly reactive and unstable reactive

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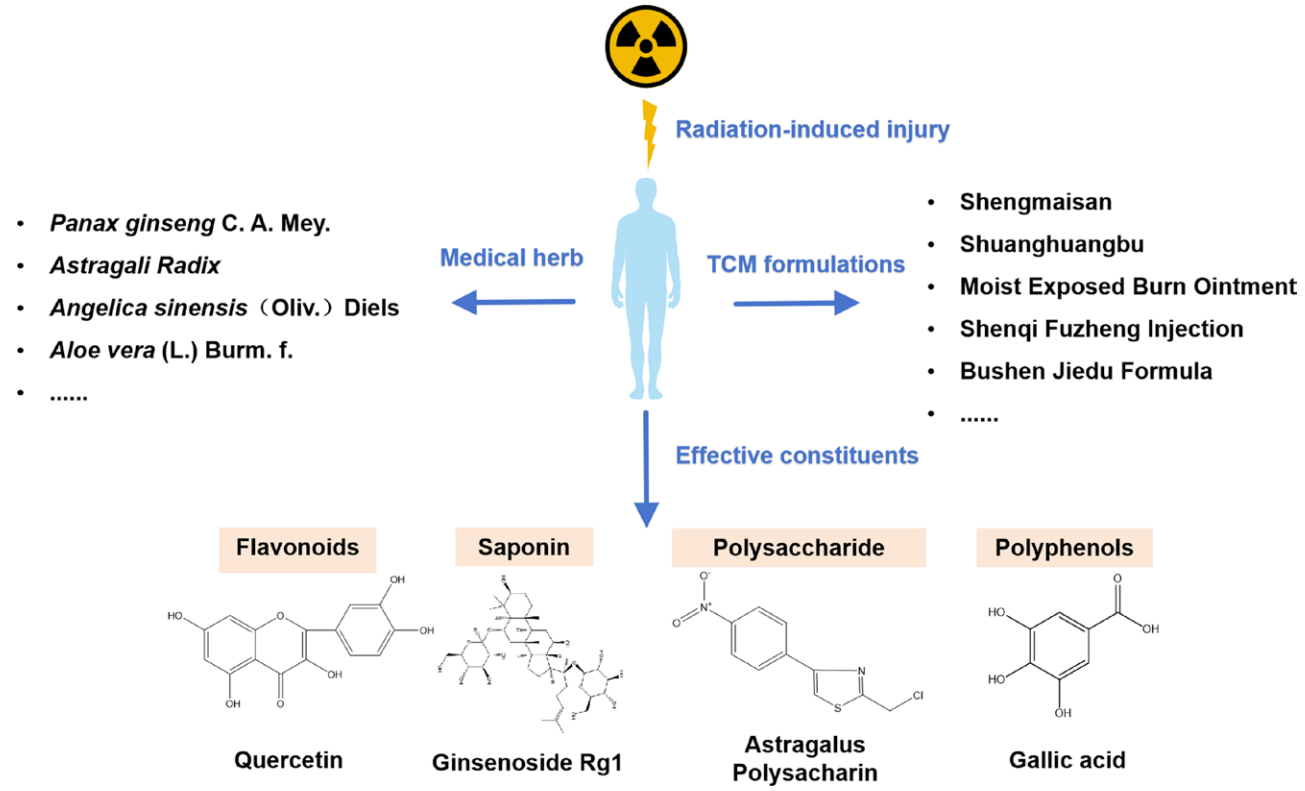

Figure 1. Formulations of traditional Chinese medicine for the prevention and treatment of radiation-induced injury. TCM: Traditional Chinese medicine.

oxygen species (ROS), which can also be expressed *via* the mitochondrial pathway[5]. An excess amount of ROS can trigger an oxidative stress response in cells, leading to cell dysfunction, lipid peroxidation, and ultimately inducing apoptosis and necrosis of cells, thus damaging tissues and organs[6].

DNA damage

Radiation-induced DNA damage occurs in two ways. First, direct DNA damage leads to base damage, single- and double-strand breakage, apoptosis, senescence, and autophagy. Second, radiation can deposit water molecules into biological macromolecules, indirectly damage DNA, destroy antioxidant capacity, and ultimately lead to oxidative stress in the body[7,8].

Inflammation

Both ROS accumulation and DNA strand breakage can cause the activation of signaling pathways (such as mitogen-activated protein kinase (MAPK), nuclear factor-κB (NF-κB), high mobility group box 1, and so on); produce pro-apoptotic proteins; participate in radiation-induced inflammation; and eventually cause aging, apoptosis and necrosis of irradiated cells[9].

Mitochondrial dysfunction

Mitochondria are organelles essential for cell survival and death signaling; they are also one of the primary sites for ROS production. IR disrupts the aerobic respiratory chain of the mitochondria, leading to ROS accumulation and triggering oxidative stress. ROS-induced oxidative stress can activate apoptotic pathways by altering mitochondrial membranes, damaging DNA, and disrupting protein structures. Additionally, IR can cause mitochondrial dysfunction and increase the mitochondrial volume, resulting in cell senescence[4].

Effective constituents of TCM

Various constituents extracted from TCM extracts have obvious preventive and therapeutic effects against RII, including flavonoids, saponins, polysaccharides, and polyphenols.

Flavonoids

Quercetin, soy isoflavone, and silymarin are the primary flavonoids with anti-radiative effects. Most flavonoids have significant antioxidant and anti-inflammatory properties that can mitigate RII by reducing oxidative stress and inflammation. Quercetin exerts neuroprotective effects, by decreasing the expression of endoplasmic reticulum stress markers such as binding immunoglobulin protein and CCAAT/enhancer-binding protein homologous proteins in the neurons of the dorsal root ganglion, decreasing the levels of tumor necrosis factor (TNF)-α and c-Jun N-terminal kinase, and increasing the expression of cytoskeletal protein neuronal class III β-tubulin and brain-derived neurotrophic factor in neurons[10]. Soy isoflavones can reduce inflammatory cell infiltration and radiation-induced pulmonary fibrosis. The mechanism may involve inhibiting the production of inflammatory cytokines such as TNF-α[11]. Silymarin reduces the risk of

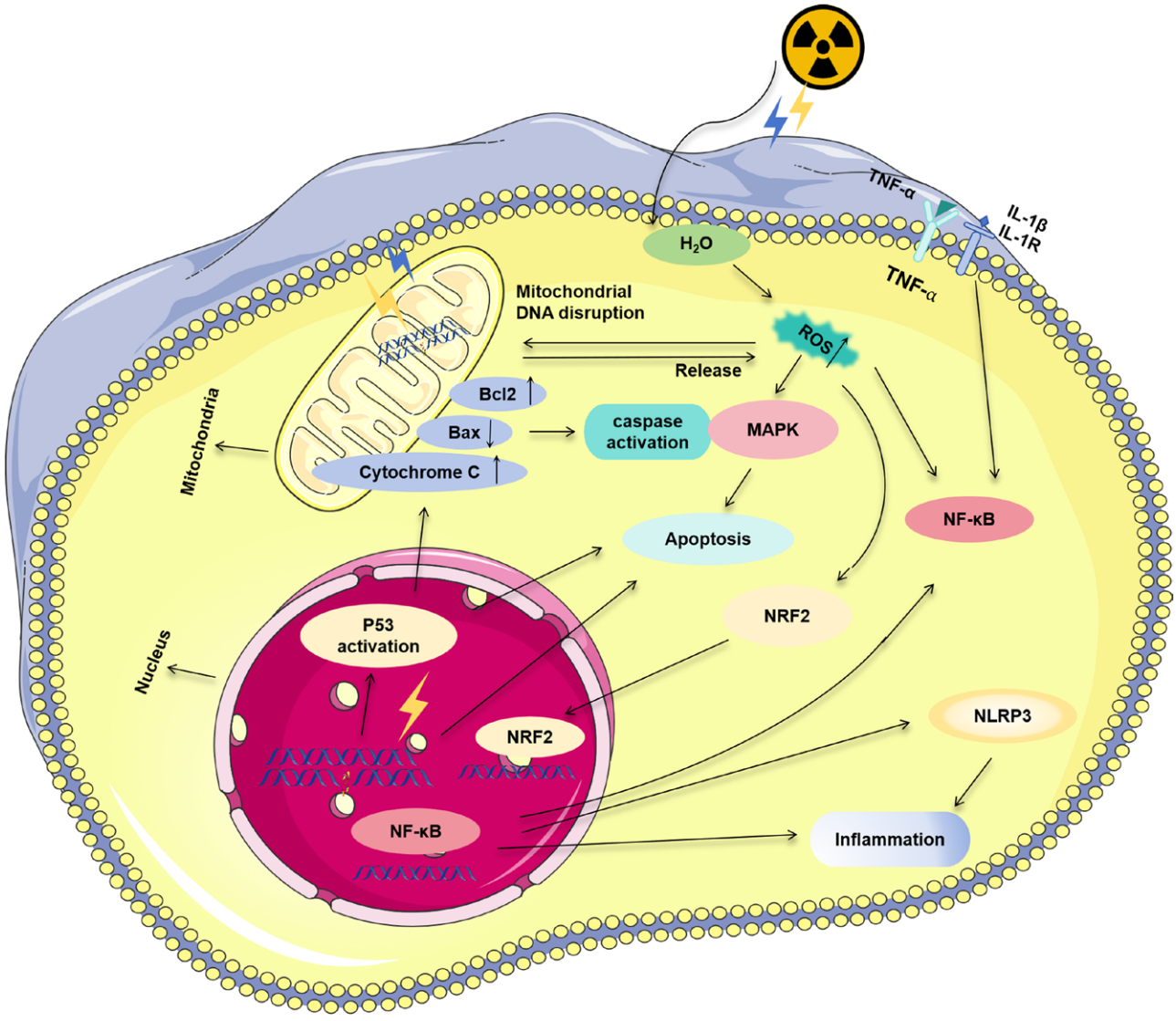

Figure 2. Mechanisms of radiation-induced injury. Bax: Bcl-2-associated X; Bcl2: B-cell lymphoma 2; IL: Interleukin; MAPK, Mitogen-activated protein kinase; NLRP3: NOD-like receptor thermal protein domain-associated protein 3; NF-κB: Nuclear factor-κB; Nrf2: Nuclear factor erythroid-2-related factor 2; ROS: Reactive oxygen species; TNF-α: Tumor necrosis factor α.

RII in the blood, organs, and immune system by increasing the expression levels of superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), glutathione (GSH) reductase, and catalase, promoting the proliferation of mouse blood cells and enhancing the immune response in mice[12].

Saponin

Many saponins have anti-radiation effects, including the well-known compounds such as baicalin IV, ginsenosides, and salidrosides. Astragaloside IV (AS-IV) can alleviate radiation-induced kidney injury by increasing mitochondrial autophagy and reducing the activation and apoptosis of NOD-like receptor thermal protein domain-associated protein 3 (NLRP3) inflammasome[13]. AS-IV protects against radiation by scavenging free radicals, reducing oxidative damage, reducing GSH and SOD levels, and improving ROS and malondialdehyde (MDA) levels[14]. AS-IV has an antagonistic effect on brain cell damage caused by radiation, possibly through the modulation of the tumor suppressor protein 53 (p53), cyclin-dependent kinase, and retinoblastoma susceptibility gene signaling pathways involved in the regulation of aging[15]. Ginsenoside RK1 can alleviate radiation-induced intestinal injury. The mechanism of its anti-apoptotic effect may be related to the inhibition of the phosphoinositide 3-kinase/protein kinase B/mammalian target of rapamycin (PI3K/Akt/mTOR) pathway[16]. Ginsenosides can effectively enhance the survival of intestinal crypt epithelial cells after radiation, inhibit their apoptosis, and prevent radiation-induced DNA damage[17,18]. Salidroside can improve the transcriptional activity and nuclear transport of nuclear factor erythroid-2-related factor 2 (Nrf2) in human keratinocyte cells, and the expression of Nrf2 is upregulated, which can prevent the ultraviolet radiation–induced oxidative damage[19].

Polysaccharide

Polysaccharides such as *Astragalus* and *Cordyceps militaris* exhibit potent radiation protection effects. *Astragalus* polysaccharide (APS), one of the main active

ingredients of *Astragali Radix*, improves immunity and antioxidative capacity and alleviates radiotherapy side effects[20,21]. APS can prevent cellular damage caused by radiation-induced A549 cells through a standardized effect, which may inhibit mitochondrial pathway activation by decreasing ROS production in bystander cells. APS can upregulate B-cell lymphoma (Bcl)-2 and Bcl-xl and downregulate Bcl-2-associated X (Bax) and recombinant Bcl-2 antagonist/killer, leading to the reduction in mitochondrial membrane potential and inducing apoptosis through caspase-dependent and non–caspase-dependent pathways[22]. *C. militaris* polysaccharides can affect the male reproductive system by reducing the oxidative damage to germ cells. *C. militaris* polysaccharides can improve the relative number of sperm, the survival rate of sperm, the activity of SOD and GSH-Px in the serum, the level of testosterone, and reduce the malformation rate of sperm and MDA content[23].

Polyphenols

Tea polyphenols and resveratrol are the primary phenols with anti-radiative activity. Gallic acid (GA) has a radiation-protective effect on mouse bone marrow cells and reduces the apoptotic rate of radiation-damaged mouse bone marrow cells, which may be related to its ability to clear free radicals and reduce ROS levels *in vivo*[24]. Green tea polyphenol (–)-epigallocatechin-3-gallate (EGCG) can reduce radiation-induced intestinal injury. EGCG mitigates damage to the gut structure and microbiota and increases the abundance of intestinal probiotics[25]. Resveratrol is a natural polyphenolic compound with various pharmacological effects that can ameliorate liver injury, hematopoietic system injury, intestinal injury, and ovarian inflammation caused by IR[26]. The commonly used effective constituents of TCM for radiation therapy are summarized in Table 1.

Medical herb

Panax ginseng C. A. Mey

Panax ginseng C. A. Mey. is commonly known as ginseng. Its mechanism may depend on the modulation of *qi*, including replenishing the blood to relieve depletion, tonifying the spleen and lungs, calming the mind, and enhancing intelligence. It can alleviate RII in mice, prolong the median survival time, reduce the rate of weight loss, improve the intestinal epithelial structure, increase the intestinal villi length and crypt depth, and enhance overall survival rates. Additionally, ginseng extract may inhibit intestinal epithelial cell apoptosis through the p53/PUMA signaling pathway, promote DNA repair, reduce DNA damage accumulation, and inhibit the expression of inflammatory factors[53]. Furthermore, ginseng extract exerts anti-inflammatory and antioxidant effects by targeting the MAPK/NF-κB and p62-Nrf2-Keap1 pathways and enhancing autophagy[54].

Angelica sinensis (Oliv.) Diels

Angelica sinensis (Oliv.) Diels (Machang Danggui) tonify and activate blood, regulate menstruation, relieve pain, moisten the intestines, and relax the bowels. It can reduce the incidence of radiation-induced immune function injury by increasing the number of peripheral white blood cells and nucleated cells in the bone marrow and improving spleen index and serum interferon-γ and interleukin (IL)-4 content in rats exposed to X-ray[55]. It can decrease the expression of ROS in mice, reduce damage to the spleen caused by radiation, and stimulate immune responses. It exerts anti-radiation effects by attenuating radiation damage to the hematopoietic and immune systems of the spleen[56]. The commonly used medicinal herbs for anti-radiation therapy are summarized in Table 2.

TCM formulations

In TCM, the symptoms of radiation injury include fatigue and weakness, dry mouth and throat, irritability, red tongue with little or no fur, and a thin pulse. Therefore, many TCM formulations focus on invigorating *qi* and blood, clearing heat, and promoting fluid balance[65]. Recent studies have confirmed the efficacy of TCM compound prescriptions in treating radioactive injuries and are mainly used for clearing heat, detoxification, improving blood circulation, resolving blood stasis, and promoting muscle growth. The different TCM formulations include decoctions, ointments, oils, sprays, and powders.

Decoction

Decoction is the most commonly used formulation in TCM owing to its easy and convenient administration route. Shengmaisan effectively inhibited radiation-induced damage to hematopoietic stem cells[66,67]. Shengmaisan protects against radiation-induced hematopoietic injury by decreasing inflammatory cytokine levels. Apoptosis occurs in the liver tissue of mice after radiation. Shengmaisan alleviates radiation-induced hematopoietic injury to a certain extent through its anti-apoptotic mechanisms. It can reduce organ index and peripheral blood cell count, relieve bone marrow-nucleated cell and bone marrow DNA damage, and promote the release of relevant inflammatory cytokines. It also regulates the expression of anti-apoptotic and pro-apoptotic proteins[68].

Danggui Buxue tang (DBT) is a TCM decoction prepared by using a 5:1 ratio of *Astragali Radix* (Huang Qi) and *Angelica sinensis* (Oliv.) Diel (Machang Danggui). It is known for its "blood-nourishing" effect[69]. DBT exerts a protective effect against radiation-induced heart disease and significantly counteracts heart injury. This protective mechanism likely involves the upregulation of Nrf2 and downregulation of HMGB1[70].

Sihuang external lotion is primarily used for the treatment of skin diseases and can reduce the severity of radiation dermatitis caused by radiotherapy. It can enhance the body's ability to clear inflammatory factors, by reducing the serum C-reactive protein levels, transforming growth factor β1 (TGF-β1) levels, and radiotherapy damage. These effects are attributed to the comprehensive action of TCM ingredients, which include clearing heat, detoxifying, nourishing yin, regulating the body's immune function, and providing anti-inflammatory and anti-tumor benefits[71].

Table 1

Commonly used effective constituents of traditional Chinese medicine for anti-radiation

Structure types	Effective constituents	Model	Action	References
Flavonoids	Quercetin	C57BL/6J mice (X-ray)	Scavenges oxidative stress, ameliorates DNA damage and cell apoptosis	[27]
		BALB/c mice (γ-ray)	Increases the cytoskeletal protein Tuj1 and the neurotrophin brain-derived neurotrophic factor in the neuron	[10]
	Soy isoflavones	BALB/c mice (X-ray)	Promotes the production of inflammatory cytokines	[11]
	Silymarin	BALB/c mice (γ-ray)	Increases expression of catalase, GSH-Px, GSH reductase, and SOD levels	[12]
	Total flavonoids of *Engelhardia roxburghiana Wall.*	C57BL/6J mice (γ-ray)	Inhibits oxidative stress, reduces DNA damage, reduces apoptosis and ferroptosis	[28]
	Apigenin	C57BL/6J mice (X-ray)	Accelerates the recovery of crypto-villi structure and reduces oxidative stress levels	[29]
	Naringenin	C57BL/6J mice Wistar rat (X-ray)	Down-regulates IL-1β, maintains the homeostasis of inflammatory factors, improves radiation-induced lung injury	[30]
Saponin	Astragaloside IV	Kunming mice PC12 cells (γ-ray)	Ameliorates radiation-induced senescence *via* antioxidative mechanism	[15]
		C57BL/6J mice (X-ray)	Activates brain-derived neurotrophic factor/tyrosine kinase receptor B signaling pathway, reduces synaptic damage and improves motor function in mice	[31]
		C57BL/6J mice (γ-ray)	Reduces the activation and apoptosis of NLRP3 inflammasome and promotes mitochondrial autophagy	[13]
		C57BL/6J mice (X-ray)	Suppresses ferroptosis, inhibits inflammatory responses and cell injury	[32]
	Ginsenoside Rk1	SD rats	Inhibits the PI3K/Akt/mTOR pathway, suppresses oxidative stress and cell apoptosis	[16]
	Glycyrrhizin	C57BL/6J mice Image-guided radiotherapy technique	Regulates NLRP3 inflammasome through endoplasmic reticulum stress	[33]
	Glycyrrhetinic Acid	C57BL/6J mice (X-ray)	Inhibits TGF-β1-mediated EMT and myofibroblast secretion by Treg cells	[34]
Polysaccharide	Astragalus polysaccharide	BMSCs (X-ray)	Increases the whole genome methylation level of BMSCs, and reduces the risk of BMSCs deterioration	[21]
		C57BL/6J mice Balb/C mice (X-ray)	Reduces lung inflammation, injury, and pulmonary fibrosis	[35]
	Cordyceps militaris polysaccharide	Kunming mice	Reduces oxidative damage to germ cells, improves the effect of microwave radiation on the reproductive system of male mice	[23]
	Aloe polysaccharide	Wistar rat (β-ray)	Promotes the formation of neovascularization in acute radiation skin injury model, accelerates wound repair	[36]
	Ganoderma lucidum polysaccharide	Balb/c mice (X-ray)	Improves the expression of related potential biomarkers and related metabolic pathways in serum of radiation-induced mice	[37]
	Gougancai polysaccharide	SD rats (γ-ray)	Inhibits the oxidative stress of parotid gland, reduces the damage of radioactive parotid gland	[38]
	Hohenbuehelia serotina polysaccharide	Kunming mice (γ-ray)	Blocks ER apoptosis pathway, prevents radiation-induced apoptosis in mouse spleen cells	[39]

(*Continued*)

Table 1

(Continued)

Structure types	Effective constituents	Model	Action	References
Polyphenols	Resveratrol	IEC-6 (X-ray)	Reduces the level of ROS, inhibits cell senescence and apoptosis, alleviates the radiation damage of IEC-6 cells	[40]
	Polydatin	Balb/c nude mice (γ-ray)	Stimulates hematopoiesis and modulates immunity	[41]
	Gallic acid	ICR mice (X-ray)	Alleviates the oxidative damage, DNA damage and cycle arrest of radiation-damaged mouse bone marrow cells	[24]
Others	Salvianolic acid B	Kunming mice (γ-ray)	Improves immunity and hematopoietic system function	[42]
	Ferulic acid	HLECs (X-ray)	Activates Nrf2 signaling pathway, inhibits oxidative stress, and reduces the apoptosis of human lens epithelial cells	[43]
	Ferulic acid	SD rats (γ-ray)	Inhibits oxidative stress and cellular apoptosis, promotes the Nrf2 signal pathway	[44]
	Crocin	C57BL/6J mice	Prevents radiation-induced peripheral blood cell injury	[45]
	Zingerone derivates	C57BL/6J mice (X-ray)	Promotes the proliferation and differentiation of intestinal crypt stem cells, inhibits cell apoptosis, reduces DNA damage, protects the radiation-induced small intestine injury	[46]
	Andrographolide	C57BL/6J mice (X-ray)	Ameliorates early radiation-induced lung tissue injury, inflammatory cell infiltration and pro-inflammatory cytokine release, and late progressive fibrosis	[47]
	Atractylenolide II	C57BL/6J mice (γ-ray)	Blocks DNA damage and ROS-induced cell death, alleviates radiation-induced ulcers	[48]
	Ginkgolide B	C57BL/6J mice (X-ray)	Regulates DCC/MST1 signaling pathway, activates PI3K/Akt	[49]
	Thymoquinone	ICR mice (γ-ray)	Inhibits ROS, improves the proliferation function of bone marrow cells, and protects hematopoietic system	[50]
	Anisodamine	C57BL/6J mice (X-ray)	Activates the Nrf2/ARE pathway, enhances cellular antioxidant capacity, and inhibits cellular senescence	[51]
	Honokiol	C57BL/6J mice (X-ray)	Enhances the expression and translocation of Nrf2 and inhibits IR-induced apoptosis and pyroptosis signaling	[52]

ARE: Antioxidant response element; BMSC: Bone marrow stromal cells; DCC: Deleted colorectal carcinoma; DNA: Deoxyribonucleic acid; EMT: Epithelial mesenchymal transition; ER: Endoplasmic reticulum; GSH: Glutathione; GSH-Px: Glutathione peroxidase; IL: Interleukin; IR: Ionizing radiation; MST1: Mammalian STE20-like kinase 1; NLRP3: NOD-like receptor thermal protein domain-associated protein 3; Nrf2: Nuclear factor erythroid-2-related factor 2; PI3K/Akt/mTOR: Phosphoinositide 3-kinase/protein kinase B/mammalian target of rapamycin; ROS: Reactive oxygen species; SD: Sprague-Dawley; SOD: Superoxide dismutase; TGF-β1: Transforming growth factor β1; Treg: Regulatory T.

Table 2

Commonly used medical herb for anti-radiation

Drugs	Model	Action	References
Panax ginseng C. A. Mey. (Ren Shen)	C57BL/6J mice (X-ray)	Inhibits cell apoptosis, reduces DNA damage, regulates the expression of related cytokines, and protects the acute intestinal injury	[53]
Angelica sinensis (Oliv.) Diels (Machang Danggui)	Kunming mice (γ-ray)	Reduces the radiation-induced injury of spleen hematopoietic system and immune system	[56]
	Hairless albino mice (UV- ray)	Inhibits epidermal hyperplasia, reduces dermal inflammation, reduces skin photo-aging	[57]
	Wistar rats (X-rays)	Inhibits miRNA-200a expression, reduces TGF-β1 release, resists radiation-induced cardiac fibrosis	[58]
Eleutherococcus senticosus (Rupr. & Maxim.) Maxim. (Ci Wujia)	Kunming mice (γ-ray)	Inhibits nerve cell swelling, protein loss, and necrotic tissue liquefaction in brain	[59]
Cordyceps (Dongchong Xiacao)	C57BL/6J mice (X-ray)	Up-regulates anti-apoptotic protein to restore radiation-induced splenic tissue apoptosis	[60]
Rhizoma cibotii (Gou Ji)	Kunming mice (X-ray)	Promotes hematopoietic stem cell progenitor cell maturation, and treats radiation-induced thrombocytopenia	[61]
Ecliptae Herba (Mo Hanlian)	SD rats C57BL/6J mice (γ-ray)	Inhibits the p53 signaling pathway, and regulates the Bax/Bcl-2 ratio	[62]
Houttuynia cordata Thunb. (Yuxing Cao)	-	Has a potential pharmacological effect against radiation-induced lung injury *via* the cancer pathways, tumor necrosis factor signaling pathway, and PI3KAkt signaling pathway	[63]
Scutellaria Barbata D. Don (Banzhi Lian)	-	Regulates oxidative stress and inflammation, and alleviates radiation pneumonia	[64]

Bax: Bcl-2-associated X; Bcl2: B-cell lymphoma 2; DNA: Deoxyribonucleic acid; PI3K: Phosphoinositide 3-kinase; SD: Sprague-Dawley; TGF-β1: Transforming growth factor β1.

Table 3

Commonly used formulations of traditional Chinese medicine for anti-radiation

Drugs	Model	Action	References
Shenqi Fuzheng injection	C57BL/6J mice (X-ray)	Inhibits nuclear factor κB signaling pathway and microglia activation, alleviates irradiation-induced acute brain injury	[78]
Shenmai injection	SD rats (X-ray)	Increases cell viability and decreases excess ROS production, inhibits oxidative stress and decreases structural remodeling	[79]
Reduning injection	C57BL/6 mice	Inhibits absent in melanoma 2 inflammasome and epithelial-mesenchymal transition to attenuate radiation lung injury	[80]
	C3H/KamL mice (X-ray)	Decreases expression of inflammatory cytokines such as TGF-β, IL-6, and IL-17 and reduces activity and metabolite of intralung cyclooxygenase 2	[81]
Liangxue Guyuan Yishen decoction	SD rats (γ-ray)	Increases the number of small intestinal crypt stem cells, up-regulates the expression of intestinal epithelial cell tight junction protein, promotes intestinal structure reconstruction	[82]
Danggui Buxue tang	C57BL/6J mice (X-ray)	Regulates Nrf2/HMGB1 pathway	[70]
Yiqi Jiedu decoction	Balb/c mice (γ-ray)	Improves the structure of seminiferous tubules, promotes the recovery of spermatogenic function, reduces the radiation-induced testis injury of mice	[83]
Guiqi Baizhu decoction	SD rats (X-ray)	Regulates the composition of intestinal microbiota, reduces the expression of inflammatory factors, reduces radiation-induced inflammation	[84]
Jiawei Maxing Shigan tang	SD rats (γ-ray)	Regulates regulatory T cells, down-regulates TGF-β1 expression, inhibits TGF-β1/Smad pathway	[85]
Bushen Jiedu formula	C57BL/6 mice (γ-ray)	Inhibits inflammation, enhances antioxidant capacity, protects important organs of the body	[86]
Jiawei Simiao Yongan fang	SD rats (electron linear accelerator)	Promotes wound repair by MAPK/ERK pathway	[87]

ERK: Extracellular regulated protein kinases; HMGB: High mobility group box 1 protein; IL: Interleukin; MAPK: Mitogen-activated protein kinase; Nrf2: Nuclear factor erythroid-2-related factor 2; ROS: Reactive oxygen species; SD: Sprague-Dawley; TGF-β1: Transforming growth factor β1.

Ointment

Ointments are commonly used in transdermal formulations. Qingre Shengji ointment clears heat, enhances blood circulation, detoxifies and removes blood stasis, eliminates slough, and promotes muscle regeneration. It also has remarkable anti-inflammatory and anti-ulcer effects and promotes the healing of sores. This ointment can decrease the incidence of acute radiation dermatitis and the severity of wound injury, effectively improve pathological symptoms, and prevent and treat acute radiation dermatitis after radiotherapy in rats with breast cancer[72].

Guiqi Yiyuan ointment is effective in tonifying the lungs to nourish the qi, yin, and blood. It can alleviate oxidative stress and inflammatory injury in the lungs, reduce ROS production, regulate the expression of NLRP3, decrease the release of downstream inflammatory factors, and enhance radiation resistance[73].

Oil

Compound ulcer oil can improve the tolerance of radiotherapy patients to radiation, reduce the severity of skin damage, and prolong the duration of injury. It can inhibit the production and release of pro-inflammatory factors (such as IL-6, TNF-α, IL-1, and IL-8) in the early stages, reduce the decline rate of anti-inflammatory factors (such as IL-10), and regulate the pro-inflammatory and anti-inflammatory systems of the body and the production of restorative factors in a bidirectional manner. This regulation decreases the occurrence of dermatitis and accelerates dermatitis healing[74].

Jiawei Simiao Yongan oil directly acts on radiation-induced skin injury to form a protective layer on the wound to prevent infection. Its active ingredients are fully absorbed through the skin, preventing and delaying the exacerbation of wound damage[75,76].

Alpine camellia oil is rich in tea polyphenols that can reduce damage to basal cells by scavenging oxygen free radicals, inhibiting the release of histamine from mast cells, and reducing the production of inflammatory factors, thus playing an anti-allergy and anti-inflammatory role[77]. The commonly used formulations of TCM for radiation therapy are summarized in Table 3.

Combined treatment of TCM and Western medicine

Combined treatment is an effective approach to administering medications. It can enhance the effect of drugs and reduce the adverse reactions. This method is widely used for its anti-tumor, anti-infection, anti-coagulation, and antihypertensive properties[88].

Aloe vera softens blood vessels, improves skin tissue recovery, promotes blood circulation, reduces wound inflammation, and accelerates granulation. Recombinant human epidermal growth factor (rhEGF), combined with its receptor, can activate proteases; accelerate protein synthesis; and facilitate the migration, division, and proliferation of epidermal keratinocytes. It promotes the formation of new granulation tissue and wound wound re-epithelialization. Combined treatments can relieve pain and promote recovery. This is likely due to the aloe vera's anti-inflammatory, analgesic, and wound-healing effects, and the rhEGF's ability to accelerate wound healing. Therefore, the combination of these two drugs can rapidly reduce skin pain caused by radiotherapy and accelerate wound healing[89,90].

Based on the conventional Western medicine treatment of radiation enteritis, retention enema using modified Huaihua Powder helps reduce clinical symptoms and inflammatory reactions, improving patients' functional status and treatment efficacy, and ensuring safety[91].

Shashen-Maidong decoction, when combined with Western medicine, has shown a good curative effect on radiation pneumonia. It significantly alleviates clinical symptoms; reduces the levels of TGF-β, IL-6, and TNF-α; and helps improve the classification of pneumonia and physical status[92].

Conclusion and Perspective

Currently, more attention has been paid to investigating the incidence of RII domestically and internationally, with increasing research on anti-radiation drugs. Owing to its multiple components, ability to target various pathways, and minimal side effects, TCM shows promising prospects as an anti-radiation therapy suitable for protecting radiation workers and supporting cancer chemotherapy. The efficacy and safety of TCM have been well-established, and studies on its anti-radiation effects, both as a single drug and in compound formulations, have yielded satisfactory results.

TCM is distinguished by its multicomponent, multipathway, and multitarget approach to treating diseases, which aligns well with the multiorgan, multitissue, and multisystem damage caused by IR. This characteristic has prompted increasing attention to the role of TCM in RII, with Chinese herbal medicines and TCM prescriptions being particularly suited for treating multisystem damage caused by IR. The synergistic effect of different herbs in TCM prescriptions enhances their curative effect and inhibits side effects. A thorough research of the anti-radiation effects and mechanisms of action of TCM is essential for the development of new anti-radiation drugs.

Conflict of interest statement

The authors declare no conflict of interest.

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Author contributions

Hong Niu: Writing-original draft, writing-review; Ziyan Tang: Writing-review and editing; Qiang Chi: Conceptualization and visualization; Lina Du: Conceptualization and writing-review and editing; Yiguang Jin: Conceptualization and writing-review and editing.

Ethical approval of studies and informed consent

Not applicable.

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Data availability

All data generated or analyzed during this study are included in this published article.

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