

Traditional Chinese medicine: an important coping strategy with challenges of radiation injury

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Abstract

People turn nervous when mention is made of radiation injuries, which cause multiple organ morbidities and are difficult to manage. However, the discovery of antiradiation drugs remains challenging. Traditional Chinese medicine (TCM) may be an effective treatment strategy because of its overall regulation. Herein, we systematically review TCM formulae, herbs, and natural products as potential antiradiation candidates. At the same time, we categorize them by their effective characteristics and target organs. In addition, TCM formulae, herbs, and ingredients used to block the absorption and accelerate the excretion of radionuclides are considered in this review. To better manage radiation injuries, the scientific basis of TCM for radioprotection requires further in-depth research.

Keywords: Antiradiation, Formulas, Herbs, Ingredients, Radiation injury, Traditional Chinese medicine

Graphical abstract: <http://links.lww.com/AHM/A145>.

Introduction

Since August 24, 2023, contaminated water from the Fukushima Daiichi Nuclear Power Plant was discharged into the Northwest Pacific. This immediately caused a new wave of public concern and anxiety concerning radiation injuries. The inherent radiosensitivity of the human body, especially the hematopoietic, cardiovascular, immune, and intestinal systems, renders it prone to damage after radiation exposure^[1]. Antiradiation medical supplies are urgently required to cope with the potential threats to human health. In this review, we focused on pharmaceutical agents that protect against radiation injuries resulting from external and/or internal overexposure to ionizing radiation (IR).

Although researchers worldwide have devoted a great deal of effort to finding effective antiradiation drugs, only a small number of agents have proven to be effective in past accidents in the treatment of radiation injuries and internal radionuclide exposure. To date, only amifostine (WR-2721) has been approved for the prevention of radiological injury by the US Food and Drug Administration (FDA). Meanwhile, only potassium iodide (KI) is the common stockpile available in most countries for radiation emergency^[1]. Furthermore, some countries have approved sulfur-containing compounds, cytokines, growth factors, estrogens, and mucopolysaccharides to manage radiation injuries. However, these drugs are used to treat acute radiation

sickness (ARS) and have significant side effects and weakness. Compared to the above antiradiation drugs, traditional Chinese medicine (TCM) may serve as a safer strategy to protect humans exposed to lower doses of IR.

Since the 1960s, research regarding radioprotectors in China has extended to TCM. Screening TCM formulas, herbs, and natural products has revealed a series of radioprotectors for different symptoms of radiation injury. This review summarizes TCM formulas, herbs, and natural chemicals used to treat internal and external radiation. TCMs are classified based on their characteristics and advantages. The aims of this review were not only to make the public aware of the contributions of TCM in radiation protection but also to serve as a scientific basis for clinicians and researchers working toward antiradiation agents.

TCM agents against external radiation injury

TCM formulas

After exposure to IR, fatigue, dizziness, dysphoria involving the chest, palms, and soles, insomnia, transportation and transformation imbalance in the spleen, and a dysfunctional digestive system are the main clinical symptoms. According to TCM theory, the pathogenic factor of radiation injury is IR, which has tremendous energy and breaks the balance of *yin* and *yang in vivo*.

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Received 7 March 2024 / Accepted 3 November 2024

How to cite this article: Shao S, Gao Y. Traditional Chinese medicine: an important coping strategy with challenges of radiation injury. *Acupunct Herb Med* 2024;4(4):427–435. DOI: 10.1097/HM9.000000000000138

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As a result, hematopoietic, immune, gastrointestinal, neurological, and reproductive dysfunction occur in IR-exposed individuals. Over the past 60 years, TCM researchers have focused on developing therapies for IR injury in immune, hematopoietic, and gastrointestinal diseases. They correspond to *qi* (immune), *blood* (hematopoietic), *Jinye*, and *Zangfu* (closely related to gastrointestinal digestive function) in TCM. The clinical manifestations of IR injury in early, middle, and late stages, as well as the TCM treatment plans, are shown in Figure 1. In the early stages of IR injury, excess heat acts on body tissues are the main cause. To countermeasure early IR injury, we need to clear away heat and toxic material, tonify *qi* to control *blood* boiling, and provide nourishing fluids and moistening dryness. In the middle stage, the main treatment for radiation injury is promoting blood circulation and removing blood stasis. In the late stage, it mainly nourishes the blood. Therefore, the impact of IR energy on the human body is reduced.

TCM formulae for IR damage in immune and hematopoietic systems

IR damage to immune and hematopoietic systems manifests as a deficiency in *qi* and *blood*. This can be referred to as *blood* deficiency syndrome caused by radiation injury. Siwu tang (SWT) represents one of the classical decoctions used to nourish *qi* and *blood*, promote blood circulation, and remove blood stasis. SWT includes *Radix*

Rehmanniae (Di Huang), *Radix Angelica* (Dang Gui), *Radix Paeoniae* (Bai Shao), and *Rhizoma Chuanxiong* (Chuan Xiong). Professor Yue Gao’s group has done much to clarify the scientific basis of SWT in terms of radiation countermeasures^[2]. Through the interdisciplinary integration of analytical chemistry, systems biology, pharmacology, computational science, and multi-omics techniques, researchers have studied the mechanism and molecular basis of blood deficiency syndrome caused by radiation injury. They also established an objective criterion for rating blood deficiency syndrome caused by radiation injury. Around peripheral blood, hematopoietic, and immune injury by IR, researchers have used *in vivo*, organ, cellular, and molecular studies to clarify how SWT functions as a radioprotector. Oral administration of SWT to irradiated mice can effectively improve the peripheral hemogram, increase the quantity and quality of bone marrow stem cells and progenitor cells, increase the proportion of CD³⁴⁺ cells in bone marrow nucleated cells, and reduce cycle arrest by immune cells^[3-5]. Additionally, researchers from other groups in China, the United States, Japan, and Korea have experimentally observed the antiradiation effects of SWT. The beneficial effect of SWT on the gastrointestinal tract of γ -ray-irradiated mice has also been proposed^[6].

In addition to SWT, researchers have observed the anti-radiation effect of Sijunzi decoction, Bazhen decoction, Shiquan Dabu decoction, Danggui Buxue decoction^[7], and Fufang E’jiao Jiang^[8], CB001^[9] in experiments. These are also decoctions used to nourish *qi* and *blood*

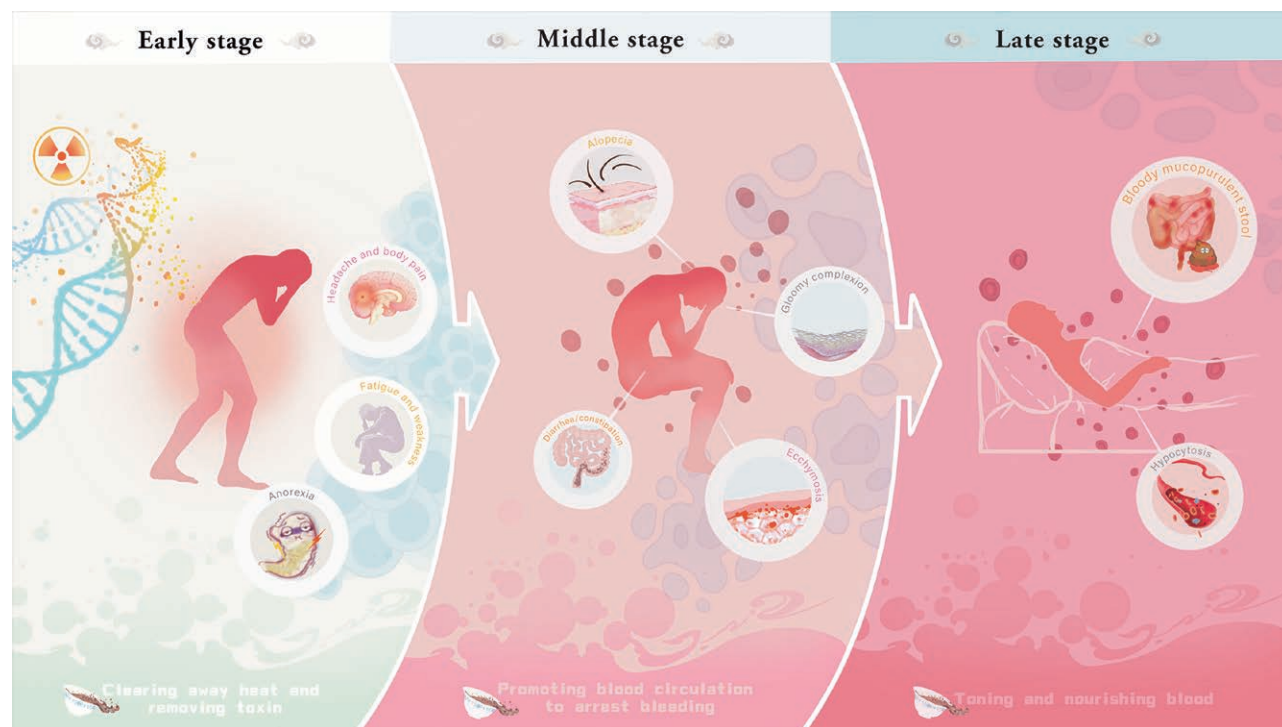


Figure 1. Clinical symptoms and TCM treatment plans for different stages of radiation sickness. At the beginning of exposure to radiation, headache, body pain, fatigue, weakness, and anorexia are the main symptoms of patients with radiation sickness. To relieve the symptoms in the early stage, we need TCM formulations with the effect of clearing away heat and removing toxins. If the IR injury persists, we need promoting blood circulation to improve symptoms with ecchymosis, gloomy complexion, and alopecia, which resulted from circulation damage such as bleeding and blood stasis. With the radiation injury further exacerbated, symptoms of hematopoietic, immune, and gastrointestinal systems are manifested. Bloody mucopurulent stool, hypocytosis, and immunocompromised are the symptoms in the late stage of radiation sickness. TCM herbs with blood toning and nourishing effect played an important role in the rescue process of this stage. IR: Ionizing radiation; TCM: Traditional Chinese medicine.

after exposure to lower radiation doses and non-lethal IR doses.

TCM formulae for IR damage in the gastrointestinal system

IR injury to the gastrointestinal tract is commonly understood as excess heat damage to the body fluids in TCM. Pathological manifestations include blunting and loss of villi, crypt hyperplasia, and irregular crypt morphology. Huangqin decoction (HQT) is a four-herb TCM decoction for radiation-induced gastrointestinal injury, including diarrhea, nausea, and vomiting. Based on systems biology research of HQT, Professor Yongqi Cheng's group at Yale University developed a new extractive formula called PHY906^[10]. Their research showed that PHY906 can reduce gastrointestinal pathological damage caused by radiation alone but does not damage healthy tissue or change tumor growth^[11]. In addition to stimulating gastrointestinal cell repopulation, PHY906 restrains the migration of inflammatory cells to the gut and inhibits the inducible inflammatory markers nitric oxide synthase, cyclooxygenase (COX)-2, and the pro-inflammatory transcription factor nuclear factor kappa-B (NF- κ B). Shaoyao decoction (SYT)^[12], another decoction that clears visceral heat, has been clinically proven to be effective in curing radiation enteritis. Studies by Li et al.^[12] have shown that SYT decreases the number of exfoliated and necrotic epithelial cells and prevents the proliferation of damaged fibrous tissue in the mucosal crypt layer. At the same time, SYT treatment could decrease levels of proinflammatory cytokines in mouse serum, such as malondialdehyde (MDA), COX, lipopolysaccharides (LPS), interleukin-6 (IL-6), interleukin-1 β (IL-1 β), and tumor necrosis factor- α (TNF- α). Furthermore, Baitouweng^[13] and Liangxue Guyuan decoctions are also effective responses to radio enteritis. In addition, decoctions that replenish *qi*, activate *blood*, and have dehumidifying effects are suitable for the treatment of colon edema induced by IR. Studies by Yongqi Liu's group found that Guiqi Baizhu decoction can improve colon edema in irradiated rats as well as alleviate inflammation^[14-15]. Moreover, Ping Zhou's group pointed out that Liujunzi decoction combined with Zuojin pills is effective in immune regulation and intestinal reparation in irradiated mice. Therefore, TCM formulae with the function of clearing visceral heat and dehumidifying should be investigated in the treatment of intestinal IR injury.

TCM formulae for IR damage involving lung and heart

Radiation injury to the lungs is associated with inflammation. Radiation pneumonitis is the first stage of irradiated lung injury. The main clinical manifestations are fever, choking cough with sputum, chest pain, dyspnea, and even death from acute cor pulmonale^[16]. In addition to pneumonitis in the acute phase, inflammation in irradiated lungs causes fibrosis, cor pulmonale, heart insufficiency, and other chronic complications. Clearing heat and detoxification are the basic rules for radiation pneumonitis. Therefore, TCM decoctions and herbs must be used to inhibit inflammation. Jiawei Maxing Shigan decoction (MXSG Plus) has been used to reduce lung radiation. Researchers have found that the decoction of

MXSG plus could inhibit lung injury *via* the transforming growth factor beta (TGF- β 1)/small mother against decapentaplegic (Smad) signaling pathway mediated by regulatory T cells. Zengxiao Jiandu decoction plays the same role in the treatment of radiation pneumonitis. Radiation-induced pulmonary heart disease, characterized by cardiac dysfunction and myocardial fibrosis of the heart and lungs, can be relieved by supplementation and boosting formulae in TCM. Danggui Buxue decoction plays a cardioprotective effect in irradiated mice^[17]. Other TCM formulae used to tonify *qi* and control blood vessels may also be effective.

TCM formulae for IR damage involving skin and other mucosa

Radiodermatitis is a form of radiation-induced skin dermatitis that belongs to the furuncle category. Radiomucositis is a radiation-induced mucosal dermatitis that affects mucosal tissues of the intestine and oral cavity. In TCM, both radiodermatitis and radiomucositis belong to heat stasis, a kind of blood stasis caused by excess heat. Modern medicine believes that these two disorders caused by radiation are related to inflammation. Currently, there is no generally accepted treatment for radiodermatitis or radiomucositis. In clinical practice, Huanglian Jiedu plaster (HJP) has been used to ameliorate radiodermatitis^[18]. Researchers in a mouse radiodermatitis model found that HJP works by inhibiting inflammatory interactions between macrophages and JB6 cells mediated by high mobility group protein 1 (HMGB1)^[18]. Jiawei Simiao Yongan plaster, another topical application used in TCM for radiodermatitis, is effective in alleviating skin reactions during radiotherapy.

Oral mucositis has attracted as much attention as radiation enteritis in clinical radiotherapy. However, oral mucositis is similar to radiation-induced dermatitis. These effects are primarily caused by high-dose head and neck radiation therapy. Clearing heat toxins is the general rule in TCM treatment of radiodermatitis and radiomucositis. Kouchuangling, a TCM formula composed of *Flos Lonicerae Japonicae* (Jin Yin Hua), *Radix Paeoniae Rubra* (Chi Shao), and *Radix Sanguisorbae* (Di Yu), exhibited clinical efficacy in a randomized trial study of oral mucositis treatments^[19]. Other TCMs for cooling blood, promoting blood circulation, and detoxification are also available in radiomucositis treatment. In December 2023, the Chinese Scientific and Technological Innovation 2030 brought TCM treatment of radiation-induced mucosal injury into focus and suggested future funding.

TCM formulae for IR damage in reproductive system

Reproductive toxicity of IR is a major public health concern worldwide. IR exposure can cause genital system injury and a decline in germ cell quality and quantity. Therefore, radiation-induced injury to the genital system and germ cells is of great concern. According to TCM theory, *qi* and *yin* are consumed during radiation exposure. As a result, tonified *qi* and nourished *yin* are the principal treatments for the reproductive toxicity of irradiation. Yiqi Jiedu decoction (YJD) is one of the

effective prescriptions for males. Researchers have found that YJD attenuates irradiated testis injury and reduces spermatogenic cell injury^[20]. Furthermore, YJD protects the testicular function of spermatogenesis and promotes the recovery of reproductive hormones, including testosterone and estradiol^[21]. Reducing IR injury to spermatogenic cells by suppressing the inhibitor of nuclear factor kappa-B alpha (IκBα)/NF-κB pathway is an important mechanism of YJD^[22]. In females, the main genital organs are the ovary and uterus, where the ovum and fertilized ovum reside, respectively. Bushen Jiedu recipe exerts a protective effect involving the ovary and uterus^[23]. In addition, an ethanolic extract of *Alocasia indica* showed a protective effect on the ovary and uterus^[24], and honokiol alleviated irradiated premature ovarian failure by enhancing Nrf2^[25].

TCM herbs

Promoting *qi*, *blood*, *jin-ye*, and *zang-fu* recovery is the core of TCM against radiation. Antiradiation herbal medicines with the effects of blood boiling control, hematopoiesis-promotion, clearing away heat and toxic material, fluid nourishing, and dryness moistening, playing the role of overall regulation and promoting repair. Antiradiation herbs and their target organs are listed in Table 1. TCM herbs with tonic effects have been reported to be helpful in treating hypohemopoiesis and immunodeficiencies. These herbs promote blood circulation and can also be used in other organs rich in capillaries, such as the lungs, brain, and liver. *Ginseng*, *Astragali*, *Acanthopanaxis senticososa*, *Notoginseng*, and *Salviae miltiorrhizae* are all TCM herbs with tonifying and blood circulation invigorating properties. Herbs that clear away heat and toxic material and herbs that promote blood circulation are useful for organ-irradiated injury with inflammation. *Notoginseng*, *Salviae Miltiorrhizae*, and other similar herbs can alleviate IR-induced inflammation.

TCM chemicals

Natural products constitute a treasury pool for identifying drugs against IR injury. They have a radiological protective effect by reducing damage to hematopoiesis, the gastrointestinal tract, the brain, and other organs. Restoring the balance of the antioxidant system, reducing inflammatory responses, and promoting the functional repair of target cells are the main mechanisms of action of these natural products. Many natural products exhibit multi-target and multi-system effects. Therefore, natural products in TCM are more suitable for treating radiation injuries that involve multiple organs, tissues, and systems. In recent years, researchers have focused on TCMs and phytomedicines and identified a series of natural products.

Natural products from tonic herbal medicines

Saponins are the main components of tonic herbs. Ginseng is the most commonly used herbal tonic medicine. Ginsenoside Rg1^[51], Rd^[52], and Rk1^[53] act against

radiation enteritis by suppressing apoptosis through the phosphatidylinositol 3-kinase (PI3K)-protein kinase B (AKT) pathway. Ginsenoside Rg3^[54] acts against radiation proctitis through the TLR4/MyD88/NF-κB pathway. Ginsenoside Rg1 has another antiradiation effect on hematopoietic stem cells (HSCs) and hematopoietic progenitor cells (HPCs) by inhibiting oxidative stress and reducing DNA damage^[55]. Dammarane saponins, hydrolyzed products of the constituent ginsenosides of *Panax ginseng*, protect against 60Co-induced myelosuppression in mice^[56]. Moreover, eleutheroside E (EE), a natural product from *Radix Acanthopanaxis Senticosi*, exhibits significantly improved radiation-induced cognitive dysfunction in mice. EE plays an important role in regulating radiation-induced oxidative stress and nerve cell protection^[32]. Phenylethanol total glycosides, which are derived from *cistanche*, also show protective effects on immune and reproductive organs in IR-injured mice^[57]. Based on the above studies, saponins in other *Araliaceae* plants and tonic herbs may have similar effects.

Flavonoids, a class of secondary metabolites in tonic herbal medicines, have also been widely studied as TCM herbs to protect against irradiation. Icariin is a natural flavonoid derived from *Epimedium* that has antiradiation effects. In the last 5 years, it has been found that icariin can promote the complex repair of hematopoietic, intestinal, reproductive, and brain radiation injuries^[58–61].

Additionally, Ginseng oligopeptides^[62] protect against IR-induced immune dysfunction and intestinal injury. Therefore, other categories of components also need to be considered, especially the antiradiation efficacy of non-small-molecule compounds, such as peptides and oligosaccharides.

Natural products from herbal medicines for circulation promotion and heat clearance

In recent years, plant polyphenols have been widely researched in herbal medicines used for circulatory-promoting and heat-clearing purposes. Flavonoids and phenolic acids are the primary polyphenols found in plants. Moreover, they play important roles in radiation injury control. Flavonoids including (-)-epicatechin^[63], (-)-epigallocatechin-3-gallate (EGCG)^[64], genistein^[65], and silibinin^[66] act as radioprotectors by antioxidant and anti-inflammatory activities. Phenolic acids provide similar cytoprotection against irradiation injuries. Among the phenolic acids, ferulic acid is one of the most representative radioprotectors. Our research has shown that oral administration of ferulic acid can effectively inhibit radiation injury involving the hematopoietic^[67,68], circulatory^[68], immune^[69], and nervous^[70] systems. Moreover, ferulic acid protects the gastrointestinal, testicular, and other organs exposed to irradiation by antioxidant and anti-inflammatory activities^[71–74]. Sesamol, another phenolic acid component, reduces radiation-induced expression of p53 and Bax apoptotic proteins in bone marrow, spleen, and gastrointestinal tract^[75]. In addition to flavonoids and phenolic acids, resveratrol^[76,77], catalpol^[78], and curcumin^[79,80] represent the most important cytoprotective polyphenols. Their radiological protection is mediated by multiple mechanisms, mainly leading to a

Table 1
Reported TCM herbs with radioprotective effects

No.	Herb name	Radioprotection (target organ)	Evidence	Ref.
1	Radix Ginseng (Ren Shen)	1. Skin 2. Renal 3. Liver 4. Lung 5. Colon	1. Against apoptosis in HaCaT. 2. Scavenged ROS of rats exposed to 6Gy irradiation. 3. Modulated oxidative stress, inflammatory reactions, and apoptosis of rats' liver. 4. Modulated early changes in oxidative stress levels, cytokine expression, and the histopathology of mouse lung tissue. 5. Decreased oxidative stress-related apoptotic cell execution in mice.	[26–30]
2	Radix Acanthopanax Senticosol (Ci Wu Jia)	1. Brain 2. Colon	1. Improved learning and memory ability in mice. 2. Inhibited inflammation levels in irradiated mice colon.	[31,32]
3	Radix Astragali (Huang Qi)	1. Lung 2. Hematopoiesis	1. Randomized controlled trials 2. Promoted hematopoiesis in irradiated myelosuppressive mice.	[33,34]
4	Radix Codonopsis Pilosulace (Dang Shen)	Immune system	Reduced the immunosuppressive effect of radiotherapy patients.	[35]
5	Fructifocation Ganodermae (Ling Zhi)	1. Immune system and marrow hematopoiesis 2. Heart	1. Prevented membrane damage in rat liver mitochondria and microsomes. 2. Prevented DNA breaks in γ -radiation-induced cells. 2. Balanced the antioxidant capacity of cells.	[36,37]
6	<i>Cordyceps militaris</i> (Yong Chong Cao)	Ovary cells	Increased free radical scavenging activity and decreased radiation-induced plasmid DNA strand breaks in hamster ovary cells.	[38]
	Epimedium (Yin Yang Huo)	Neurogenesis and cognition	Improved spatial learning and memory of mice by preventing the loss of proliferation cells, newly generated neurons, and interneurons in the hilus, particularly in the subgranular zone of the dentate gyrus.	[39]
7	Fructifocation Tremellae (Yin Er)	1. Components of peripheral blood 2. Bone marrow 3. Spleen	1. Restored hemoglobin, white blood cell counts, and red blood cell counts in irradiated mice. 2. Restored the number of nucleated cells in mice bone marrow 3. Restored spleen colony forming units and spleen index of irradiated mice.	[40]
8	Heridium erinaceus (Hou Gu)	1. Survival rate 2. DNA content of bone marrow	1. Raised the survival rate of irradiated mice 30 days after irradiation. 2. Increased the DNA content of bone marrow of irradiated mice.	[41]
9	Amillariellae Tabescens (Liang Jun)	Hematopoiesis	1. Promoted the repair of hematopoietic suppression in irradiated mice and dogs. 2. Increased the white blood cell count in the peripheral blood.	[42]
11	Radix Bupluri (Chai Hu)	1. Survival rate 2. DNA content of bone marrow 3. Spleen	1. Raised the survival rate of irradiated mice 30 days after irradiation. 2. Increased the DNA content of bone marrow of irradiated mice. 3. Restored spleen colony forming units and spleen index of irradiated mice.	[43]
12	Radix Angelicae Sinensis (Dang Gui)	Lung	Prevented the pulmonary fibrosis of irradiated mice.	[44]
13	Rhizoma Chuanxiong (Chuan Xiong)	1. Hematopoiesis 2. Spleen	1. Promoted the repair of hematopoietic suppression in irradiated mice. 2. Inhibition of apoptosis of splenic cells.	[45,46]
14	Radix Et Rhizoma Notoginseng (San Qi)	Bone	Promoted bone formation and resorption of irradiated mice and suppressed osteoporosis.	[47]

(Continued)

Table 1
(Continued)

No.	Herb name	Radioprotection (target organ)	Evidence	Ref.
15	Radix Salviae Miltiorrhizae (Dan Shen)	Lung	Suppressed radiation pneumonia by PI3K-AKT, HIF-1, TNF signaling pathways.	[48]
16	<i>Podophyllum hexandrum</i> (Tao Er Qi)	Thymocytes	Scavenged free radicals, thereby preventing DNA damage and stimulating its repair in mice.	[49]
17	Nutmeg (Rou Dou Kou)	30-day survival	Enhanced hepatic GSH and decreased testicular lipid peroxidation level of mice.	[50]
18	<i>Alocasia indica</i> (Guan Yin Lian)	Ovary and uterus	Reduced the oxidative stress and thereby restored the ovarian and uterine alterations of mice.	[24]

GSH: Glutathione; HaCaT: Human immortal keratinocyte line; HIF-1: Hypoxia inducible factor-1; PI3K-AKT: Phosphatidylinositol 3-kinase-protein kinase B; ROS: Reactive oxygen species; TCM: Traditional Chinese medicine; TNF: Tumor necrosis factor.

direct or indirect reduction in cellular stress and down-regulation of pro-inflammatory cytokines.

Additionally, studies have found that andrographolide^[81] and cryptotanshinone^[82] inhibit radiation pneumonitis and radiation fibrosis in mice exposed to IR. Hesperidin alleviates irradiation-induced submandibular gland damage induced by irradiation^[83]. Ligustilide prevents radiation-induced skin aging by inducing apoptosis in senescent cells^[84]. Natural products extracted from TCMs are becoming a hotspot in research surrounding radioprotective agents.

TCM agents against internal radiation injury

Upon contact with the body, radionuclides may enter *via* the mouth, nose, and broken skin. If these radionuclides are retained in the body or cannot be eliminated rapidly, their radiotoxicity and chemical toxicity can damage the body. Therefore, agents are needed to block absorption, accelerate the elimination of radionuclides, and protect against internal radiation injury. Among TCM agents, diuretic herbs can accelerate the metabolism and excretion of radionuclides and prevent their retention in the body.

Tritium, a radioactive isotope of hydrogen, is the largest and most widely distributed radionuclide found in nuclear-contaminated water. Tritium is brought into the atmospheric/hydrological circulation as tritiated water and readily enters the human body. If tritiated water is not excreted over time, it accumulates as organically bound tritium (OBT) in cellular DNA or lipids^[85]. Although the energy of β -rays from tritium is quite low, the physical half-life of tritium is 12.3 years, and its biological half-life is 4 months to 1 year^[86]. Thus, accumulated OBT can induce persistent inflammatory responses in living organisms^[85]. In addition, pancytopenia, carcinogenesis, and cerebral nervous system deficits triggered by tritium exposure cannot be ignored. Accelerating the excretion of tritiated water from the body at an early stage is the best method for internal radiation protection. To guard against internal radiation injury by tritium, pharmacists have designed a new TCM formula; Paichuan tablets. *Radix Astragalus*, Tuckahoe, Polyporus, *Rhizoma Alismatis*,

and *Rhizoma Atractylodis Macrocephalae* are herbs used in Paichuan tablets. Removing moisture and promoting diuresis are the core principles of these TCM formulas. With Paichuan tablet administration, tritium retention in the sera of exposed mice was significantly reduced^[87].

In addition to diuretic herbs, herbs rich in polysaccharides and tannins also effectively block radionuclide absorption. These include seaweed and kelp. The brown alga *Laminaria japonica* is a proven herb for the bio-sorption of uranium (VI) from aqueous solutions^[88]. In addition to suppressing the uptake of radioactive iodine by the thyroid gland and promoting its displacement, kelp blocks the absorption of strontium and accelerates its excretion through feces^[89,90]. Alginates, a broad family of linear polysaccharides derived from seaweed and kelp, can be used as strontium absorption blockers in alginate gelation^[91]. Moreover, natural metal chelators such as tropolone block the absorption of lanthanide and actinide elements and attenuate damage caused by radiation^[92,93].

Conclusion and perspective

TCM is a well-documented specialty for the treatment of complex diseases involving multiple organs, including radiation injuries. In the fight against radiation, TCM serves as a safer coping strategy for patients exposed to lower doses of external irradiation and internal radionuclides. We systematically reviewed antiradiation TCM formulae and herbs and grouped them according to target organ damage and effective characteristics. Promising components and active ingredients derived from TCMs have also been listed to promote the discovery of antiradiation drug candidates. These compounds may exert antiradiation effects through their anti-inflammatory, antioxidative, and hematopoietic repair effects. Furthermore, TCM formulae, herbs, and ingredients used to block absorption and accelerate the excretion of radionuclides were considered in this review. Therefore, radiation countermeasures should consider TCM. The material basis of TCMs and the scientific mechanisms driving their efficacy in radioprotection warrant in-depth and

immediate investigation to help better cope with the consequences of IR.

Conflict of interest statement

Yue Gao is the editorial board member of this journal and other author declare no conflicts of interest.

Funding

This study was financially supported by the Innovation Team and Talents Cultivation Program of National Administration of Traditional Chinese Medicine (ZYYCXTD-D-202207), the Young Scholar Science Foundation of Chinese Center for Disease Control and Prevention (2022A304), and the Young Elite Scientists Sponsorship Program by China Association of Chinese Medicine (CACM-2019-QNRC2-B01).

Author contributions

Shuai Shao drafted the manuscript. Yue Gao designed and revised the manuscript. All the authors have reviewed and approved the final manuscript.

Ethical approval of studies and informed consent

Not applicable.

Acknowledgments

None.

Data availability

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

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