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Clinical characteristics of stem cell application in the surgical management of post-traumatic and trophic skin defects. Literature review

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Chronic post-traumatic and trophic skin defects present a significant clinical challenge, particularly in the context of ischemia, infection, diabetic angiopathy and neuropathy, or severe traumatic injuries. Conventional treatments such as debridement, skin grafts, and local or free flaps often fail to achieve durable healing, thereby increasing interest in regenerative technologies. Mesenchymal stem cells (MSCs), particularly those derived from bone marrow and adipose tissue (ADSCs), exert significant paracrine, angiogenic, and immunomodulatory effects. These properties enhance the wound microenvironment and augment the efficacy of standard surgical interventions. Clinical studies and meta-analyses indicate that autologous MSC therapy accelerates healing of diabetic, venous, arterial, and mixed ulcers, decreases the risk of amputation, and improves tissue perfusion. In reconstructive surgery for post-traumatic defects, ADSC/SVF-assisted lipofilling and nanofat technologies are widely utilized. These approaches promote scar tissue remodeling, improve tissue elasticity, reduce contractures, and optimize conditions for subsequent flap reconstruction. Furthermore, cellular or cell-matrix constructs (MSCs combined with scaffolds) have the potential to manage complex soft-tissue defects with bone exposure, thereby reducing the need for extensive reconstructive procedures. Despite these promising outcomes, current evidence is limited by small sample sizes, methodological heterogeneity, the absence of standardized dosing protocols, and a lack of large multicenter randomized controlled trials. Furthermore, although no significant risks have been reported in existing studies, the issue of long-term oncological safety warrants continued monitoring. Emerging strategies include cell-free approaches such as exosomes and MSC secretions. Additionally, the integration of cellular technologies with 3D-printed and bioengineered matrices, as well as the development of standardized surgical algorithms that leverage MSCs to enhance the efficacy of conventional reconstructive techniques, are being explored.

Keywords
chronic wounds, trophic ulcers, post-traumatic defects, reconstructive surgery, mesenchymal stem cells (MSCs), adipose-derived stem cells (ADSCs), stromal vascular fraction (SVF), skin regeneration.

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Chronic post-traumatic and trophic skin defects, including venous, arterial, and mixed ulcers, diabetic foot, pressure ulcers, radiation injuries, and postoperative wounds, represent a significant medical and social challenge. In the United States alone, chronic wounds affect approximately 6.5 million patients and require more than $25 billion annually for treatment; this burden continues to rise due to an aging population and the increasing prevalence of diabetes and obesity [65]. The prevalence of chronic wounds in developed countries is estimated at 1–2 % of the population, and the high frequency of complications such as infection, osteomyelitis, amputation, and disability makes them a major cause of disability [21, 24, 50]. Standard interventions, including surgical debridement, necrectomy, split-thickness skin grafts, local and regional flaps, negative pressure therapy, compression therapy, and revascularization, often fail to achieve stable epithelialization, particularly in cases of severe ischemia, diabetic angiopathy and neuropathy, systemic connective tissue diseases, radiation injury, or military trauma [65, 66]. The frequent recurrence of ulcers, prolonged disease course, and substantial costs have driven the search for regenerative strategies, with stem and progenitor cells emerging as key therapeutic options [15, 53, 55].

This review aims to synthesize current evidence on the clinical application of stem cells in the

surgical management of post-traumatic and trophic skin defects, with particular emphasis on integrating cellular technologies into surgical protocols, including debridement, skin grafting, flap reconstruction, lipofilling, and combined techniques.

Pathophysiological prerequisites and limitations of traditional surgery

Chronic wounds are characterized by a delayed inflammatory phase, manifested by prolonged neutrophil and macrophage activity and persistent secretion of proinflammatory cytokines (TNF-α, IL-1β) [36, 53]. They also have impaired angiogenesis [26], a deficiency of local precursor cells (fibroblasts, endothelial progenitor cells) [25], an imbalance of metalloproteinases (MMP) and their inhibitors (TIMP) in favour of proteolysis [26, 53], as well as damage and destruction of the extracellular matrix (ECM) [46, 53].

In diabetic foot and ischemic ulcers, additional factors such as micro- and macroangiopathy, neuropathy, and increased susceptibility to infection are present. In contrast, post-traumatic defects are characterized by cicatricial changes, the presence of foreign bodies, and trophic disorders after multistage reconstructions [5, 82].

Even when debridement and split-thickness skin graft (STSG) are performed optimally, the presence of poor perfusion or a significantly altered wound bed is associated with a high incidence of partial or complete graft necrosis [39]. Flap reconstruction in patients with severe comorbid conditions is also associated with an increased risk of complications [54]. This creates a niche where adjuvant regenerative approaches can accelerate wound healing, improve the quality of the wound bed tissues, and increase the chances of skin graft engraftment.

Biological foundations of stem cell applications in skin regeneration

Mesenchymal stem cells (MSCs) derived from bone marrow, adipose tissue, umbilical cord, dental pulp, placenta, and other adult stem cells have a number of properties essential for wound healing. These include the capacity to differentiate into fibroblasts, endothelial cells, pericytes, and keratinocytes; robust secretion of growth factors such as VEGF, bFGF, TGF-β, and HGF; production of cytokines and chemokines; and immunomodulatory effects, including reduced proinflammatory cytokine production and polarization of macrophages toward the M2 phenotype [35, 36, 53, 55].

Recent reviews indicate that the clinical efficacy of MSCs in chronic wound treatment is primarily mediated by paracrine signaling and modification of the wound microenvironment, rather than by extensive direct differentiation into skin cells [15, 19, 34, 53]. This distinction carries significant clinical implications:

- Therapeutic effects may be achieved with relatively small numbers of cells.
- Cell-free technologies, such as conditioned media and exosomes, represent promising, safer, and more standardized alternatives.
- The interaction of cells with the surgically prepared wound bed is more critical than their physical integration into the tissue.

Sources and types of stem cells used in the clinical practice

Bone marrow-derived mesenchymal stem cells

Bone marrow mesenchymal stem cells (BM-MSCs) are among the earliest sources used for the treatment of chronic wounds. In the early 2000s, E. V. Badiavas and V. Falanga demonstrated that local application of autologous bone marrow cells, which may not be highly purified MSCs, promotes healing of refractory chronic skin ulcers in humans [8].

A prospective study by N. R. Dash et al. involved 24 patients with chronic lower extremity ulcers who received local injections of BM-MSCs (approximately 10^6 cells per 1 cm^2 of wound area) at the periphery and base of the defect following surgical debridement. The study reported a significant reduction in ulcer area and a higher rate of complete healing compared to historical controls, with an acceptable safety profile [17].

Contemporary approaches emphasize the topical application of allogeneic BM-MSCs as components of ready-to-use products for the treatment of chronic ulcers. Phase I/II studies have confirmed good tolerability, a tendency to accelerate epithelialization, and improvements in pain and quality of life [7].

Adipose-derived stem cells and stromal vascular fraction

Adipose tissue represents the most accessible source of MSCs. Adipose-derived stem cells (ADSCs) and the stromal vascular fraction (SVF) can be isolated via liposuction with minimal donor morbidity, a factor of particular significance in surgical patients [31, 32, 62, 63].

A systematic review by J. S. Holm et al. demonstrated that, in most studies, ADSCs and adipose tissue derivatives used for treating chronic ulcers (venous, diabetic, ischemic) result in accelerated healing, reduced pain, and an acceptable safety

profile. However, the included trials often exhibit heterogeneous designs and small sample sizes [32].

ADSCs may be administered through several approaches:

- local injection into the wound bed and edges as a cell suspension [20, 30];
- as a component of SVF, a minimally manipulated concentrate containing MSCs, pericytes, endothelial cells, fibroblasts, and immune cells [18, 27, 45];
- as part of nanofat, which is mechanically emulsified fat with a high concentration of progenitor cells [18, 71];
- in combination with platelet-rich plasma (PRP), hydrogels, or collagen matrices [45, 64].

Other sources: umbilical cord, placenta, Wharton's jelly, and epidermal stem cells

Perinatal sources of MSCs, such as the umbilical cord, placenta, and Wharton's jelly, are of increasing interest due to their high secretory potential, low immunogenicity, and the feasibility of standardized allogeneic production in accordance with good manufacturing practice (GMP). Wharton's jelly-derived MSCs are found in the mucopolysaccharide connective tissue of the umbilical cord, situated between the amniotic epithelium and the umbilical cord vessels. These cells exhibit a potent paracrine profile (VEGF, HGF, TGF-β, IL-10), high proliferative capacity, and the ability to differentiate into both mesenchymal and angiogenic lineages [6, 49, 75].

Experimental data and initial preclinical or small clinical studies indicate that placenta-derived MSCs (PMSCs) or their exosomes may enhance skin wound healing, stimulate angiogenesis, and modulate inflammation. However, large-scale randomized studies are still lacking [43, 72, 78].

Epidermal and dermal stem cells, delivered as cell coverings, keratinocyte sheet grafts, or composite skin substitutes (including cultured epidermal autografts), have been used in burn centers for many years to treat extensive post-burn and post-traumatic defects. Clinical evidence demonstrates that these grafts can achieve sufficient re-epithelialization, restore barrier function, and enable defect closure when donor sites are limited [10, 67]. However, outcomes are highly dependent on the wound bed conditions, and complications such as contractures or partial loss of coverage are common. Complete regeneration of all skin structures, including dermis, appendages, nerves, and vessels, remains unachievable [10]. Consequently, these technologies are less frequently incorporated into treatment protocols for chronic trophic ulcers, where ischemia, infection, and trophic disturbances hinder the successful integration of cell sheet grafts.

Dental pulp stem cells (DPSCs), which originate from the neurectoderm, exhibit high proliferative capacity, the ability to differentiate into mesenchymal (osteogenic, chondrogenic, adipogenic) and neuronal lineages, and a robust secretory profile (VEGF, NGF, BDNF, HGF) that supports angiogenesis, inflammation modulation, and tissue regeneration. Unlike many adult MSC sources, DPSCs are readily accessible, free from ethical concerns, and consistently express early stem cell markers (STRO-1, CD146) [4, 80]. Experimental studies indicate that DPSCs can accelerate skin wound healing by promoting fibroblast proliferation, enhancing vascularization, and reducing local inflammatory responses, although clinical application for skin defects remains limited to preclinical models [16, 29].

Clinical application of stem cells in the management of trophic defects

Diabetic foot

Diabetic foot ulcer represents one of the most extensively studied indications for autologous cell therapy of the lower extremities, often in conjunction with surgical debridement and reconstructive procedures.

A meta-analysis by X. Jiang et al., which included 10 clinical studies involving BM-MSCs, ADSCs, and bone marrow mononuclear cells, demonstrated that in patients with lower extremity ulcers–primarily diabetic foot and ischemic ulcers associated with occlusive disease–autologous stem cell therapy increases the frequency of ulcer healing and reduces the risk of lower extremity amputations compared to conservative or standard surgical approaches [37]. Specifically, autologous stem cell therapy was linked to improved healing of lower extremity ulcers (12 comparisons, 290 patients, partial healing relative risk (RR) = 3.07, 95 % confidence interval [CI] 1.14–8.24; p = 0.03; complete healing RR = 2.26; 95 % CI 1.48–3.16; p < 0.001) with minimal heterogeneity (I = 0 %). Additionally, autologous stem cell therapy resulted in a greater reduction in mean ulcer size (SMD = –0.63; 95 % CI from –1.03 to –0.22; p = 0.002).

A more recent meta-analysis by Y. Sun et al., which included 14 studies with 683 participants and focused specifically on diabetic foot, demonstrated that stem cell therapy (primarily BM-MSCs and ADSCs) was more effective than conventional therapy. Improvements were observed in ulcer or wound healing rate [odd ratio (OR) = 8.20 (5.33; 12.62)], lower limb ischemia (neovascularization) [OR = 16.48 (2.88; 94.18)], ankle-brachial index (ABI) [mean differences (MD) = 0.13 (0.04; 0.08)], transcutaneous oxygen

pressure ($TcPO_2$) [MD = 4.23 (1.82; 6.65)], pain-free walking distance [MD = 220.79 (82.10; 359.48)], and resting pain score [MD = –1.94 (–2.50; –1.39)]. The amputation rate was also significantly reduced [OR = 0.19 (0.10; 0.36)] [69].

Current clinical experience with autologous adipose-derived mesenchymal cells in chronic diabetic lower limb ulcers is primarily based on small phase I–II studies and non-randomized clinical trials. In a phase I study by M. H. Carstens et al., local injections of ADSCs following surgical debridement of diabetic ulcers were found to be safe and to accelerate epithelialization [12]. Comparable outcomes have been reported in other clinical studies utilizing SVF containing ADSCs. Several prospective and open-label studies have shown that administration of autologous SVF in combination with standard therapy leads to a reduction in diabetic ulcer area, improved tissue perfusion, enhanced granulation, more rapid wound area reduction, decreased need for amputation, and a higher rate of complete healing compared to standard treatment [11, 22, 74, 81]. While these findings support the therapeutic potential of adipose tissue-derived cells in diabetic foot ulcers, large-scale randomized trials of ADSCs in this context remain limited.

Notably, most clinical studies do not consider stem cells as a stand-alone therapy, but rather as an adjunct to standard surgical interventions, including radical wound debridement, infection control, correction of ischemia through endovascular or open reconstructive procedures, and optimization of glycemic and metabolic status. This integrative approach aligns with current understanding of stem cells as modifiers of the wound microenvironment, capable of reducing inflammation, stimulating angiogenesis, improving wound bed quality prior to skin grafting, and enhancing the likelihood of secondary epithelialization. The most significant clinical outcomes are observed when cell therapy is combined with active surgical and vascular interventions.

Venous, arterial, and mixed lower leg ulcers

A systematic review by B. Amato et al. evaluated clinical trials investigating adult tissue stem cells for the treatment of chronic lower leg ulcers of various etiologies, including venous, arterial, and post-traumatic. Most studies reported improved healing rates and reduced pain; however, the overall quality of evidence is moderate, primarily due to small sample sizes and heterogeneity in study design [3]. X. Jiang et al. further demonstrated that autologous stem cell therapy is associated with a higher rate of complete ulcer closure and a greater reduction in defect area compared to controls [37].

Meta-analyses and systematic reviews indicate that autologous stem cell therapy (BM-MSC/ADSC/SVF), may improve perfusion, promote ulcer healing, and reduce the risk of amputation in cases of critical lower limb ischemia. This approach is considered a potential solution when standard vascular or plastic surgical methods have been exhausted or proven ineffective [76, 77, 79]. However, current evidence is primarily derived from small case studies rather than large randomized controlled trials, so MSC therapy should be regarded as experimental or adjuvant rather than standard care.

Pressure ulcers, radiation, and postoperative defects

Although data on pressure ulcers and radiation injuries are limited, available clinical studies suggest the potential of MSC therapy. In case studies involving patients with pressure ulcers resulting from spinal cord injury, the application of autologous bone marrow cells (BM-MNC or BM-MSC), including delivery within plasma or fibrin matrices, has resulted in healing of deep defects that previously necessitated extensive flap reconstruction [2, 61].

For patients with chronic radiation ulcers, the use of bone marrow-derived or perinatal (placental, amniotic) MSCs in combination with biomatrices, such as decellularized amniotic membrane, lyophilized placental membrane, or other placental coatings, has demonstrated healing of defects that are resistant to standard treatment methods [13, 38, 58].

The role of stem cells in plastic and reconstructive surgery for post-traumatic defects

In plastic and reconstructive surgery, post-traumatic defects resulting from high-energy trauma, burns, blast injuries, or onco-orthopedic resections are characterized by loss of soft tissue volume, fibrosis, contractures, impaired microcirculation, and chronic inflammation. Even technically successful flap reconstructions or skin grafts frequently result in hard, painful, adhesive scars that limit function. In this context, cell-based technologies, particularly those utilizing ADSC or SVF, are regarded as adjuncts to conventional reconstructive methods rather than as replacements [27, 68, 70].

Clinically, the predominant strategy involves the use of autologous fat enriched with the SVF or progenitor cell-rich nanofat to address post-traumatic and post-burn scars, soft-tissue deformities, and contour defects [23, 40]. Systematic reviews of clinical studies indicate that ADSC/SVF-assisted lipofilling in scarred areas results in scar softening,

increased elasticity, reduced pain and itching, improved pigmentation and skin thickness, and high patient satisfaction, with an acceptable safety profile [68, 70]. However, the supporting evidence is primarily level III–IV, consisting of case studies, prospective uncontrolled trials, and small cohort observations [51, 52, 60, 68].

Seminal studies by G. Rigotti et al. demonstrated that transplantation of purified lipoaspirate, rich in adult adipose tissue stem cells, significantly improves soft tissue condition in areas affected by radiation damage, including reductions in pain, fibrosis, and scar retraction, as well as enhanced skin trophism and the feasibility of further reconstructive procedures [59]. Subsequent research by M. Klinger et al. found that repeated lipofilling sessions in patients with severe post-burn complications result in clinically meaningful scar remodeling, including improved elasticity, reduced contractures, and superior aesthetic outcomes, which correlate with morphological evidence of neovascularization and partial normalization of the dermis [40]. These findings are particularly relevant for surgeons managing complex post-traumatic defects with concurrent burn or radiation fibrosis.

Review summaries indicate that ADSC/SVF-assisted lipofilling is applied in reconstructive practice primarily in two scenarios: first, as a form of biological preprocessing to optimize the recipient bed prior to complex skin-flap reconstruction or future endoprosthesis placement (such as after oncological resection or severe soft tissue trauma); and second, as repeated staged interventions to address residual scar deformities, contractures, and volume deficits following primary reconstruction [19, 28, 39, 52]. The primary objectives in the first scenario are to enhance vascularization, decrease fibrosis, and create a more receptive environment for grafts or flaps. In the second, the focus is on long-term scar tissue remodeling and improved functional outcomes, including increased joint range of motion, prosthesis compatibility, and reduced pain on exertion.

Some clinical studies have described the use of BM-MSCs, perinatal MSCs (from amniotic or placental membranes), and combined constructs, such as «MSCs + biomatrix», in managing complex post-traumatic soft tissue defects. In these approaches, cell-rich matrices are employed to cover exposed bone or fill defects, either prior to or in conjunction with flap reconstruction. Observational reports highlight the formation of high-quality granulation tissue, a reduced need for extensive reconstructive procedures, and a lower incidence of wound-edge dehiscence compared with standard techniques [1, 44, 47]. Nevertheless, the patient cohorts are typically heterogeneous, encompassing mixed trophic, oncological, and post-traumatic wounds, and the study designs preclude definitive conclusions regarding the superiority of any specific MSC type.

Overall, clinical evidence indicates that, in plastic and reconstructive surgery for post-traumatic defects, stem cells–primarily ADSC/SVF–should be regarded as adjuncts to enhance the tissue microenvironment, including scar quality, vascularization, and elasticity. These approaches complement but do not replace established methods such as skin grafts, local and free flaps, and microsurgical techniques. Current data support their use in complex cases resistant to standard treatments, provided that rigorous patient selection and adherence to oncological safety protocols are maintained. However, there remains a clear need for large-scale randomized studies to assess efficacy and long-term outcomes.

Clinical features of the use of stem cells in the surgical treatment of skin defects

Current evidence allows for the identification of several key clinical aspects relevant to surgical practice.

Patient selection

Patients most likely to benefit from stem cell therapy include the following groups:

- with chronic (> 3–6 months) trophic ulcers that do not heal despite optimal standard treatment [3, 37, 69];
- those with combined pathologies, such as diabetic foot with critical ischemia or post-traumatic defects in the context of obesity or systemic diseases;
- individuals at high risk of amputation for whom standard reconstructive options have been exhausted or present excessive risk [14, 37, 55, 69].

However, stem cell therapy does not replace the fundamental principles of wound management, such as the «TIME» framework (tissue, infection/inflammation, moisture, edge), or modern vascular interventions. Instead, it enhances their effectiveness [9, 41].

Wound preparation and the surgical «window of opportunity»

Almost all studies emphasize the need for radical surgical debridement, infection control, and optimization of systemic factors before stem cell administration [3, 32, 53, 55].

This sequence establishes a critical period for intervention, commonly referred to as a «window of opportunity»:

- stage 1 – radical debridement, correction of ischemia, and stabilization of the general condition;

• stage 2 – cell therapy (injectable, topical, or within a matrix or adipose tissue) for the prepared wound bed;

• stage 3 – if necessary, skin grafting or flap reconstruction of the prepared wound bed (often after 1–3 weeks).

For example, combined techniques such as nanofat with STSG or high-density nanofat with NPWT have been used to manage chronic lower leg defects [18, 39].

Routes of administration and doses

Clinical studies have employed various routes of stem cell administration:

• **local injections** into the wound bed and edges, using BM-MSC, ADSC, or SVF, represent the most common approach;

• **intramuscular administration** in the vicinity of the ischemic zone, particularly in cases of critical limb ischemia;

• **topical application** incorporated into gels, fibrin sprays, or three-dimensional matrices [7, 8, 53, 57].

Typical doses for local administration range from 10^6 to 10^7 cells/cm^2 of defect area, or 10^7 to 10^8 cells for the entire wound. When using SVF or nanofat, the administered volume of lipoaspirate (in milliliters) is more commonly reported than the absolute cell count [32, 57, 62]. The absence of standardized dosing regimens remains a significant barrier to widespread clinical adoption.

Combination with other regenerative technologies

Stem cell therapies are increasingly integrated with the following adjunctive modalities:

• **platelet-rich plasma** (PRP), which contains high concentrations of growth factors such as PDGF, TGF-β, VEGF, and EGF, and may potentiate the paracrine effects of MSCs [57];

• **negative pressure therapy** (NPWT) – high-density nanofat + NPWT in chronic wounds [18];

• **biomatrices,** including collagen, acellular dermal matrices, and placental matrices [31, 55].

In practical terms, this approach represents a shift from single-stage procedures to stepwise combination therapies, in which cellular components are integrated alongside flaps, grafts, and physiotherapeutic interventions.

Safety and potential risks

Serious adverse events directly attributable to stem cell therapy are infrequent in most clinical trials [14, 32, 37, 55, 69]. The most frequently reported events include:

• local pain at the injection site, hematoma, or transiently increased exudation;

• infectious complications, which are typically associated with the underlying wound condition rather than the cellular product.

Concerns about the potential stimulation of tumour growth have not been substantiated in clinical trials with limited follow-up. Nevertheless, reviews emphasize the necessity for ongoing oncological vigilance, especially when allogeneic cells are used or in patients with a history of cancer [15, 55].

Regulatory requirements, including GMP standards, classification as Advanced Therapy Medicinal Products (ATMP), and logistical complexity, continue to present significant barriers to the widespread adoption of stem cell therapy outside research centers.

Unresolved issues and prospects

Although recent findings are promising, current reviews consistently identify several critical gaps in the literature:

Study heterogeneity: Variability in cell sources, collection and cultivation protocols, dosing regimens, administration routes, and efficacy criteria complicates the development of unified recommendations [3, 14, 15, 55].

Insufficient large-scale multicenter RCTs with long-term follow-up (i 2–3 years), particularly for specific surgical indications such as post-traumatic defects and complex reconstructions.

Lack of standardized study endpoints: There is a need for unified outcome measures, including time to complete epithelialization, sustained healing over 6–12 months, recurrence rates, and both functional and cosmetic results.

Comparative evaluation of different cell sources (BM-MSC vs. ADSC vs. placental MSCs) within standardized surgical treatment protocols.

Promising avenues

Promising avenues for future research include the following:

• cell-free strategies, such as the use of exosomes and MSC conditioned media, which may offer more standardized and potentially safer alternatives [33, 56];

• integration of stem cells with 3D-printed and bioengineered matrices to enable individualized reconstruction of tissue defects [48, 75];

• systematic incorporation of cell-based technologies into military and trauma surgery protocols, including early application of MSCs for extensive soft tissue injuries [42, 73, 75].

Conclusions

Chronic post-traumatic and trophic skin defects represent a persistent clinical and economic challenge. Traditional surgical interventions, such as debridement, skin grafting, and flap procedures, often fail to achieve stable healing in certain patient populations.

Stem cells, particularly BM-MSCs and ADSCs, have demonstrated efficacy in enhancing chronic wound healing through paracrine, angiogenic, and immunomodulatory mechanisms. These therapies are regarded as adjuncts to standard surgical approaches rather than replacements.

Clinical trials and meta-analyses indicate that autologous stem cell therapy for lower limb ulcers, including diabetic foot, venous, and ischemic ulcers, increases the rate of complete healing, accelerates epithelialization, and reduces amputation risk, while maintaining an acceptable safety profile.

In surgical practice, combined approaches involving stem cell therapies are of particular interest. These include:

- local injections of MSC/ADSC/SVF into the prepared wound bed;
- application of nanofat and SVF beneath split-thickness skin grafts for challenging post-traumatic defects;
- stem cell-enriched lipofilling for the correction of post-traumatic scars and contractures.

The safety profile of stem cell therapy for skin defects is generally favourable; however, extended long-term follow-up is necessary, particularly concerning potential oncogenic risks and the application of allogeneic cells.

Major barriers to widespread adoption include the absence of standardized protocols, heterogeneity among clinical trials, regulatory constraints, and high associated costs.

A promising direction involves developing explicit surgical algorithms that integrate stem cells, their secretions, or exosomes into sequential treatment regimens for post-traumatic and trophic defects. This approach may include debridement, followed by cell or exosome therapy and subsequent skin graft or flap reconstruction, with further validation required through well-designed multicenter randomized trials.

Declaration of interests

The author declares no conflicts of interest.

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Клінічні особливості застосування стовбурових клітин при хірургічному лікуванні посттравматичних і трофічних дефектів шкірних покривів. Огляд літератури

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Хронічні посттравматичні й трофічні дефекти шкіри залишаються складною клінічною проблемою, особливо в умовах ішемії, інфекції, діабетичної ангіопатії та нейропатії чи наслідків високотравматичних ушкоджень. Традиційні методи (дебридмент, шкірні трансплантати, місцеві й вільні клапті) не завжди забезпечують стійке загоєння, що стимулює інтерес до регенеративних технологій. Мезенхімальні стовбурові клітини (MSC), насамперед кістково-мозкові й адипозо-деривовані (ADSC), чинять виразний паракринний, ангіогенний та імуномодулювальний вплив, поліпшуючи мікрооточення рани та підвищуючи ефективність стандартних хірургічних втручань. Клінічні дослідження й метааналізи демонструють, що автологічна терапія MSC сприяє швидшому загоєнню діабетичних, венозних, артеріальних і змішаних виразок, знижує ризик ампутацій та поліпшує перфузію тканин. У реконструктивній хірургії посттравматичних дефектів найбільш затребуваними є ADSC/SVF-асистований ліпофілінг і nanofat-технології, які забезпечують ремоделювання рубцевої тканини, підвищення її еластичності, зменшення контрактур і поліпшення умов для подальших клаптевих реконструкцій. Клітинні або клітинно-матриксні конструкції (MSC + scaffold) продемонстрували потенціал у лікуванні складних дефектів м'яких тканин з оголенням кістки, зменшуючи потребу в об'ємних реконструкціях. Незважаючи на обнадійливі результати, докази мають обмеження: невеликі вибірки, гетерогенність методик, відсутність стандартизованих доз і недостатня кількість великих багатоцентрових рандомізованих контрольованих досліджень. Питання щодо тривалої онкологічної безпечності потребує подальшого спостереження, хоча значущих ризиків у наявних серіях не виявлено. Перспективними є безклітинні підходи (екзосоми, секретом MSC), інтеграція клітинних технологій із 3D-друкованими та біоінженерними матрицями, розробка чітких хірургічних алгоритмів, де MSC є інструментом для підсилення ефективності стандартних реконструктивних методів.

Ключові слова: хронічні рани, трофічні виразки, посттравматичні дефекти, реконструктивна хірургія, мезенхімальні стовбурові клітини, адипозо-деривовані стовбурові клітини, стромально-васкулярна фракція, регенерація шкіри.

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