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Construction of a Specialized Nursing System for Stereotactic Precise Multi-Target Intracerebral Stem Cell Transplantation in the Treatment of Ischemic Brain Injury

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Abstract: Stereotactic multi-target precise transplantation of stem cells into the brain is an innovative neural repair approach that integrates minimally invasive neurosurgery and regenerative medicine. Under precise image guidance, stem cells can be delivered accurately into ischemic-injured areas and functional nuclei, thereby promoting neural circuit reconstruction and neurological function recovery. With the clinical transformation of this technique, establishing a systematic, standardized, and specialized nursing system is crucial to ensure surgical safety, reduce intracranial complications, improve therapeutic effect, and accelerate neurological recovery. Based on the technical characteristics, repair mechanisms and pathophysiological features of ischemic brain injury, this study constructed a comprehensive specialized nursing system including perioperative management, intraoperative cooperation, complication monitoring, immune rejection control, rehabilitation training, psychological intervention and continuous follow-up, so as to provide a reliable reference for clinical nursing practice.

Keywords: Stereotactic technique; Multi-target transplantation; Neural stem cells; Ischemic brain injury; Specialized nursing system

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1. Introduction

Ischemic stroke is characterized by high incidence, disability, recurrence, and mortality rates, making it the leading cause of long-term neurological dysfunction in adults [1,2]. Current conventional clinical treatments are constrained by a definitive time window and are often ineffective in repairing necrotic neural cells and damaged neural circuits, failing to meet the clinical needs of patients for functional reconstruction. In recent years, neural stem cells (NSCs), with their biological properties of self-renewal, multidirectional

differentiation, and paracrine neuroprotection, have provided a new direction for neural repair following ischemic brain injury [3].

Stereotactic precise multi-target intracerebral stem cell transplantation, as a minimally invasive neurosurgical technique, enables the accurate and multi-site implantation of NSCs into the ischemic penumbra and functionally critical regions such as the cortex, striatum, and thalamus under CT or MRI imaging guidance. This approach effectively crosses the blood-brain barrier, enhances cell engraftment rates and local bioavailability, and represents one of the most promising techniques for clinical translation in the field of ischemic brain injury repair [4]. However, this procedure involves precise intracranial puncture, multi-channel implantation, modulation of the intracerebral microenvironment, and long-term immune management, demanding a far higher level of professionalism, precision, and systematicity in nursing care compared to conventional stroke nursing. Currently, a unified and standardized specialized nursing model for this procedure has not been established in clinical practice, and nursing practices still lack a systematic framework [5].

This article constructs a comprehensive, full-cycle specialized nursing system covering preoperative, intraoperative, postoperative, and long-term follow-up care, based on the technical characteristics and neural repair mechanisms of stereotactic precise multi-target intracerebral stem cell transplantation, combined with clinical nursing practice experience [6]. This system aims to provide nursing support for enhancing treatment safety, optimizing patient outcomes, and promoting the clinical application of this technology.

2. Overview of mechanisms for stereotactic multi-target intracerebral stem cell transplantation in repairing ischemic brain injury

2.1. Precise multi-target engraftment and neural circuit reconstruction

Stereotactic technology establishes intracranial puncture channels through three-dimensional coordinate positioning, enabling multi-target and multifocal cell infusion. This allows stem cells to be directly distributed in regions with impaired neural function, replacing some necrotic neural cells, activating endogenous neurogenesis, and promoting structural repair and functional reconstruction of damaged neural circuits [3,7].

2.2. Paracrine effects and improvement of the injured microenvironment

Transplanted NSCs can release various neurotrophic factors and cellular active substances, such as BDNF, VEGF, and bFGF, through paracrine pathways. These factors inhibit neuronal apoptosis, alleviate local inflammatory responses, promote angiogenesis in ischemic regions, and create stable microenvironmental conditions for neural repair.

2.3. Immunomodulation and control of neuroinflammation

Excessive neuroinflammatory responses following ischemic brain injury are significant factors exacerbating secondary brain injury. NSCs can modulate the polarization direction of microglia, reduce the expression of pro-inflammatory factors such as IL-1β and TNF-α, mitigate inflammatory damage to neural tissue, protect the integrity of the blood-brain barrier, and lower the risk of immune reactions post-transplantation [1,8].

2.4. Correlation between transplantation timing and nursing interventions

Clinical studies indicate that the subacute phase of cerebral ischemia (7–14 days) is characterized by a stabilization of inflammatory responses and sustained high levels of neural plasticity, making it an ideal time window for stereotactic multi-target transplantation. Nursing staff should strengthen condition assessments, intracranial pressure monitoring, and infection prevention during this phase to ensure the safe implementation of the procedure [1,4].

3. Construction of a specialized nursing system for stereotactic precise multi-target intracerebral stem cell transplantation

3.1. Precise perioperative nursing

3.1.1. Preoperative multidimensional assessment and specialized preparation

A multidisciplinary collaboration model involving neurology, neurosurgery, rehabilitation, nursing, and psychology departments should be established. Nursing staff should conduct comprehensive systematic assessments, including:

(1) Neurological function assessment, using scales such as NIHSS, mRS, and Barthel index to quantify neurological function and activities of daily living;

(2) Imaging and surgical risk assessment, completing thin-slice cranial MRI or CT scans to clarify target positioning, puncture paths, and surgical risk points;

(3) Baseline status assessment, monitoring blood pressure, blood glucose, coagulation function, and infection markers, and actively managing underlying diseases to reduce surgical risks;

(4) Psychological status assessment, using SAS and SDS scales to screen for anxiety and depression, and implementing interventions for high-risk individuals in advance. Strict preoperative preparations should include head skin preparation, positional adaptation training, respiratory management, and fasting and fluid restriction guidance.

Patients and their families should be thoroughly briefed on the surgical procedure, key points of cooperation, and expected outcomes to enhance treatment compliance and cooperation.

3.1.2. Preoperative psychological interventions

Patients undergoing intracranial minimally invasive transplantation often experience significant fear, tension, and uncertainty, which can affect immune function and surgical tolerance due to emotional stress. Nursing staff should provide targeted psychological counseling, clearly explaining the advantages of stereotactic technology, such as its minimally invasive, precise, safe, and low-trauma nature. Sharing recovery cases of similar patients can boost confidence, while encouraging family emotional support helps stabilize the patient's psychological state and lays the foundation for successful surgery.

3.1.3. Intraoperative specialized cooperation

Intraoperative nursing cooperation directly impacts surgical precision and safety. Nursing staff should assist in securing the head frame, maintaining a neutral and stable head position to avoid target deviation due to intraoperative movement; strictly adhere to aseptic principles for intracranial surgery and strengthen surgical site management to minimize the risk of intracranial infection; carefully verify the number, concentration, viability, and infusion dose of the stem cell preparation before transplantation, ensuring proper temperature-

controlled storage; and continuously monitor consciousness, pupils, blood pressure, heart rate, and other indicators throughout the procedure, promptly identifying and assisting in managing abnormalities [9].

3.1.4. Postoperative monitoring and positional management

Patients should be instructed to remain absolutely bedridden for 24–48 hours postoperatively, with the head of the bed elevated to 15–30° to promote intracranial venous return, reduce cerebral edema, and lower intracranial pressure. Nursing care should avoid vigorous head movements to prevent bleeding from the puncture channel; continuously monitor consciousness, pupils, limb movements, language function, and other indicators every 30–60 minutes, with appropriate extensions of monitoring intervals as the patient's condition stabilizes [10].

3.2. Nursing care for immunosuppressive therapy

To reduce immune rejection following allogeneic stem cell transplantation, short-term immunosuppressive regimens are commonly used clinically. Nursing staff should strictly administer medications on time and in the correct dosage as prescribed, instructing patients not to discontinue, reduce, or alter the dosage without authorization; regularly monitor liver and kidney function and blood counts during treatment, observing for gastrointestinal reactions, oral mucosal changes, and signs of infection; and strengthen health education, emphasizing the importance of standardized medication adherence for improving cell survival rates and reducing rejection reactions.

3.3. Precise observation and intervention for complications

3.3.1. Acute intracranial complications (within 72 hours postoperatively)

Stereotactic multi-target puncture, due to the increased number of channels, carries a higher risk of intracranial complications than single-target transplantation, requiring focused monitoring:

(1) Intracranial hemorrhage

Closely observe for changes in pupil size, headache intensity, vomiting, and sudden decline in limb muscle strength, promptly assisting with cranial CT scans if abnormalities occur;

(2) Cerebral edema and increased intracranial pressure

For patients with worsening headache, altered consciousness, or elevated blood pressure, administer dehydrating agents as prescribed, maintain a quiet environment, and avoid actions that increase intracranial pressure, such as forceful coughing or straining during defecation;

(3) Seizures

Due to potential irritation of the cerebral cortex by the puncture path, emergency supplies should be routinely prepared at the bedside postoperatively. If a seizure occurs, maintain airway patency, ensure safety, and accurately record the seizure form and duration;

(4) Incision complications

Observe for incision bleeding, exudate, redness, and swelling, keeping the dressing dry and clean to prevent incision and intracranial infections.

3.3.2. Monitoring for delayed complications and rejection reactions

Long-term nursing care should focus on delayed adverse events:

(1) Infections

Due to immunosuppression-induced decreased resistance, patients are prone to infections in the lungs, urinary system, and intracranial regions. Strengthen oral, skin, respiratory, and urinary tract care, limit visitors, and monitor body temperature and inflammatory markers;

(2) Delayed immune rejection

Despite the immune-privileged nature of the central nervous system, remain vigilant for unexplained fever, headache, neck stiffness, and sudden neurological decline, regularly reviewing imaging and immune-related indicators;

(3) Neurological fluctuations

Some patients may experience transient changes in muscle strength or language function, requiring careful differentiation between transient microenvironmental reactions and secondary neural injury, with enhanced observation and timely rehabilitation interventions.

3.4. Holistic psychological nursing

Postoperatively, patients may experience anxiety, depression, and frustration due to the prolonged neural function recovery period and concerns about treatment outcomes. Nursing staff should proactively communicate with patients daily, promptly providing feedback on neurological improvements, offering positive encouragement and psychological support, and reinforcing rehabilitation confidence. For patients with low mood or decreased cooperation, strengthen personalized counseling and, if necessary, collaborate with the psychology department for professional interventions to prevent negative emotions from affecting sleep, immune function, and rehabilitation training adherence, thereby influencing neural repair outcomes.

3.5. Neurological rehabilitation nursing

Neurological rehabilitation is a core factor influencing the efficacy of stem cell transplantation and should follow principles of early intervention, standardized and orderly progression, individualization, and gradual advancement, synergizing with stem cell repair effects. Early rehabilitation should be initiated 24–48 hours postoperatively when the patient's condition stabilizes, including proper limb positioning, passive joint movements, swallowing function assessment, airway management, and prevention of pressure ulcers and deep vein thrombosis. Mid-term rehabilitation (1–4 weeks postoperatively) should involve muscle strength training, balance training, fine hand movement training, and activities of daily living training. During the recovery phase, focus on intensifying language, cognitive, and gait function training to promote neural plasticity and improve patients' self-care and social participation abilities.

3.6. Discharge guidance and continuity of care system

Before discharge, nursing staff should provide systematic guidance to patients and their families:

(1) Medication guidance

Clarify the administration methods, dosages, timing, and adverse reaction observation points for immunosuppressive agents and medications for underlying diseases [11];

(2) Home rehabilitation guidance

Teach home-based rehabilitation training methods, intensity control principles, and safety protection techniques;

(3) Self-identification of complications

Educate patients and families on recognizing danger signs such as fever, severe headache, seizures, worsening limb weakness, or altered consciousness, and clarify indications for emergency medical attention;

(4) Long-term follow-up management

Establish a specialized follow-up file, with regular outpatient reviews at 1, 3, 6, and 12 months postoperatively to assess neurological function, cranial MRI, immune function, and liver and kidney function, dynamically evaluating treatment efficacy and safety;

(5) Caregiver support

Provide caregiving skill training and psychological counseling for families to alleviate caregiving stress and establish a stable home care system.

3.7. Key nursing regulation points affecting transplantation outcomes

Nursing interventions can directly influence stem cell engraftment, survival, and neural repair outcomes. Core regulation points include: maintaining a stable intracranial microenvironment and effectively controlling inflammation and cerebral edema; standardizing immunosuppressive management to balance immune rejection and infection risks; initiating early rehabilitation training to maximize neural plasticity activation; providing holistic psychological interventions to reduce the inhibitory effects of stress responses on the repair process; and accurately identifying and intervening in complications to prevent secondary neural injury from negating treatment effects [9].

4. Outlook

Stereotactic multi-target precise transplantation of brain stem cells is currently at a critical stage of clinical translation and application promotion, necessitating a transformation in nursing models from traditional operational coordination to precision, specialization, full-cycle, and systematization. In the future, personalized nursing pathways tailored to different injury sites, cell types, and disease stages can be further explored. An early warning nursing system for immune rejection can be established, and an integrated psychological-rehabilitation-immune nursing model can be optimized to drive the standardization, scientific advancement, and high-quality development of stem cell transplantation nursing.

5. Conclusion

Stereotactic multi-target precise transplantation of brain stem cells offers a precise, minimally invasive, and efficient new strategy for neural repair following ischemic brain injury. Establishing a comprehensive specialized nursing system that covers preoperative assessment, intraoperative coordination, postoperative monitoring, complication prevention and control, immune management, rehabilitation training, psychological support, and long-term follow-up is crucial for ensuring surgical safety, enhancing stem cell repair efficacy, and promoting neural functional recovery in patients. Nursing staff should deeply understand the technical characteristics of the surgical procedure and the mechanisms of neural repair, implementing precise, standardized, and individualized specialized nursing to provide solid and reliable nursing support for advancing the clinical application and sustained development of this new technology.

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Disclosure statement

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