Efficacy and safety of human-derived neural stem cell in patients with ischaemic stroke: study protocol for a randomised controlled trial

Chong Xie, Kan Wang, Jing Peng, Xianguo Jiang, Shuting Pan, Liping Wang, Yifan Wu, Yangtai Guan

ABSTRACT

Introduction Stroke is the most common cause of neurological disability in adults worldwide. Neural stem cell (NSC) transplantation has shown promising results as a treatment for stroke in animal experiments. The pilot investigation of stem cells in stroke phase 1 and phase 2 trials showed that transplantation of the highest dose (20 million cells) was well tolerated. Preliminary clinical benefits have also been observed. However, the trials were open-label and had a small sample size. Furthermore, human NSCs (hNSCs) were intracerebrally implanted, and some serious adverse events were considered to be related to the surgical procedure. Therefore, we plan to conduct a double-blind, randomised controlled trial to test the safety and efficacy of intranasal injection of hNSCs.

Methods and analysis This single-centre, randomised, double-blinded, parallel-controlled trial will be conducted in China. Sixty patients with ischaemic stroke who met the qualification criteria will be randomly divided into two groups: the NSCs and control groups. All participants will receive intranasal administration of hNSCs or placebo for 4 consecutive weeks. Patients will be followed up at baseline and at 4, 12, 24 and 48 weeks after intervention. The primary outcome is the National Institutes of Health Stroke Scale score (4, 12, 24 weeks after intervention). Secondary outcomes include the modified Rankin scale, Barthel index, Mini-Mental State Examination score (4, 12, 24 weeks after intervention) and cranial MRI changes (24 and 48 weeks after intervention). All adverse events will be recorded during the study period.

Ethics and dissemination The study protocol was approved by the Ethics Committee of Ren Ji Hospital (2018-009). All subjects will provide informed consent. The results will be accessible in peer-reviewed publications and will be presented at academic conferences.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study is a prospective, randomised controlled trial.
⇒ Participants with ischaemic stroke 3–24 months before screening will be recruited.
⇒ Participants will receive intranasal injection of neural stem cells or placebo for 4 consecutive weeks.
⇒ The study's small sample size and single-centre design may affect its generalisability.
⇒ No restriction on participant's rehabilitation exercise may affect the efficacy assessment.

INTRODUCTION

Stroke is the most common cause of neurological disabilities in adults worldwide. Every year, more than 795,000 people in the USA have a stroke. About 61,000 of these are first or new strokes. About 87% of all strokes are ischaemic strokes. China faces great challenges from stroke. In 2018, the death rate from cerebrovascular diseases in China was 149.49 per 100,000, accounting for 1.57 million deaths. Disability after stroke causes a serious social and economic burden. Methods to effectively prevent stroke and improve functional recovery in patients with stroke are urgently needed.

Rehabilitative approaches aid functional recovery and brain reorganisation, but the effect diminishes over time, which indicates that neurological recovery is time limited. Owing to the limitations of endogenous repair, cell-based exogenous therapies have been investigated. Neural stem cells (NSCs) are ideal candidates for treating stroke and neurodegenerative diseases. Intracerebral delivery of NSCs, the preferred route in animals, significantly improves sensorimotor function in rats. NSCs achieved functional recovery of the injured brain mainly by cell replacement (neuron and glia regeneration), nutritional effects (paracrine effects) and immune-regulation (neuro-protective) effects. NSCs were also reported to promote vascular remodelling in brain lesions.

To date, many modified stem cell preparations have been developed, and preclinical evidence supports their long-term safety.
The first in-human trial, a pilot investigation of stem cells in stroke (PISCES) phase I dose-escalation trial, was reported in 2016. PISCES is a phase I, open-label, single-centre, dose-escalation trial of the intracerebral stereotactic implantation of CTX-DP, a human NSC line. Men aged ≥60 years with stable disability (National Institutes of Health Stroke Scale (NIHSS) score<6 and modified Rankin Scale (mRS) score 2–4) were implanted with single doses of 2, 5, 10 or 20 million cells by stereotactic ipsilateral putamen injection 6–60 months after ischaemic stroke. Clinical and brain imaging data were collected over a period of 2 years. The primary endpoint was safety (adverse events (AEs) and neurological changes). Thirteen male patients were recruited, of whom 11 underwent CTX-DP treatment. No immunological or cell-related AEs were observed. Other AEs were related to the procedure or comorbidities. At 2 years, improvement in the NIHSS score ranged from 0 to 5 (median, 2) points.11

The PISCES study offers preliminary data on the feasibility, tolerability and cell-related safety of stereotactic intracerebral injection of human NSCs (hNSCs) in patients with chronic ischaemic stroke. The PISCES phase II study was also completed as a multicentre, single-arm, open-label study in adults aged >40 years with significant upper-limb motor deficits. Twenty-three patients underwent cell implantation at eight hospitals. Transient procedure-related AEs were observed; however, no cell-related AEs occurred up to 12 months of follow-up.15 In addition to the PISCES study, the results of another trial have been published. NSI-566, a stable, primary adherent NSC line derived from a single human fetal spinal cord, was evaluated for feasibility and safety in the treatment of stroke. Three cohorts (n=3 per cohort) were transplanted with single intracerebral injections of 1.2×10⁷, 2.4×10⁷ or 7.2×10⁷ cells. The study demonstrated that transplantation of the highest dose (7.2×10⁷ cells) was well tolerated and exerted preliminary clinical benefits. MRI results indicated new neural tissue formation in the stem cell implantation area.13

However, all the above studies were open-labelled and had a small sample size. Thus, the exploratory efficacy data should be regarded with extreme caution because of the open-label design. Therefore, some potential AEs with low incidence might not be identified. Furthermore, the hNSCs were implanted intracerebrally and some AEs were considered to be related to the surgical procedure. Therefore, we plan to conduct a double-blind, randomised controlled trial to further test the safety and efficacy of hNSCs in the treatment of ischaemic stroke. In contrast to previous studies, hNSCs will be administered intranasally. Intranasal injections of stem cells have been used to treat animal models of stroke, MS and other diseases.14-16 Studies have shown that nasal administration of NSCs is safe, and that NSCs can migrate to lesions in the CNS. In this trial, we will further explore the safety and efficacy of intranasal injection of hNSCs in the treatment of ischaemic stroke.

METHODS
Study design, setting and approval
This study is a single-site, double-blinded, randomised controlled trial. Random treatment allocation will be done at the individual level. The trial protocol is illustrated in figure 1. Sixty patients will be recruited at Ren Ji Hospital, affiliated with the Shanghai Jiaotong University School of Medicine, Shanghai, China. The study has been approved by the Ethics Committee of Ren Ji Hospital. The approved trial protocol was registered in the Chinese Clinical Trial Registry on 24 April, 2019. The current status of this trial is recruiting.

Inclusion criteria
(1) Aged 18–80 years old; (2) with ischaemic stroke 3–24 months before screening, and stroke was caused by stenosis or embolism of the unilateral anterior and/or middle cerebral artery; (3) hemiplegia (NIHSS score ≥6 and at least one limb exits motor dysfunction); (4) stable neurological deficits for at least 2 months before screening (a variety of NIHSS scores no greater than 2); (5) mRS scores of 2–4; (6) mini-mental state examination (MMSE) score is smaller than 24; (5) a history of gastrointestinal bleeding or other severe haemorrhagic diseases within 1 month before screening; (8) surgical history 1 week before screening; (9) abnormal coagulation (prothrombin time, activated partial thromboplastin...
time, fibrinogen, international normalised ratio exceeding or below 50% of the institute’s normal limit), severe liver and kidney diseases (total bilirubin, aspartate transaminase, alanine transaminase, creatinine exceeding 50% of the institute’s normal limit), mental disorders, malignant tumour or history of malignant tumour, primary or secondary immunodeficiency; (10) pregnant or lactating women; (11) involved in other trials within 3 months before screening and (12) any other factors that could influence the study results or lead to study termination, as deemed by the investigators.

**Baseline assessment**
Detailed demographic data such as age, sex, race and education will be collected. The following results will also be collected: (1) vital signs and physical examination; (2) laboratory test or examination: routine blood, liver and kidney function, blood coagulation detection, tumour marker detection, ECG, chest radiograph, heart colour Doppler ultrasound, abdominal ultrasound examination and cranial MRI examination and (3) neurological evaluation: NIHSS, Barthel index, mRS and MMSE.

**Randomisation, allocation concealment**
Randomisation sequence was created using SAS V.9.4 statistical software (procedure 'PROC PLAN') with a 1:1 allocation. The randomisation list will be sealed in sequentially numbered opaque envelopes. The envelopes will be stored in a double-locked cabinet and will only be opened by the practitioner to assign participants to the NSC or control group after obtaining informed consent and performing eligibility screening.

**Blinding**
This trial used a double-blinded design. hNSCs will be diluted with saline and appear nearly colourless with minimal visual difference compared with placebo (saline only). The participants, investigator and statistician will be blinded to the treatment allocation. A specific statistical researcher will prepare emergency letters containing random numbers and treatment assignments. Only emergencies when actual intervention is necessary for further management could allow code breaks.

**Interventions**
All participants will receive intranasal administration of agents for 4 consecutive weeks (two sets of agents once a week one set for each side of the nose). One set of agents contained 2.5×10⁶ hNSCs diluted in 100 µL saline or saline only. The administration of hNSCs or placebo is add-on and does not change the participants’ original therapy. hNSCs will be supplied by Shanghai Angecon Biotechnology Corporation and subjected to quality testing at the China National Institutes for Food and Drug Control. hNSCs were isolated from donated placentas and cultured without modifications.

The nasal delivery process of the control group was the same as that of the NSC group: (1) The nasal cavity will be cleaned, and a nasal endoscope will be used to observe and clean the nasal cavity. If one side of the nasal cavity is obviously obstructed, the operation will immediately stopped to clean the opposite side. (2) Intranasal administration: participants will be instructed to adopt the supine position and a pillow will be placed on the back of the participant’s shoulder. A special delivery tube will be used to inject hNSCs/saline into the surface of the middle turbinate using a nasal endoscope. The participant will be then instructed to rotate his/her head slowly. Five minutes later, the same operation will be performed in the other nasal cavity. If one side of the nasal cavity is obviously obstructed, two sets of agents will be injected into the same side, 5 min apart. (3) Observation: the participant will be instructed to remain lying down on the pillow in the original position for 30 min after the administration. The pillow will then be removed, and the participant lay down in the same position for another 30 min.

**Outcomes**
The overall schedule of the trial is shown in table 1. The primary outcome is the NIHSS score (at weeks 7, 15 and 27). The secondary outcomes are (1) mRS score (at weeks 7, 15 and 21), (2) Barthel index (at weeks 7, 15 and 27), (3) MMSE score (at weeks 7, 15 and 27) and (4) cranial MRI changes (at weeks 27 and 51).

**Safety assessment**
The potential AEs may include (1) AEs during injection: local complications (dizziness, headache, bleeding, nerve damage, nasal congestion, nasal pain); allergic reactions (fever, tachycardia, dyspnoea); systemic complications (infection including encephalitis, embolism); (2) long-term AEs: the following indicators are obviously abnormal: tumour markers, haematuria routine, liver and kidney function, blood coagulation test, ECG, chest radiograph, heart colour Doppler ultrasound, abdominal ultrasound, cranial MRI examination or other proven events including tumour formation and nerve injury.

Any serious clinical AEs or abnormal laboratory values, which occur during the study, must be reported to the institutional academic committee and ethics committee within 24 hours after the investigator is informed of the event, and subsequently reported to the local Health Commission and the National Health Commission.
Observe patients for 1 hour after administration, further recording vital signs.

**Data collection and management**

All data for every participant will be recorded by investigators in case report forms. Electronic data capture system will be built for this study. To improve participant adherence, the researchers will telephone the participants in advance of every visit and follow-up session.

**Data monitoring**

Data monitoring and auditing will be conducted to ensure the quality of the study. Safety outcomes will be continuously recorded and reported to a data safety monitoring committee (DSMB). In the case of safety concern, the DSMB will advise the trial to be stopped by notifying the principal investigator and study team. The DSMB can unblind their review as needed. The trial could be terminated in the event the DSMB advises termination for safety reasons or by the principal investigator in case of low recruitment.

Materials such as the research records, informed consent forms and data of all participants will be reviewed by a committee of Clinical Research Center of Ren Ji Hospital to ensure the accuracy and integrity of the data at every important time point in the trial, for example, participant enrolment, the study midway point and study completion.

**Sample size**

The effectiveness and safety of intranasal administration of hNSCs for stroke treatment have not been previously studied. To calculate the sample size for this trial, we...
reviewed the PISCES I study, in which the NIHSS score improved by a median of 2.0 point in subjects who underwent stereotactic injection of hNSCs. We assumed a 1.0-point improvement in this trial. The NIHSS scores (6 months) in the control group and NSCs group were estimated as 8.0 (SD=1.2) and 7.0 (SD=1.2), respectively. The sample size per group was calculated to be 24 using a two-sided 0.05 significance level and 80% statistical power. The total sample size was 60 (30 per group), indicating a lower drop rate.

**Statistical analysis**

An independent statistical expert blinded to the group allocation will implement the statistical analysis. Patients who are enrolled in this study and receive nasal administration at least once, with at least one post-administration evaluation, will be included in the full analysis set (FAS). The FAS analysis set will be used for statistical analysis. Subjects who withdraw after receiving the treatment, or subjects who were excluded during treatment will be included; however, we will not use data from illegible participants, subjects who have not received any intervention, or subjects who have not undergone any outcome measurement. Participants who are administered the hNSCs at least once will be included in the safety set. SAS V.9.4 will be used for statistical analysis. Demographic characteristics, general conditions and baseline conditions (before treatment) will be compared.

For the primary outcomes, NIHSS score at weeks 7, 15 and 27, the rank sum test will be used for comparison between two groups. For the secondary outcomes, the Barthel index and MMSE score will be analysed using a two-sample T-test or Mann-Whitney U-test. The mRS score will be analysed using the rank sum test. For cranial MRI changes, a radiological expert will analyse the images and calculate the estimated infarct volume.

**ETHICS AND DISSEMINATION**

Any protocol amendments will be reapproved by the Ethics Committee of Ren Ji Hospital, revised at the Chinese Clinical Trial Registry and reflected in the participants' informed consent form. A signed consent form reflecting the modification will be acquired from all participants. The results of this trial will be reported in the relevant academic journals and conferences.

**Patient and public involvement**

The patients and public were not involved in planning and design of this study.

**DISCUSSION**

This is the first RCT study of intranasal administration of hNSCs in the treatment of ischaemic stroke. The nasal administration technique adopted in this study has been proven to be safe in animal experiments, and operators will also receive professional training to ensure the safety of administration.14 15 17

The previously published PISCES I and II studies indicated that intracranial injection carries certain risks, including intracranial haemorrhage, epilepsy, infection, etc.11 12 Those side effects are sometimes fatal. It is for this reason that we decide to take the intranasal route. In this study, we will inject hNSCs at a low dose. Only after obtaining safety data will we begin to try different doses of hNSCs.

Stem cell research in China is currently performed only under strict supervision. A registration and recording system has been established. For each patient enrolled, relevant information must be submitted to the national medical research registration and management system. The Clinical Research Center of Ren Ji Hospital will also ensure compliance with national policies and protect the rights of participants. The primary concern of this study is safety. In addition to systemic risks such as tumour formation and abnormal immune response, we will also observe AEs related to nasal administration, such as nasal congestion, nasal pain, headache and bleeding. We also purchased insurance for every participant. In addition, we will continue the long-term follow-up protocol after the end of follow-up.

We will recruit participants with ischaemic stroke 3–24 months before screening. The purpose of setting this time range is to evaluate the effect of hNSCs on patients whose physical rehabilitation level is stable. According to the previous study, nasally administered cells mainly migrated to the olfactory bulb, hippocampus, thalamus and cortex; therefore, we recruit patients with ischaemic stroke caused by pathologies in the carotid artery system.18 Patients with ischaemic stroke caused by the vertebrobasilar artery will be excluded because the migration route of hNSCs to brainstem and cerebellum may be more difficult. Participants who experienced more than one stroke will also be excluded.

Considering the possibility that hNSCs may aggravate stroke, NIHSS score is selected as the primary endpoint of this study. The NIHSS not only provides a quantitative measure of stroke-related neurologic deficit but can also help to determine the appropriate treatment and predict patient outcomes. Of course, the mRS score and Barthel index will also be recorded at every follow-up visit to assess disability.

One disadvantage of this study is that there is no restriction on the rehabilitation exercise of participants during the study period. Rehabilitation exercises are essential for poststroke recovery. The speed and level of function recovery are largely determined by rehabilitation training. In this trial, we will not control the participant’s secondary prevention therapy of stroke. However, since this study is a randomised controlled placebo study, the theoretical level of rehabilitation exercise in the two groups may be consistent.

Another limitation of this study is the efficacy of intranasal administration is unknown. Although animal
experiments have demonstrated that intranasal transplantation of NSCs results in their appearance in the CNS, it is difficult to observe whether NSCs migrate and plant in the human CNS. Cell labelling and imaging using various imaging modalities such as positron emission tomography, single-cell MRI may help to achieve cell tracking in vivo, but it is not allowed in human beings by the ethic committee.19 20

Overall, this pilot study will explore the safety and effectiveness of intranasal administration of hNSCs for ischaemic stroke. Although the small sample size and single-centre design may affect its generalisability, we expect that the result of this study will provide clinical evidence for the use of hNSCs.

Contributors (1) Conception and design: CX and KW; (2) administrative support: YG; (3) provision of study materials or patients: XJ and LW; (4) collection and assembly of data: JP, KW and YW; (5) data analysis and interpretation: CX and SP; (6) manuscript writing: all authors; (7) final approval of manuscript: all authors.

Funding This research is supported by Shanghai Shenkang Hospital Development Center (SHDC2020CRZ204B) and Shanghai Angecon Biotechnology Company (LYZXHXKT200039).

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement The datasets generated and/or analysed during the current study will be available upon request from the principle investigator. Individual participant data that underlie the results reported in final report will become available for share, after deidentification. Researchers should provide a methodologically sound proposal to get data access. To gain access, data requestors will need to sign a data access agreement. Further, inform consent may be considered according to the study aims. The shared data will only be allowed to be used by the applicant for scientific studies. No commercial activities are allowed.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

ORCID iD Chong Xie http://orcid.org/0000-0001-9604-5921

REFERENCES
1 Tsao CW, Aday AW, Almarzooq ZI, et al. Heart disease and stroke Statistics-2022 update: a report from the American heart association. Circulation 2022;145:e153–639.
2 Wang Y-J, Li Z-X, Gu H-Q, et al. China stroke statistics 2019: a report from the National center for healthcare quality management in neurological diseases, China national clinical research center for neurological diseases, the Chinese stroke association, National center for chronic and non-communicable disease control and prevention, Chinese center for disease control and prevention and Institute for global neuroscience and stroke collaborations. Stroke Vasc Neurol 2020;5:211–39.
3 Barker RA, Götz M, Parmar M. New approaches for brain repair—from rescue to reprogramming. Nature 2018;557:329–34.
4 Annesi V, Navarro-Guerrero E, Rodríguez-Prieto I, et al. Physiological plasticity of neural-crest-derived stem cells in the adult mammalian carotid body. Cell Rep 2017;19:471–8.
5 Trounson A, McDonald C. Stem cell therapies in clinical trials: progress and challenges. Cell Stem Cell 2015;17:11–22.
6 Hermann DM, Chopp M. Promoting brain remodelling and plasticity for stroke recovery: therapeutic promise and potential pitfalls of clinical translation. Lancet Neurol 2012;11:369–80.
7 Liao L-Y, Lau BW-M, Sánchez-Vidania DI, et al. Exogenous neural stem cell transplantation for cerebral ischemia. Neural Regen Res 2019;14:1129–37.
8 Zhang ZG, Buller B, Chopp M. Exosomes - beyond stem cells for restorative therapy in stroke and neurological injury. Nat Rev Neuro 2019;15:193–203.
9 Li Y, Lu Z, Kheog CL, et al. Erythropoietin-induced neurovascular protection, angiogenesis, and cerebral blood flow restoration after focal ischemia in mice. J Cereb Blood Flow Metab 2007;27:1043–54.
10 Mathe Z, Dupraz P, Rinsch C, et al. Tetracycline-Regulated expression of VEGF-A in beta cells induces angiogenesis: improvement of engraftment following transplantation. Cell Transplant 2006;15:621–36.
11 Kalladka D, Sinden J, Pollock K, et al. Human neural stem cells in patients with chronic ischaemic stroke (Pisces): I phase 1, first-in-man study. Lancet 2016;388:787–96.
12 Muir KW, Bulters D, Willmot M, et al. Intracerebral implantation of human neural stem cells and motor recovery after stroke: multicentre prospective single-arm study (PISCES-2). J Neurol Neurosurg Psychiatry 2020;91:396–401.
13 Zhang G, Li Y, Reuss JL, et al. Stable intracerebral transplantation of neural stem cells for the treatment of paralysis due to ischemic stroke. Stem Cells Transl Med 2019;8:999–1007.
14 Wu S, Li K, Yan Y, et al. Intranasal delivery of neural stem cells: a CNS-specific, non-invasive cell-based therapy for experimental autoimmune encephalomyelitis. J Clin Immunol 2013;4.
15 Zhong S-J, Gong Y-H, Lin Y-C. Combined intranasal nerve growth factor and ventricle neural stem cell grafts prolong survival and improve disease outcome in amyotrophic lateral sclerosis transgenic mice. Neurosci Lett 2017;656:1–8.
16 Ye Q, Wu Y, Wu J, et al. Neural stem cells expressing bFGF reduce brain damage and restore sensorimotor function after neonatal hypoxia-ischemia. Cell Physiol Biochem 2018;45:108–18.
17 Galeano C, Qiu Z, Mishra A, et al. The route by which intranasally delivered stem cells enter the central nervous system. Cell Transplant 2018;27:501–14.
18 Danielyan L, Schäfer R, von Ameln-Mayrhefer A, et al. Intranasal delivery of cells to the brain. Eur J Cell Biol 2009;88:315–24.
19 Bansal A, Pandey MK, Demirhan YE, et al. Novel (89)Zr cell labelling approach for PET-based cell trafficking studies. EJMMR Res 2015;3:19.
20 Shapiro EM, Sharer K, Skrtic S, et al. In vivo detection of single cells by MRI. Magn Reson Med 2006;55:242–9.