



Stem Cells & neurodegenerative diseases

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Central Nervous System



Neurodegenerative Diseases

- A wide range of acute and chronic conditions in which neurons and glial cells in the brain and spinal cord are lost.
- Acute: ischemic stroke or spinal cord injury
- Chronic: Parkinson disease (PD), amyotrophic lateral sclerosis (ALS), or Alzheimer disease (AD).



Main considerations when we use stem cells to treat neurodegenerative diseases

- What is required for the stem cell-based approach to be clinically competitive?
- **Risks** to the patient that are acceptable, depending on disease **severity**. Animal models may not fully predict their **toxicity**, occurrence of **immune** and other biologic responses, and risk for **tumor formation** after implantation in patients.
- The **variability** between neurodegenerative diseases in the **degree of disability** that they cause and in the therapeutic options that are available.

e.g PD- symptomatic treatment

- The easiness to differentiate stem cells to neurons. For example, the differentiation of iPSCs into mature neurons is more complicated than for ESCs



Main considerations when we use stem cells to treat neurodegenerative diseases

- The **cell type** to be regenerated and transplanted.

PD- dopamine neurons

ALS – motor neurons

Stroke and Alzheimer's disease-several cell types

- The stem cell–based approach should show **substantial improvement** of functional deficits in animal models before their use in clinical application.
- To determine the **biological mechanism** underlying the observed effects of a stem cell–based treatment in an animal model. e.g. reconstruction of neuronal circuitry



Common considerations when translating stem cell therapies to neurodegenerative disease patients

Inclusion/exclusion criteria	Enrolling late-stage patients may prevent loss of quality of life Late-stage patients may mask any positive effects due to the intervention occurring too late in the disease course
Realistic expectation	Informed consent forms must clearly illuminate the goals of the study Safety trials vs. efficacy trials Expectations of therapeutic effects based on disease state at intervention
Controlled study	Ideal study is a double-blind placebo study Late-stage patients may mask any positive effects not observed due to the intervention occurring too late in disease Original PD studies offered control arms treatment after a 1-year follow-up which confuses interpretation of efficacy
Immunosuppression	While the brain remains an immunologically privileged site due to the blood-brain-barrier, there is evidence that this barrier can be compromised in disease Studies into cell graft survival demonstrate that immunosuppression increases that survival of graft tissue
Potential side effects	Prevent/minimize potential side effects (i.e. meningitis, fever) Avoid exacerbation of disease and tumor formation Risk vs. quality of life
Safety of cellular therapy administration	Consider CNS accessibility and safety of delivery methods Pros/cons of systemic delivery, lumbar puncture or stereotactic injection are important

Abbreviations: PD, Parkinson's disease; CNS, central nervous system.



Examples on Neurodegenerative Diseases Targeted by Stem Cell therapy



Parkinson's disease (PD)



Characteristic symptoms are rigidity, hypokinesia, tremor, and postural instability

Degeneration of nigrostriatal DA neurons is the main pathology

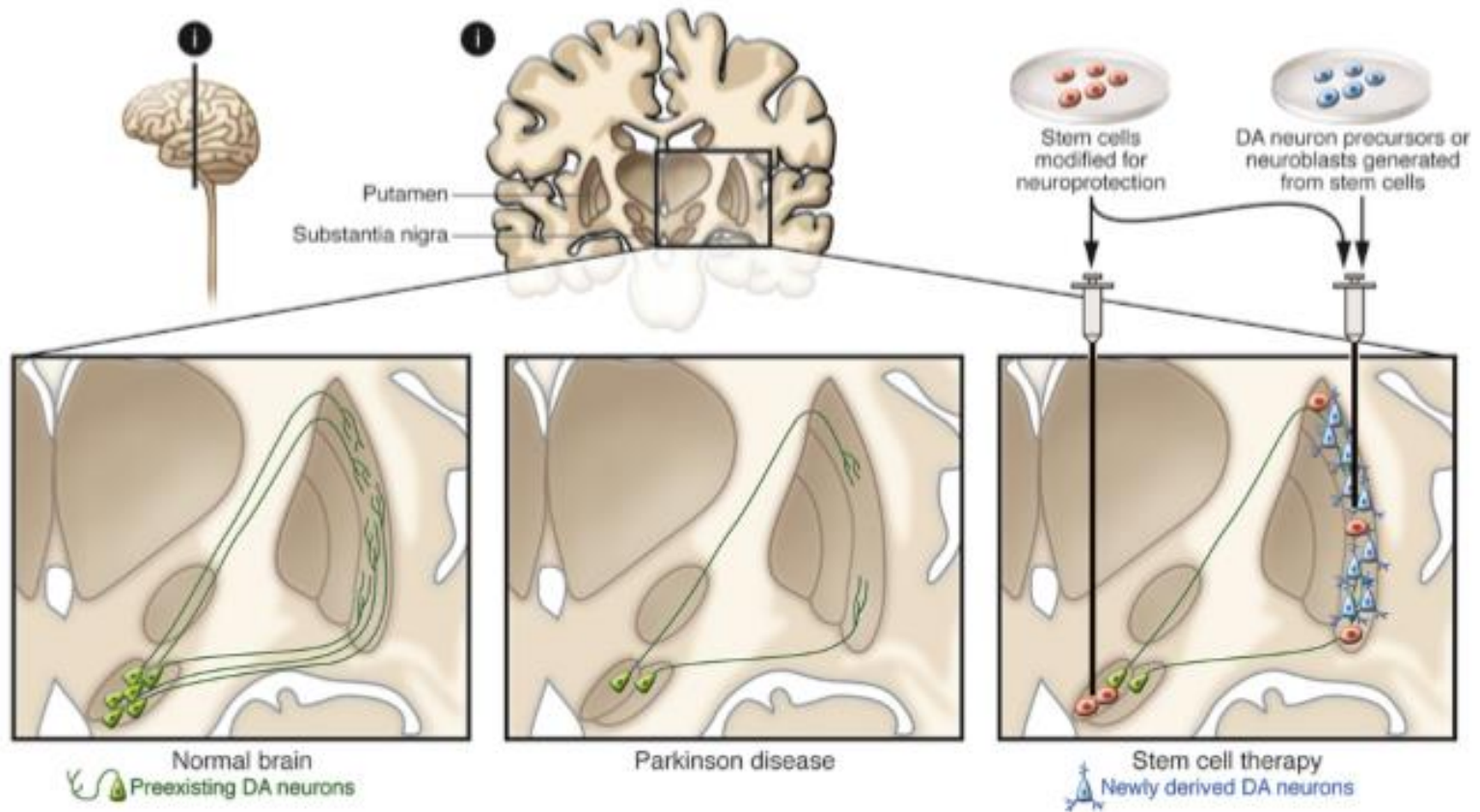
Tx: l-DOPA, DA agonists, enzyme inhibitors, and deep brain stimulation

No Tx for dementia

iPSCs for modelling the genetically complex PD

Stem cell-based therapies for PD

Proof of principle: clinical trials with intrastriatal transplantation of human embryonic mesencephalic tissue (rich in postmitotic DA neuroblasts).



Stem cell–based therapies for PD

Pros	Cons
<p>-The DA neurons that form from the transplanted tissue reinnervate the denervated striatum and become functionally integrated, restoring striatal DA release and giving rise to clear symptomatic relief in some patients.</p>	<p>-A small fraction of graft-derived DA neurons contain Lewy bodies (the hallmark of PD). - Availability of human embryonic mesencephalic tissue is limited.</p>
<p>11–16 years after transplantation, cell replacement remains a viable therapy.</p>	<p>Variability of functional outcome after transplantation is high.</p>
<p>The progression of pathology in graft-derived neurons is slow, and they are still functional after a decade.</p>	<p>Poor standardization of the transplanted cell material contributes to the high variability</p>



Stem cell–based therapies for PD

Other sources of DA neurons:

- ✓ ES cells
- ✓ Cloned ES cells
- ✓ NSCs and progenitors of embryonic ventral mesencephalon
- ✓ Adult NSCs from the subventricular zone (SVZ)
- ✓ Bone marrow stem cells
- ✓ Fibroblast-derived iPS cells

Human stem cell–derived DA neuron precursors/neuroblasts can survive in animal models of PD and can be functional after maturation.



Stem cell–based therapies for PD

Hurdles that prevent stem cell therapy for PD from bench to clinic:

- ✓ PD is a **multisystem disorder**, if **nondopaminergic** systems are affected, they will not improve by intrastriatal DA grafts.
- ✓ **Substantial re-innervation** of striatum has not been demonstrated.
- ✓ **Restoration of DA release** in vivo has not been demonstrated.
- ✓ **Marked improvement** (50-70%) in the deficits and symptoms experienced by PD patients has not been demonstrated.
- ✓ Risk of **tumor formation**-even if minor, it is not acceptable.
- ✓ The need to inject cells at **all sites of injury**.



Clinical trials-PD

- By International Stem Cell Corporation (ISCO)
- Parthenogenetic cells derived of unfertilized oocytes after suppression of the second meiotic division
- Drawbacks:

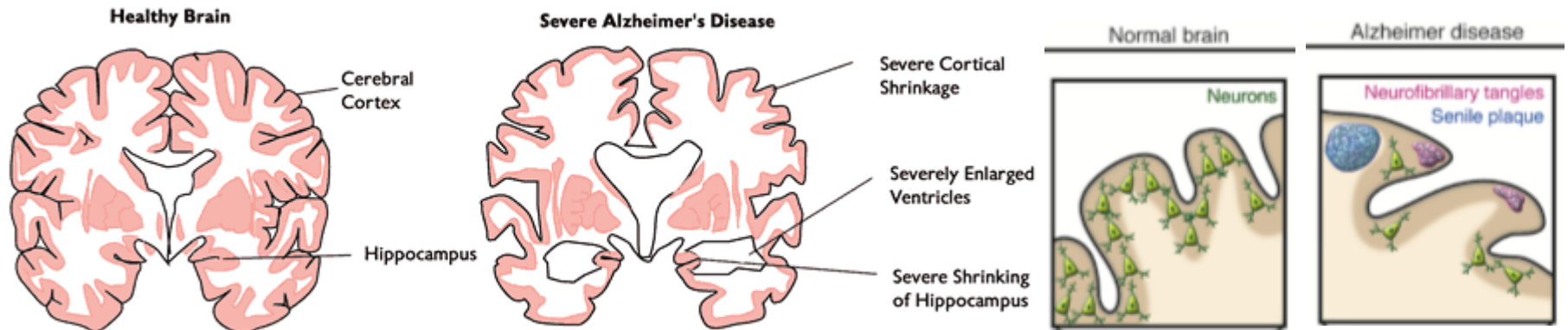
Used cells are PAX6-positive suggesting that they are of a dorsal neural fate. In contrast authentic midbrain dopaminergic neurons are derived from a PAX6-negative ventral midbrain neural precursor.

- Schwarz et al. used human-fetus-derived dopaminergic neurons and transplanted them into PD patients' depleted striata.
- Takagi et al. demonstrated functional recovery after successfully transplanting dopaminergic neurons from monkey ESCs into PD patients' brains

Clinical trials-PD

- Another study also confirmed the influential role of undifferentiated ESCs in functional recovery by differentiating dopaminergic neurons in a PD rat model
- Two other clinical studies using human ESCs are ongoing in Australia and China, where their preclinical studies' results were reported
- Garitaonandia et al. described the preclinical tumorigenicity and biodistribution safety in vitro before conducting a phase I clinical trial to evaluate the safety and tolerability of stem cells for the treatment of PD

Alzheimer's disease (AD)

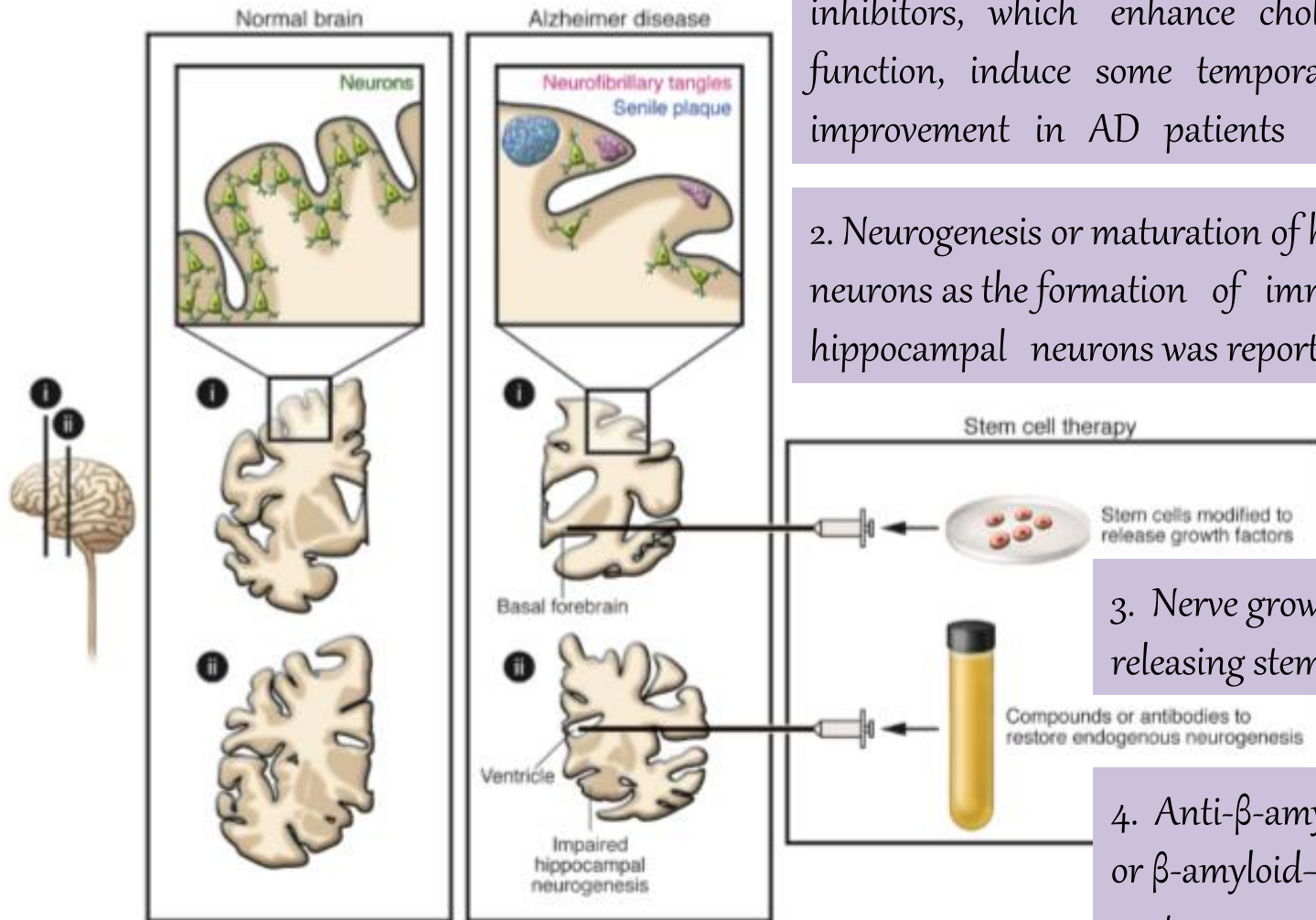


Memory impairment, cognitive decline, and dementia due to widespread and progressive pathological changes

Neuronal and synaptic loss, neurofibrillary tangles, and deposits of β -amyloid protein involve the basal forebrain cholinergic system, amygdala, hippocampus, and cortical areas.



Stem cell-based therapies for AD



1. Cholinergic neurons: acetylcholinesterase inhibitors, which enhance cholinergic function, induce some temporary improvement in AD patients

2. Neurogenesis or maturation of hippocampal neurons as the formation of immature hippocampal neurons was reported in AD.

3. Nerve growth factor (NGF) releasing stem cells.

4. Anti- β -amyloid antibodies or β -amyloid-degrading protease neprilysin.



Stem cell–based therapies for AD

Hurdles that prevent stem cell therapy for AD from bench to clinic:

- ✓ Stem cells have to be pre-differentiated in vitro to **many different types of neuroblasts** for subsequent implantation in **many brain areas**.
- ✓ For a long-lasting symptomatic benefit, cholinergic cell replacement requires intact target cells (host neurons that the new cholinergic neurons can act on) that are damaged in AD.
- ✓ Stem cell–based cell replacement strategies are very far from clinical application in AD

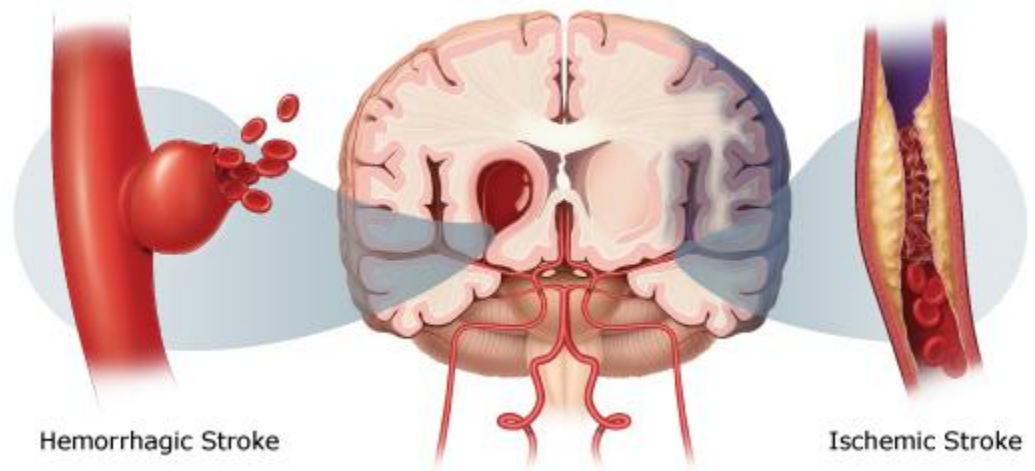


Clinical trials-AD

- By stemmedica cell technologies
- Stem cells from healthy people to mild to moderate AD patients
- To test if stem cells work for AD
- The clinical trials for AD treatment are still in their infancy, where the FDA approved the first clinical trial of MSCs for AD treatment in 2015.
- Similar trials are currently underway or under development in Europe and Asia to assess the safety, tolerability, and preliminary efficacy of human MSCs in patients with mild-to-moderate AD

Stroke

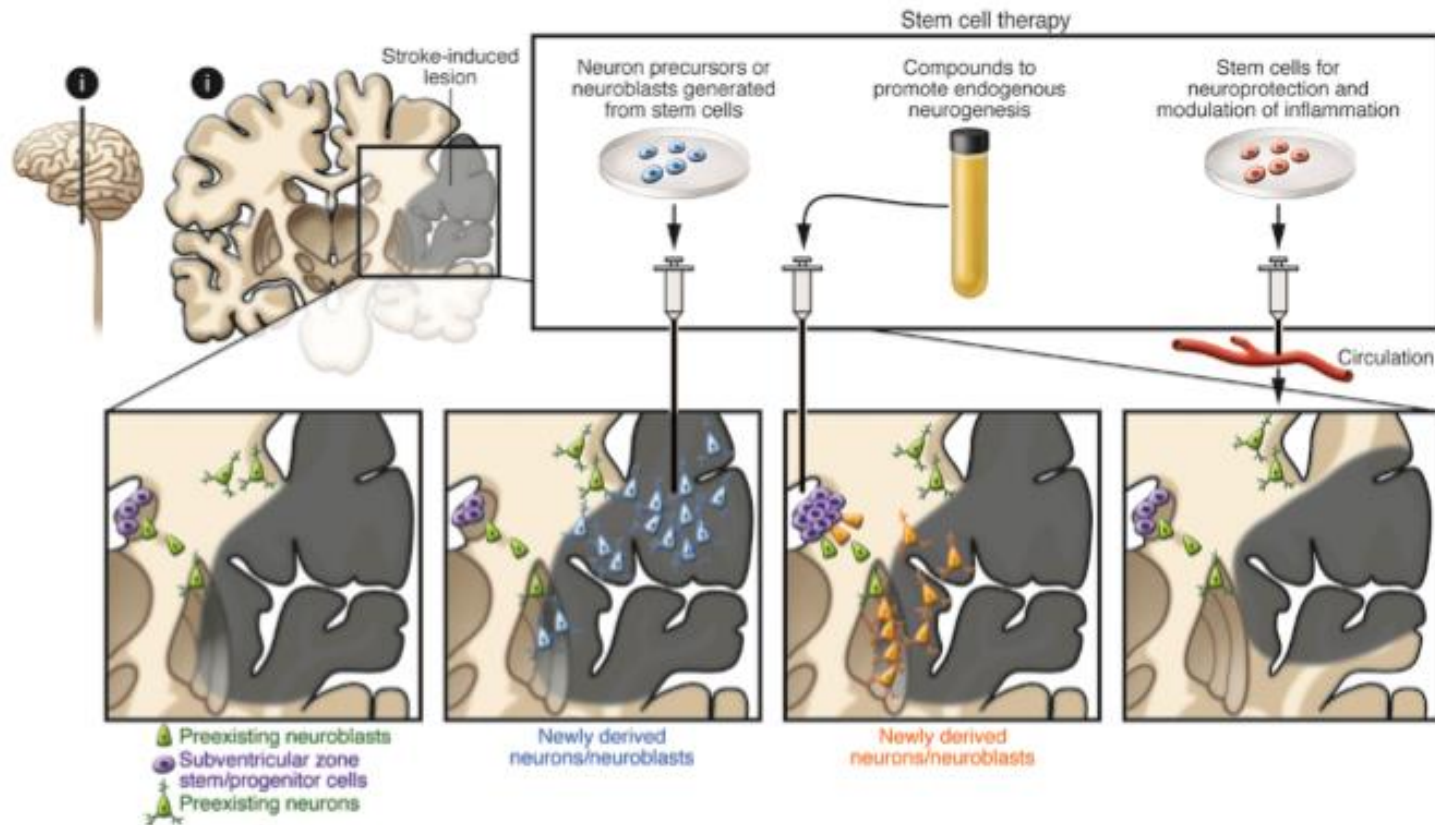
Ischemic stroke, caused by occlusion of a cerebral artery, leads to focal death of multiple neuron types, as well as oligodendrocytes, astrocytes, and endothelial cells.



Neuronal plasticity and reorganization of neural circuitries contribute to spontaneous recovery to varying degrees, but most patients exhibit persistent motor, sensory, or cognitive impairments

Stem cell-based therapies for stroke

Human ES cell-derived NSCs and MSCs, grafted into rat stroke site, migrated toward the lesion and improve forelimb performance.



IV injection of human NSCs induced improvements after hemorrhagic stroke in rats, probably through antiinflammatory actions

Stem cell–based therapies for stroke

- ✓ No substantial clinical improvements were detected after IV injection of autologous MSCs in patients with an ischemic lesion in the regions supplied by the middle cerebral artery (MCA).
- ✓ Several clinical studies using intravenous or intraarterial (into damaged territory) infusion of autologous bone marrow–derived stem cells in stroke patients are ongoing.
- ✓ A clinical trial in stroke patients involving transplantation of clonal, conditionally immortalized NSCs isolated from human fetal cortex is being tested.
- ✓ 80% of neuroblasts and neurons die during the first two weeks after formation at stroke site in rats.



Clinical trials

- Transplanted ESCs, iPSCs, and NSCs can replace the missing brain cells in the infarcted area
- Non-neuronal adult stem cells, such as MSCs provide trophic support to enhance self-repair systems such as endogenous neurogenesis

Spinal cord injuries

Pathological changes after spinal cord injury are complex and include:

1. Interruption of ascending and descending pathways
2. Loss of neurons and glial cells
3. Inflammation
4. Scar formation
5. Demyelination

- ✓ Patients experience loss of movement, sensation, and autonomic control below the level of the injured spinal segment.
- ✓ Available treatments are ineffective.
- ✓ Different types of stem cells were tested and improved functional outcome in animal models through **secretion of neurotrophic factors, remyelination of spared axons, or modulation of inflammation**

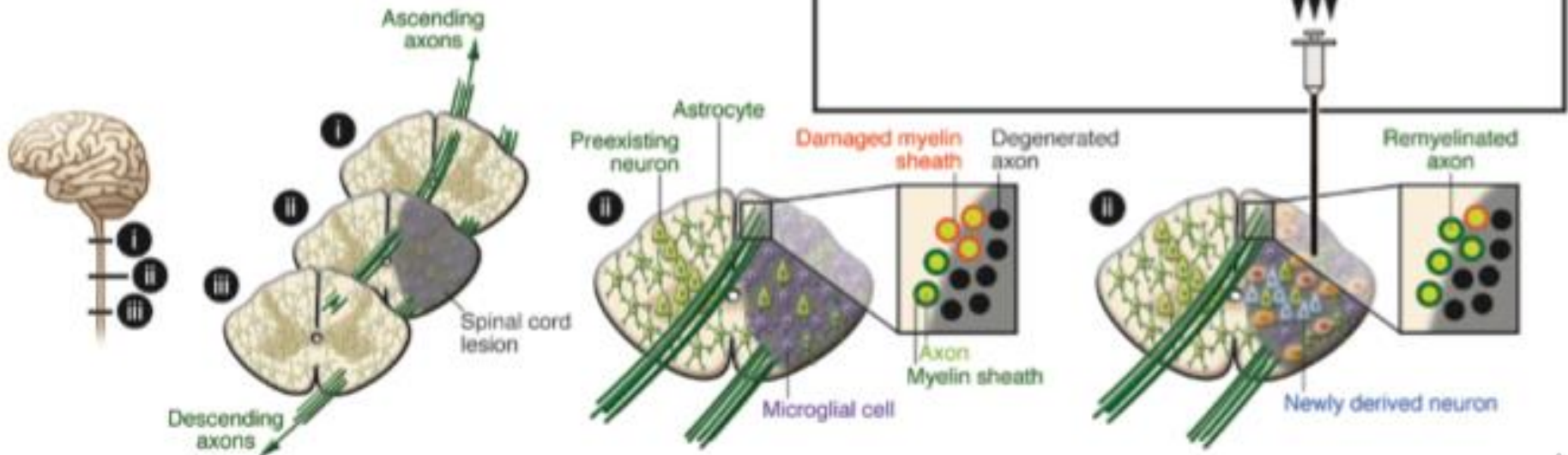


Stem cell-based therapies for spinal cord injuries

Formation of **neurons, oligodendrocytes, & astrocytes.**

Formation of **synapses and axons**

Remyelination: high-purity oligodendrocyte progenitor cells (OPCs) generated from human ES cells in vitro can differentiate into oligodendrocytes (clinical trial)



Stem cell–based therapies for spinal cord injuries

Before moving to clinic:

Determine how to control the proliferation of transplanted stem cells and their progeny

Determine how to enhance the differentiation of these cells to the specific types of neurons that have been lost

Determine how the resulting neurons can be directed to format appropriate synaptic contacts



Stem cell–based therapies for spinal cord injuries

Other stem cell types

Umbilical cord blood, bone marrow–derived HSCs, and MSCs have already been applied in patients with spinal cord injury, with claims of partial recovery.

Problems in these trials:

1. The implanted cells were often poorly characterized.
2. The preclinical evidence of efficacy for several of these approaches was insufficient.
3. The therapeutic benefit was reported from open-label trials where patients had been subjected to physiotherapy.
4. The mechanisms underlying observed improvements were unclear.



Hindrances in stem cell therapies' progression

1. Learning how stem cells work in the body and how they integrate with the targeted tissue/organ.
2. The safe and cost-effective generation of these cells in adequate quantities. For example, ESCs and iPSCs can be grown indefinitely in the lab, but the procedures are very complex and demanding, limiting these cells' overall availability.
3. Risk of post-implant rejection, which adds the burden of needing a close compatible donor for the cells' recipient.
4. Identifying the proper conditions to culture these cells, the most suitable route of administration, delivery, and the target site
5. Most of the data available to researchers were derived from animal studies, hence, direct extrapolation of the results from these in vivo studies into human patients is not feasible at this stage.
6. The cost, time, and labor-intensive nature of stem cell therapy limit its use, especially in developing countries. Additionally, safety considerations, such as the potential for malignant transformation and side effects, such as epilepsy, immune allergic reactions, and injection site injuries, remain significant concerns.

Neurodegenerative Diseases & Stem Cell Therapy

- Clinical trials using stem cells have already been performed or initiated (e.g., for the rare, fatal, autosomal recessive neurodegenerative disorder Batten disease)
- No stem cell-based therapy has yet been proven beneficial for any neurodegenerative condition.
- Despite this fact, unproven treatments for several neurodegenerative diseases are offered at “clinics” around the world without rationale and with poor scientific and clinical basis.
- Ethical, regulatory, societal, and economical issues need to be addressed.

Translating a stem cell-based treatment from the bench to bed

Road map to a FDA-approved Phase I human safety trial for stem cell therapy for ALS

