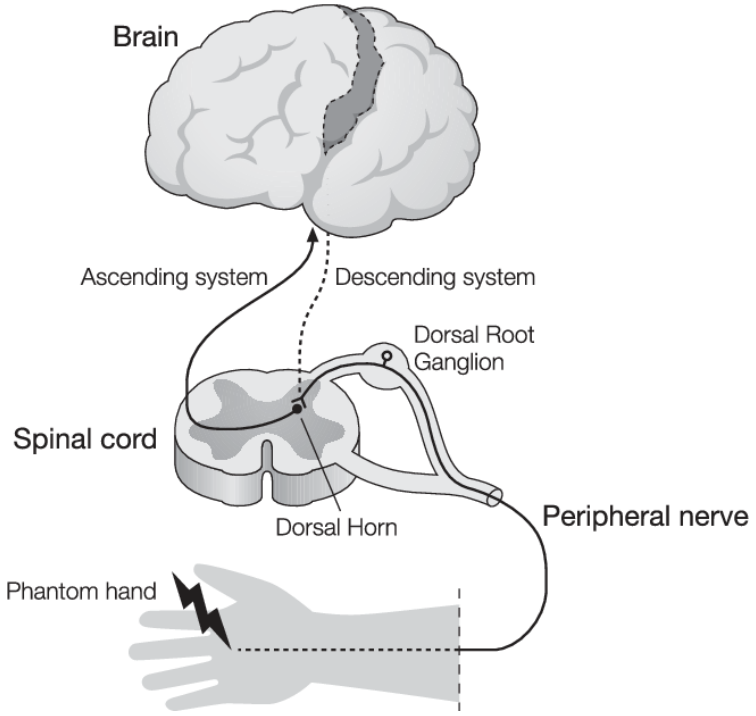
# Phantom Link: Bioengineered Nerve Channels for Phantom Pain Treatment

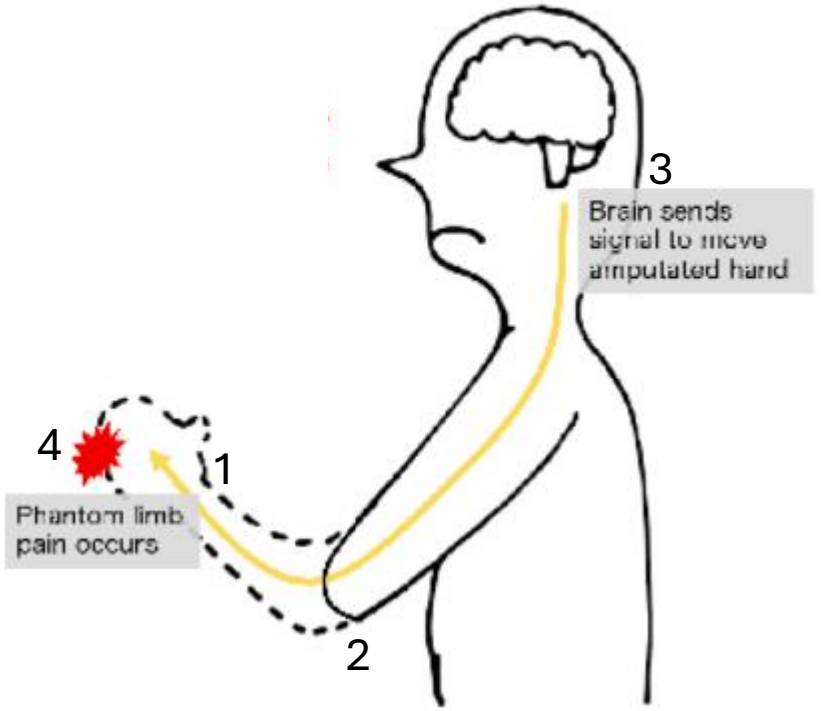
An Innovative Approach to Treating Phantom Pain Through Advanced Nerve Regeneration

Amputees need a comprehensive treatment that not only alleviates phantom limb pain but also regenerates severed nerves, reduces psychological distress, and improves overall quality of life without long-term side effects

# Phantom Pain

1. Limb gets amputated
2. Nerve is severed at amputation site, formation of a neuroma occurs
3. Brain doesn't immediately realize the limb is missing, still receives signals from the severed nerve
4. Phantom Pain occurs due to neuroma sending pain signals to the brain



# 13 Million

people in the world are currently living with an amputation, missing limb, or limb differences

Approximately

# 60-80%

of amputees report phantom pain

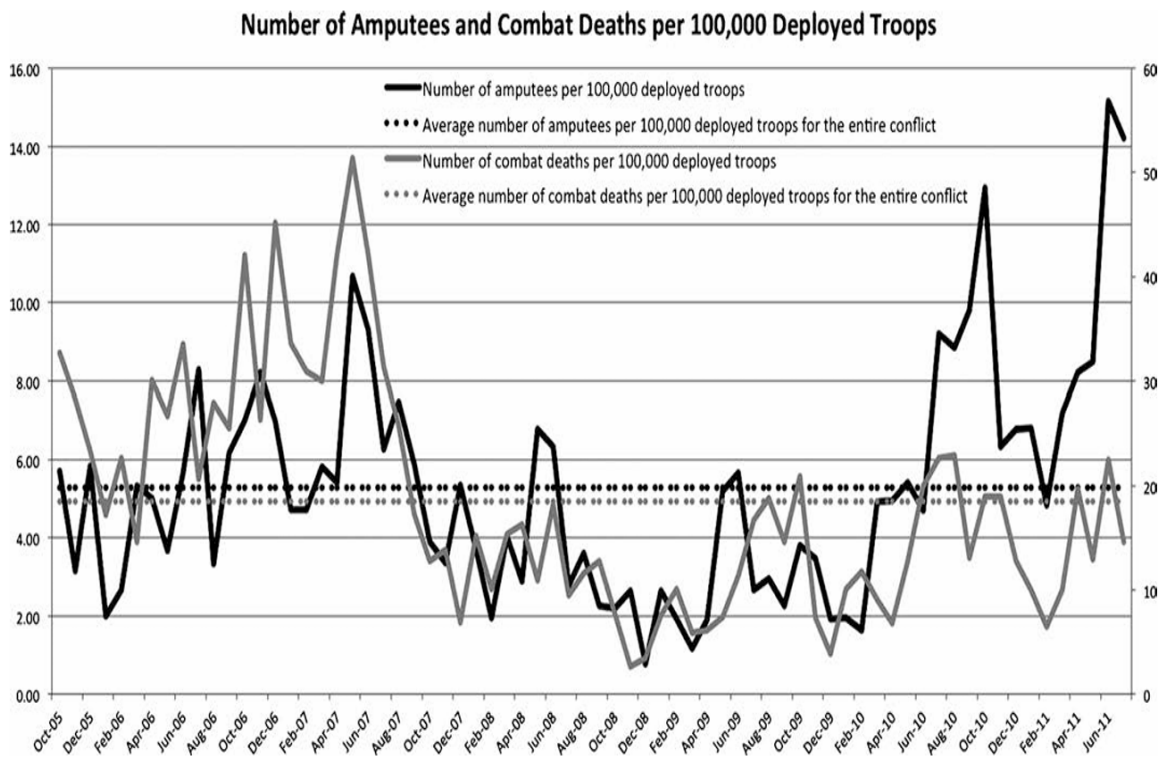
# 185,000

new amputations every year as well, with an increased rate in adults above

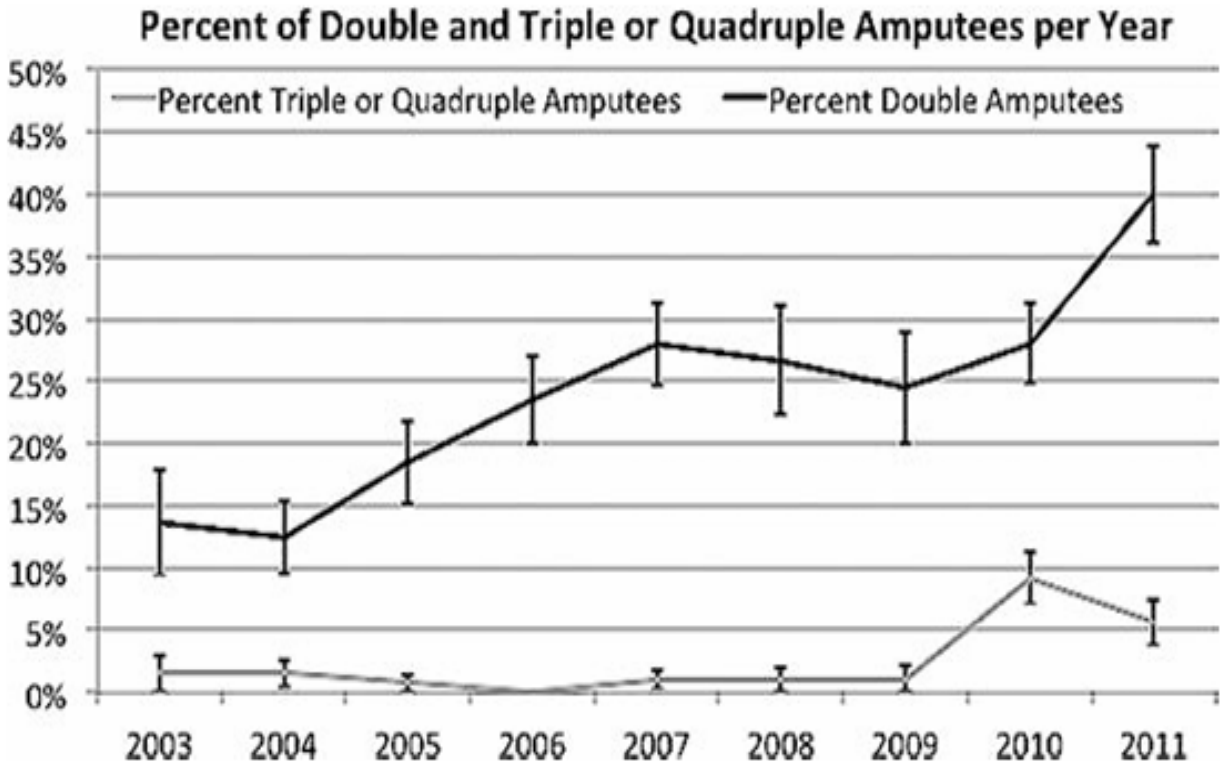
65.



# US War Amputation Statistics




- The # of amputations per 100 traumatic admissions increased from 3.5 to 14 from 2010 to mid-2011.
- The # of amputations per 100,000 deployed troops increased from 2 to 14 from 2010 to mid-2011.




- 30% of the amputees from 2010 to mid-2011 experienced triple and in some cases quadruple amputations.

# Current Treatments

| Treatments | Pros | Cons |
|---|---|---|
| **Medications**<br>Pain relievers, antidepressants, anticonvulsants, ketamine<br>Local anesthetics, beta-blockers | ▪ Quick relief for some<br>▪ Easy to administer<br>▪ Widely available.<br>▪ Targeted pain relief<br>▪ Useful for residual limb pain | ▪ Potential side effects<br>▪ May not address root causes<br>▪ Effectiveness varies.<br>▪ Short-term effects<br>▪ Limited effectiveness for some patients. |
| **Physical Therapies**<br>Mirror therapy<br>TENS, acupuncture, massage<br>Physical therapy | ▪ Proven effectiveness for many<br>▪ Non-invasive<br>▪ Low cost.<br>▪ Non-invasive<br>▪ Can be combined with other treatments<br>▪ Improves overall limb function<br>▪ May alleviate residual limb pain. | ▪ Requires patient commitment and regular practice<br>▪ May not work for all patients.<br>▪ Limited scientific evidence for long-term relief<br>▪ Accessibility may vary.<br>▪ Time-intensive<br>▪ Less effective for severe phantom pain |
| **Psychological Therapies**<br>CBT, biofeedback<br>Hypnosis, VR Therapy | ▪ Addresses emotional and psychological components<br>▪ Non-invasive.<br>▪ Effective for some with chronic pain.<br>▪ Non-invasive. | ▪ May not directly reduce pain<br>▪ Requires trained professionals and patient effort.<br>▪ Limited scientific evidence<br>▪ May not work for everyone. |

| | | |
|---|---|---|
| **Interventional Procedures**<br>Nerve blocks<br>Spinal cord or nerve stimulation | ▪ Temporary pain relief<br>▪ Targeted approach.<br>▪ Effective for medication-resistant pain<br>▪ Adjustable for patient needs. | ▪ Short duration of relief<br>▪ Requires repeated procedures.<br>▪ Expensive<br>▪ Requires surgery, risk of complications |
| **Surgical Options**<br>Targeted Muscle Reinnervation (TMR)<br>Residual limb surgery | ▪ Reduces neuromas and pain signals<br>▪ Can improve prosthetic control.<br>▪ Addresses neuromas. | ▪ Highly invasive<br>▪ Requires specialized surgical expertise.<br>▪ More recovery time<br>▪ Not always successful.<br>▪ Nerve still stays severed<br>▪ Doesn't completely eliminate the formation of a neuroma |
| **Emerging Treatments**<br>Virtual reality therapy<br>Graded motor imagery<br>Cannabis or CBD<br>Cryotherapy | ▪ Engaging and innovative<br>▪ Builds on proven mirror therapy.<br>▪ Gradual reprogramming of brain-body connections.<br>▪ Can be effective for nerve pain<br>▪ Generally well-tolerated.<br>▪ May help reduce residual limb sensitivity. | ▪ Costly equipment<br>▪ Limited availability.<br>▪ Requires consistent effort and time.<br>▪ Legal and accessibility issues in some areas<br>▪ Lack of robust clinical trials.<br>▪ Short-term relief<br>▪ Accessibility varies. |

# Bioengineered Nerve Channels

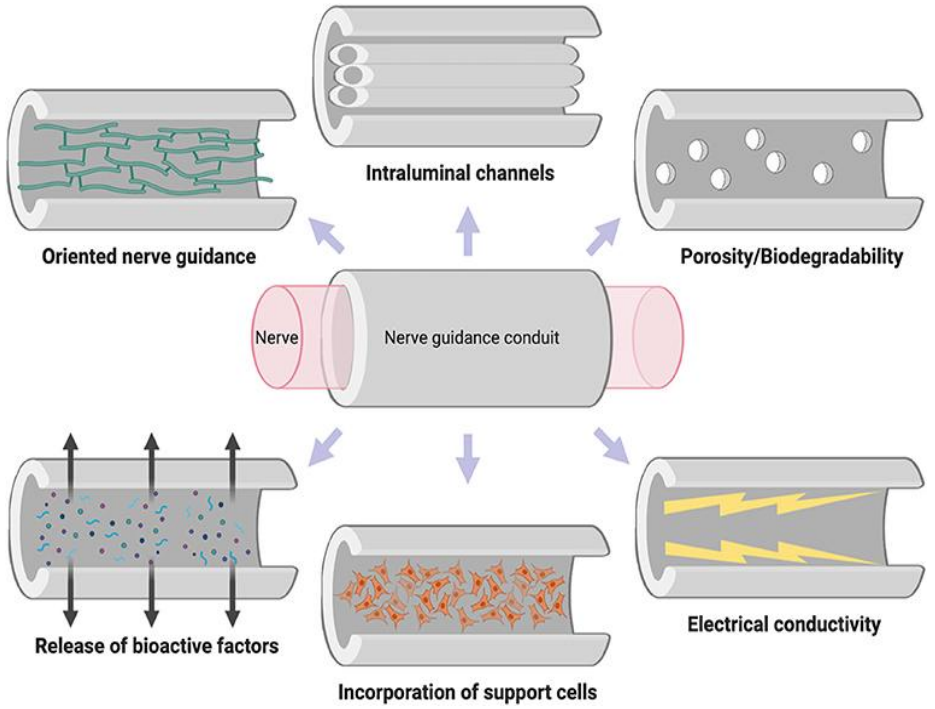
**Artificial Biocompatible Nerves**

These nerves are artificial and biocompatible, designed to support nerve regeneration and healing.

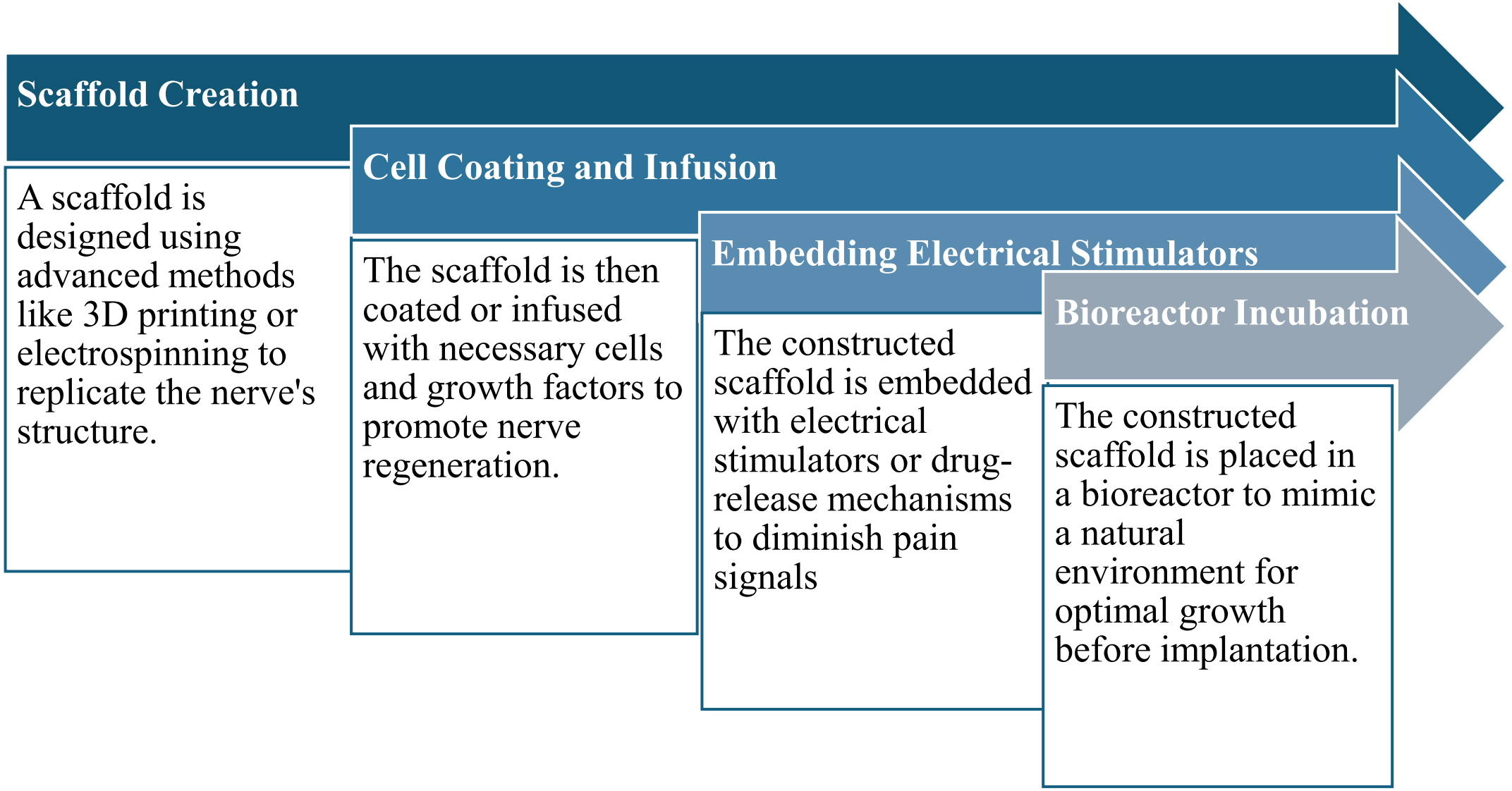
- **Facilitates Nerve Growth** - The channel plays a crucial role: by promoting growth of the nerve ends/stumps, it disperses the area of the pain and consequently minimizes it.

- **Reduced Pain Signal -** Embedded electrical stimulators or drug-release mechanisms are used to diminish pain signals during the nerve regeneration process.

- **Customized Dimensions -** The dimensions of the nerve channels are customized to match individual nerve anatomy, facilitating proper integration and function.



# Phantom Link Creation Process



# Scaffolding Creation

- A scaffold is made to look and act like the natural framework of a nerve, with tiny channels to guide nerve growth.
- The scaffold is sized and shaped to match the injured nerve, ensuring a good fit and proper function.
- Tools like 3D printers or special machines called electrospinners are used to make it.
- The nerve channels are made from biodegradable and biocompatible materials like polylactic acid and collagen-based scaffolds, ensuring safe integration in the body and naturally dissolves in the body over time.
- Typically, the scaffold is created through bio-engineering, but there are two other ways: animal and human nerves. This process is also applicable, but there is higher risk of rejection due to them being foreign substances, and there is also a more extensive process for harvesting and decellurization.

# Cell Coating & Infusion

- Chemicals called growth factors are added to encourage nerve fibers to grow and heal faster.
- Special cells (like Schwann cells and stem cells) are added to the scaffold to enhance tissue regeneration.
- The scaffold is coated or injected with the cells and growth factors to make sure everything is spread out properly.
- The scaffold is cleaned before and after adding cells to ensure no bacteria or contamination is present.

# Electrical Stimulators/Drug-Release Mechanisms

Electrical stimulators work synergistically with the drug-release system for comprehensive treatment. Drugs provide immediate biochemical support for pain management and regeneration. Electrical stimulation enhances and sustains the regeneration process, creating a highly effective environment for healing.

Electrical Stimulators:

- Tiny electrical parts are built into scaffold channels with conductive polymers (e.g., polypyrrole or PEDOT) and connected to an external or wireless power source.
- Low-voltage impulses mimic natural signals to encourage nerve growth, axonal regeneration, phantom pain reduction. Continuous stimulation helps the brain and nervous system adapt by rewiring neural pathways for better functionality.

Drug-Release:

- The drug-release devices are embedded into the scaffold during the manufacturing process, positioned along the inner lining of the scaffold to ensure drugs are released near regenerating nerve fibers.

# Bioreactor Incubation

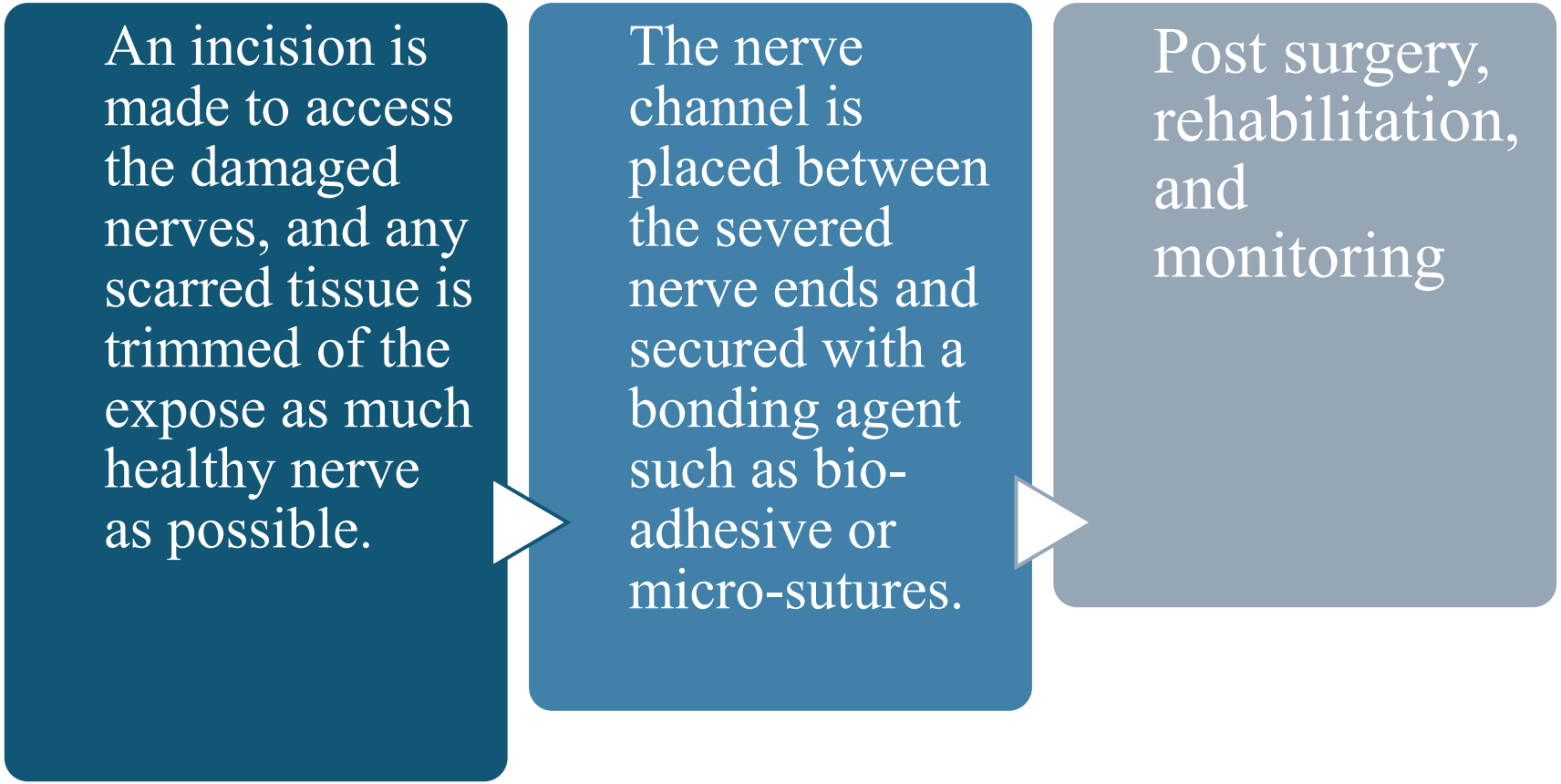
- The scaffold is placed in a special machine called a bioreactor that copies the conditions of the human body (like temperature and nutrients).
- The bioreactor provides food and oxygen to the cells and helps remove waste, so the cells grow properly.
- Sometimes, the bioreactor uses gentle electrical stimulation to prepare the scaffold for the body.
- The scaffold is checked to make sure it's working correctly and is ready to implant.

## References


Ten years at war: Comprehensive analysis of amputation trends
Limb Loss Statistics - Amputee Coalition
How to Manage Phantom Pain After Amputation | PAM
Phantom Limb pain - A Literature review

# Surgical Procedure

Once the nerve channels are created and prepared, the surgery takes place.



# Advantages of Phantom Link

**The use of bio-engineered nerve channels is especially effective in severe cases of phantom pain and in cases where someone has multiple amputations.**

## Minimally Invasive

- Smaller incisions and less infection risks
- Enhanced Precision and Control
- Shorter recovery/return to daily life

## Faster Recovery

- Stabilizes Nerves
- Targeted Regeneration
- Less discomfort and improved QoL

## Improved Outcomes

- Enhanced quality of nerve-to-muscle reinnervation
- Enhances patient functionality

# Considerations

## Material Biocompatibility

### Immune Responses

- Immune system responds to bioengineered materials, leading to complications in treatment and recovery.

### Tailored Material Solutions

- Tailoring materials based on individual biocompatibility testing can significantly reduce adverse immune responses in patients.

## Regulatory Issues

### Preclinical Trials

- Conducting rigorous preclinical trials is essential for ensuring the safety and efficacy of bioengineered devices before seeking approval.

### Breakthrough Device Programs

- Securing expedited review under breakthrough device programs can help accelerate the regulatory approval process.

## Initial Costs/Development

### High Initial Investment

- Developing bioengineered channels demands significant initial investment, making funding a critical challenge.

### Partnership Solutions

- Collaborating with research institutions and biotech companies can help share the costs of development and production.
- Engaging governmental programs can aid in scaling production, leading to reduced costs over time.