What is spinal cage and how do they work

The purpose of using cages is to restore/replace a lost disc height resulting from a collapsed disc and to relieve pressure on nerve roots. Interbody cages are placed between the bodies of 2 adjacent vertebrae. This procedure is typically done after removing the intervertebral disc that typically occupies in this space. There are multiple materials spinal cages can be made of and that includes metal, polymer, ceramic, or a combination of different materials. Two commonly used materials include titanium and polyetheretherketone. The inside of the cage is hollow in the centre. In the centre (and around) the cage, a bone-growth promoting material is placed in (see figure 1.1), such as beta-tricalcium phosphate or your own bone which can be taken from your hip during the same surgery as the fusion. The bone graft begins to grow through the perforated walls of the cages eventually forming a solid bond holding the vertebrae together (see figure 1.2 for labelled parts of the spine).

During the surgery, the parts of the spine that are involved in this surgery include the lumbar spine, pedicles, nerve roots, and laminae (for more about the anatomy of the spine check out section …). The design of a cage typically depends on many things which include the material of the cage, the placement, and the technique used to deliver it into the interbody or disc space of the spine. For example, a cage that covers more surface area of the vertebral endplates (a patient-specific 3D printed cage) helps achieve higher stability. This is because it decreases the forces directly impacting the unsupported areas of the endplates.

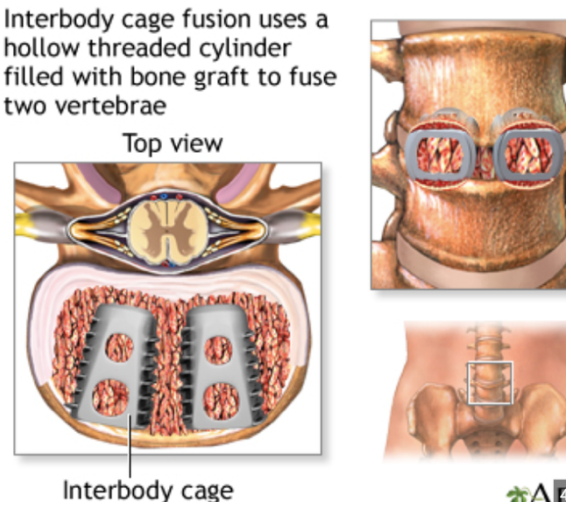

Figure 1 - Bone grafting is a surgical procedure that uses transplanted bone to repair and rebuild diseased or damaged bones

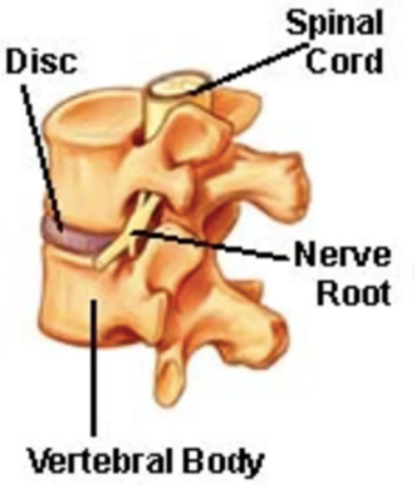

Figure 2 – Labelled picture of the relevant parts of interbody fusion

The interbody cage's purpose is to improve the stability and balance of the treated spinal segment. It also helps in relieving pain and restoring function. The aims of spinal cages include:

- Restoring the height which was by the original intervertebral disc
- Supporting the anterior (front) part of the spine
- Expanding the bony openings between the vertebrae (foramina), providing more space for spinal nerves
- Restoring the normal lordotic (S-shaped) curve of the lower (lumbar) spine
- Transferring loads from the upper segments to lower sections of the spine
- Promoting a solid fusing of the adjacent vertebral segments by promoting bone growth (using bone graft)
- Increasing the spaces within the spinal canal to decrease the compression of neural tissue that may be indirectly compressed

Note: For more specific conditions which are treated by spinal cages see section …

How are spinal cages infused between two vertebrae?

There are many ways the intervertebral fusion cages are used. One of them is done by making an incision in the back of the spine and inserting the cage between the vertebrae from the back side. However, the procedure which is commonly done consists of operating on the front of the spine using either an open incision - or the laparoscopic approach.

To perform the procedure from the front, a laparoscope can be inserted, or an open incision is made so the doctor can see the front of the spine. The disc that is to be replaced with the interbody cage is located using a fluoroscope (a special X-ray machine that shows the images on a TV screen). In many cases, two interbody cages are used in each disc and are placed side by side using special instruments (also seen in figure 1.1). Two holes are drilled into the disc to place the interbody cages next to each other.

Bone graft is then placed inside the hollow intervertebral fusion cage (This bone graft will most likely be taken from your pelvis through using a small incision). Then finally the two cages inserted into place between the vertebrae. The fluoroscope will be used to ensure that the interbody cages are placed in the correct position.

Surface modification of spinal cages and bone growth

Although polyetheretherketone and titanium (the two common materials spinal cages are made of) have desirable biocompatibility and mechanical properties, they require further modification to support osseointegration (osseointegration: a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant). In an unaltered state both polyetheretherketone and titanium have limited bioactivity. To achieve bioactivity in an orthopaedic implant, its materials must elicit a specific biological response at the interface of the material, thus facilitating formation of a bond between the tissues and the material. This can be verified by in vivo tests or soaking in simulated body fluids and investigating surface precipitation of hydroxyapatite.

Surface modification can happen in the material titanium by creating rougher surfaces. This modifies its surface topography, physical and chemical treatment and creating a porous material with high interconnectivity in turn improving its osseointegrative potential. Another way we can improve osseointegrative potential is by coating the surface with osteoconductive materials like hydroxyapatite. Polyetheretherketone may also be coated with titanium, bio-activating the coating.

Titanium and Titanium Alloys

Titanium and titanium alloys were first brought into the orthopaedic world in the 1940s and later into the world of spinal couple decades later. This material is well suited for spines because of its biocompatibility, robust repassivation (repassivation: repeating the passivation process, which is a technique to make a material less affected by environmental factors (water or air etc) by coating it with a protective material) that is attributable to TiO2 formation, which provides excellent resistance to corrosion, and low density. However, titanium does have some disadvantages. One of the disadvantages is the mismatch in elastic modulus (110 GPa) compared with that of bone (10–30 GPa) (see figure 3). This can potentially lead to stress shielding around the implant and with local inflammation, causing bone atrophy, subsidence, and ultimately implant failure.

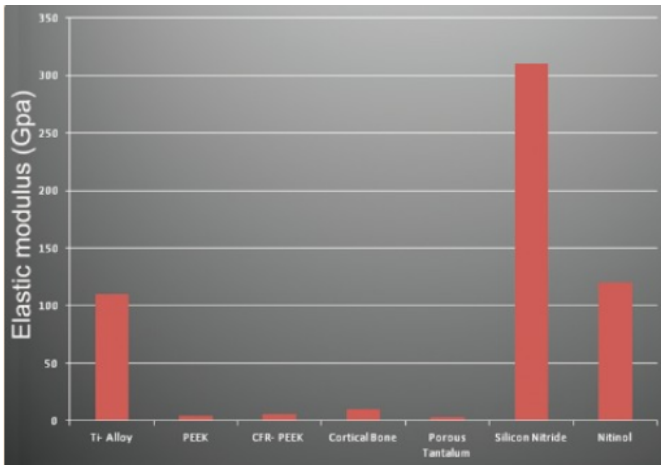

Figure 3 – Elastic modulus for some available spinal implant materials.

Surface modification of Titanium can improve both on-growth (the direct apposition of bone to the surface) and in-growth (the interlocking or bone growth into the surface of a material) of bone.

There are quite a lot of treatments available for titanium and polyetheretherketone which make these material bioactive. The following table summarises these treatments.

Implant Material	**How the material is made bioactive**
Titanium	• Rough surface • Modification of surface topography • Heat treatment • Alkali treatment • Removal of Na ions • Porous material conversion HA coating
Polyetheretherketone	• Ti composite • HA composite • Calcium silicate composite • Bioglass composite • β-TCP composite

Figure 4 – Treatments available for titanium and polyetheretherketone which make them bioactive

Use of sensors inside a cage and monitoring

A spinal cage may contain sensors that can be used to track the condition of the spine in real time. The temperature, pressure, and strain of the spinal cage are only a few of the different characteristics that these sensors can assess. They can also spot changes in the chemical makeup of the spinal fluid, which may point to an infection, inflammation, or other problems.

Wireless transmission of the data gathered by the sensors to a computer or other monitoring equipment allows for real-time analysis. This enables medical personnel to spot possible problems before they develop into serious ones and to take the necessary precautions to stop future harm. For instance, if a sensor notices a rise in pressure inside the spinal cage, this can be a sign of inflammation in the patient, and anti-inflammatory drugs might be recommended to treat it.

The ability of sensors inside a spinal cage to offer more accurate data than conventional monitoring methods is another benefit. For instance, imaging methods like X-rays and others can only produce static images of the spine, which might not fully depict any problems. Sensors, on the other hand, can offer continuous monitoring, enabling medical personnel to monitor changes over time and modify treatment as necessary.

Dealloying

Dealloying is a process of selectively dissolving one or more elements from an alloy, leaving behind a nano-porous structure with enhanced mechanical and biological properties. Note that a nano-porous structure is a subset of nanomaterials with pores 1–100 nm size that allow certain materials to pass through them while other materials are restricted depending on the size of the pores.

Dealloyed implants have a higher surface area, improved biocompatibility, and better cell adhesion compared to conventional metallic implants. Dealloying can be utilised in spinal cage implants to make the implant's surface porous, which promotes better bone ingrowth and fusion. Dealloying can also be done to make the implant less rigid, which can aid to lessen stress shielding and encourage bone remodelling. Note that stress shielding refers to the reduction in bone density (osteopenia) because of removal of typical stress from the bone by an implant.

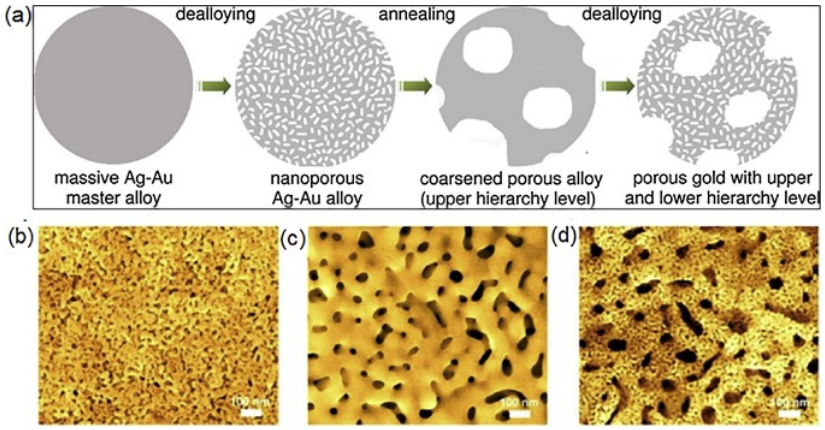

Figure 4 – Visual Representation on dealloying and annealing

In the figure above, annealing refers to when a material is heated to a specified temperature, maintained there for a predetermined amount of time, then allowed to cool gradually. The method can be used to change a material's microstructure, which can significantly affect its mechanical and physical properties. This is done to tailor the surface properties of a material to meet specific requirements.

Dealloying and surface modification combined

These two methods (dealloying and surface modification) can both be used at the same time to make a material as biocompatible as possible. They can be used to produce hybrid implants with enhanced characteristics. For instance, a hydroxyapatite coating can be applied to a dealloyed implant to encourage bone ingrowth and fusion.

Disadvantages of dealloying

Although dealloying has many advantages in terms of biocompatibility, such as improved corrosion resistance and increased surface area for cell attachment, there are also some potential disadvantages. This can include:

1. Due to the removal of one or more components, dealloyed structures may have lower mechanical strength than the original alloy. This might be a problem in biomedical applications that require load bearing.

2. Dealloying can be difficult to regulate exactly, which could result in variations in the final composition of the material. This lack of control may have unanticipated consequences for biocompatibility.

3. Dealloyed materials can have a rough surface due to their porous structure, which may not be appropriate for some biological applications where a smooth surface is required to lower the risk of infection or inflammation.

4. Dealloying can be a complicated and time-consuming operation, which could limit its scalability and raise the entire cost of production.

5. During the dealloying process, the selective removal of some components can cause the release of poisonous substances that could be damaging to living tissue.

References

1. Umms.org. (2019). *Fusion with Interbody Cages*. [online] Available at: https://www.umms.org/ummc/health-services/orthopedics/services/spine/patient-guides/fusion-interbody-cages.

2. FAANS, J.J., MD (n.d.). *What Are Cages and Why Is Your Surgeon Putting One in Your Spine?* [online] Spine-health. Available at: https://www.spine-health.com/blog/what-are-cages-and-why-your-surgeon-putting-one-your-spine.

3. Jagannathan, J., MD and Peer-Reviewed, F. (n.d.). *Interbody Cages for Spine Fusion | Spine-health*. [online] www.spine-health.com. Available at: https://www.spine-health.com/treatment/spinal-fusion/interbody-cages-spine-fusion [Accessed 2 Mar. 2023].

4. Rao, P.J., Pelletier, M.H., Walsh, W.R. and Mobbs, R.J. (2014). Spine Interbody Implants: Material Selection and Modification, Functionalization and Bioactivation of Surfaces to Improve Osseointegration. *Orthopaedic Surgery*, 6(2), pp.81–89. doi:https://doi.org/10.1111/os.12098.

5. Qiu, Z.-Y. ., Chen, C., Wang, X.-M. . and Lee, I.-S. . (2014). Advances in the surface modification techniques of bone-related implants for last 10 years. *Regenerative Biomaterials*, 1(1), pp.67–79. doi:https://doi.org/10.1093/rb/rbu007.

6. Kim, S.J., Wang, T., Pelletier, M.H. and Walsh, W.R. (2022). 'SMART' implantable devices for spinal implants: a systematic review on current and future trends. *Journal of Spine Surgery*, 8(1), pp.117–131.
7. doi:https://doi.org/10.21037/jss-21-100.

8. J. Regan, J. (2010). *New Device for Cervical Spine Surgery*. [online] Available at: https://www.spineuniverse.com/exams-tests/devices/new-device-cervical-spine-surgery.