**Tritanium Technology**

**Tritanium** = 3-Dimensional CP Ti or Ti Alloy
- Proprietary highly porous material designed for biological fixation
- Tritanium closely resembles the structure of trabecular bone
  - Pore size
  - Amount of porosity
  - Interconnectivity of pores

![Human Trabecular Bone](image)

![Tritanium Technology](image)
The Stryker Spine Tritanium PL Cage is an intervertebral body fusion device indicated for use with autograft and/or allogenic bone graft comprised of cancellous and/or corticocancellous bone graft when used as an adjunct to fusion in patients with degenerative disc disease (DDD) at one level or two contiguous levels from L2 to S1.
**Tritanium PL Cage**

**Material:**
- Ti Alloy Ti6Al4V

**Porous surface parameters:**
- Porosity: mean 60%\(^1,2,4\)
- Pore size: 100-700µm; mean 438µm\(^3,4\)

**Sizing:**
- Height: 7-14mm
- Width: 9 and 11mm
- Length: 23 and 28mm
- Lordosis: 0° and 6° (oblique for 28mm)

**Phase 2:** 6mm height, 32mm length, 12°

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4. DHF 42351
The science behind Tritanium Technology

The parameters for Tritanium were defined based on published literature and Stryker pre-clinical animal studies. Over time, Stryker's Research & Development teams have optimized the findings for successful biological fixation which have since become the principle attributes of Tritanium.
The science behind Tritanium Technology

What is the goal of porous surfaces?
• Biological fixation

How is this accomplished?

1. Pore optimization:
• Mean pore size
• Pore size range
• Porosity

2. Process parameters:
• Material
• Additive Manufacturing
• Heat treatment

Next generation porous metals for biologic fixation
JD Bobyn
The science behind Tritanium Technology

Bobyn, et al (1980)*:
• Transcortical canine model
• Optimum pore size = 50-400μm
• Fastest rate of max fixation

Karageorgiou, Kaplan (2005)*:
• Pore sizes > 300μm
• Smaller pores – hypoxic conditions with osteochondral formation first
• Larger pores – well vascularized with direct osteogenesis

* These are pre-clinical animal studies or clinical studies looking at porous materials and porous coated surfaces.
The science behind Tritanium Technology

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<td>&quot;Bone ingrowth into porous coated canine acetabular replacements: the effect of pore size, apposition, and dislocation.&quot; Hip: 214-34. <strong>Demonstrated better bone ingrowth at pore diameters compared with ( \mu 140 )</strong></td>
<td>&quot;The clinical results and basic science of total hip arthroplasty with porous-coated prostheses.&quot; J Bone Joint Surgery Am 75(2): 299-310. <strong>The strength of the implant bond correlates to the volume and maturity of ingrown bone</strong></td>
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<td>“Effect of porosity on the osteointegration and bone ingrowth of a weight-bearing nickel-titanium bone graft substitute” Biomaterials, 24(25), November 2003, 4691-4697. <strong>Demonstrated statistically similar bone ingrowth with Nickel Titanium porous structures at 259±30 ( \mu m ) and 505±136 ( \mu m ) mean pore diameters</strong></td>
<td>Porous Ti6Al4V Cage Has Better Osseointegration and Less Micromotion Than a PEEK Cage in Sheep Vertebral Fusion. Artificial organs 37(12). <strong>Complete fusion of vertebra with 710( \mu m ) diameter pore size Ti6Al4V sheep model</strong></td>
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* These are pre-clinical animal studies or clinical studies looking at porous materials and porous coated surfaces.
The science behind Tritanium Technology

Bobyn, et al (1999)*:
- 75% porous tantalum
- 430µm pores
- 2, 3, 4, 16, and 52 weeks

Bobyn (2011)*:
- Laser 3D printed titanium
- 420µm pores, ~65% porosity

* These are pre-clinical animal studies or clinical studies looking at porous materials and porous coated surfaces.


Next generation porous metals for biologic fixation
JD Bobyn
Stryker’s Orthopaedics Division

Pre-clinical Animal Studies:

**Phase I** (2004, Tritanium)
- Porosity and pore size vs bone ingrowth

**Phase II** (2005, Vapor Deposition Process of Polyurethane Foam) ¹
- Bone ingrowth for pore sizes 700-900µm

**Phase III** (2006, Sacrificial Pore Former and Titanium Sintering Process)
- Bone ingrowth for pore sizes 475-525µm³
- Heat treat vs no heat treat

**Phase IV** (2012, LRM)
- Bone ingrowth for pore sizes 500µm⁴
- Heat treat temperature
- Variations in post processing steps

Stryker’s Spine Division

Tritanium Pore Optimization:

Mean pore size: 400-500µm⁴,⁷
Pore size range: 100-700µm²-4,⁷
Porosity: ≈ 60%⁵,⁶,⁷

**Process Parameters:**

Heat treat: Yes
Temperature: Optimized for spinal implants *

*Tritanium implants are heat treated at temperatures specifically optimized for each implant’s geometry.

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¹ Tritanium Particle Sintered Foam (PSF) (2004) (ref.: RD-05-033)
³ Zhang, R. et al. (2007, February). The Osseointegration of Selective Laser Melted (SLM) Porous titanium in Rabbit Femoral Defect Model presented at The Orthopaedic Research Society, San Diego, CA
⁷ DHF 42351
Tritanium PL Cage
design features & benefits

Threaded Inserter attachment hole for rigid Inserter to cage connection

Solid-tipped, precisely angled serrations designed for bidirectional fixation and to maximize surface area for endplate contact with the implant

Large window to reduce stiffness of cage and aid in visualization of fusion

Highly porous titanium alloy material on top and bottom surfaces and on all sides of internal graft window

Smooth wedge nose to facilitate insertion

Thin layer of solid material to provide smooth surface during insertion and reduce potential to catch soft tissue
Tritanium PL Cage imaging*

*Images taken from a cadaveric study (PROJ 47030 Tritanium PL Cage cadaveric image folder).
Tritanium PL Cage testing overview
Tests conducted on the Tritanium PL Cage that are required by the U.S. FDA:

Compression¹
Compression-shear¹
Torsion¹
Subsidence²
Expulsion³
Wear debris analysis⁴

Additional tests performed:
Impaction⁴
Insertion⁴

¹ ASTM F2077
² ASTM F2267
³ ASTM F04-25-02-02
⁴ No published standard
Tritanium PL Cage testing

Example test set-ups:

Shear\(^1\)

Torsion\(^1\)

Impaction\(^2\)

1 ASTM F2077
2 No published standard
Wear debris

After the Laser Rapid Manufacturing (LRM) production process, all parts progress through the following steps:

- Blast off loose powder from process with inert gas
- Wash parts through multiple cleaning steps
- Place in oven to sinter any remaining loose particles to surface

Wear debris analysis was conducted post-testing and the results met U.S. FDA requirements.
Biomechanical testing: subsidence

Test standard:
- Per ASTM F2267
- Required by the U.S. FDA

Parameters:
- Cage in between 15 pcf foam blocks (simulate bone)
- Axial compressive load applied
- Displacement of cage into foam blocks measured
- Test method to allow for consistent comparison between different cage shape and materials
Biomechanical testing: subsidence

Subsidence versus Material and Footprint

Normalized Displacement into Foam Blocks (%)

- Tritanium PL IBD 23x9: 100%
- Bone IBD 25x9: 118%
- PEEK IBD 33x11: 145%
- PEEK IBD 20x9: 164%
- Solid Ti IBD 20x11: 182%

Posterior IBD and Footprint (length x width in mm)

Note: all measurements at 500N of compressive load
Biomechanical testing: expulsion

Test Standard:
- Per ASTM F04-25-02-02 (draft)
- Required by the U.S. FDA

Parameters:
- Cage in between 15 pcf foam blocks (simulate bone)
- Compressive load applied to cage
- Force to move cage 3mm is measured
Biomechanical testing: expulsion force comparison

Normalized Expulsion Force to PEEK IBD

- PEEK Cage (0.5mm teeth height) 100%
- PEEK Cage (1mm teeth height) 119.2%
- Plasma Sprayed Ti PEEK Cage 115.5%
- Tritanium PL Cage (0.5mm teeth height) 116.0%
- Tritanium PL Cage (1mm teeth height) 131.0%
Biomechanical testing: insertion & expulsion comparison

Tritanium PL Cage Insertion and Expulsion Force

Aided by:
- Tooth design
- Material Coefficient of Friction
Questions?
Tritanium PL Cage
pre-clinical study information
Why do a pre-clinical study?

- An In-Vivo (Animal) model allows us to study outcomes that would be otherwise impossible to measure within an Ex-Vivo (Cadaveric) or Clinical (Human) environment
  - Bone-ingrowth, implant resorbability, infection rates, unknown adverse events, effectiveness in low-bone quality environments, etc.
- Several different types of models exist that can be used to investigate properties of orthopaedic and spine implants
  - Animals: Bovine, Ovine, Canine, Rat, Rabbit, etc.
  - Design: TKA, THA, Defect Model, ACDF, LIF, etc.
Why use a sheep model for spine?

Anatomy of the Sheep Spine and Its Comparison to the Human Spine

HANS-JOACHIM WILKE,* ANNETTE KETTLER, KARL HOWARD WENCER, AND LUTZ EBERHARDT CLAES
Department Unfallchirurgische Forschung und Biomechanik, Universität Ulm, Ulm, Germany
Why use a sheep model for spine?
Tritanium pre-clinical competition

Note: The images on this slide are intended to generically represent study methodologies typically used in orthopaedic pre-clinical research.
Pre-clinical study\(^1\) model

- Executed study at Colorado State University due to expertise with developing and improving LIF model in conjunction with experience
- Animal model:
  - Two Level (L2/L3 & L4/L5) LIF with autograft (ICBG) (0.5cc)
  - Implants & surgeons randomized to reduce bias
- Comparison groups:
  - Stryker Spine Tritanium PL Cage
  - PEEK IBD Cage
  - PEEK IBD Cage coated with plasma sprayed titanium
- Two sacrifice time points:
  - Group One: 16 Weeks (12 sheep)
  - Group Two: 8 Weeks (15 sheep)
Tritanium PL Cage vs. surface coated cage¹

Tritanium Foam Thickness

Ti Plasma-Sprayed Coating Thickness on PEEK Implant

¹ SRL 15-02 / Stryker -02-15
Pre-clinical study\textsuperscript{1} goals

- Non-destructive kinematic testing was performed in the three primary directions:
  - Axial rotation
  - Flexion-extension
  - Lateral bending
- All specimens then underwent micro-computed tomography (µCT) and quantitative measures of the bony fusion were performed
- Histological sections were then taken through the sagittal plane through the fusion mass / interbody device
- Histomorphometric measurements were calculated to quantify the area of new bone within / around the implant.
Understanding histology images

- Pale green: fibrous tissue
- Disc space
- Pink/red: calcified bone matrix
- Caudal vertebra
- Cranial vertebra
- Empty space
- Dark green: osteoid
- Tan/black: cage body

Sagittal View
Histology\textsuperscript{1} – coating delamination\textsuperscript{*}

8 weeks post-operatively

16 weeks post-operatively

*Correlation to human clinical outcomes has not been demonstrated or established.
Pre-clinical study histology summary

Total region of interest (ROI)

- Tritanium demonstrated increased amount of bone within ROI at the 16 week time point compared to the 8 week time point. This statistically significant increase was not seen in any other treatment groups.
- Tritanium demonstrated increased amount of bone within the ROI compared to all PEEK implants at the 16 week time point (statistically significant).

Implant region of interest (ROI)

- Tritanium demonstrated increased amount of bone within ROI compared to all other treatment variants at the 8 and 16 week time points (statistically significant).
- Tritanium demonstrated increase in the amount of biologic elements (bone marrow cells, blood cells, etc.) within the ROI compared to all other treatment variants at both the 8 and 16 week time points (statistically significant).

*Correlation to human clinical outcomes has not been demonstrated or established.
Core region of interest (ROI)

- Tritanium demonstrated **increased amount of bone within ROI** at the 16 week time point compared to the 8 week time point. *This statistically significant increase was not seen in any other treatment groups.*

Qualitative fusion assessment (assessed by blinded 3rd party)

- Tritanium demonstrated a **greater bony bridging score** compared to all other treatment variants at the 16 week time point.
- Tritanium demonstrated an **increase in the bony bridging score** at the 16 week time point compared to the 8 week time point. *This statistically significant increase was not seen in any other treatment groups.*
Pre-clinical study micro-CT images & summary*

Sagittal View | 16 weeks post-op in an ovine model

- 3-D reconstructions visually demonstrate **bony ingrowth** into Tritanium PL Cages at both 8 and 16 weeks.
- Tritanium PL Cage demonstrated **statistically greater bone volume / total volume** at the 8 week time point as compared to all other treatment variants.
- Tritanium PL Cage demonstrated **statistically greater bone volume / total volume** at the 16 week time point as compared to all other treatment variants.

*Correlation to human clinical outcomes has not been demonstrated or established.
Pre-clinical study\textsuperscript{1} biomechanical (range of motion)*

At 16 weeks post-op in an ovine model, Tritanium PL Cages showed statistically significant reduction in range of motion (ROM) when compared to PEEK Cages and Ti Plasma Sprayed PEEK Cages.

*Correlation to human clinical outcomes has not been demonstrated or established.
Pre-clinical study\(^1\) biomechanical (stiffness)*

At 16 weeks post-op in an ovine model, Tritanium PL Cages showed greater average construct stiffness when compared to PEEK Cages and Ti Plasma Sprayed PEEK Cages.

*Correlation to human clinical outcomes has not been demonstrated or established.
Pre-clinical study biomechanical summary*

Range of motion (ROM) | Tritanium PL Cage demonstrated:

- Decrease in ROM across all three primary loading directions (axial rotation, flexion/extension and lateral bending) following 16 weeks of healing compared to 8 week samples. This difference was not evident in the other treatment groups.
- Decrease in ROM for flexion / extension compared to all other treatment variants (statistically significant).
- Across treatment groups and sacrifice time points, Tritanium PL Cage consistently had the lowest ROM mean magnitude in all loading directions at 16 weeks.

Stiffness | Tritanium PL Cage demonstrated:

- Increase in stiffness across all three primary loading directions (axial rotation, flexion/extension and lateral bending) following 16 weeks of healing compared to 8 week samples. This difference was not evident in the other treatment groups.
- Across treatment groups and sacrifice time points, Tritanium PL Cage consistently had the highest mean stiffness values in all loading directions at 16 weeks.

*Correlation to human clinical outcomes has not been demonstrated or established.
Questions?
The Stryker Spine Tritanium PL Cage is an intervertebral body fusion device indicated for use with autograft and/or allogenic bone graft comprised of cancellous and/or corticocancellous bone graft when used as an adjunct to fusion in patients with degenerative disc disease (DDD) at one level or two contiguous levels from L2 to S1.

**Tritanium PL Cage**
- Created to allow visualization\(^5\)
- Developed to minimize subsidence\(^2\)
- Engineered for stability\(^3,4\)

**Tritanium In-Growth Technology\(^1\)**
- Designed for **in-growth**\(^1\)
- Empowered by expertise

1. PROJ 43909
2. PROJ 42624
3. PROJ 42623
4. PROJ 44960
5. Data on file
U.S.A and Canada Indications for Use:

The Stryker Spine Tritanium PL Cage is an intervertebral body fusion device indicated for use with autograft and/or allogenic bone graft comprised of cancellous and/or corticocancellous bone graft when used as an adjunct to fusion in patients with degenerative disc disease (DDD) at one level or two contiguous levels from L2 to S1.

DDD is defined as back pain of discogenic origin with degeneration of the disc confirmed by history and radiographic studies. The DDD patients may also have up to Grade I spondylolisthesis at the involved level(s). These patients should be skeletally mature and have six months of nonoperative therapy.

Additionally, the Tritanium PL Cage can be used as an adjunct to fusion in patients diagnosed with degenerative scoliosis.

The Tritanium PL Cage is to be implanted via a posterior approach.

The Tritanium PL Cage is intended to be used with supplemental spinal fixation systems that have been cleared for use in the lumbosacral spine.
**Tritanium PL Cage**

**Outside U.S.A and Canada Indications for Use:**

The Tritanium PL cage is an intervertebral body fusion device indicated for the treatment of spondylolisthesis, degenerative spine disorders and discal and vertebral instability, and may also be used in cases of spine revision surgery. Packing bone graft material within the implant is recommended.

The Tritanium PL cage is to be implanted via a posterior approach.

The Tritanium PL cage is intended for use with supplemental fixation.
A surgeon must always rely on his or her own professional clinical judgment when deciding whether to use a particular product when treating a particular patient. Stryker does not dispense medical advice and recommends that surgeons be trained in the use of any particular product before using it in surgery. The information presented is intended to demonstrate the breadth of Stryker product offerings. A surgeon must always refer to the package insert, product label, and/or instructions for use before using any Stryker product. Products may not be available in all markets because product availability is subject to the regulatory and/or medical practices in individual markets. Please contact your Stryker representative if you have questions about the availability of Stryker products in your area.