AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Root analog 3D printed dental implant

The nano level challenges

OVERVIEW

- Tooth fracture
- Dental implants
- Systematic literature review
- 3D Printed Results

Most common causes of teeth loss

The three most common causes of teeth loss:

- Caries

- Periodontal disease

- Vertical root fractures (VRF)

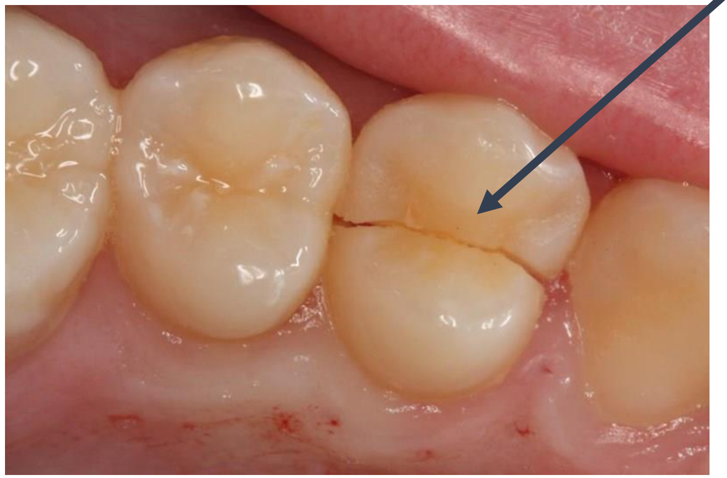
- VRF originate in the root and are generally complete, sometimes they may be incomplete [1]
- VRF occur 94% of the time in endodontically treated teeth [2]
- Teeth that have VRF are hopeless and need to be extracted. [3]

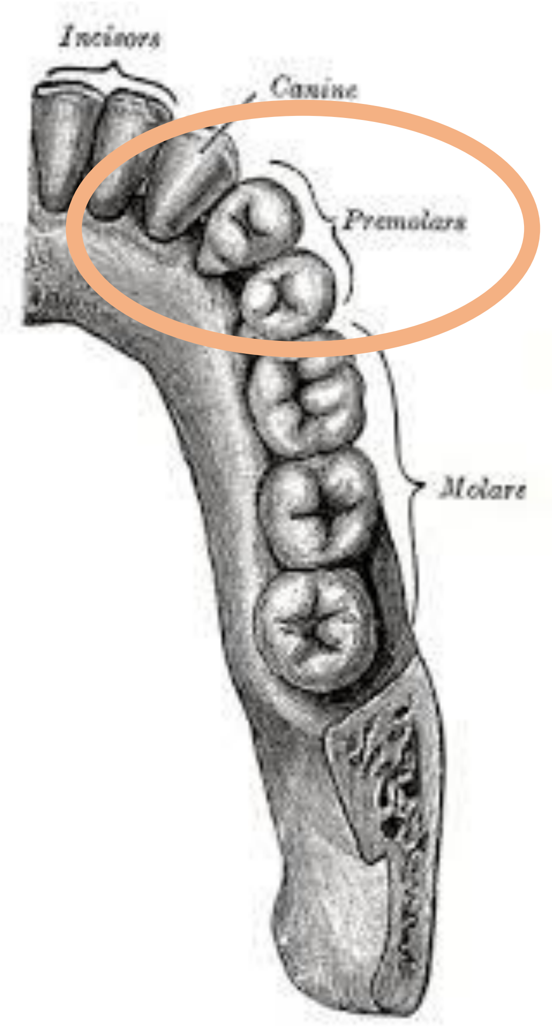
AAIDF
AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Tooth fracture

Premolar teeth are one of the most commonly fractured. Usually, the fracture is so deep that it goes through the root

Fractured premolar





AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Maxillary Second premolar

Buccal

Lingual

Occlusal

Mesial

Distal

[4]

Implant systems

There are several ways to replace missing tooth. An alternative to bridges, partials or complete dentures may be dental implants. Implants are used to replace missing roots and support artificial replacement teeth.

More than 200 companies with more than 300 different implant systems ranges of designs exist today

[5]

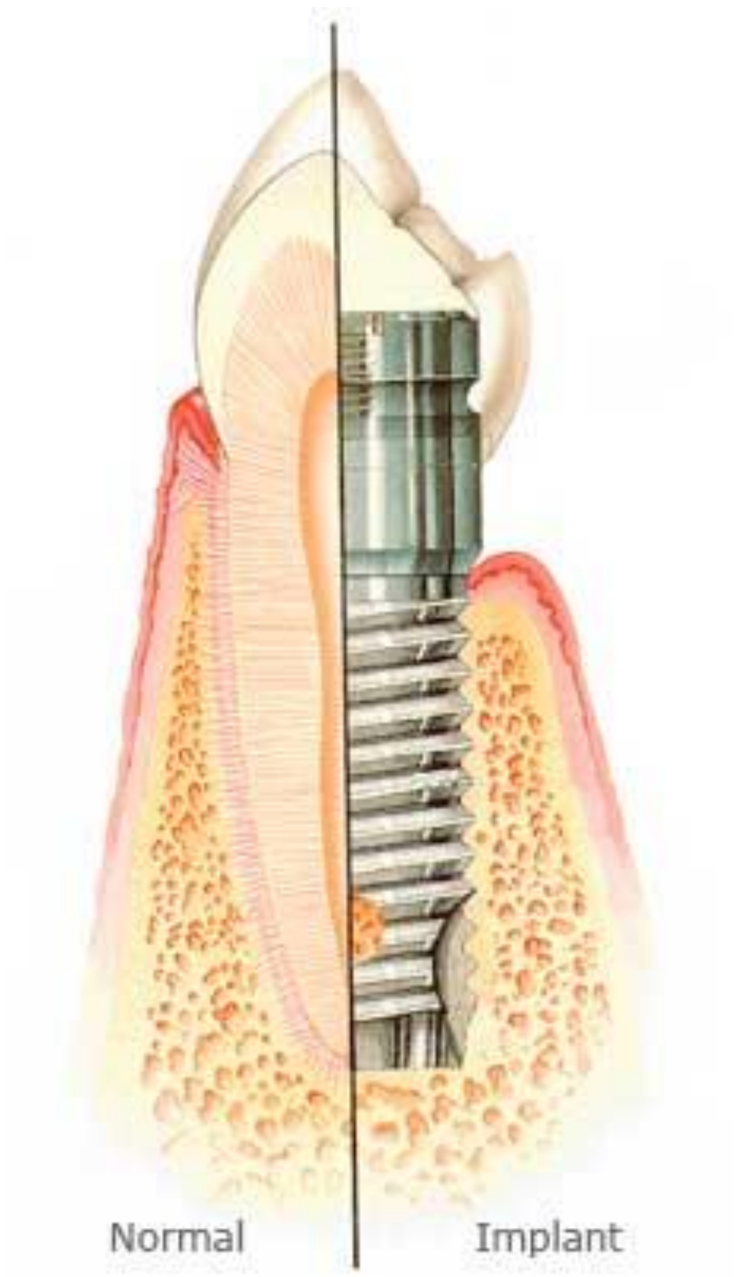
AAIDF AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Differences between the natural tooth and implant

	Natural tooth	**Implant**
Connection	Periodontal ligament (PDL)	Osseo integration, functional ankylosis
Proprioception	Periodontal mechanoreceptors	Osseo perseption
Tactile sensitivity	High	Low
Axial mobility	25-100 microns	3-5 microns
Movement phases	Two phases Primary: non-linear and complex Secondary: linear and elastic	One phase Linear and elastic
Movement patterns	Primary: immediate movement Secondary: gradual movement	Gradual movement
Fulcrum to lateral force	Apical third of root	Crestal bone
Load-bearing characteristics	Shock absorbing function Stress distribution	Stress concentration at crestal bone
Signs of overloading	PDL thickening, mobility, wear facets, fremitus, pain	Screw loosening or fracture, abutment or prosthesis fracture, bone loss, implant fracture

[6]

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION



The major difference between a tooth and an implant

Healthy Gums

Healthy Bone Structure

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

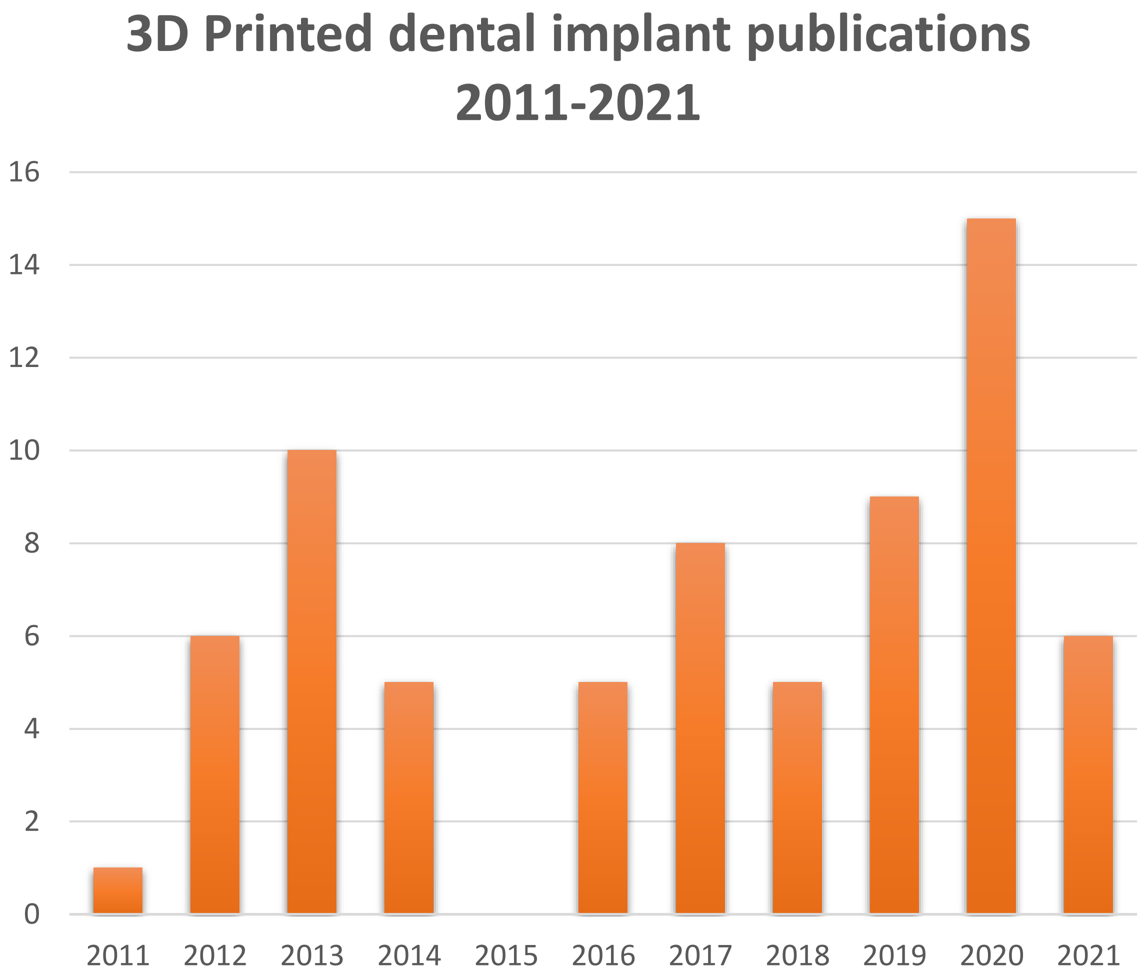
3D Printed Root Analogue

New advances have been made in the fabrication of Root Analogue Implants (RAI), where the non-restorable root of a tooth is 3D printed prior to extraction by Direct Metal Laser Sintering (DMLS) and placed immediately after extraction [7]

[8] Figliuzzi M. et al. Periodontics and Prosthodontics v.2 (01), 2016

3D Printed dental implant

The data available on such titanium dental implants in the current literature is limited. Even though the concept of AM and DMLS manufactured implants are known



AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Article main topic distribution

15%

Manufacturing

26%

Histologic/
histomorphometic

Mechanical,
surface, topology

47%

33 out of
70 studies

11%

Clinical/
radiographic

1%

Design

Common design path on fabricating the implant for 3D printing

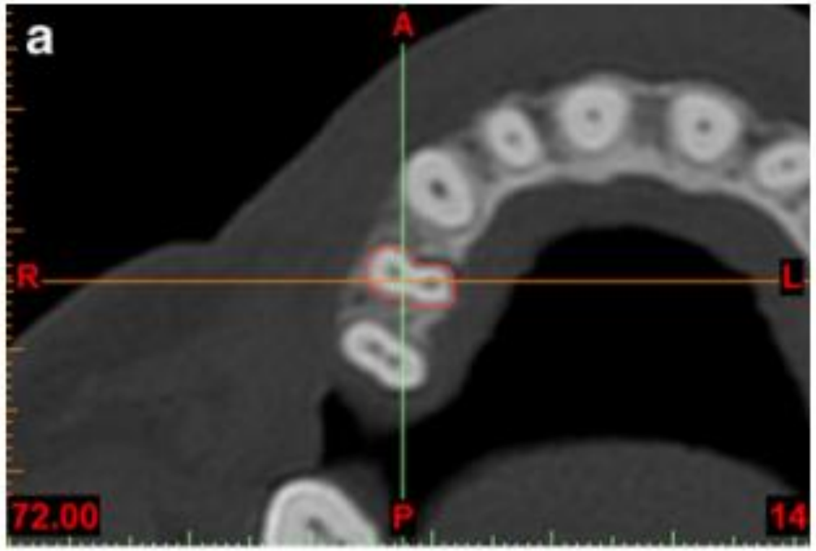
CT scan → Mimics → CAD → Magics → Final STL

3D reconstruction image processing software for 3D design and modeling

Reverse engineering software

Leader-NovaxaR, Milan, Italy
Pro/Engineering CAD
SolidWorks etc.

STL editor and repair



[9]

Deviations between the real root and final STL sizes

The deviation between the CAD model and the fabricated implants is common in this process

Reasons:

- Insufficient resolution of the initial CT-Scan data
- Manufacturing deviations
- Shrinkage of material

Test the dimensional distortion and congruence between the root and the alveolar socket

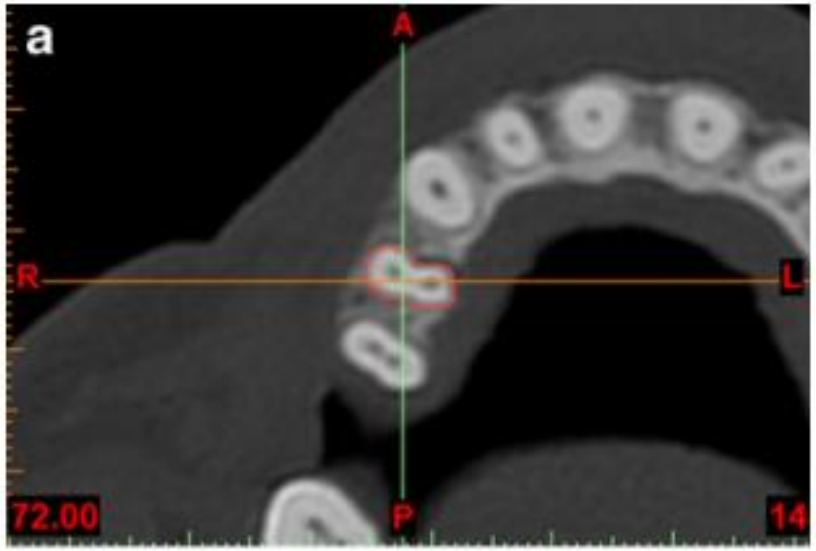
CT scan → Mimics → CAD → Magics → Final STL

3D reconstruction image processing software for 3D design and modeling

Reverse engineering software

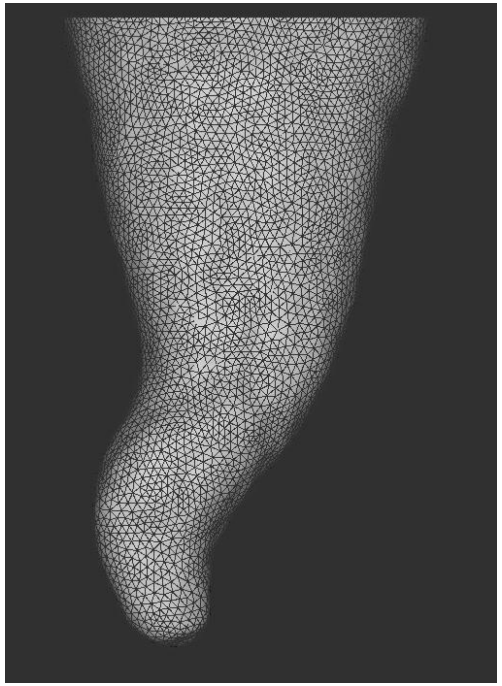
Leader-NovaxaR, Milan, Italy
Pro/Engineering CAD
SolidWorks etc.

STL editor and repair

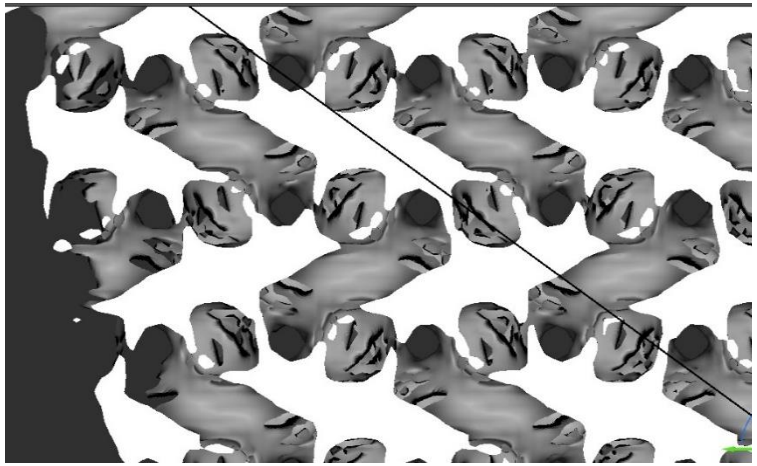


Parameters to be considered for the internal design

- Pore size
- Cell geometry
- Pore distribution
- Interconnectivity
- Percentage of porosity



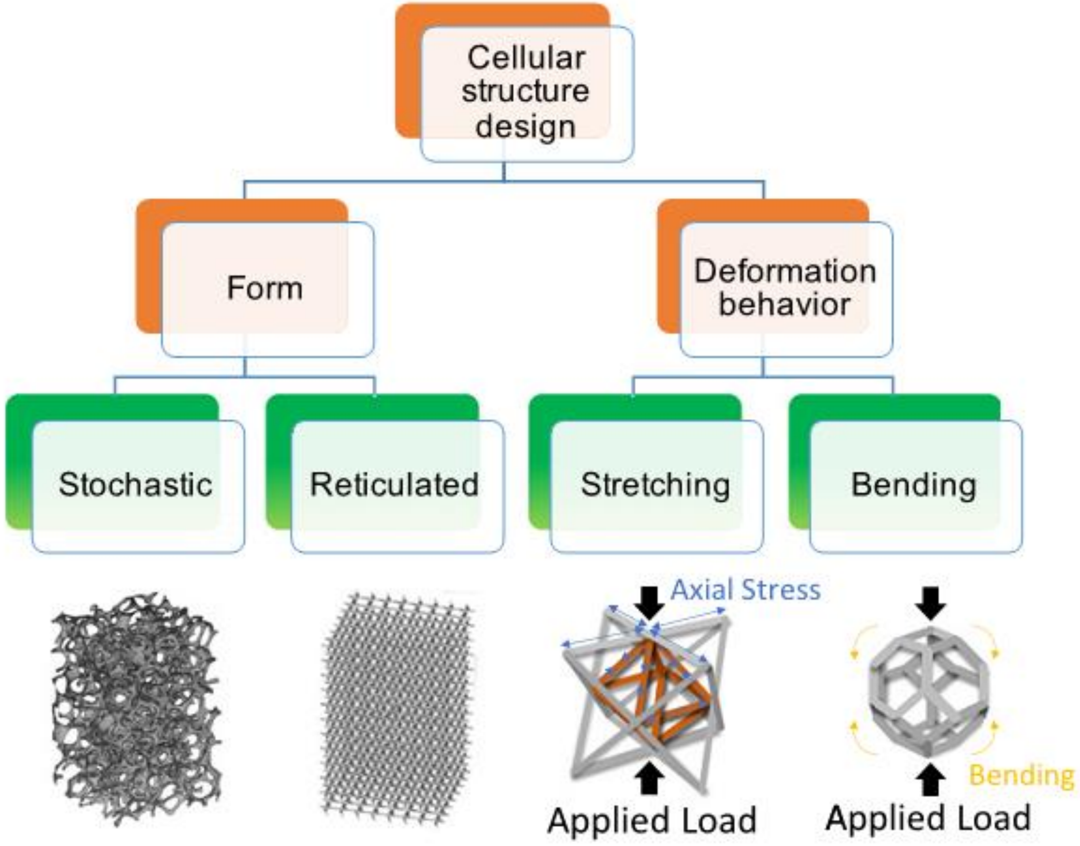
Example of a root mesh



Internal pore design

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Cellular scaffold design in terms of forms and their deformational behavior



AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Parameters to be considered

Internal design	Surface	Titanium powder	Post-processing
Pore size	Micro-roughness	Chemical composition	Heating
Cell geometry	Nano-roughness	Particle size distribution	Washing
Pore distribution	Surface chemical composition	Amount of reused material	Additional surface treatment, coating
Interconnectivity		Stress of the particles	
Percentage of porosity		Process parameters: Temperature, pressure, sintering time	

Manufacturing inputs and clinical outcomes

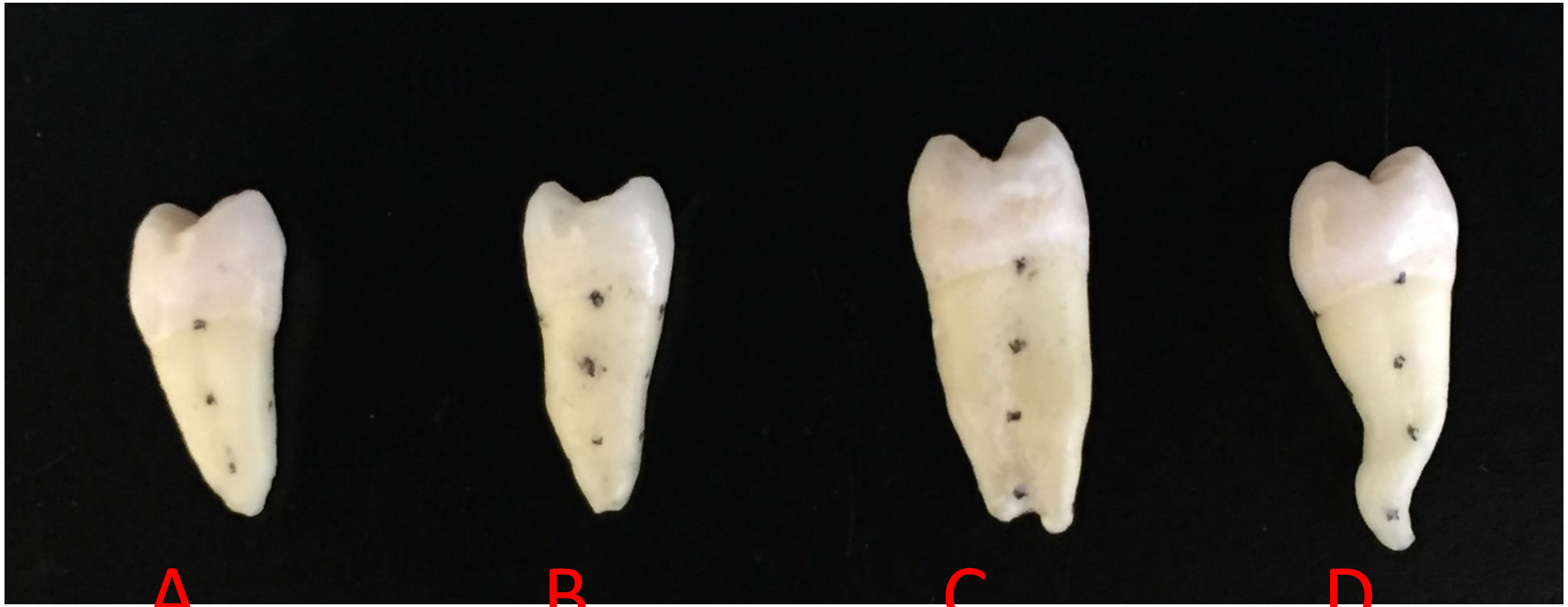
Observed manufacturing inputs and clinical outcomes.

Study	Tunchel, S. et al [20].	Mangano, C. et al [21].	Mangano, F. G. et al [22].	Mangano, F. G. et al [5].	Mangano, F. et al [23].	Mangano, C. et al [24].
Manufacturing	All implants were printed with the same parameters in argon atmosphere using a powerful Yb (ytterbium) fiber laser system with the capacity to build a volume up to 250 × 250 × 215 mm using a wavelength of 1054 nanometers with a continuous power of 200 W at a scanning rate of 7 m/s. The size of the laser spot was 0.1 mm					
Powder, particle size, composition	Ti6Al4 V titanium (90.08%), aluminum (5.67%), and vanadium (4.25%)	Ti6Al4 V 25–45 µm Composition data is not provided				
Macro and micro features employed	25–45 µm *Ra* value of 66.8 µm, *Rq* value of 77.55 µm, and *Rz* value of 358.3 µm	Ra 66.8 ± 6.6 µm, Rq 77.6 ± 11.1 µm, and Rz 358.3 ± 101.9 µm	66.8 ± 6.6 µm, 77.6 ± 11.1 µm, and 358.3 ± 101.9 µm	66.8 (6.6)µm, 77.6 (11.1)µm, and 358.3 (101.9)µm	Ra value of 66.8, Rq value of 77.55, and Rz value of 358.3	Ra value of 66.8, Rq value of 77.55, and Rz value of 358.3 µm
Survival rate[**]	94.5%	98.9%	94.6%	100%	97.4%	99.5%

AAIDF
AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Methodology

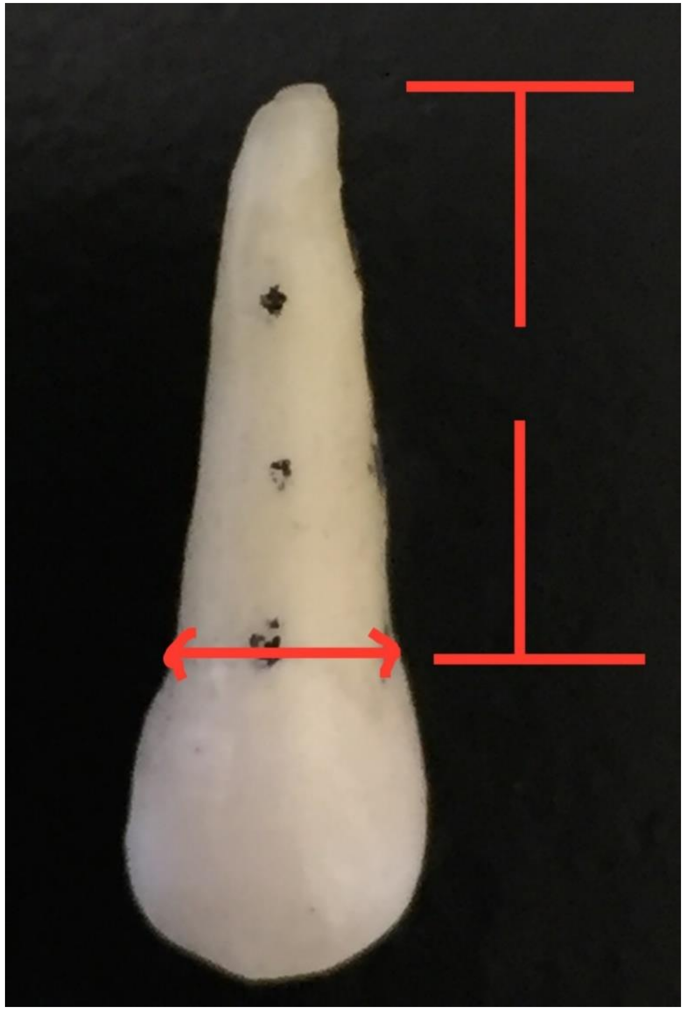
The non-restorable tooth root is scanned pre-extraction using Optical Computed Tomography (OCT). The Digital Imaging and Communication in Medicine (DICOM) files of the OCT is then converted to a 3D imaging file.



A B C D

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Average Measurements



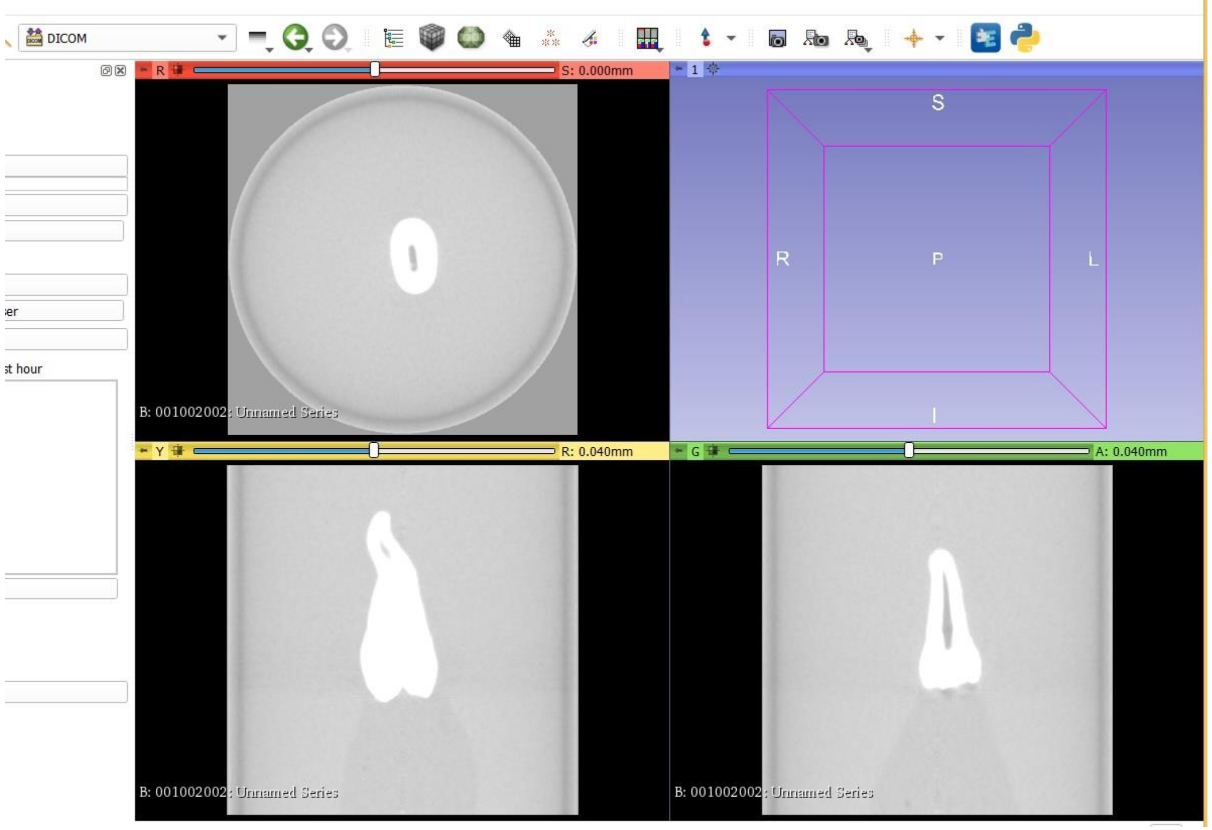
Buccal View

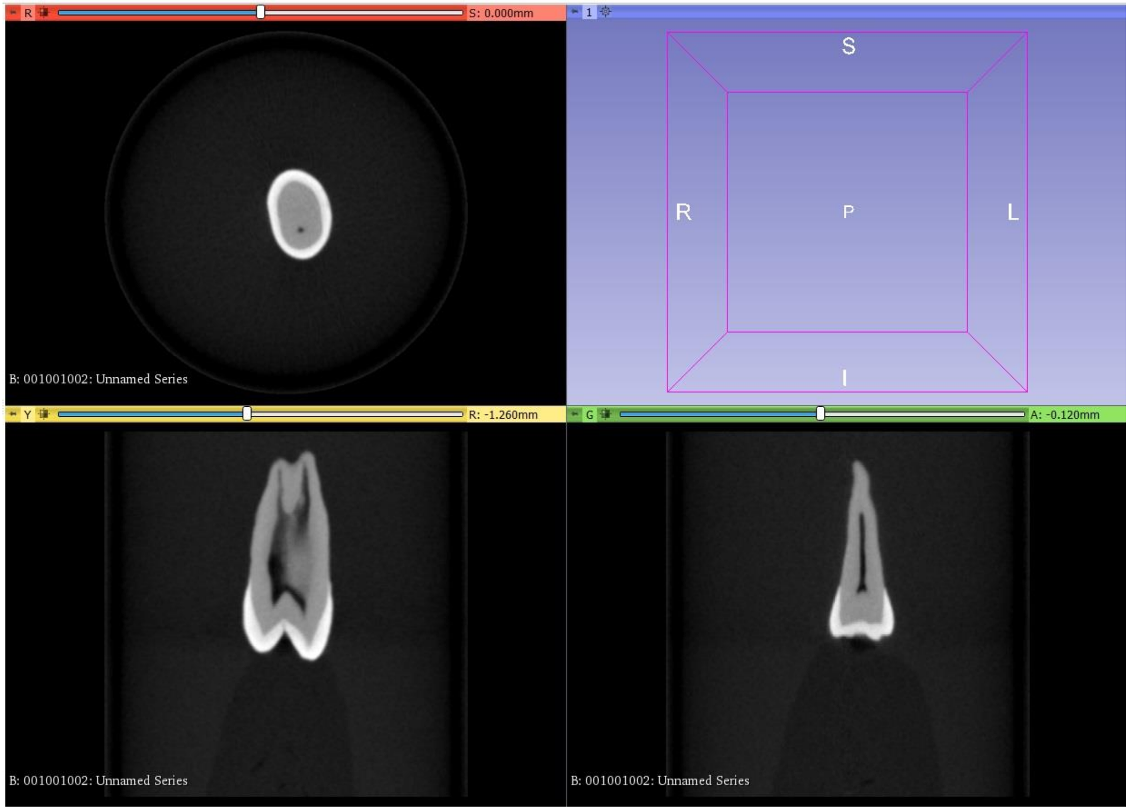
Sample	Tooth D
Tooth length (mm)	18.60
Root length (buccal surface) (mm)	10.14
Mesial-distal width at CEJ (mm)	4.83
Buccal-lingual width at CEJ (mm)	7.17

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Mounting for Scanning

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

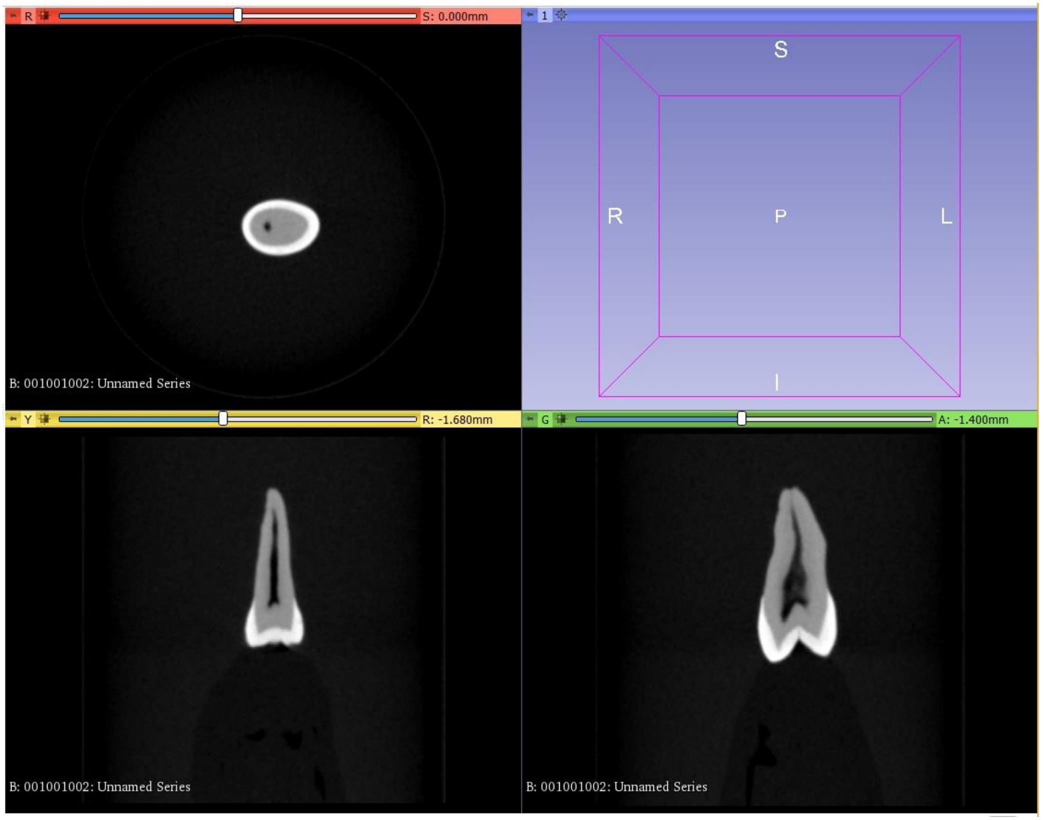


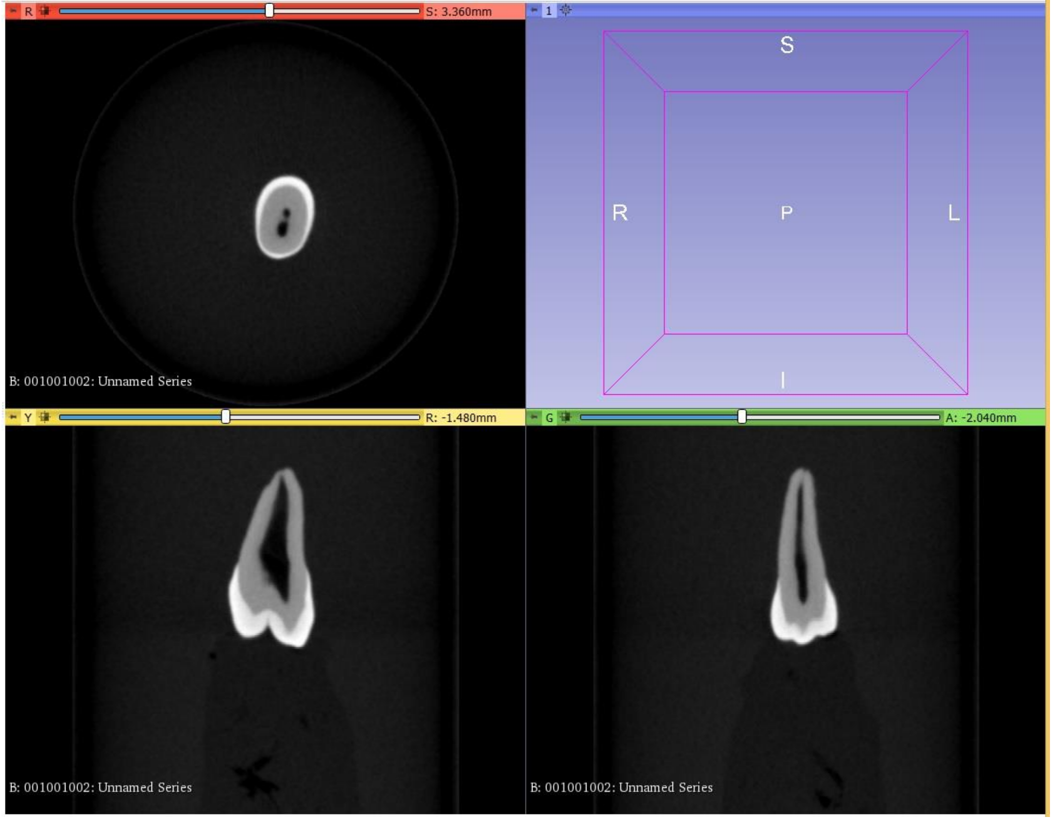


Tooth A

Tooth B

AAIDF
AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION





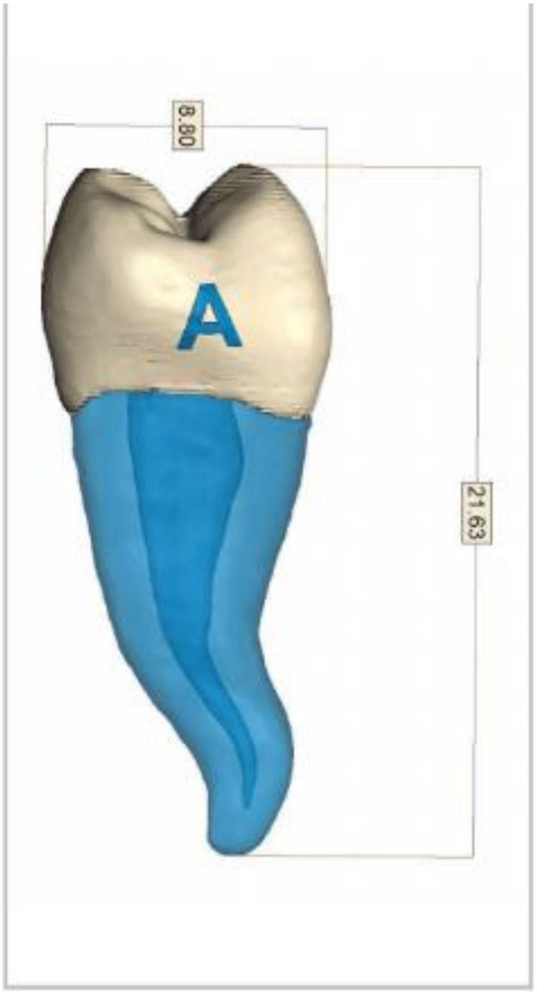
Tooth C

Tooth D

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

3D Printing

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

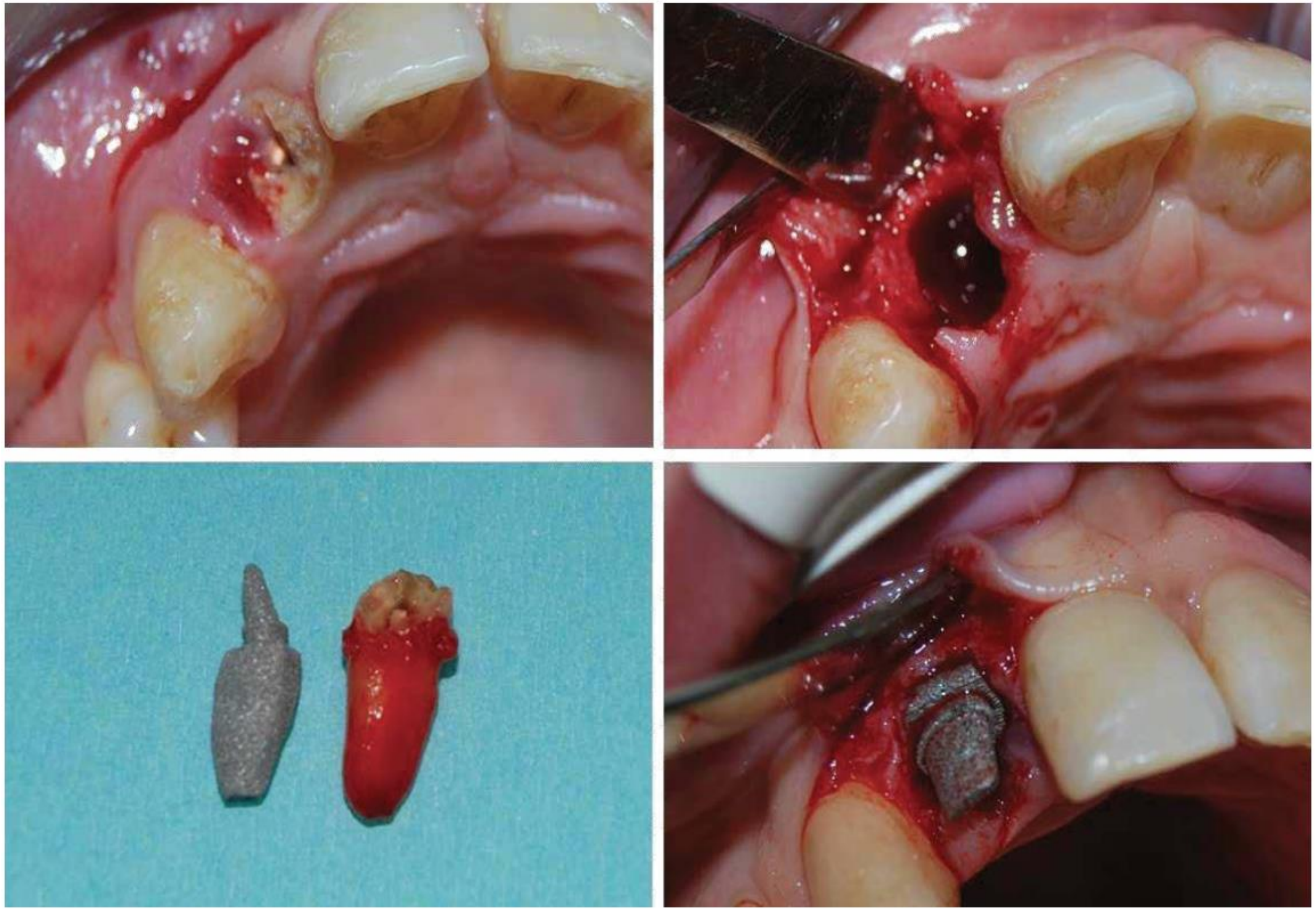


	Extracted (in mm)	Printed (in mm)	Difference in mm	Difference in %
A				
Width	8.80	9.50	0.70	7.95%
Length	21.63	22.23	0.60	2.77%
B				
Width	9.54	10.15	0.61	6.39%
Length	22.83	22.76	-0.07	-0.31%
C				
Width	8.19	9.40	1.21	14.77%
Length	18.45	18.66	0.21	1.14%
D				
Width	9.54	9.22	-0.32	-3.35%
Length	22.83	18.50	-4.33	-18.97%

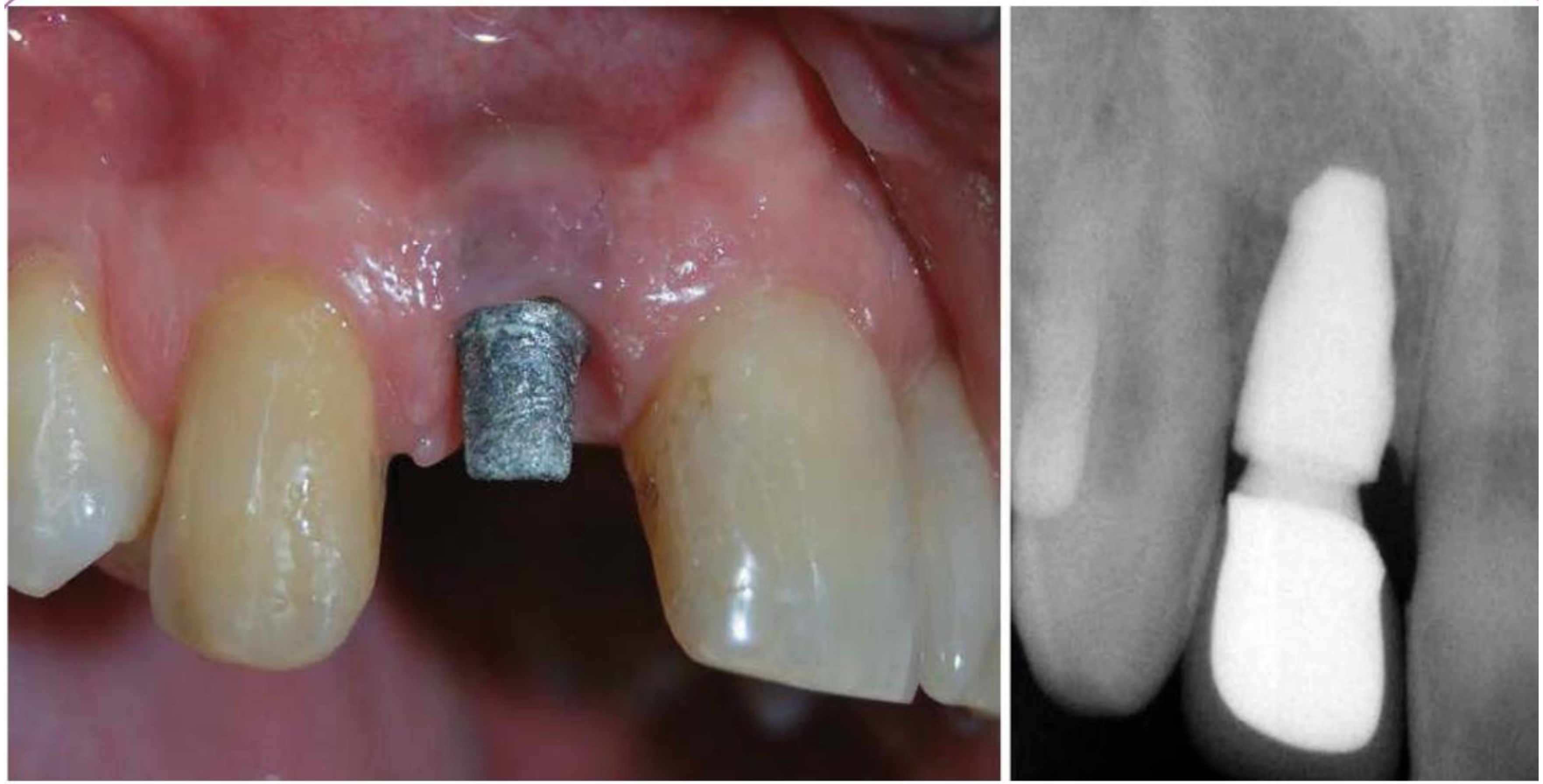
Clinical outcomes

Study	Tunchel, S et al [20]	Mangano, C et al [21]	Mangano, F. G. et al [22]	Mangano, F. G. et al [5]	Mangano, F. et al [23]	Mangano, C et al [24]
Powder, particle size, composition	Ti-6Al-4V 25–45 μm					
Survival rate*	**94.5%**	**98.9%**	**94.6%**	**100%**	**97.4%**	**99.5%**

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION



Figliuzzi M. et al. Periodontics and Prosthodontics v.2 (01), 2016

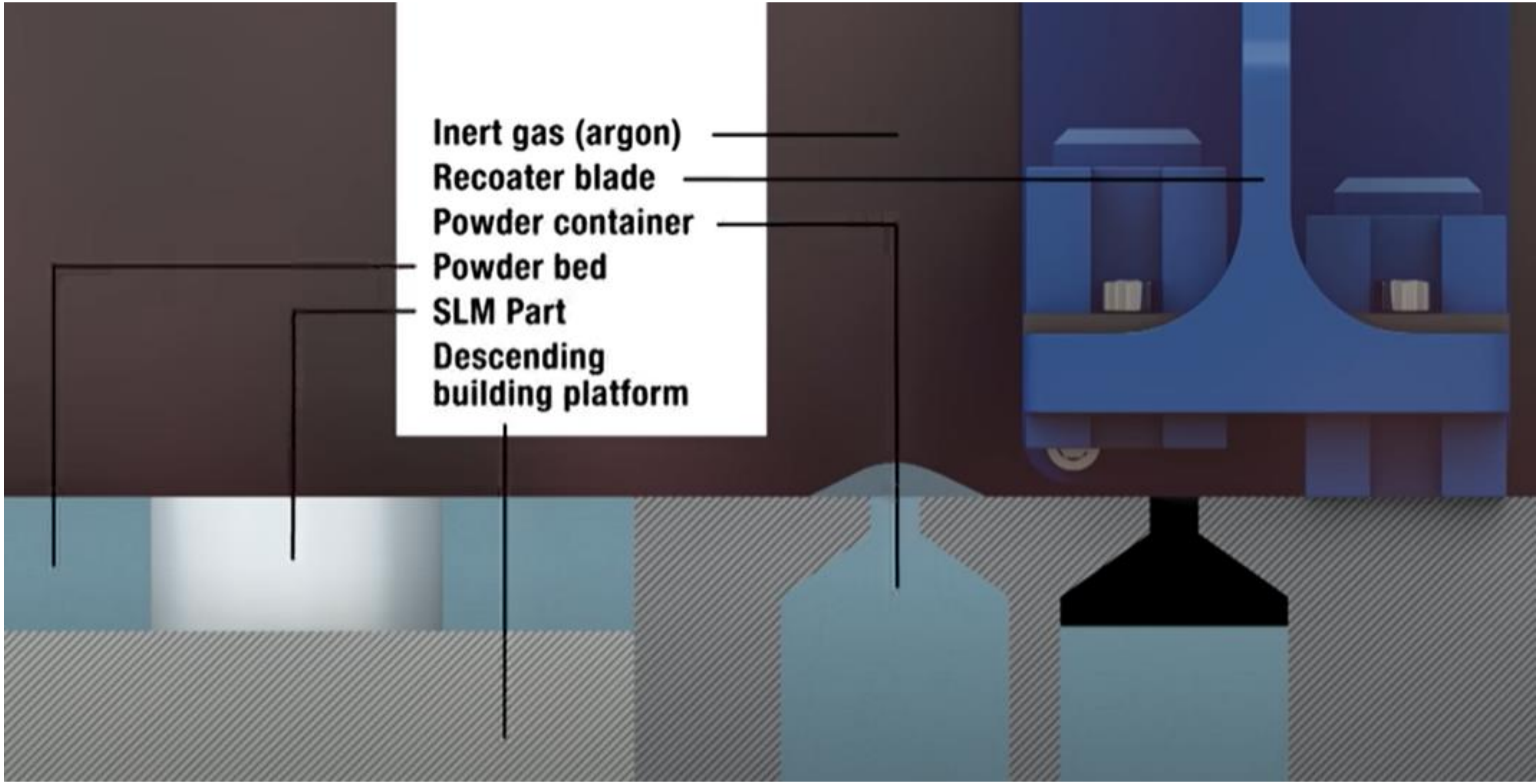


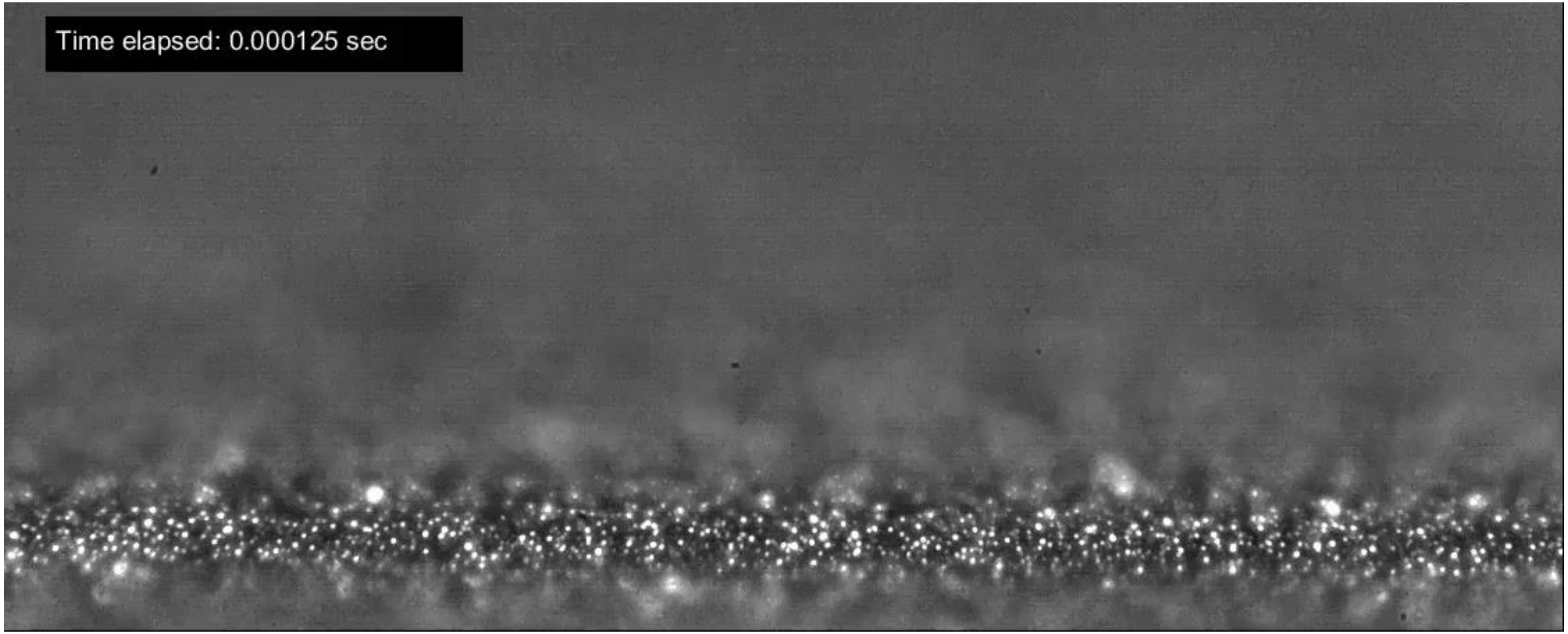
Figliuzzi M. et al. Periodontics and Prosthodontics v.2 (01), 2016

Figliuzzi M. et al. Periodontics and Prosthodontics v.2 (01), 2016

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Process of RAI fabrication




Time elapsed: 0.000125 sec

Key numbers

31%

Material feedstock in EBM processes can affect up to 31% of the cost of built parts

95–98%

Amount of powder approximated to be reusable from the EBM process

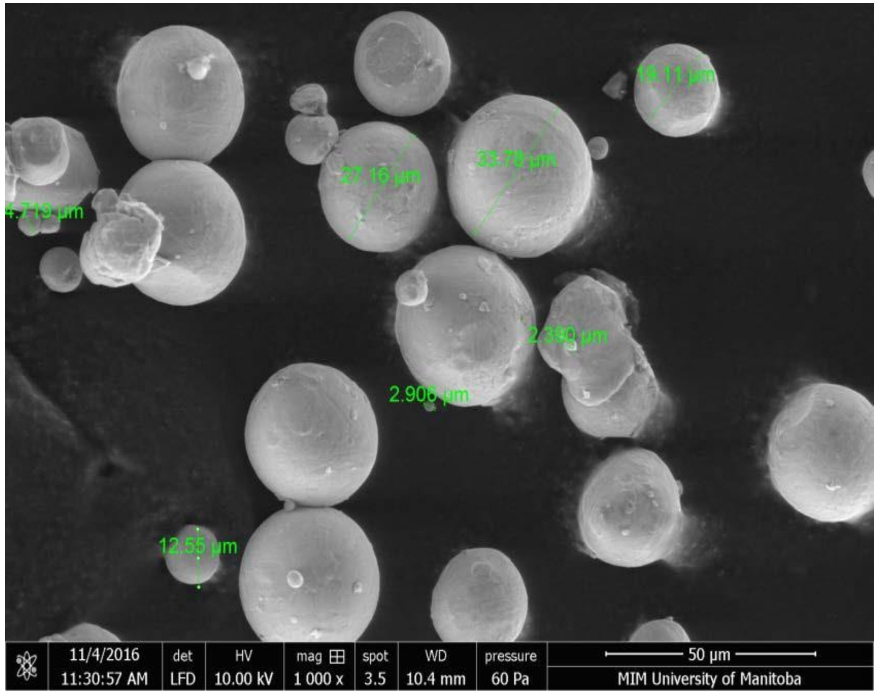
> 21 times

powder can be reused; the O content is 0.18 wt%

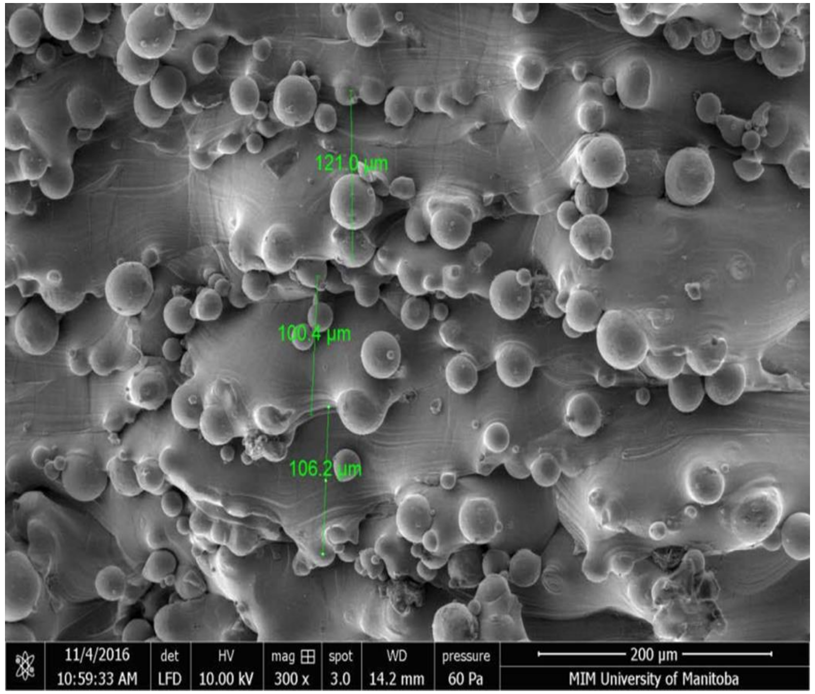
Titanium powder degradation during additive manufacturing is a considerable issue since implant chemical composition may influence osteointegration and, thus, is vital for implant survival. Component percent composition of the implant alloy surface affects the interaction between the implant and the bone at the biological level.

AAIDF
AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Metal prototypes – surface analysis



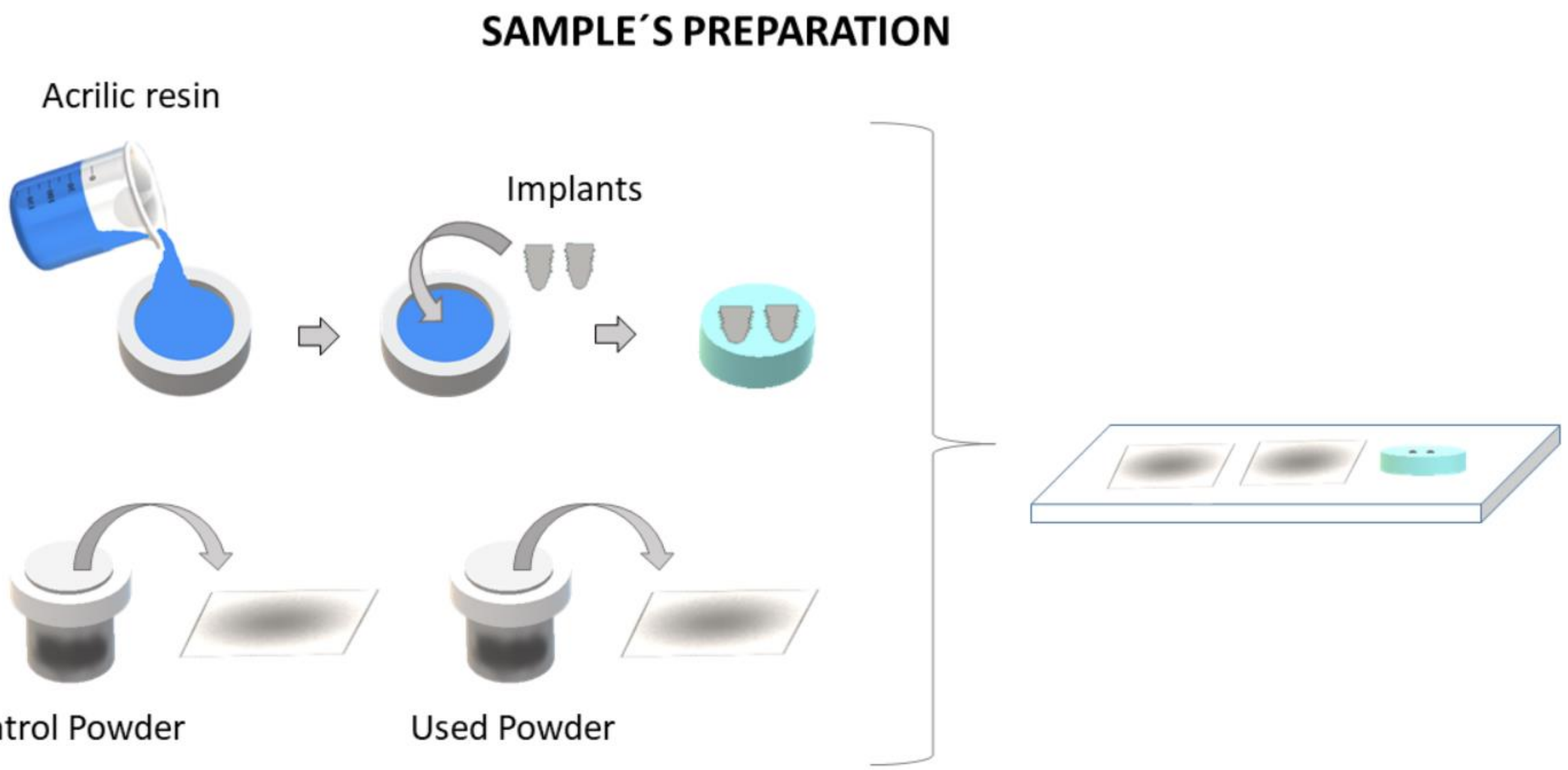
SEM image of the Ti6Al4V alloy powder



SEM images of the surface of the Ti6Al4V implant

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Metal prototypes – surface analysis



Samples Preparation

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Metal prototypes – surface analysis

- X-ray Photoelectron Spectroscopy is used to determine the chemical surface composition of four different Ti-6Al-4V alloy samples.

- Two titanium alloy powders; one from the manufacturer directly and the other is recycled from a previous DMLS process. The other two samples are two implants; one manufactured from new alloy powder and the other is from recycled alloy powder.

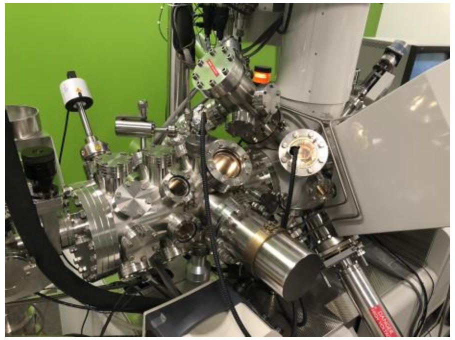
Kratos Axis Ultra X-ray Photoelectron Spectroscopy (Wharfside, Manchester, UK)

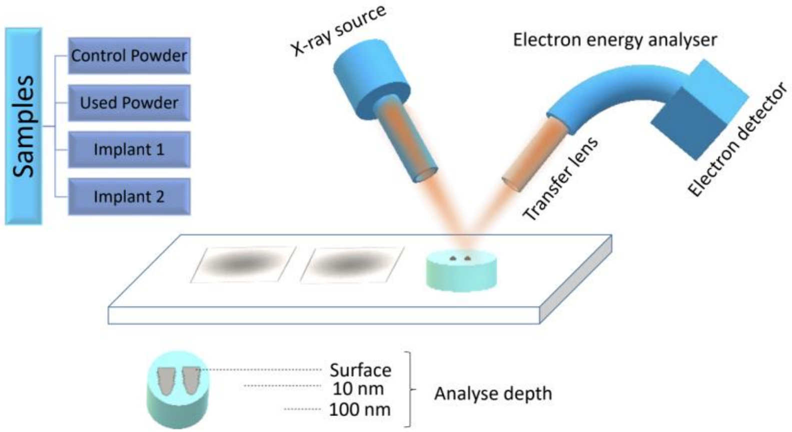
AAIDF
AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Metal prototypes – surface analysis

- X-ray Photoelectron Spectroscopy:
  - X-ray irradiates the sample surface, targeting the core electrons of atoms.
  - Core electrons are close to the atom nucleus and have binding energies characteristic of their element
  - Binding energy is the attraction between the electron and the nucleus
  - Ejected electrons have a kinetic energy
  - XPS instrument measures the kinetic energy of all collected electrons

- Sample preparation
  - Etching with Argon to analyze composition at 10nm and 100nm depth

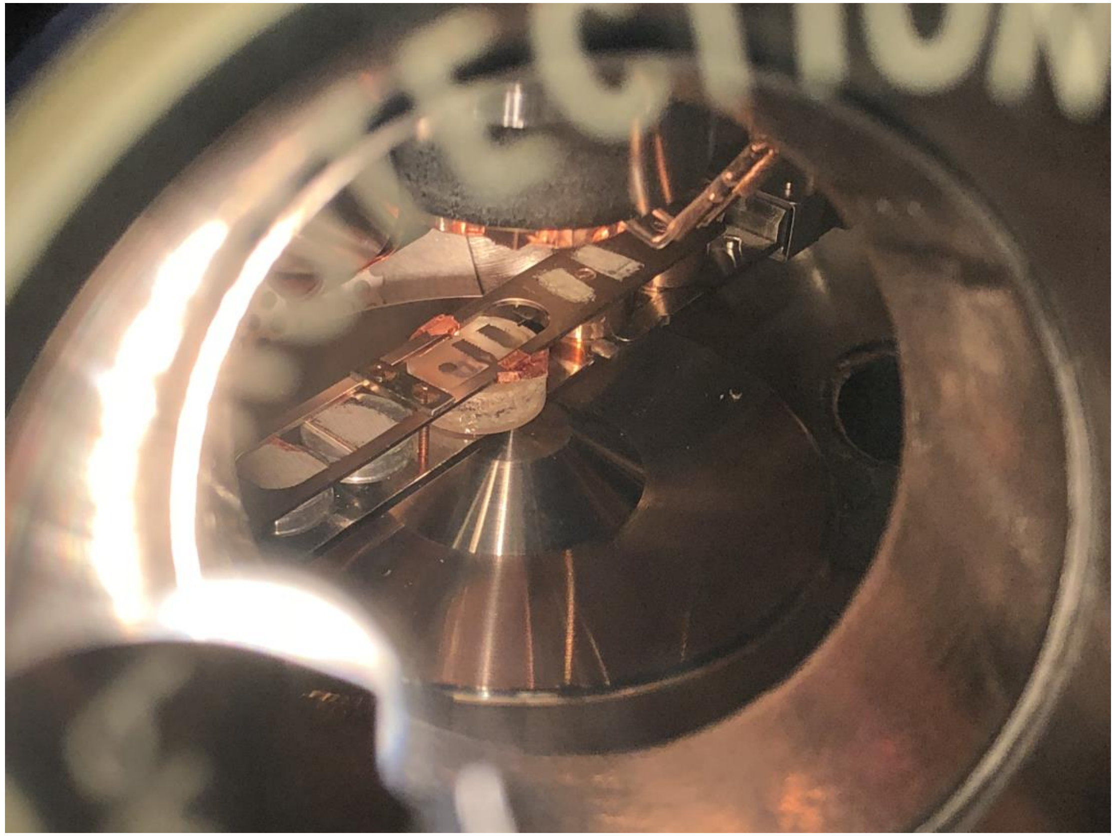




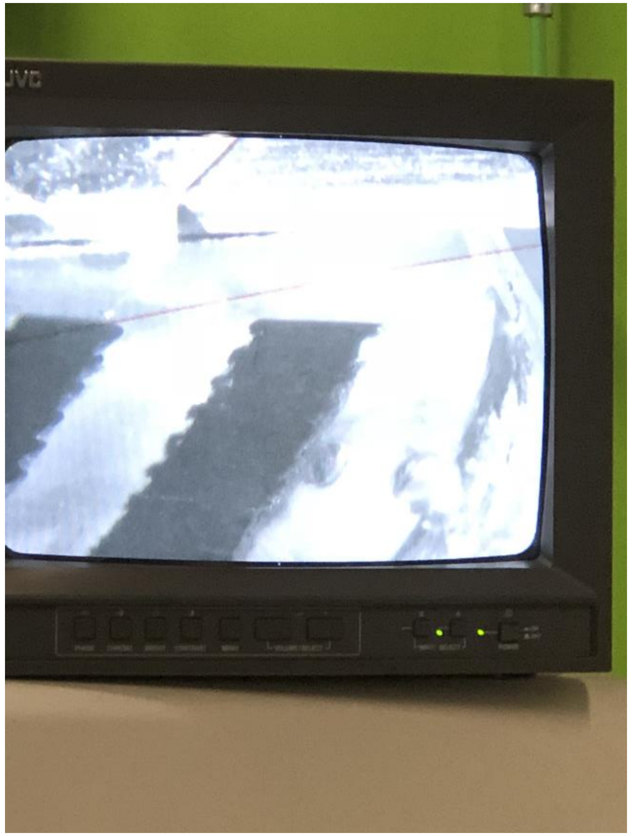
XPS process

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Metal prototypes – surface analysis



Samples inside XPS



XPS monitor

AAIDF
AMERICAN ACADEMY OF
IMPLANT DENTISTRY FOUNDATION

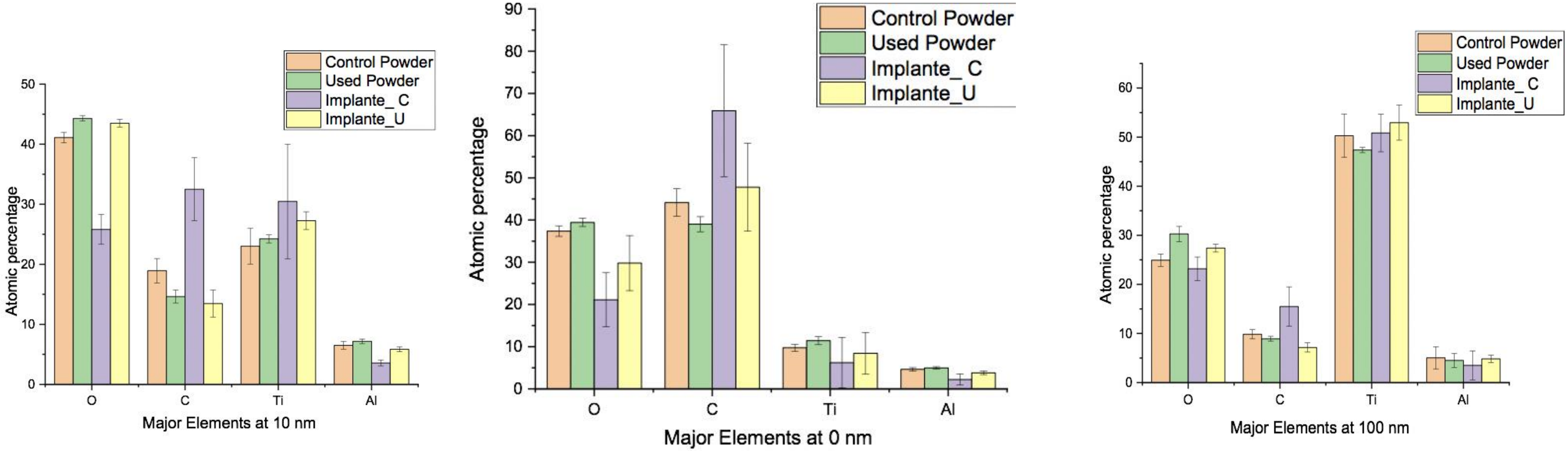
Metal prototypes – surface analysis results

	Control Powder		Used Powder		Implant_C		Implant_U	
Elements	%	SD	%	SD	%	SD	%	SD
O	37.4	1.3	39.4	1.0	21.1	6.4	29.8	6.5
C	44.1	3.3	39.0	1.8	65.9	15.6	47.8	10.4
N	0.8	0.3	0.8	0.3	0.3	0.3	0.7	0.6
Na	0.6	0.4	0.7	0.2	1.1	1.6	0.1	0.1
Ti	9.7	0.8	11.4	1.0	6.2	6.0	8.4	5.0
Si	2.7	0.8	2.7	0.7	1.9	0.7	0.3	0.6
Al	4.6	0.4	5.0	0.3	1.5	1.6	3.8	0.4
Ru	0.0	0.0	1.0	1.8	0.0	0.0	0.0	0.0
Zn	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.1
Ca	0.0	0.0	0.0	0.0	1.4	0.2	1.3	0.1
V	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Cu	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Mg	0.0	0.0	0.0	0.0	0.0	0.0	6.3	1.4
P	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4

Atomic percentage and standard deviation of the tested samples at surface (0 nm).

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Metal prototypes – surface analysis results



Major elements at different depth

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

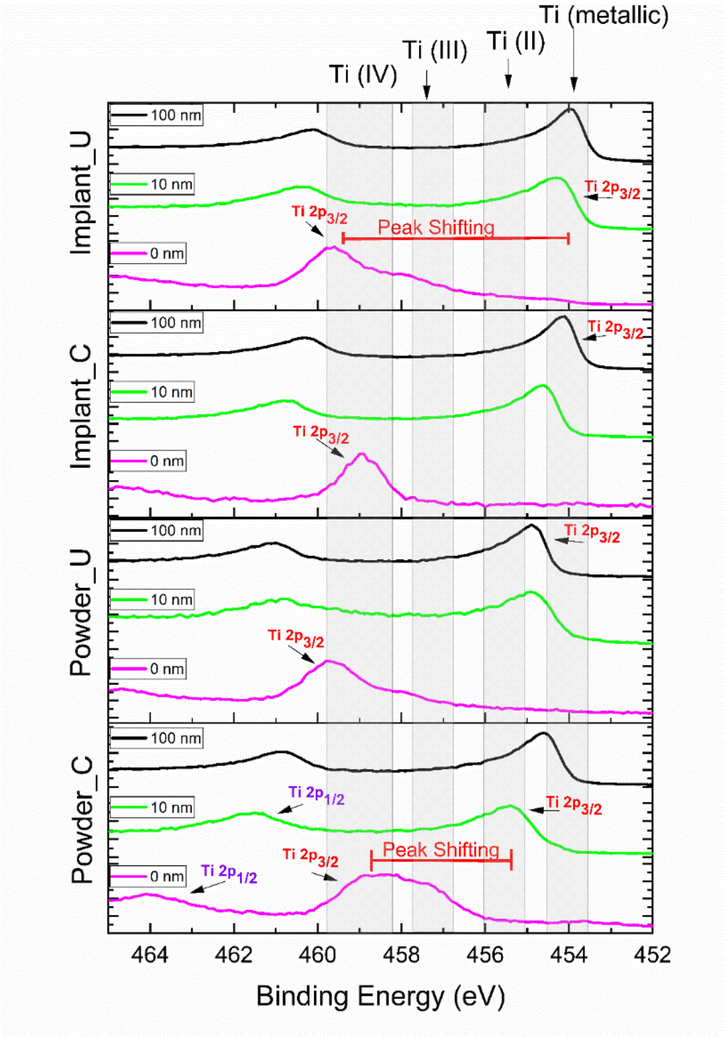
Metal prototypes – surface analysis results

		Powder_C			Powder_U			Implant_C			Implant_U		
Peak position (eV)	Compound	0 nm	10 nm	100 nm	0 nm	10 nm	100 nm	0 nm	10 nm	100 nm	0 nm	10 nm	100 nm
454.0 (±0.4)	Ti (metallic)	-	-	62		8.6	4.5	-	31.2	60.7	5.7	58.9	60.4
455.8 (±0.6)	Ti (II)- TiO	20.9	63.7	25.7		65.6	64.5	-	44.8	27.9	11.9	28.5	26.1
457.4 (±0.5)	Ti (III)- Ti2O3	37.2	25.4	12.3	43.7	25.8	30	5.1	24	11.4	26.8	12.6	13.6
458.8 (±0.4)	Ti (IV)- TiO2	41.9	10.9	-	56.3			94.9	-	-	55.6	-	-

High-Resolution XPS results: Atomic Percentage of the Ti 2p peak contribution (%)

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Metal prototypes – surface analysis results



High-Resolution XPS results for Ti 2p peak, according to the probed depth. Ti 2p is composed of two spin-orbit peaks: Ti $2p_{3/2}$ and Ti $2p_{1/2}$. The Ti $2p_{3/2}$ peak sifting from 0 nm to other experimental conditions is noticeable.

AAIDF AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Conclusions

- Knowing the chemical composition of prothesis used in the oral cavity will help ensure the biosafety of the material and the adequate mechanical properties are maintained
- Re-using powder from the DMLS process makes it economically feasible for manufacturers
- Even with the degradation of powder properties through the DMLS process, the surface oxide layer has a sufficient presence of TiO_2. The above results show that Ti6Al4V powder could be used in up to 20 cycles for RAI manufacturing

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Thank you

- **Nader Shaker** Department of Restorative Dentistry, College of Dentistry, University of Manitoba
- **Ana Carla B.C.J. Fernandes** Department of Oral Biology, College of Dentistry, University of Manitoba
- **Asmaa Haimer** Department of Restorative Dentistry, College of Dentistry, University of Manitoba

- **Rodrigo França, DDS, MSc, PhD**
- Associate Professor, Head of Dental Materials Division
- Director of Dental Biomaterials Research Laboratory
- Core member of the Biomedical Engineering Graduate Program
- Member of Manitoba Institute for Materials
  College of Dentistry, Faculty of Health Sciences
  Department of Restorative Dentistry
- Department of Oral Biology

AMERICAN ACADEMY OF IMPLANT DENTISTRY FOUNDATION

Thank you

Thank you

References

1. Lubisich EB, Hilton TJ, Ferracane J, Northwest P. Cracked teeth: a review of the literature. J Esthet Restor Dent. 2010;22(3):158-67.
2. Garcia-Guerrero C, Parra-Junco C, Quijano-Guauque S, Molano N, Pineda GA, Marin-Zuluaga DJ. Vertical root fractures in endodontically-treated teeth: A retrospective analysis of possible risk factors. J Investig Clin Dent. 2017.
3. Lertchirakarn V, Palamara JE, Messer HH. Patterns of vertical root fracture: factors affecting stress distribution in the root canal. Journal of endodontics. 2003;29(8):523-8.
4. Root form and canal morphology of maxillary first premolars of a Yemeni population https://bmcoralhealth.biomedcentral.com/articles/10.1186/s12903-018-0555-x
5. R. Franca 3D root analogue presentation 2019
6. Dr.John Davies, CARDP Toronto conference 2019
7. Traini, T., et al. (2008). "Direct laser metal sintering as a new approach to fabrication of an isoelastic functionally graded material for manufacture of porous titanium dental implants." Dent Mater 24(11): 1525-1533.
8. Figliuzzi, M., et al. (2012). "A novel root analogue dental implant using CT scan and CAD/CAM: selective laser melting technology." Int J Oral Maxillofac Surg 41(7): 858-862
9. Custom-made, root-analogue direct laser metal forming implant: a case report Francesco Guido Mangano & Bruno Cirotti & Rachel Lilian Sammons & Carlo Mangano
10. Patient specific root-analogue dental implants – additive manufacturing and finite element analysis Johannes Gattinger, Christian N. Bullemer and Ola L. A. Harrysson
11. Custom-made, root-analogue direct laser metal forming implant: a case report Francesco Guido Mangano,
12. Tan, X. P., et al. (2017). "Metallic powder-bed based 3D printing of cellular scaffolds for orthopaedic implants: A state-of-the-art review on manufacturing, topological design, mechanical properties and biocompatibility." Mater Sci Eng C Mater Biol Appl 76: 1328-1343.
13. Starch-Jensen, T., et al., A systematic review and meta-analysis of long-term studies (five or more years) assessing maxillary sinus floor augmentation. Int J Oral Maxillofac Surg, 2018. 47(1): p. 103-116.