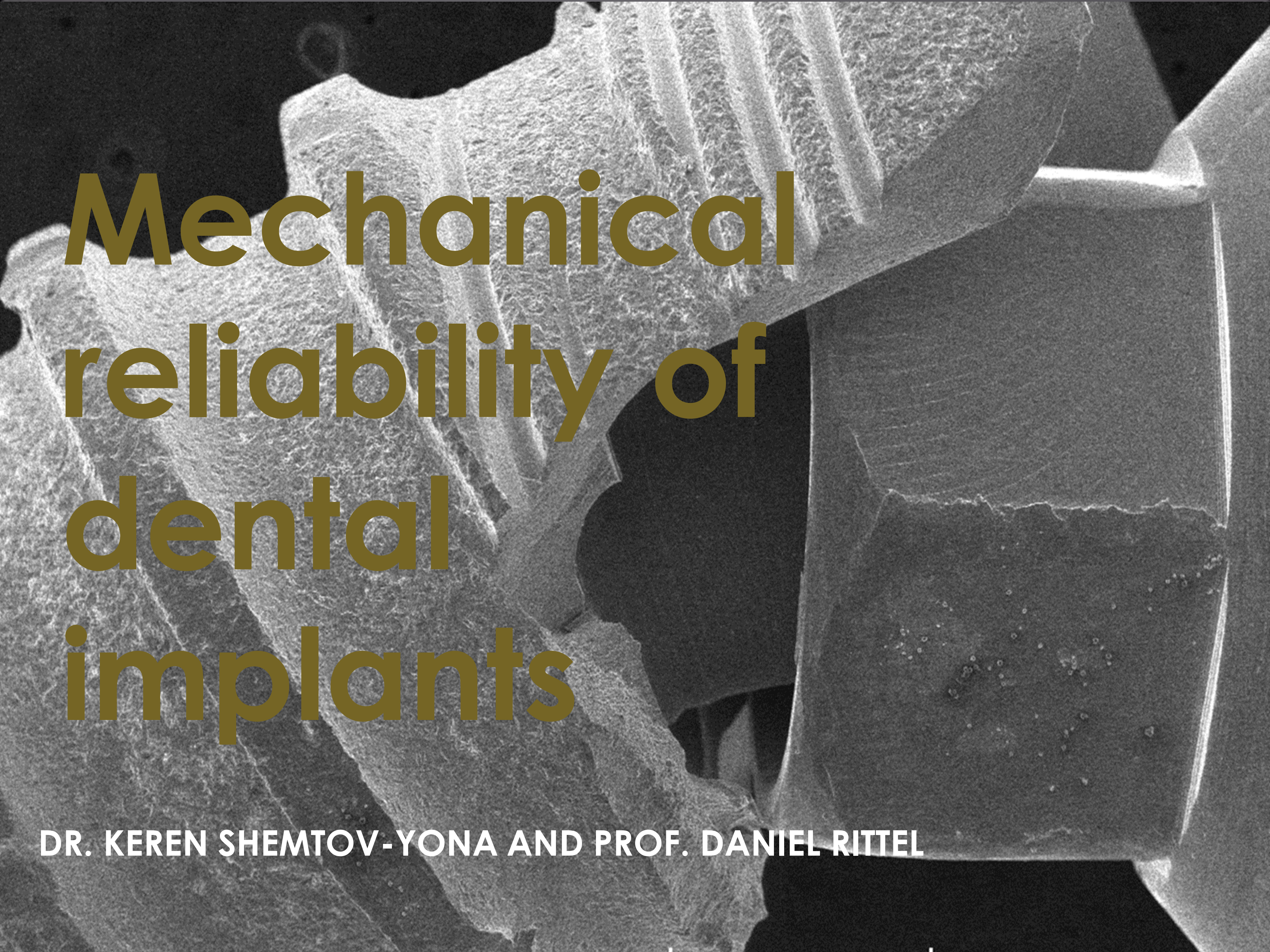
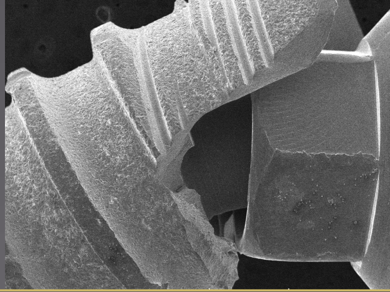


Mechanical reliability of dental implants

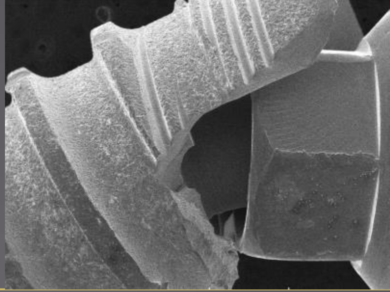
DR. KEREN SHEMTOV-YONA AND PROF. DANIEL RITTEL

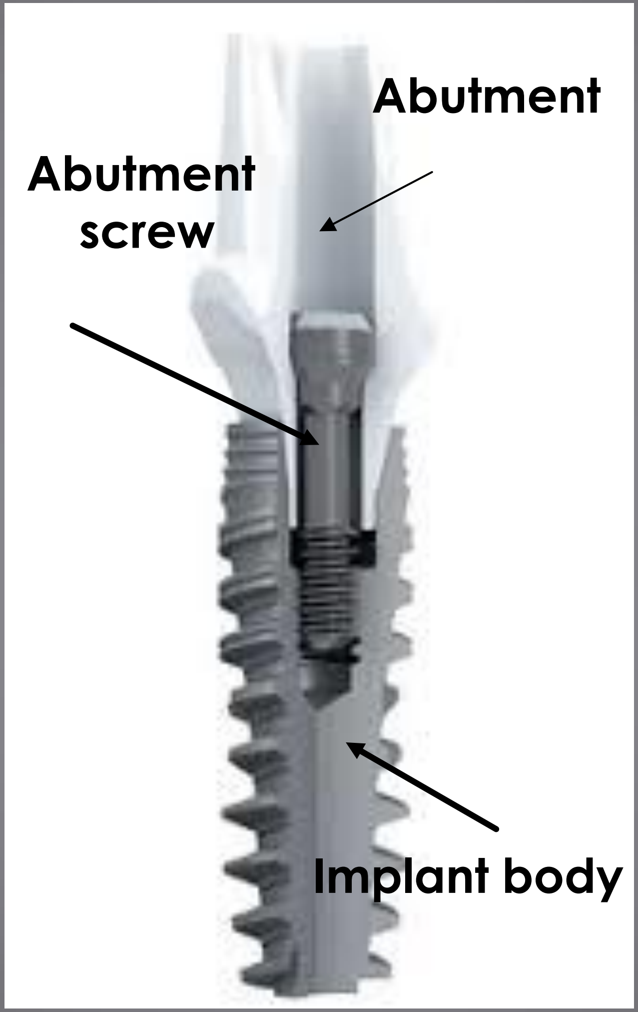
Outline



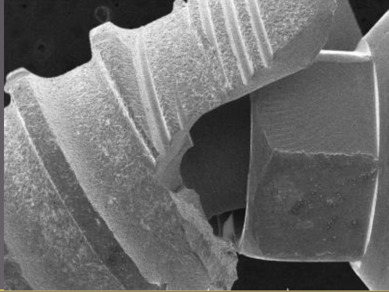
- Dental implants. A brief introduction
- Implant failure and mechanical complications
- Open issues in mechanical reliability
- Failure analysis in implant dentistry
- A new approach to functional performance evaluation
- Conclusions

Components:





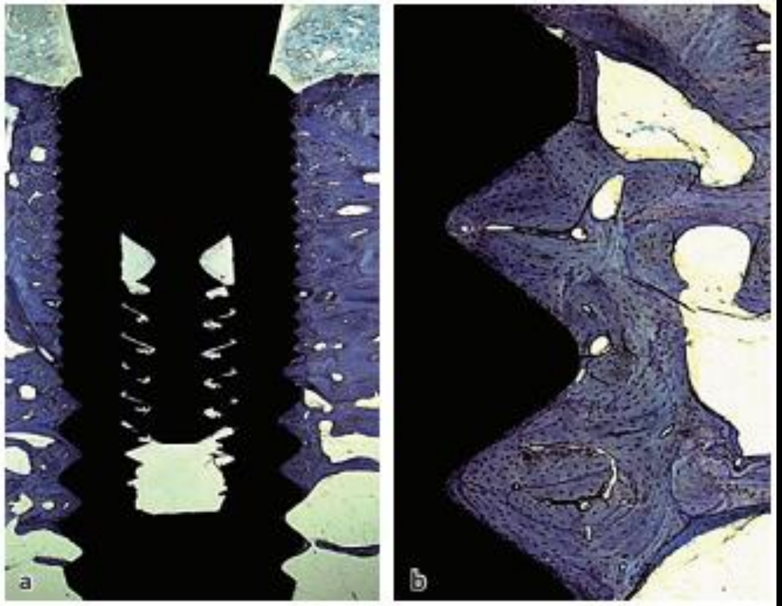
Material



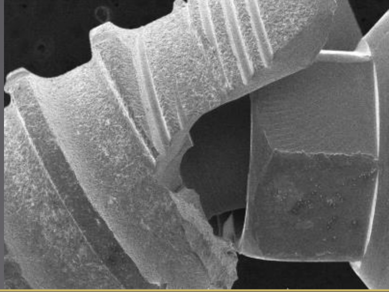
CP-TI: Grades 1-4

Ti-6Al-4V

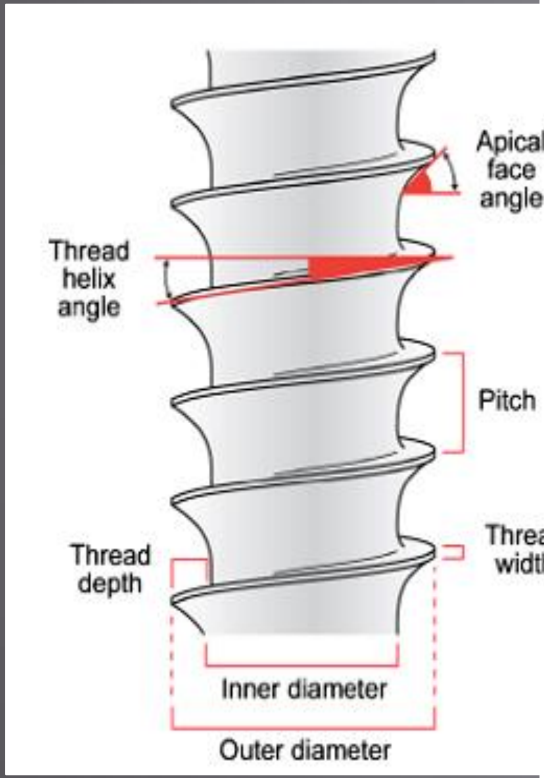
Osseointegration



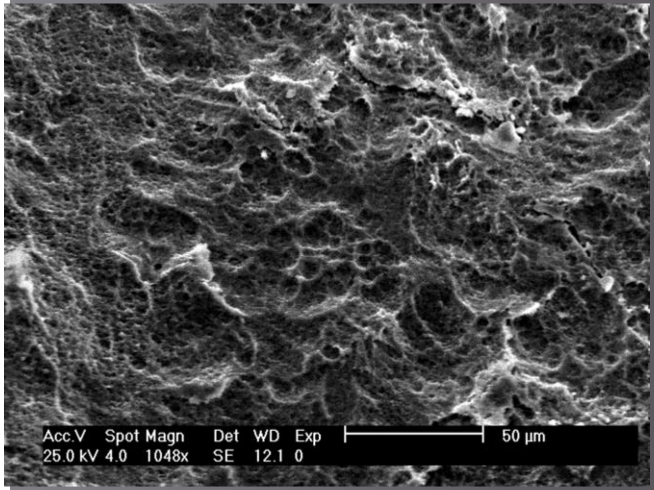
Design



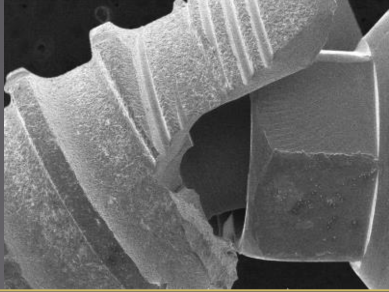
Macro-design



Micro-design- Surface topography

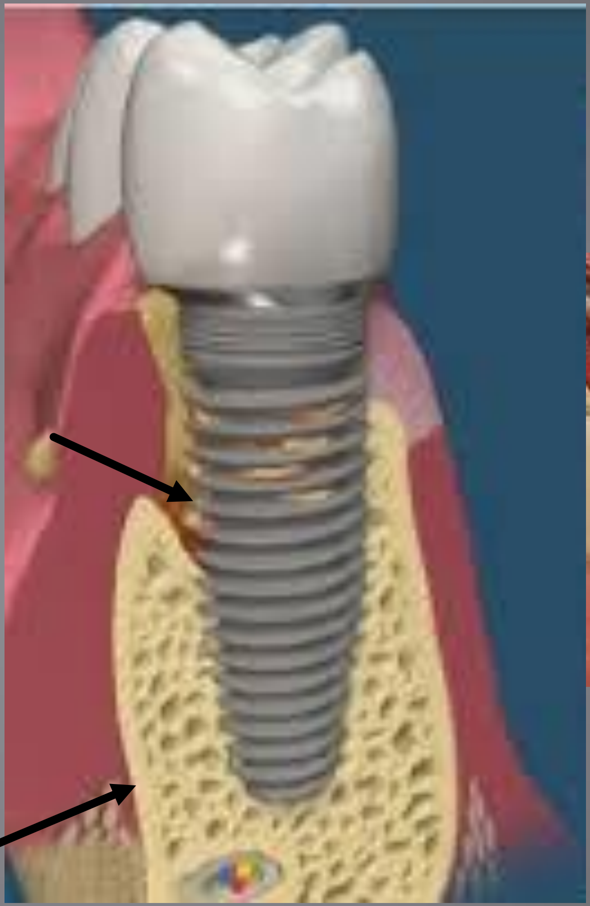


Service conditions



Environment

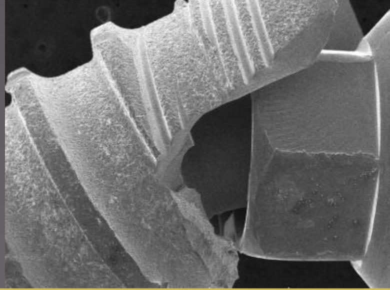
Peri-implant crevicular fluid



Saliva

Bone

Service conditions



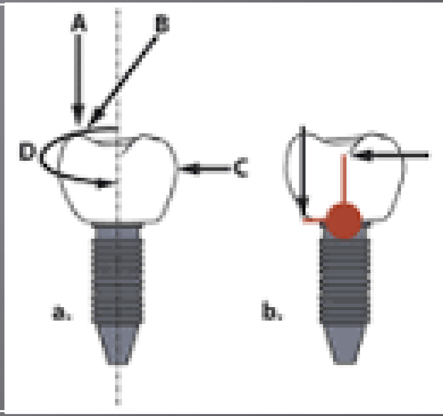
Mastication loads

Type: Cyclic and intermittent

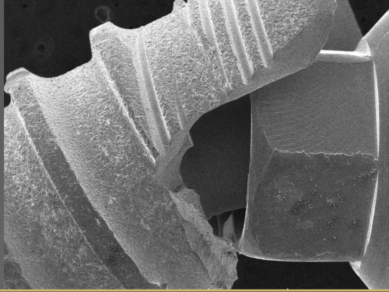
Direction: Depends on tooth position and jaw movement

Magnitude: Tooth position, food type, gender, type of rehabilitation

Axial component: 100-2400N (A)
Lateral component: 20-120N (C)
Duration: 30 min daily
Frequency: 48-112 cycles/minute



Implants failures



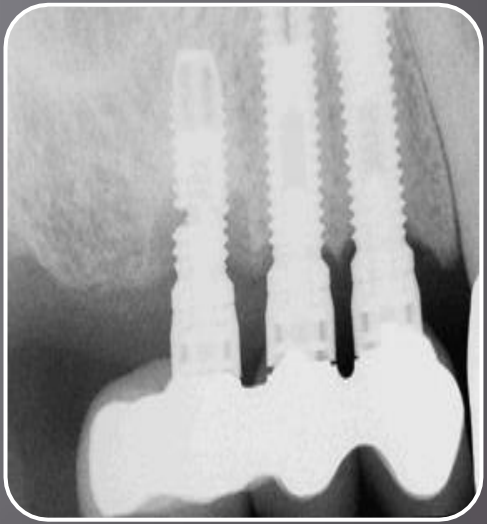
Early failure

Biological Processes

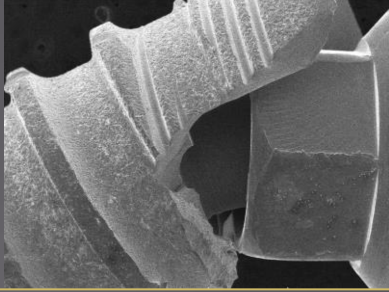
Late failure

Biological Processes

Mechanical complications



Mechanical complications



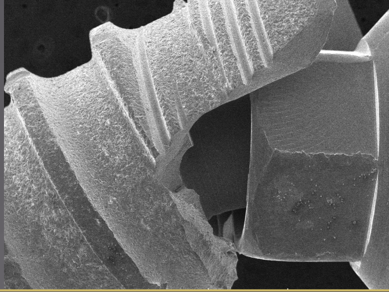
Mechanical complications-16.3%-53.4% 5 year complication rates (Pjetursson et al. 2014)

Screw fracture - 9.3% (5 years) and 18.5% (10 years) complication rates (Papaspyridakos et al. 2012)

Implant fracture - 4% 5 year complication rate (Pjetursson et al. 2014)

Service time makes things worse

Mechanical reliability
Open Issues



Detailed Failure Analysis

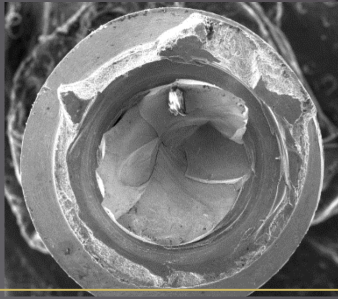
I. Identification of failure mechanism(s)

II. Identification of cause(s) of failure
- Design considerations
- Surface considerations

III. Data from the clinic

Evaluation of functional performance

Failure analysis in implant dentistry



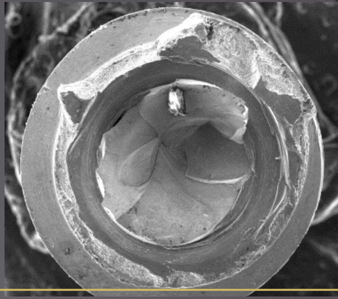
Failure definition :

"The inability of a component, machine or process to function as expected"

- Problems in collection of implants and their components
- Problems in fracture surface preservation
- Small number of samples
- CP-Ti vs. Ti-6Al-4V

Is it **fatigue / corrosion fatigue**?
What causes crack **initiation**?
What causes crack **propagation**?
Does **oral environment** have an effect?

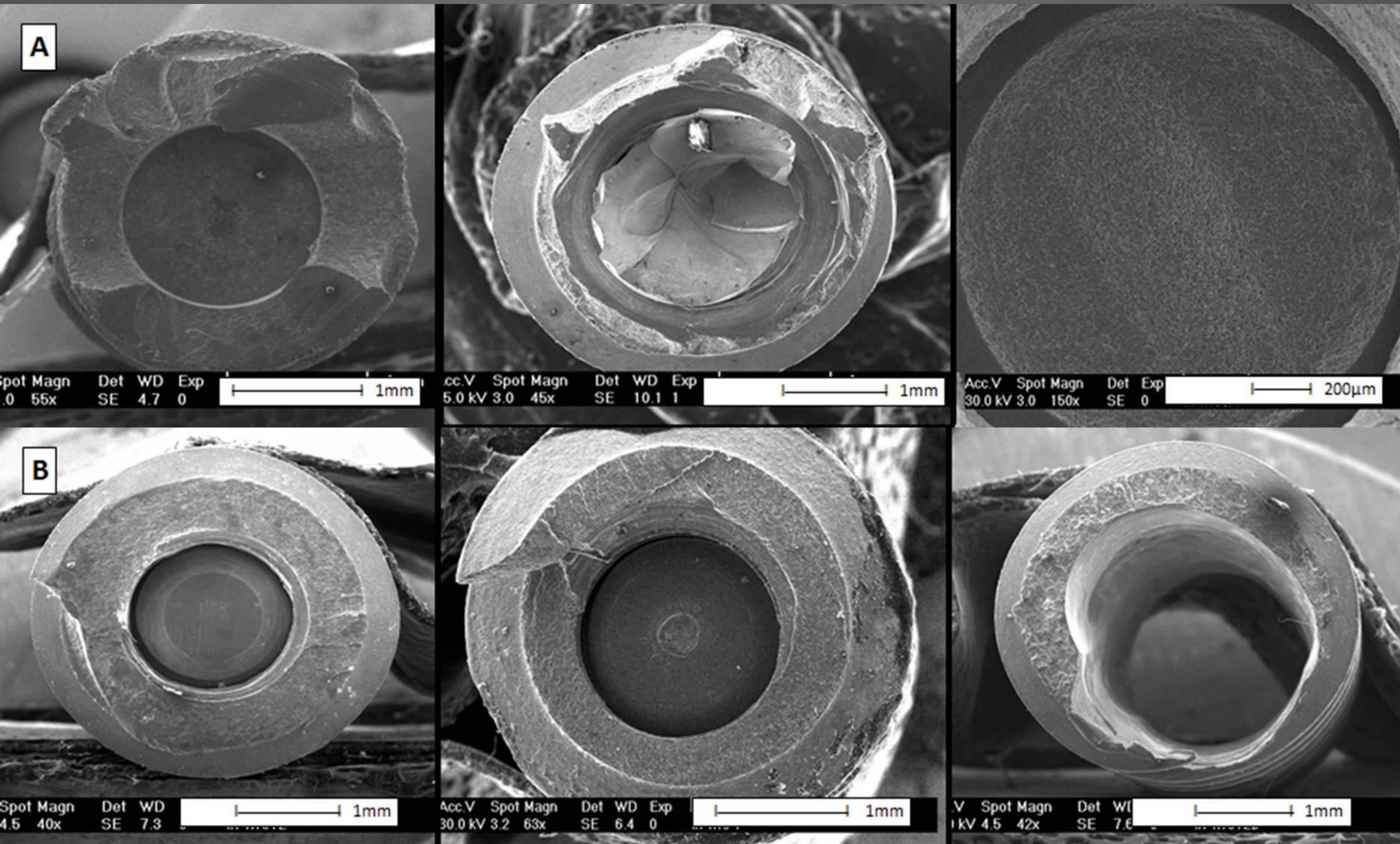
I. Identification of failure mechanisms in retrieved fractured dental implants



- A total number of 10 CP-Ti and 8 Ti-6Al-4V retrieved dental implants were collected
- A detailed failure analysis was conducted (SEM-EDX).
- Examplar testing was performed

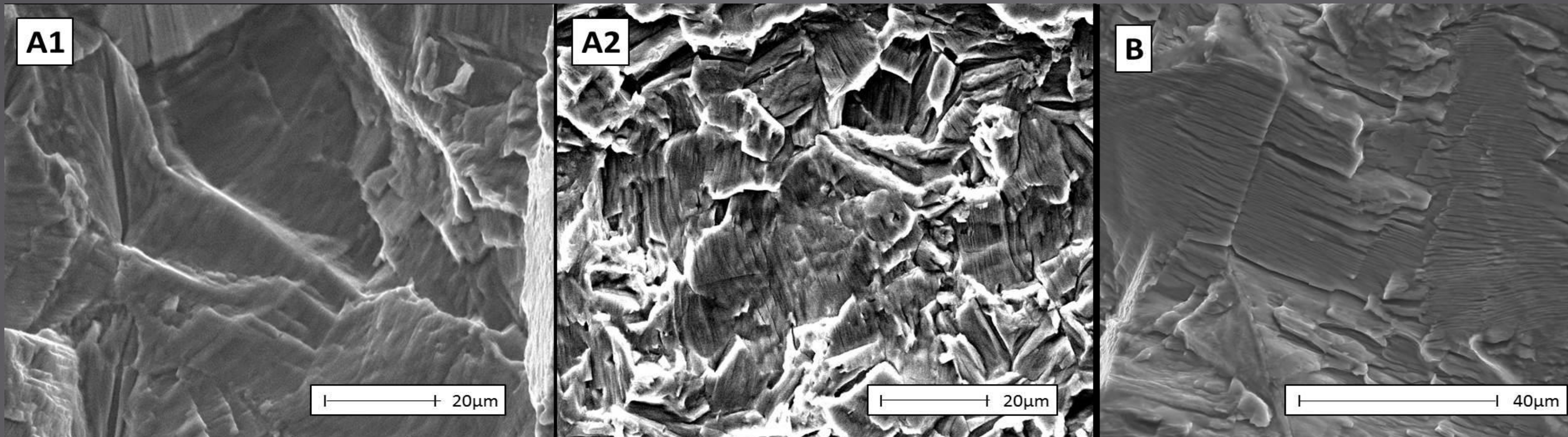
Shemtov-Yona, K. and Rittel, D. (2014) Engineering Failure Analysis 38: 58-65.

Fracture surfaces

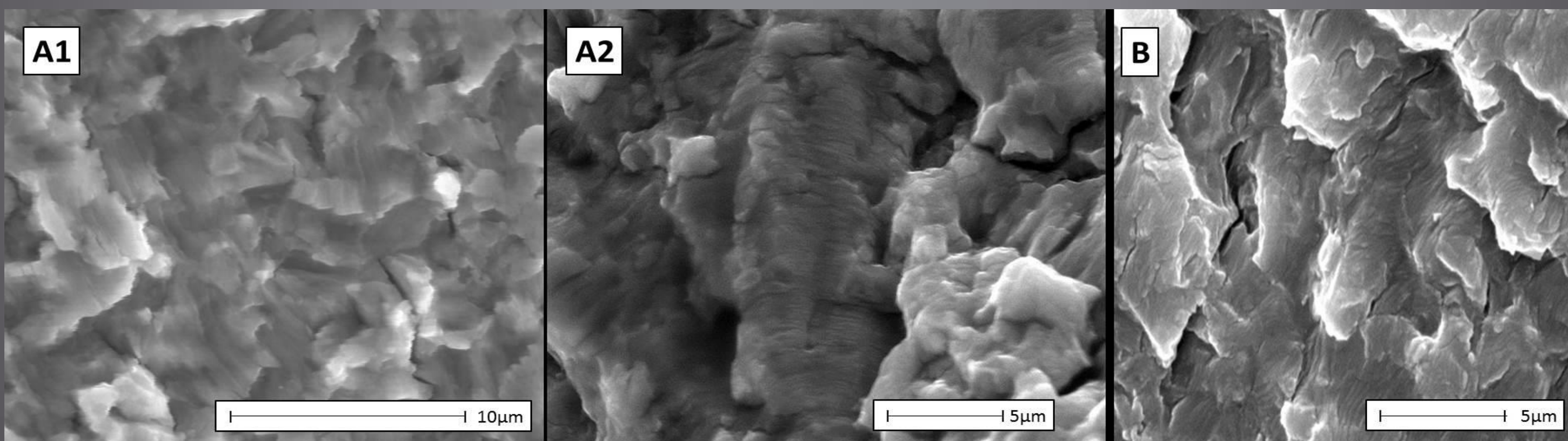


A. Ti-6Al-4V retrieved fractured implants B. CP-Ti retrieved fractured implants

CP-Ti

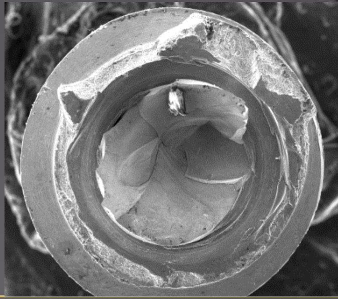


Ti-6Al-4V



Fatigue striations in CP-Ti and Ti-6Al-4V dental implants. A1 and A2 from retrieved implants. B. dental implants fractured in lab conditions

LESSON 1: Identification of failure mechanism



- Large scale study that identified **metal fatigue** as the main failure mechanism.

- First to show and identify failure mechanisms in **Ti-6Al-4V** implants.

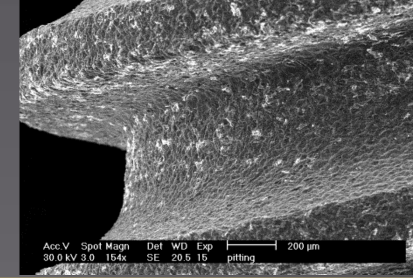
- Fracture occurs at relatively low cyclic load levels, matching those generated during mastication.

- Identification of the **causes** for fatigue crack development in dental implants **still missing**.

Shemtov-Yona, K. and Rittel, D. (2014) Engineering Failure Analysis 38: 58-65.

II. Identification of the cause(s) of failure

Design considerations



Thread design
Thread shape
Pitch
Thread helix angle

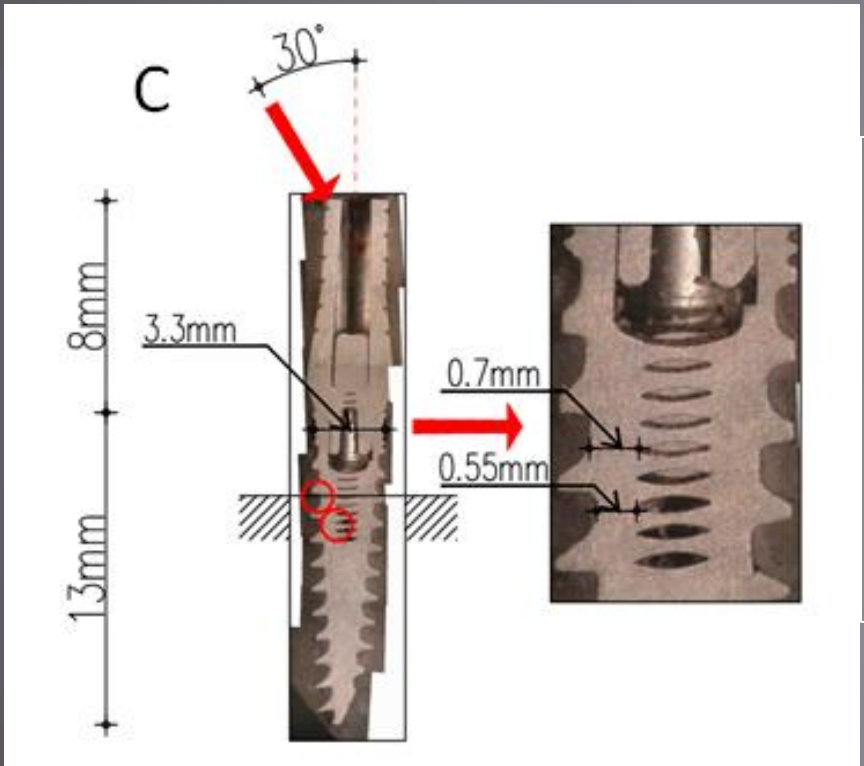
Implant dimensions
Implant diameter
Implant length
Platform switching

Joint design
External vs. internal
Type of internal hex

Metallurgical consideration
Titanium Alloy vs. CP
Metal processing

Example

- **Stress concentration** might be generated along the implant geometry due to faulty design parameters

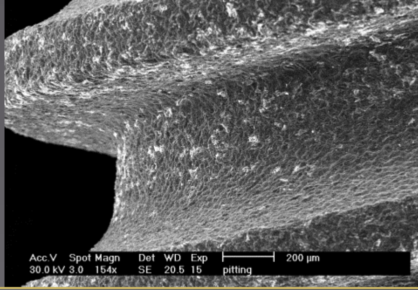


The combination of **sharp notches** (thread) and **narrow metal cross-section** affects negatively the implants fatigue performance

Shemtov-Yona K, Rittel D, Machtei EE, Levin L.(2014b) Effect of dental implant diameter on fatigue performance. Part II: failure analysis. *Clin Implant Dent Relat Res.* 16:178-84

II. Identification of cause of failure

Surface considerations



- **Surface treatments in implant dentistry:**

  Machining

  Plasma spray

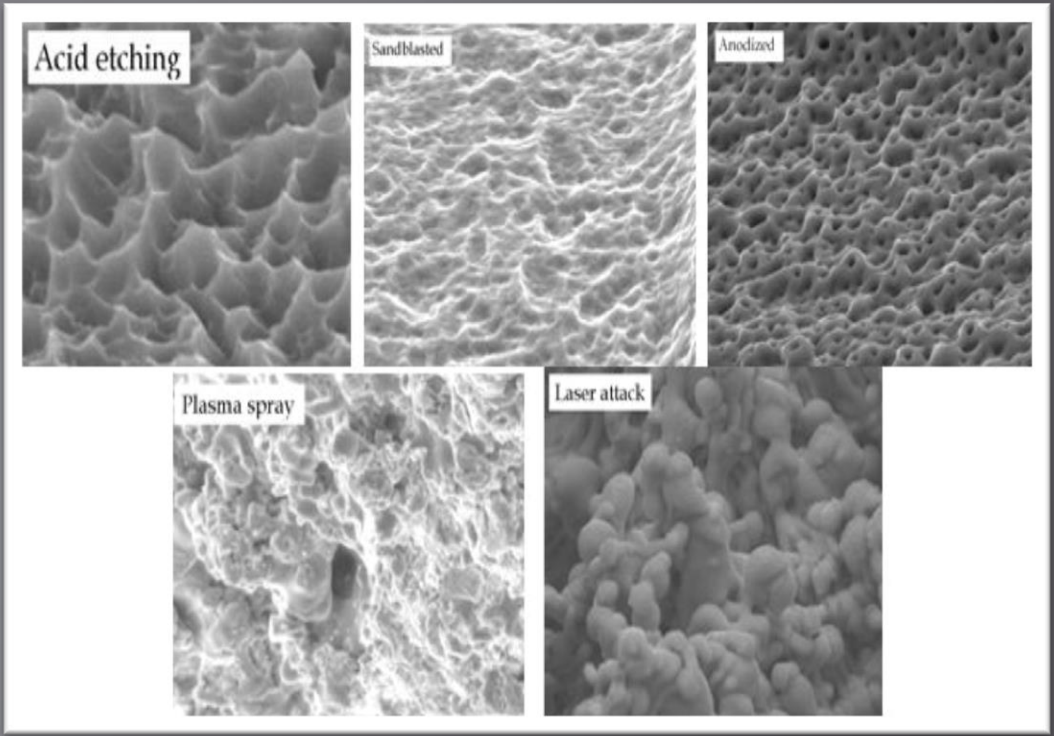
  Laser peening (LST),

  Acid etching

  Grit blasting

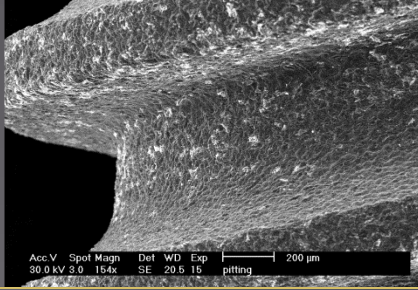
  Anodizing

  Biomimetic coating.



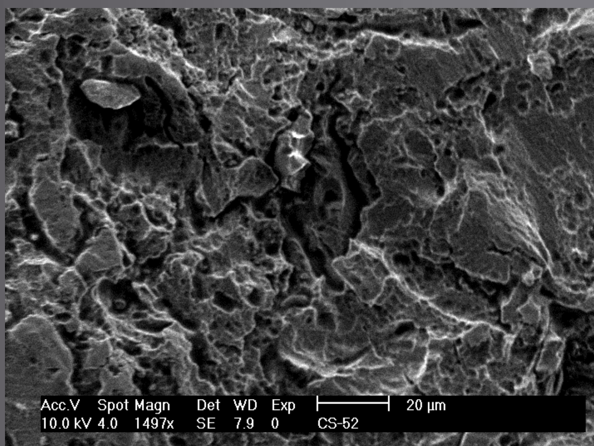
- **Proprietary information**

Elias, C.N. (2011) factors affecting the success of dental implants . Cp. 14 in: Implant dentistry-a rapidly evolving practice

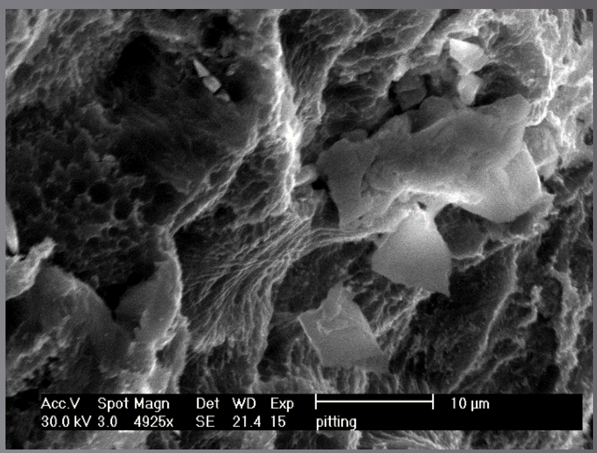


Stress concentrations created due to:

- surface irregularities



surface cleanliness



Baleani et al. (2000)
Multigner et al. (2009)
Aylon et al. (2014)
Gil et al. (2014)
Leinenbach and Eifler (2006)

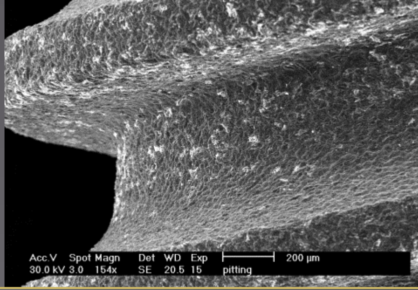
→ Effect of GB on fatigue behavior of CP-Ti And Ti-6Al-4V

→

− Sharp defects
− Embedded particles
+ Compressive Residual stress layer

II. Identification of cause of failure

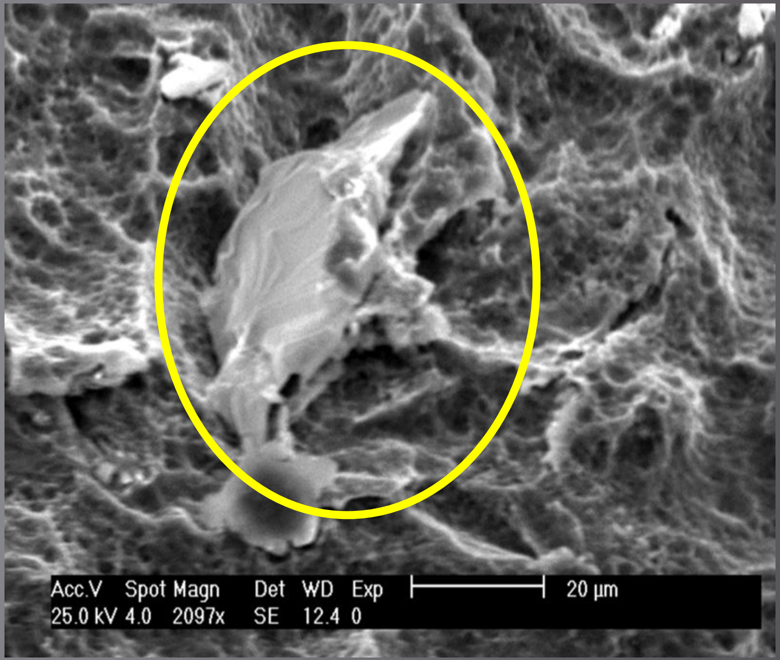
Surface considerations



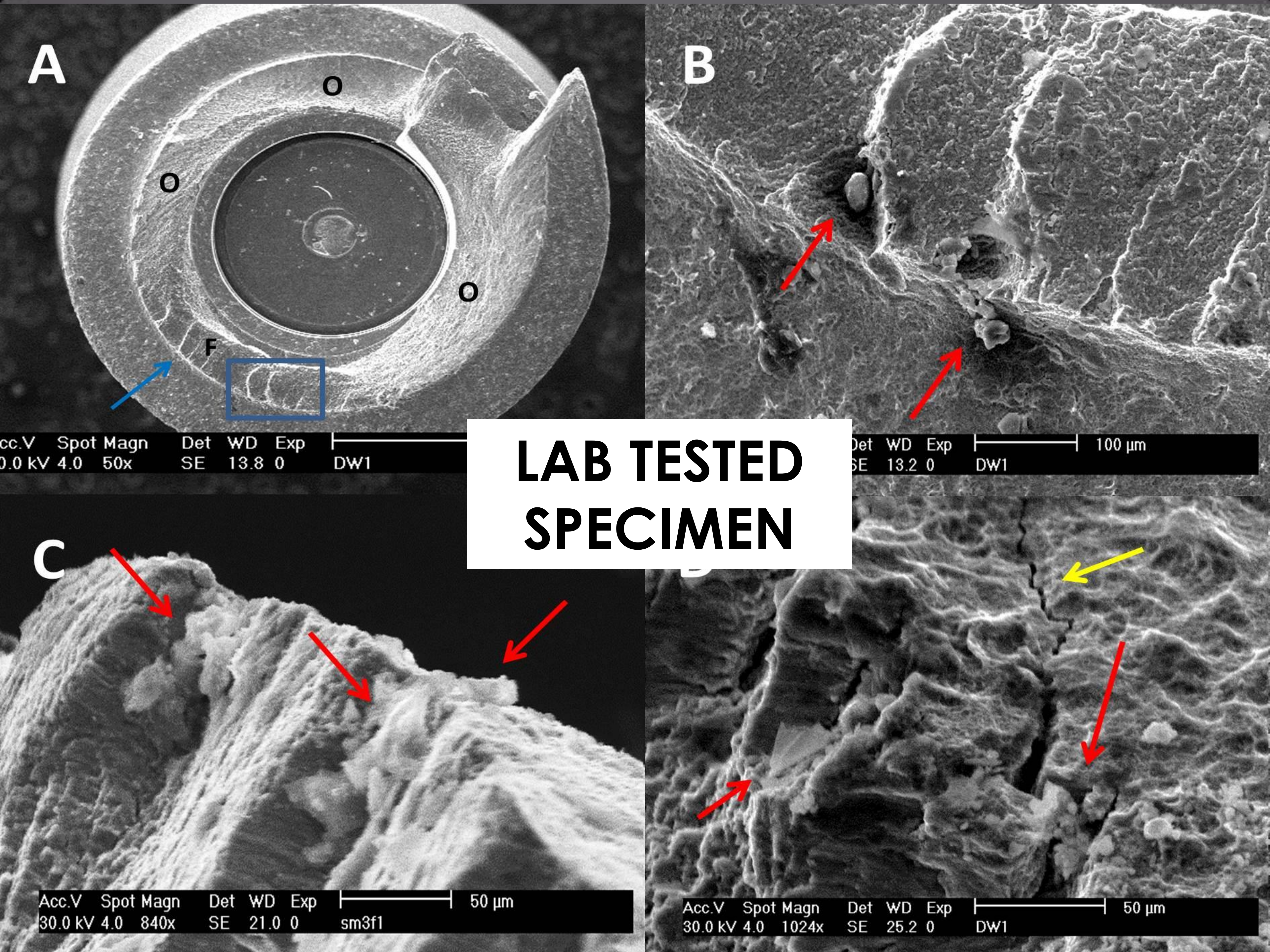
- The influence of GB surface treatment on commercial and retrieved dental implants was studied by:
- Limited fatigue testing,

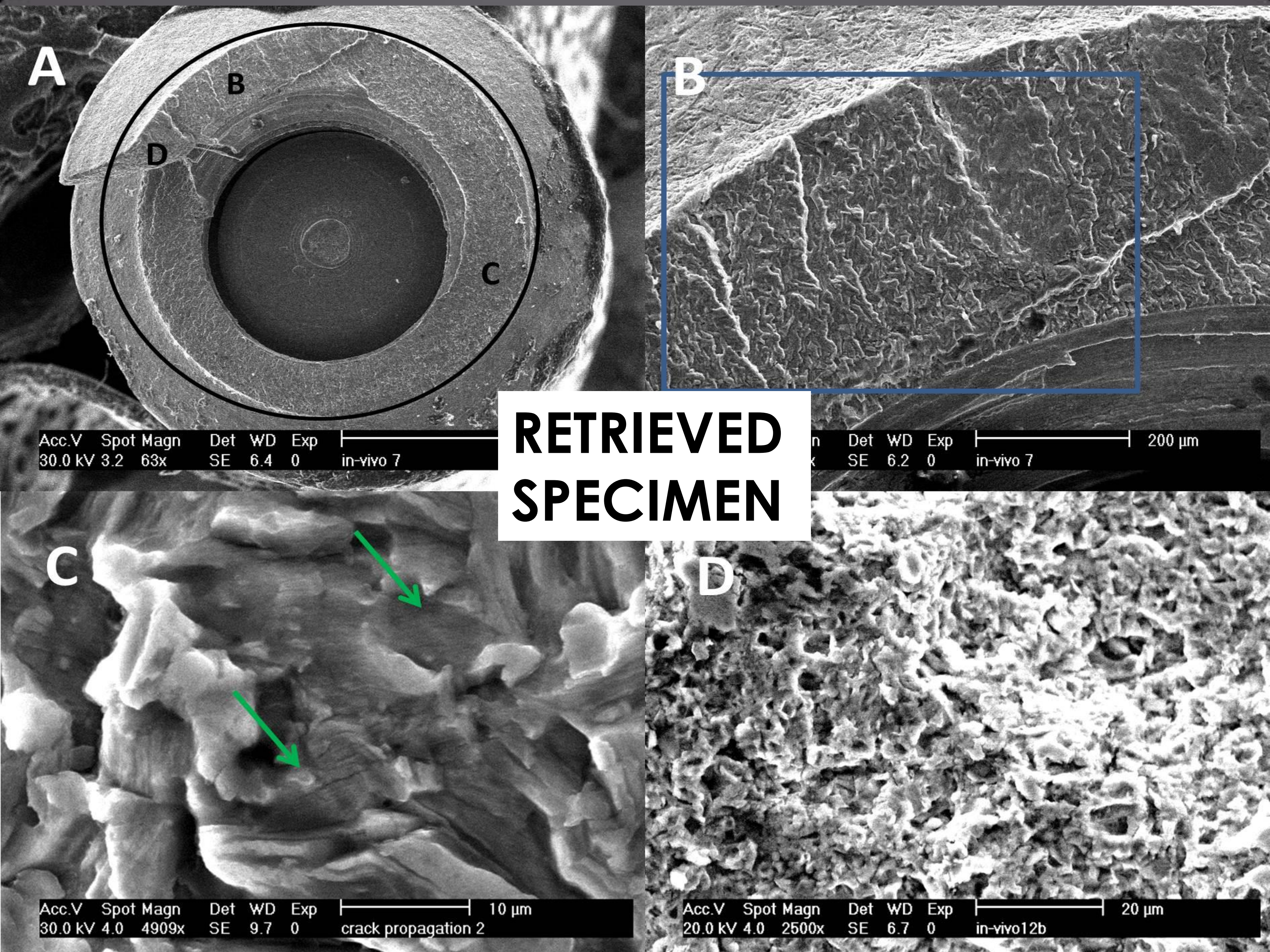
  Failure analysis

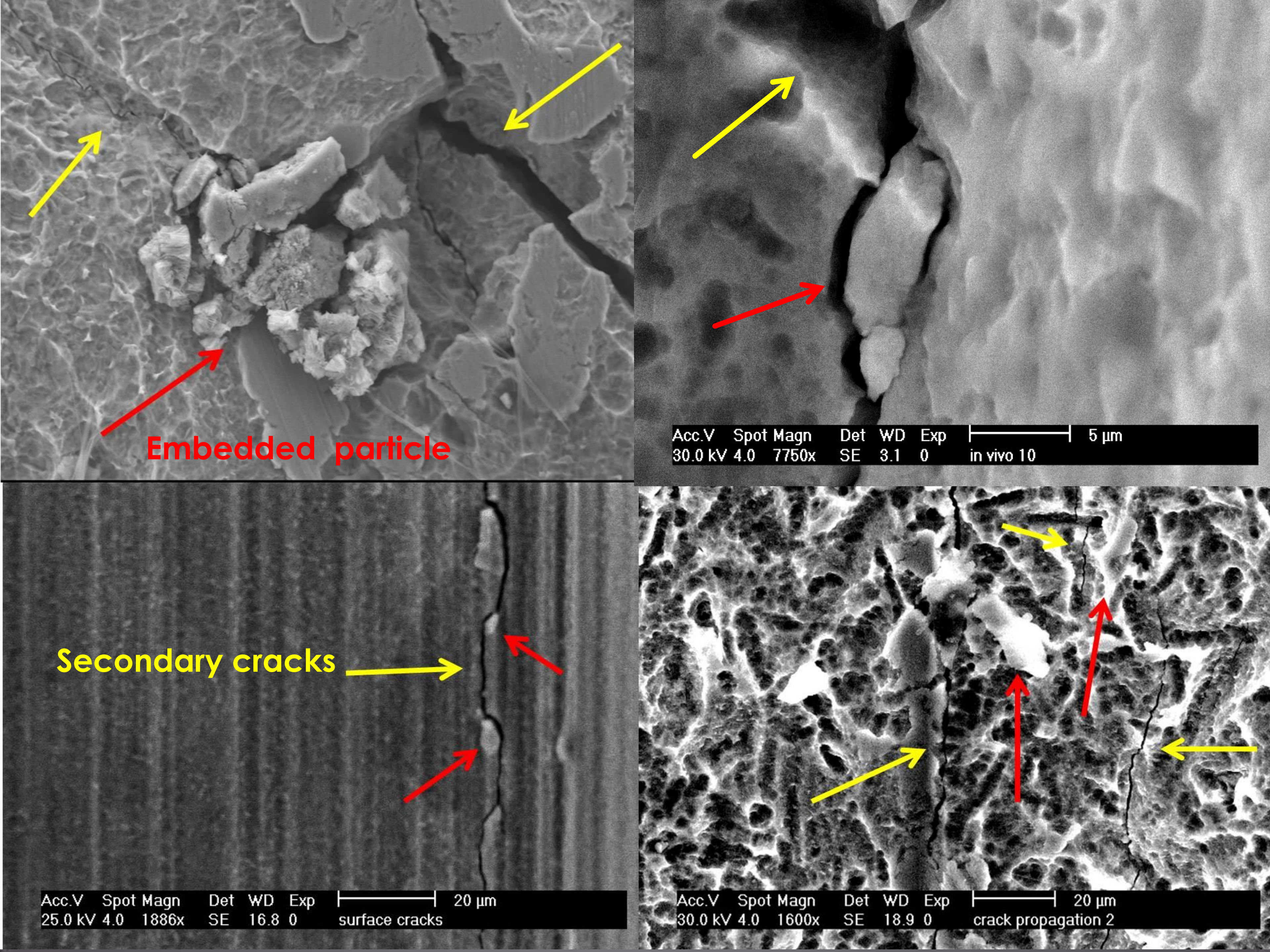
  Numerical simulations

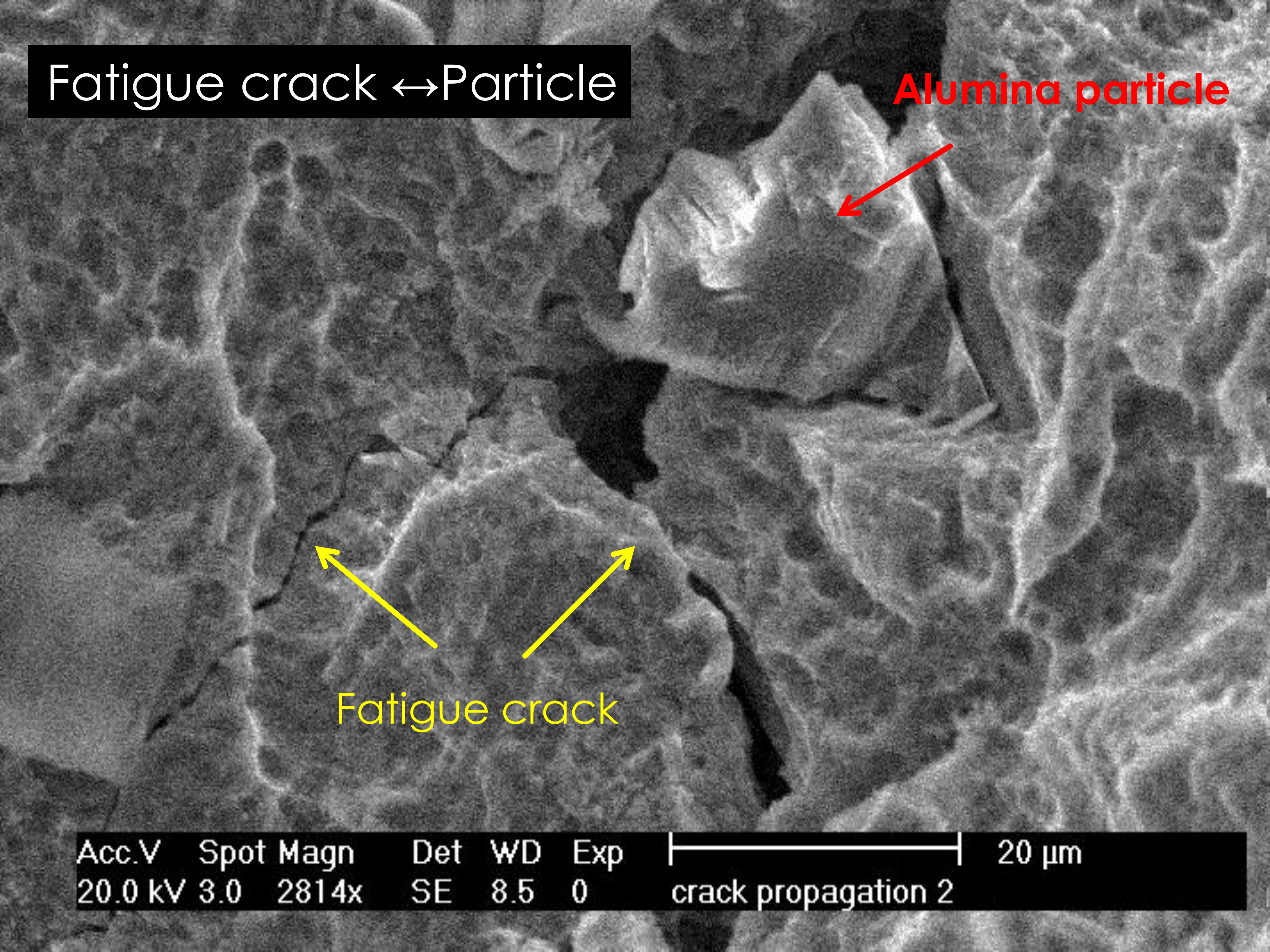


Shemtov-Yona, K., Rittel, D. and Dorogoy, A. (2014) JMBBM 39:375-390


A
O
O
O
F
cc.V Spot Magn Det WD Exp
0.0 kV 4.0 50x SE 13.8 0 DW1
B
Det WD Exp 100 µm
SE 13.2 0 DW1
LAB TESTED SPECIMEN
C
Acc.V Spot Magn Det WD Exp 50 µm
30.0 kV 4.0 840x SE 21.0 0 sm3f1
Acc.V Spot Magn Det WD Exp 50 µm
30.0 kV 4.0 1024x SE 25.2 0 DW1


RETRIEVED
SPECIMEN
A
B
C
D
Acc.V Spot Magn Det WD Exp
30.0 kV 3.2 63x SE 6.4 0 in-vivo 7
B
Det WD Exp 200 µm
SE 6.2 0 in-vivo 7
C
Acc.V Spot Magn Det WD Exp 10 µm
30.0 kV 4.0 4909x SE 9.7 0 crack propagation 2
D
Acc.V Spot Magn Det WD Exp 20 µm
20.0 kV 4.0 2500x SE 6.7 0 in-vivo12b


Embedded particle
Acc.V Spot Magn Det WD Exp
30.0 kV 4.0 7750x SE 3.1 0
5 µm
in vivo 10
Secondary cracks
Acc.V Spot Magn Det WD Exp
25.0 kV 4.0 1886x SE 16.8 0
20 µm
surface cracks
Acc.V Spot Magn Det WD Exp
30.0 kV 4.0 1600x SE 18.9 0
20 µm
crack propagation 2



Fatigue crack ↔Particle
Alumina particle
Fatigue crack
Acc.V Spot Magn Det WD Exp
20.0 kV 3.0 2814x SE 8.5 0
20 µm
crack propagation 2

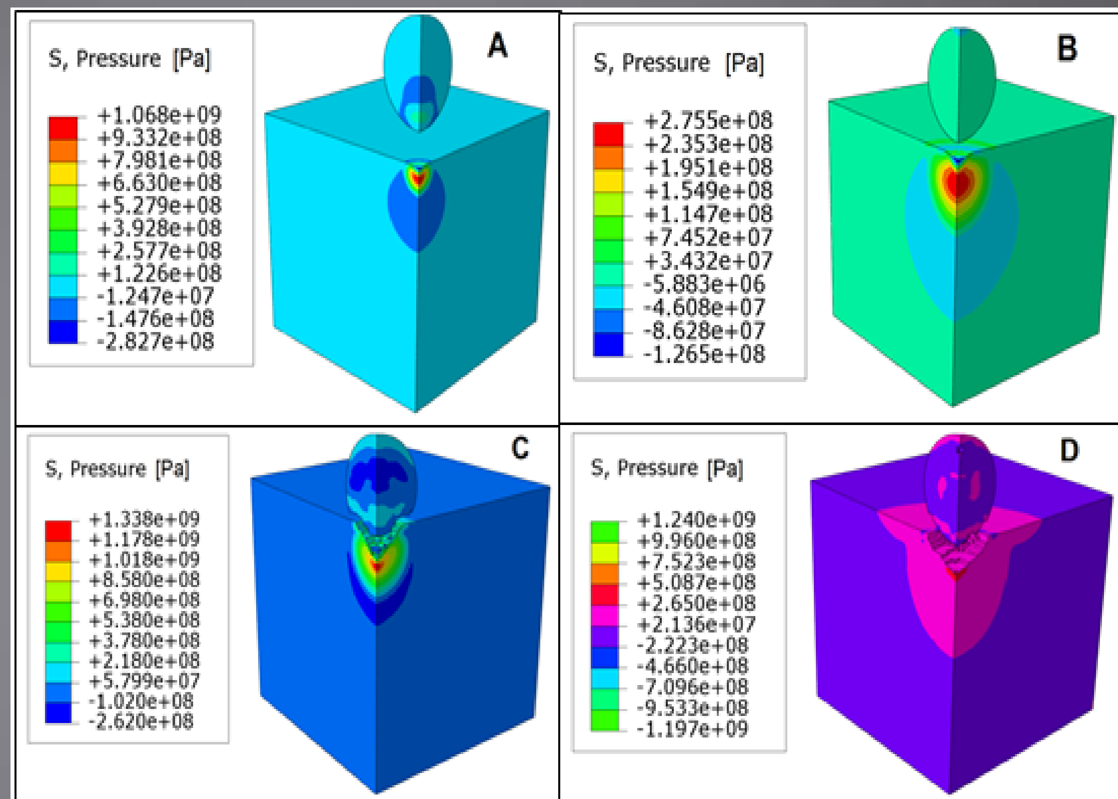
Contour maps of residual pressure due to impact

Ti-6Al-4V

CP-Ti

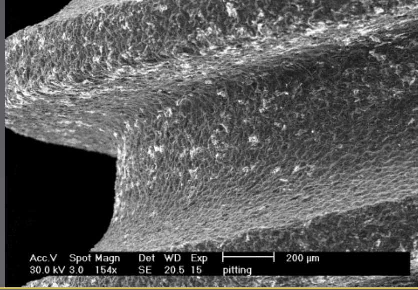
50 [m/s]

250 [m/s]



Shemtov-Yona, K., Rittel, D. and Dorogoy, A. (2014) JMBBM 39:375-390

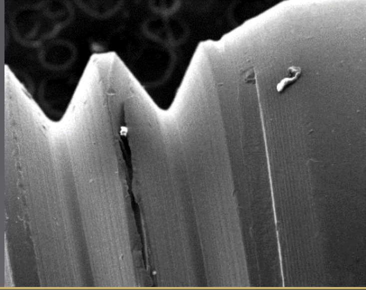
LESSON 2: On the influence of grit blasting



- **Potentially adverse effects of grit blasting** surface treatment were characterized.
- Surface topography and cleanliness both influence surface cracks initiation, hence **overall fatigue life** of the implant.
- **Surface preparation must be carefully controlled.**
- **Numerical modeling** has a strong potential in implant dentistry.

Shemtov-Yona, K., Rittel, D. and Dorogoy, A. (2014) JMBBM 39:375-390

III. Data from the clinic

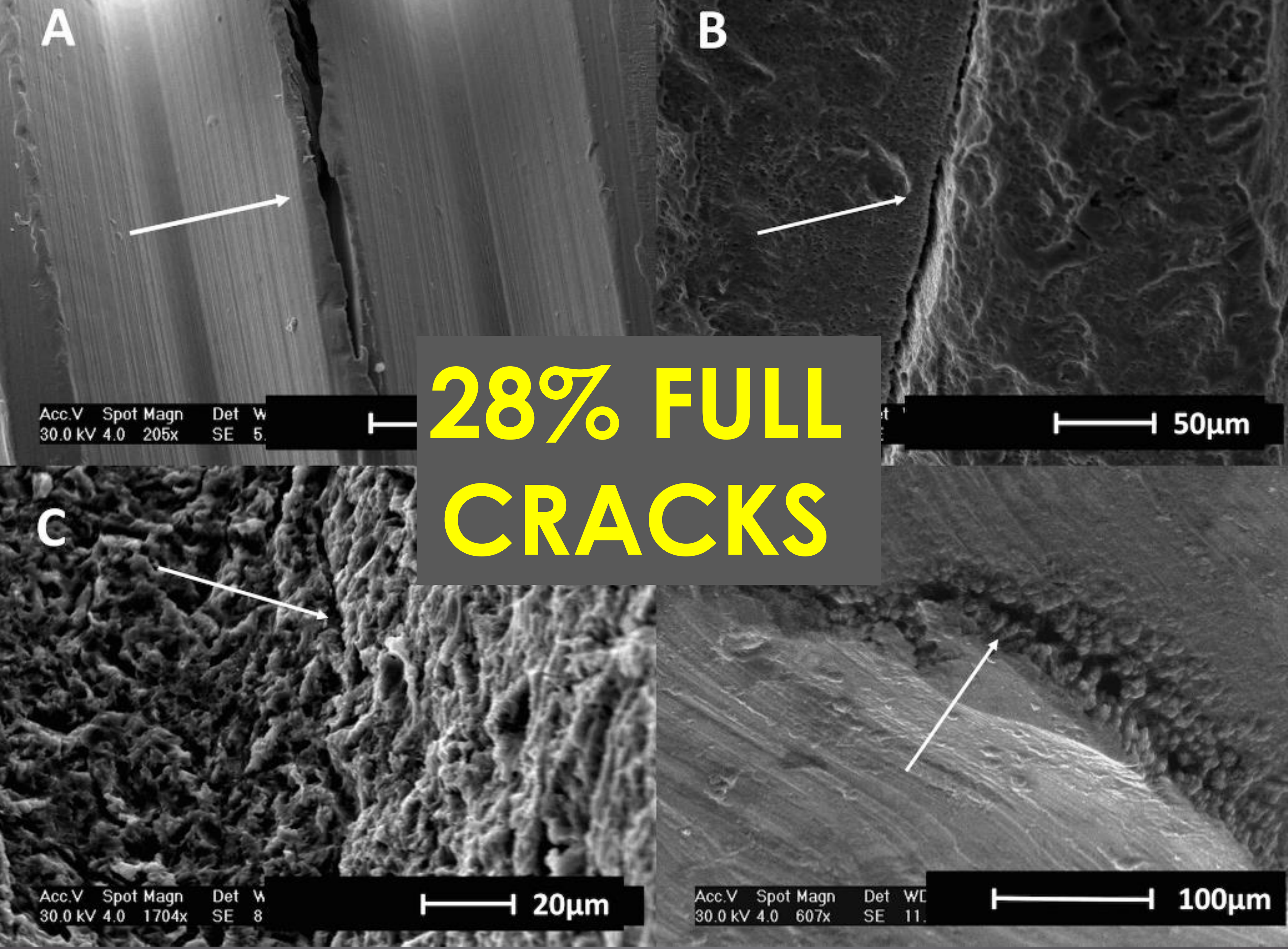


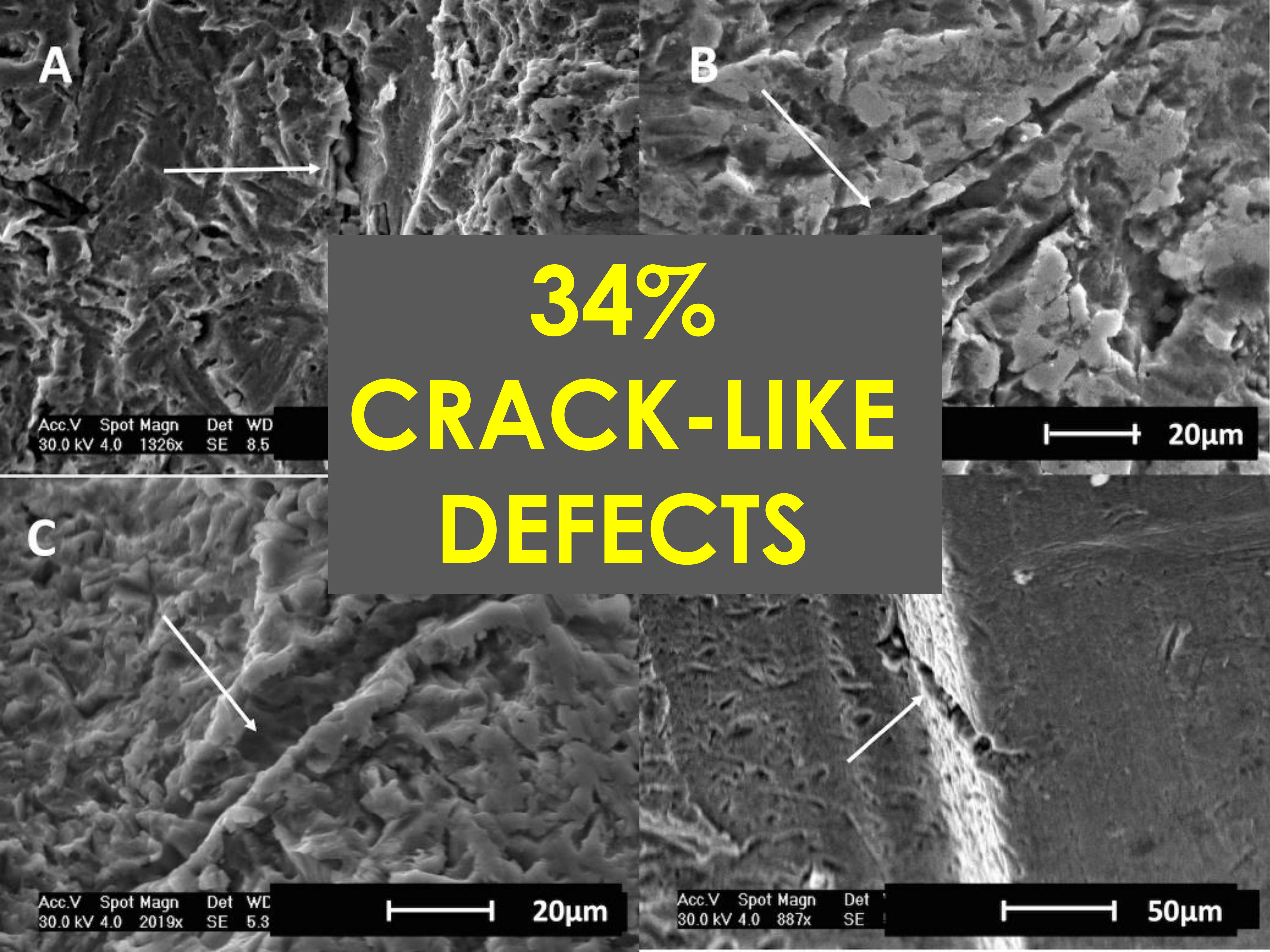
- 100 implants, extracted **only due to bone loss,** were examined for early signs of mechanical failures
- **Thorough surface scanning** of the implant on its entire periphery (360°)
- 5 primary properties were evaluated:

1. Presence and characterization of defects
2. Implant diameter and length,
3. Defects' location,
4. Surface treatment if any
5. Involvement of embedded foreign particles

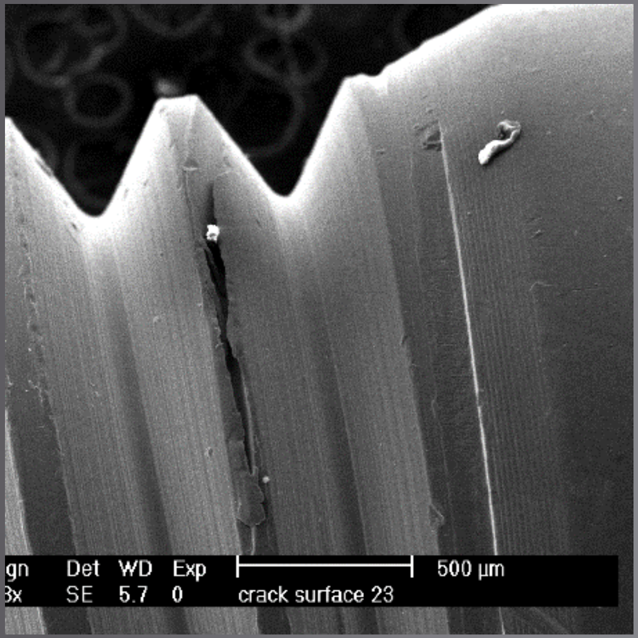
Shemtov-Yona, K. and Rittel, D. (2015) JMBBM 39:375-390

28% FULL CRACKS




A
B
C
34%
CRACK-LIKE
DEFECTS
Acc.V Spot Magn Det WD
30.0 kV 4.0 1326x SE 8.5
20µm
Acc.V Spot Magn Det WD
30.0 kV 4.0 2019x SE 5.3
20µm
Acc.V Spot Magn Det
30.0 kV 4.0 887x SE
50µm

Some statistics



Implant material

CP-Ti is more prone to damage (73% vs. 22.5%)
P=0.0038

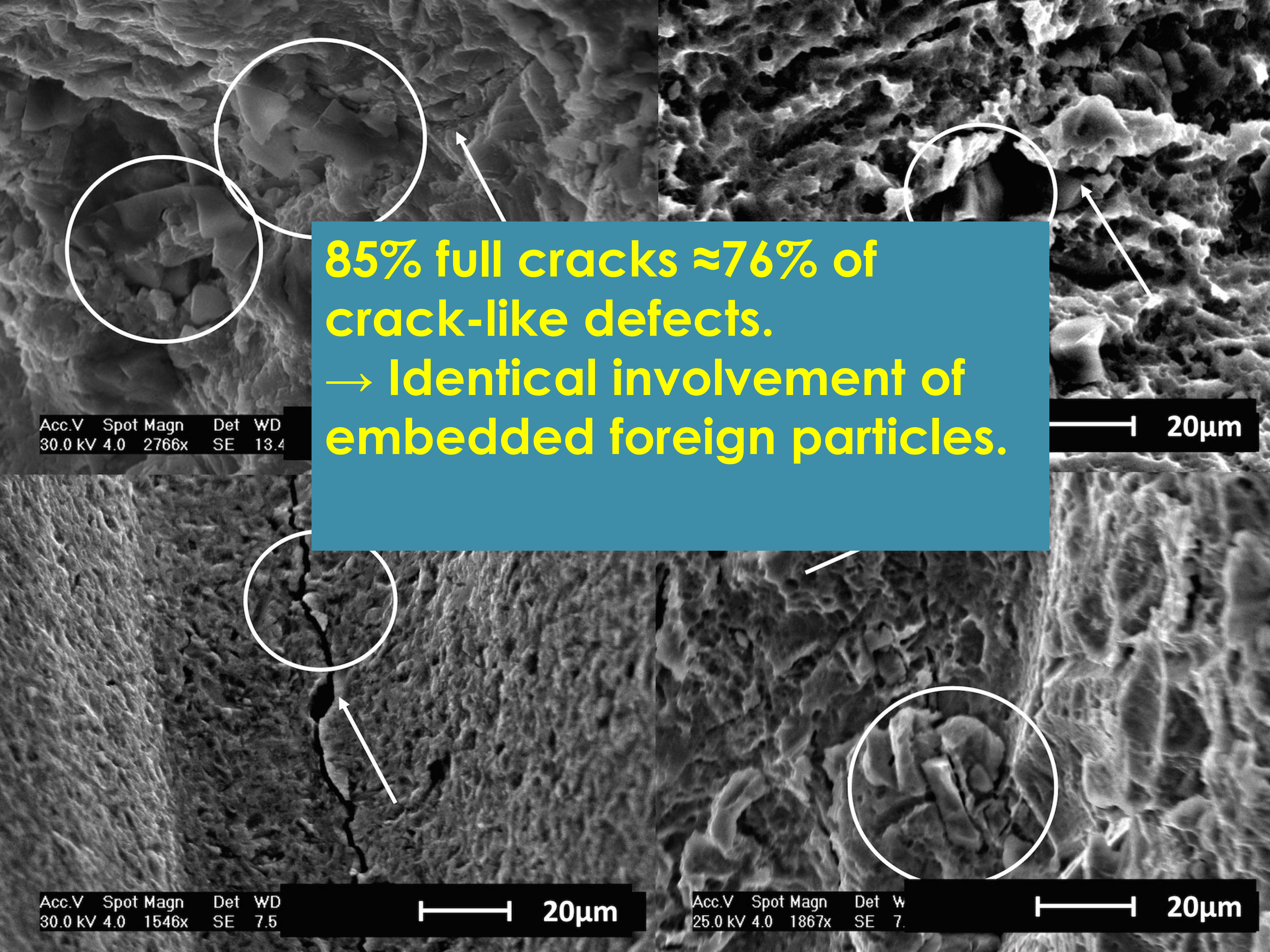
Implant design
30% narrow vs. 33% standard vs. 11% wide
28% long vs. 30% short
NS

Defect location
Most defects in the threads
100% of defects found on the neck=full cracks
P=0.0025

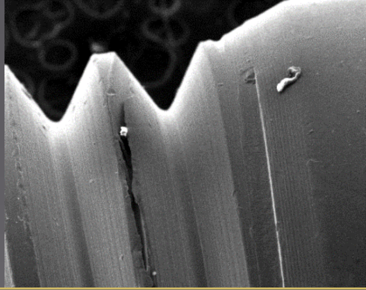
Surface treatment
Full cracks in **100%** as-machined, **24%** non coated, **23%** coated
P=0.0060

Shemtov-Yona, K. and Rittel, D. (2015) JMBBM 39:375-390

85% full cracks ≈76% of crack-like defects.
→ Identical involvement of embedded foreign particles.



LESSON 3: From the clinic



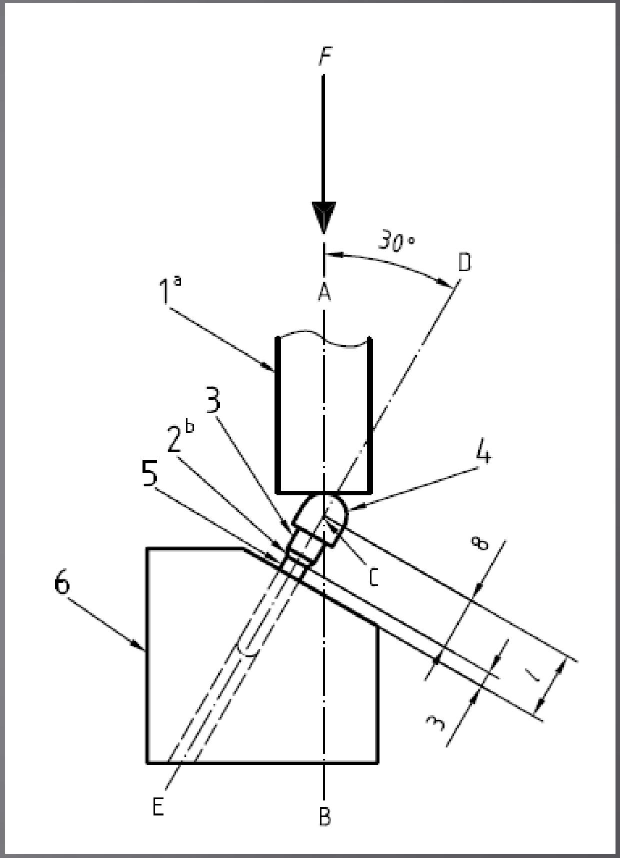
- About 60% of the examined implants contained flaws.
- CP-Ti implants were more damaged than Ti-6Al-4V implants.
- When relevant, embedded foreign particles were strongly correlated to defects.
- Early biological failure causing extraction does not allow for later mechanical complications.
- The occurrence of mechanical failures of dental implants is likely to increase as the frequency of biological failures will decrease.

Shemtov-Yona, K. and Rittel, D. (2015) JMBBM 39:375-390

Evaluating dental implants fatigue life

ISO 14801 inspired philosophy

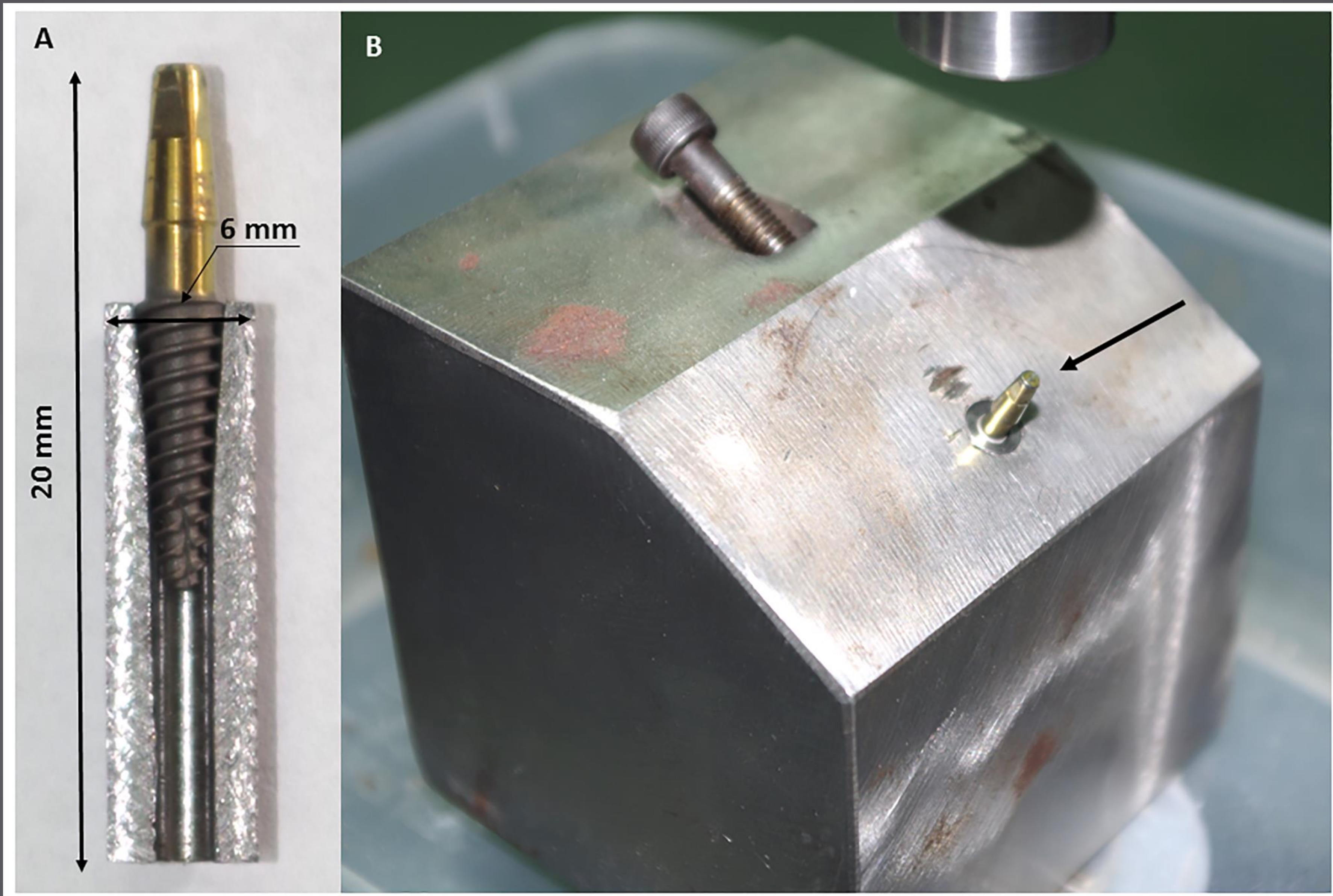
- Cyclically loading specimens at various loads
- Identify a lower load limit (endurance limit)
- “worst-case” conditions
- Environment effect not addressed



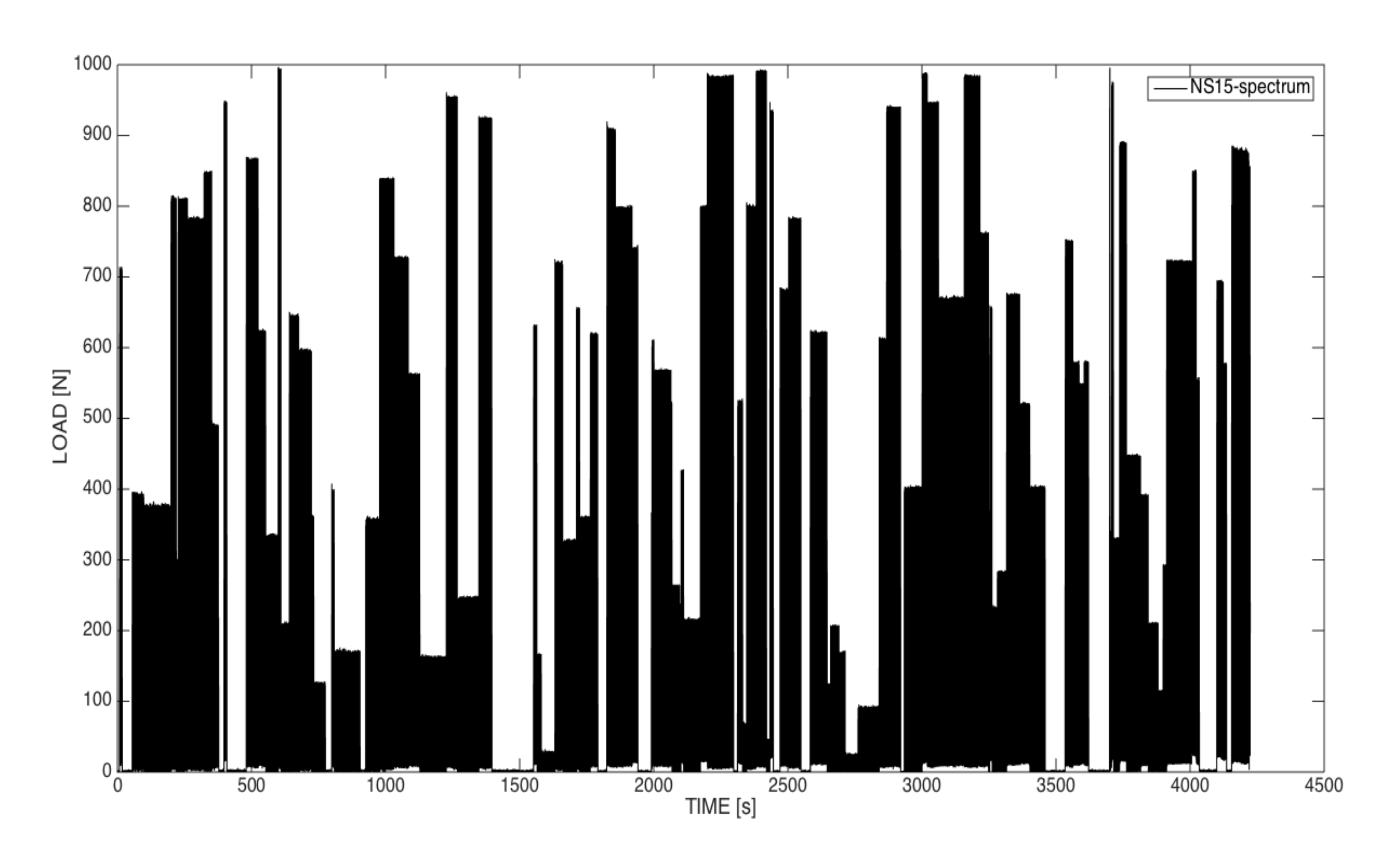
ISO 14801:2003

Functional testing of dental implants

- Subject the implants to *spectrum* loading.
- Any load can be applied randomly between 0 and X [N] at a variable frequency.
- Random blocks that mimic actual mastication (in load amplitude)
- Generate a *benchmark* spectrum to test and compare *any kind* (design + surface condition) of implants in any atmosphere


A
6 mm
20 mm
B

The spectrum



Cyclic loading VS. Spectrum loading

Results

Quasi static test results = 1136.5 ±57N

Random spectrum test result=4644 ±3042s

No. of load points above 980N= 1837 ±330 **0.66%**

Cyclic test results= 101 ±41s

No. of load points above 980N= 911 ±521 **8.1%**

Lower loads also contribute to failure (Palmgren-Miner)

DON'T COMPARE CYCLIC AND SPECTRUM

Lesson 4: functional implant testing

- A new methodology to assess the *functional performance* of dental implants.
- Random spectrum loading is used as an *alternative* to traditional cyclic tests.
- The performance until fracture is evaluated instead of the fatigue limit.
- The approach allows for a rapid assessment of the implant with *minimal statistics*.
- **Different implant designs or materials can be readily and reliably compared**.

Shemtov-Yona, K. and Rittel, D. (2015) JMBBM under review

Concluding remarks

- Mechanical reliability of dental implants has long been considered as a "non-issue".
- Consequently, it has/is not extensively investigated
- This presentation has reviewed various recent results that can be summarized as follows.

Lessons summary

- **Lesson 1: Metal fatigue** is the main failure mechanism of CP-Ti and Ti-6Al-4V dental implants
- **Lesson 2**: Surface topography and cleanliness have a profound influence on surface cracks initiation, hence **overall fatigue life** of the implant
- **Lesson 3**: The occurrence of mechanical failures of dental implants is **likely to increase** as the frequency of biological failures will decrease.
- **Lesson 4**: Different implant designs or materials can be readily and reliably compared in terms of performance using **random spectrum loading**

THANK YOU!