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Yung Chen

University of Minnesota, chen1954@umn.edu

Alex Fok

University Minnesota, alexfok@umn.edu

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Structural Optimization of Fiber-Reinforced Composite Dental Bridges

Yung-Chung Chen^{1,2}

Alex Fok¹

1. MINNESOTA DENTAL RESEARCH CENTER FOR BIOMATERIALS & BIOMECHANICS

School of Dentistry, University of Minnesota

2. INSTITUTE OF ORAL MEDICINE

College Of Medicine, National Cheng Kung University

Replacing lost teeth



Dental implant



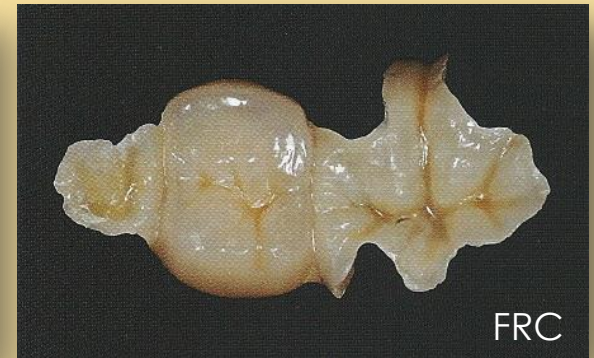
Dental bridges



Metal



Ceramic



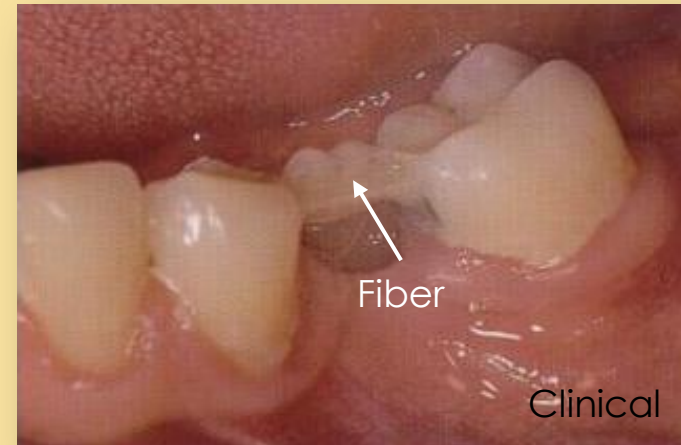
FRC

Failure of FRC bridges

High failure rates

73.4% after 4.5 years

- Heumen et al., European Journal of Oral Sciences, 2009. **117**(1): p. 1-6.



Main failure modes

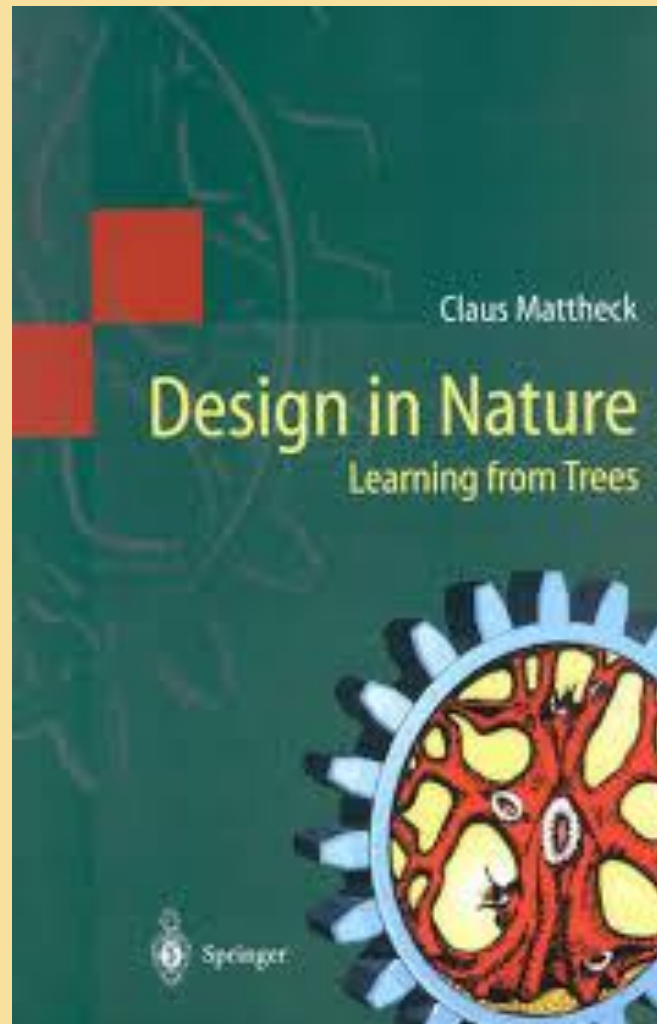
- Fracture and delamination of veneering composite
- Fracture of connectors
- Debonding from supporting tooth



Aim of this study

- To create stronger dental bridges using bio-inspired structural optimization techniques

Learning from trees ...

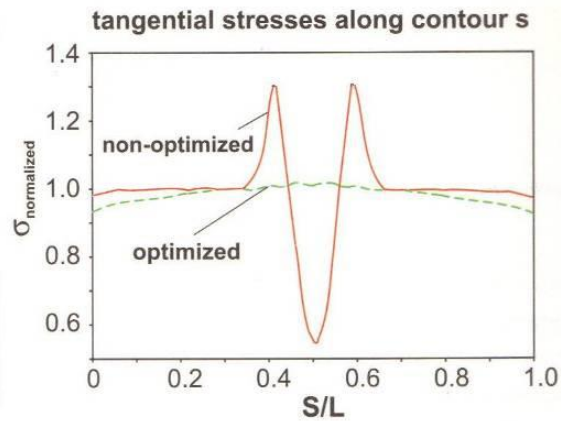
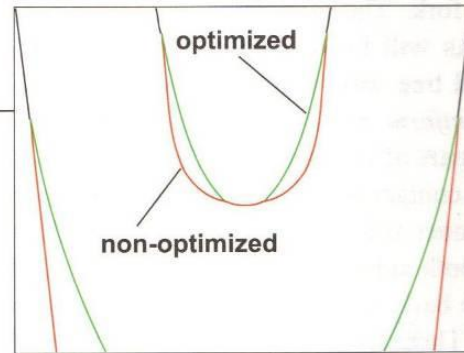
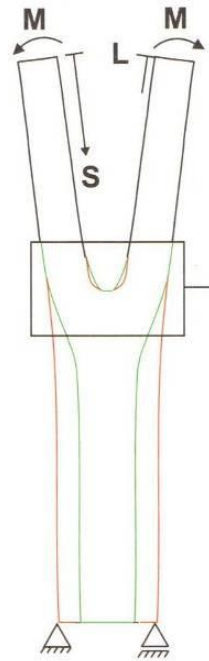


Axiom of Uniform Stress - Claus MATTHECK

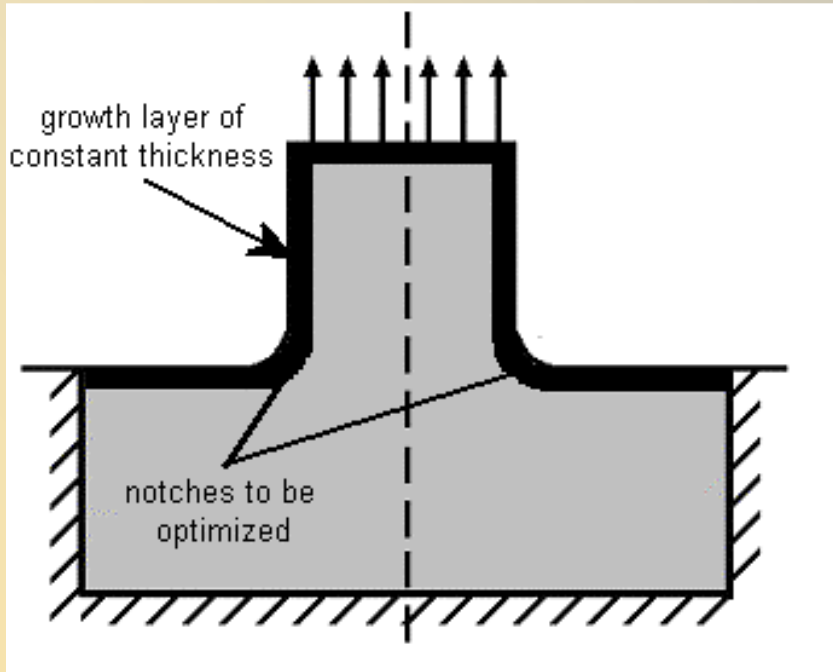
- Build-up of material in overloaded zones
- No build-up (or even reduction) in underloaded zones
- Derived structures are uniformly stressed



Validating using trees

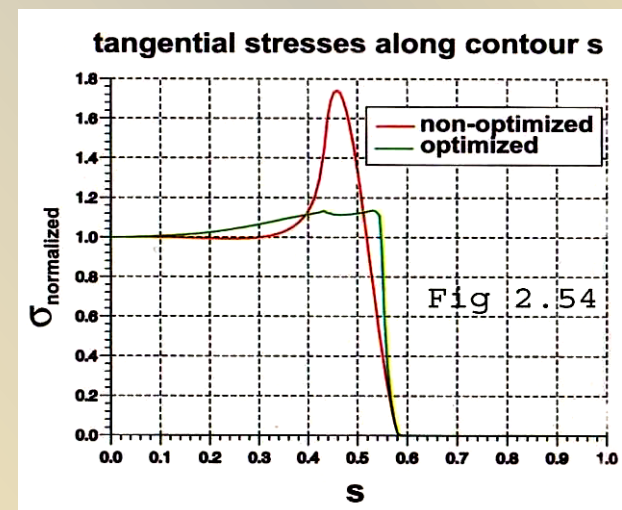
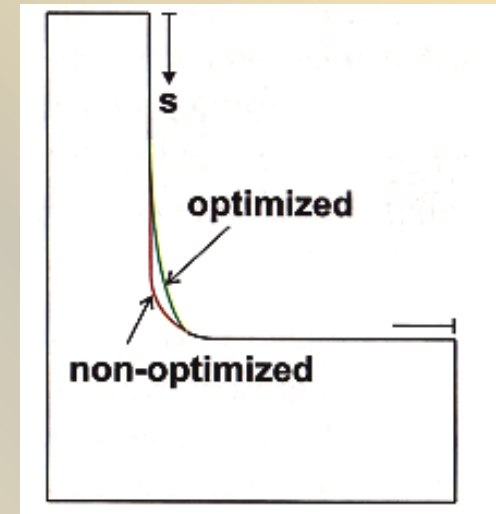


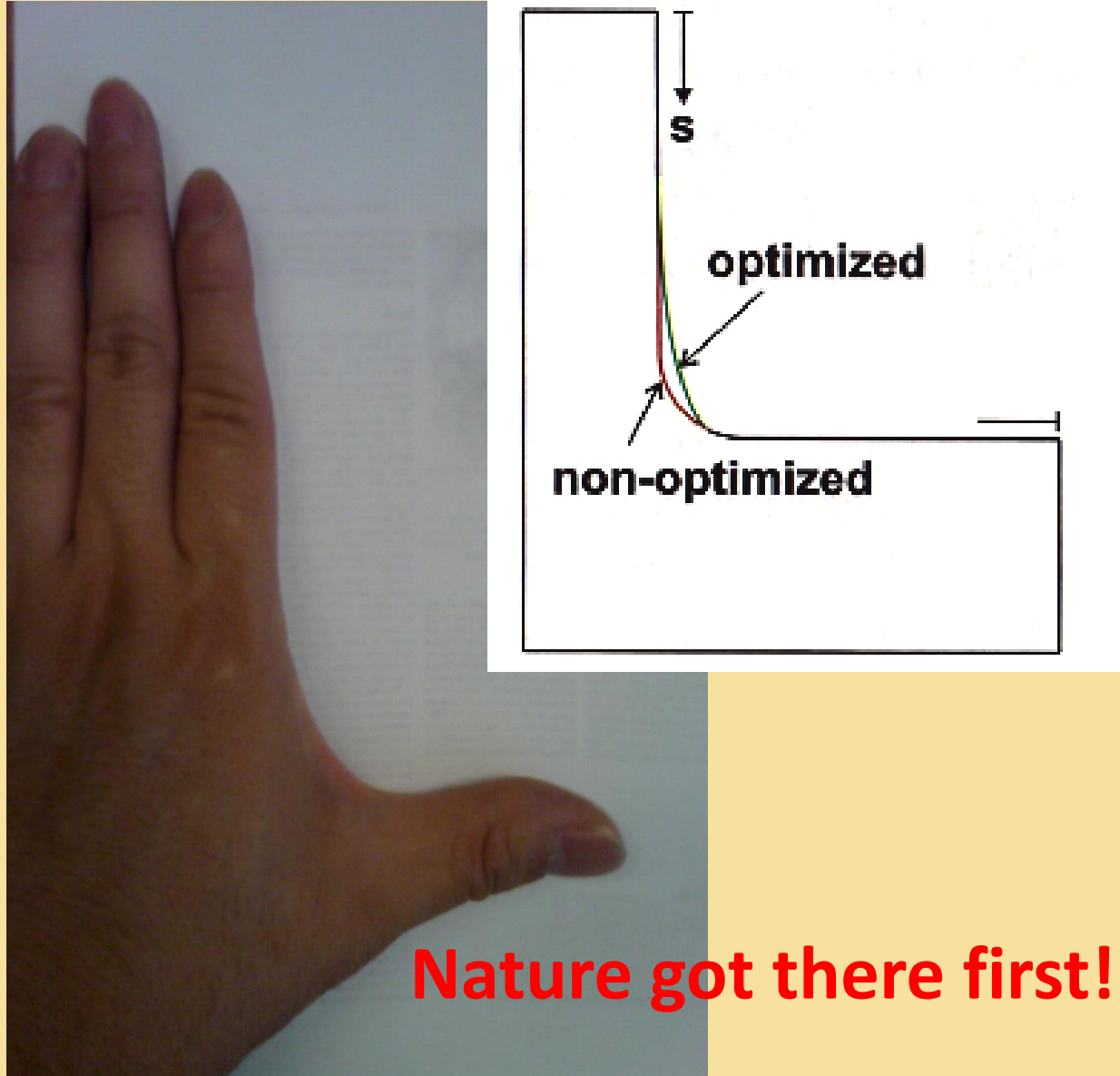
Applying axiom to engineering components



Claus MATTHECK, 1998, *Design In Nature*, Springer

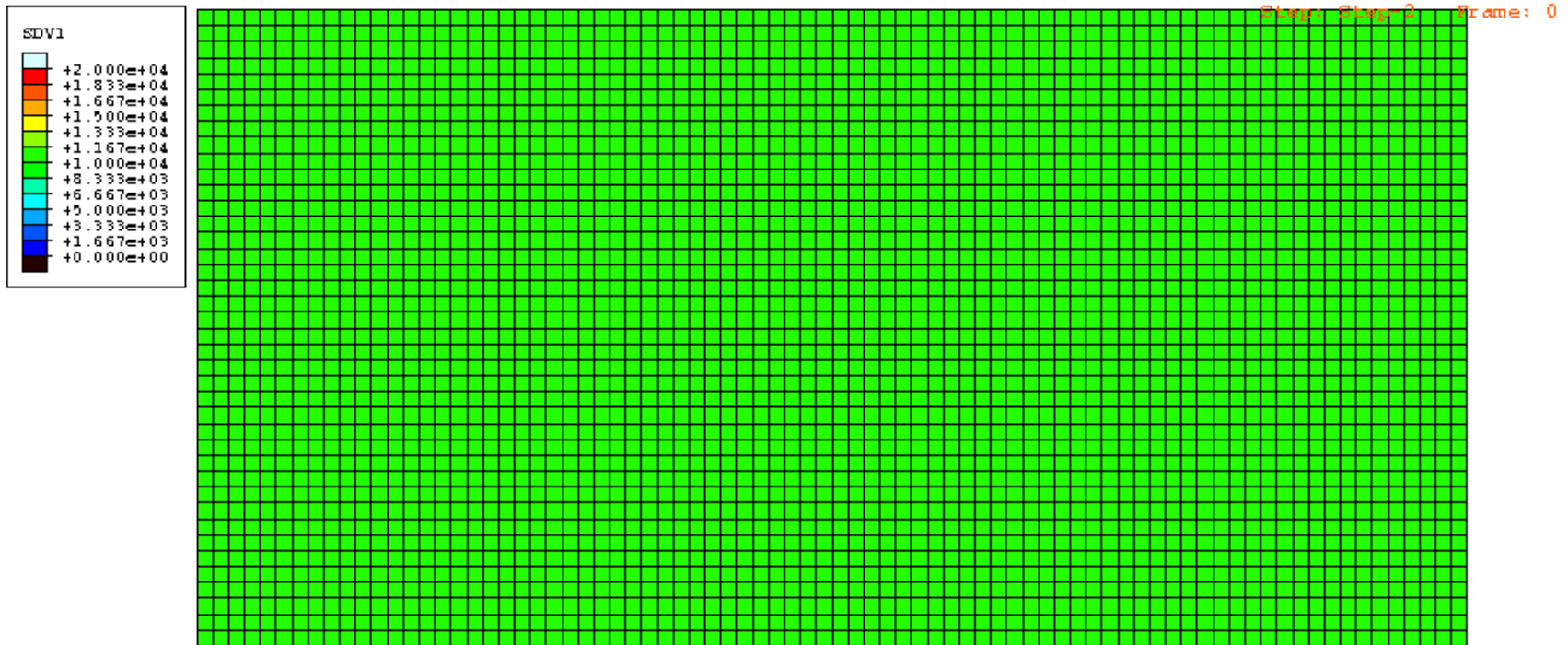
Fatigue life greatly increased





Nature got there first!

Optimization of a cantilever beam



2
1
3

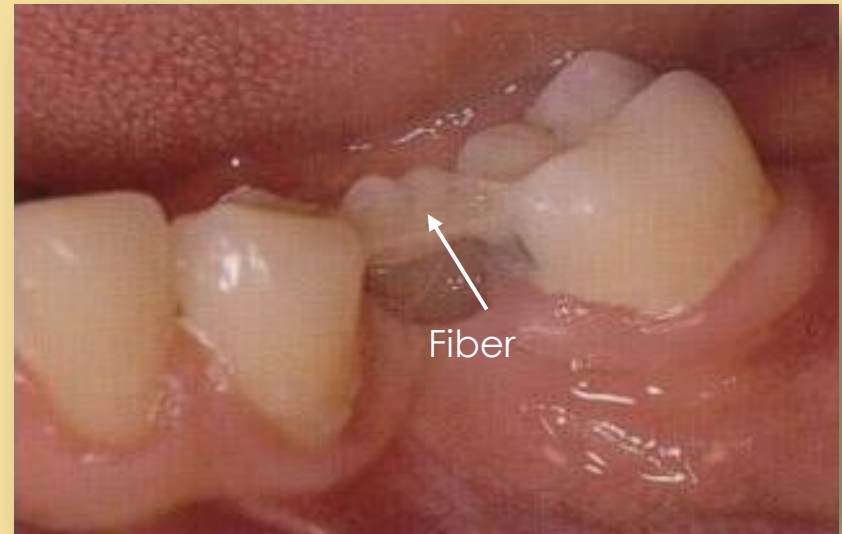
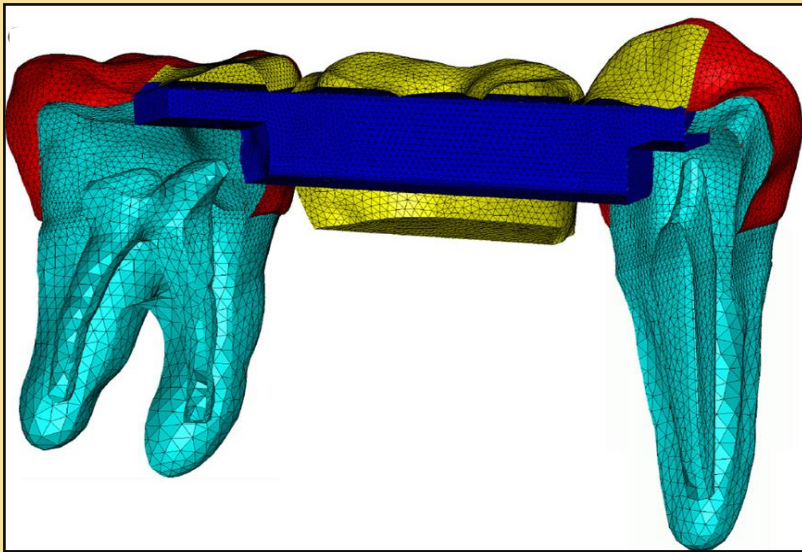
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Step: Step-2  
Increment 0: Step Time = 0.0000E+00  
Primary Var: SDV1
```

Real-world examples



Nature, again, got there first!

3-unit FRC bridge

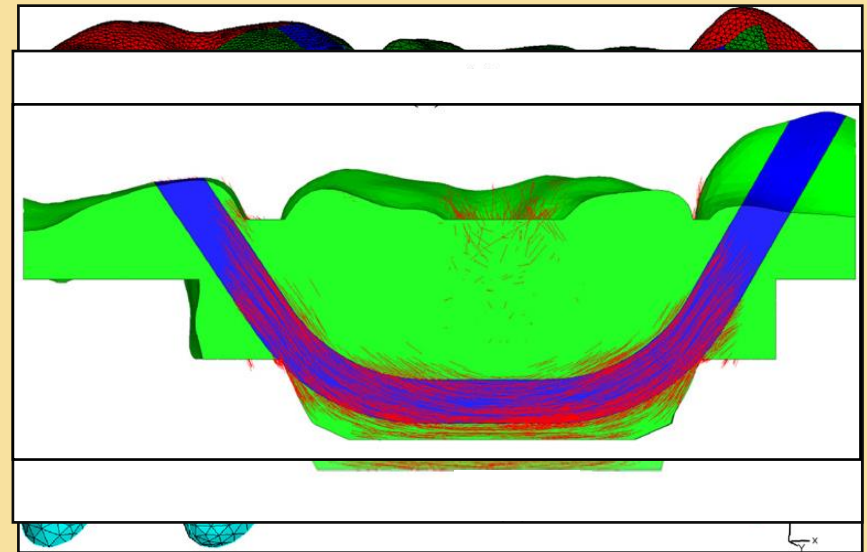
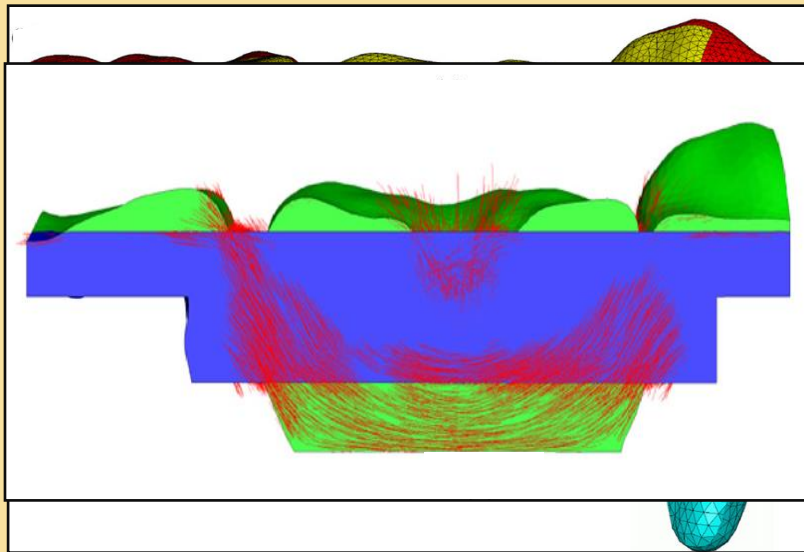


Conventional design

Optimization of a 3-unit FRC bridge

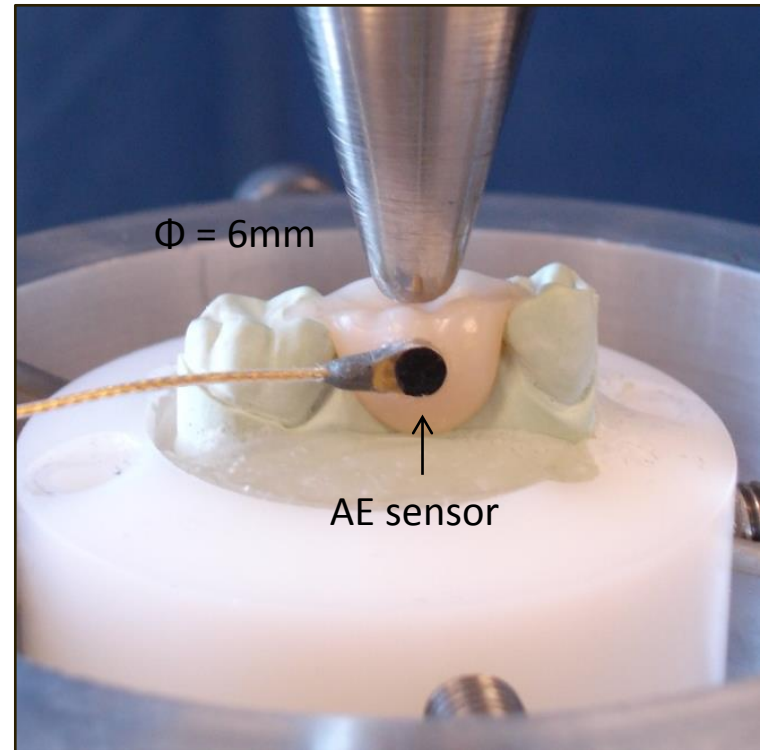
After optimization:

1. 30% reduction of maximum principal stress
2. 30% volume reduction of fiber substructure



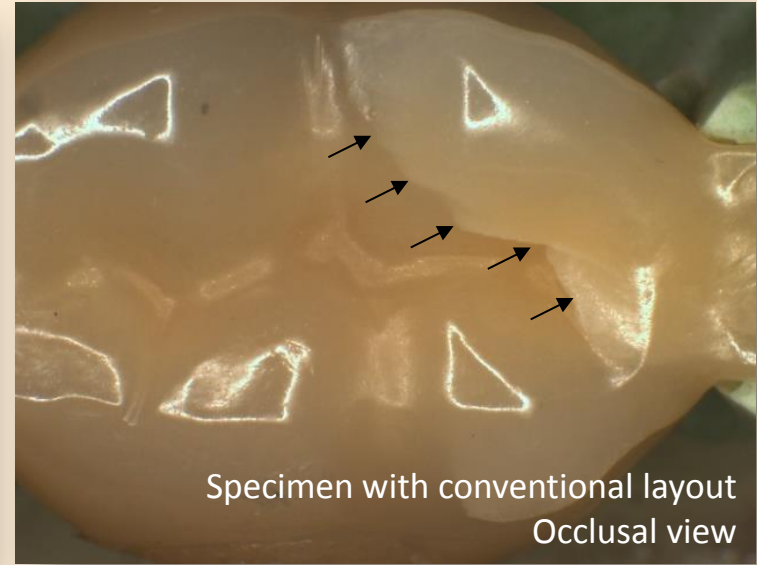
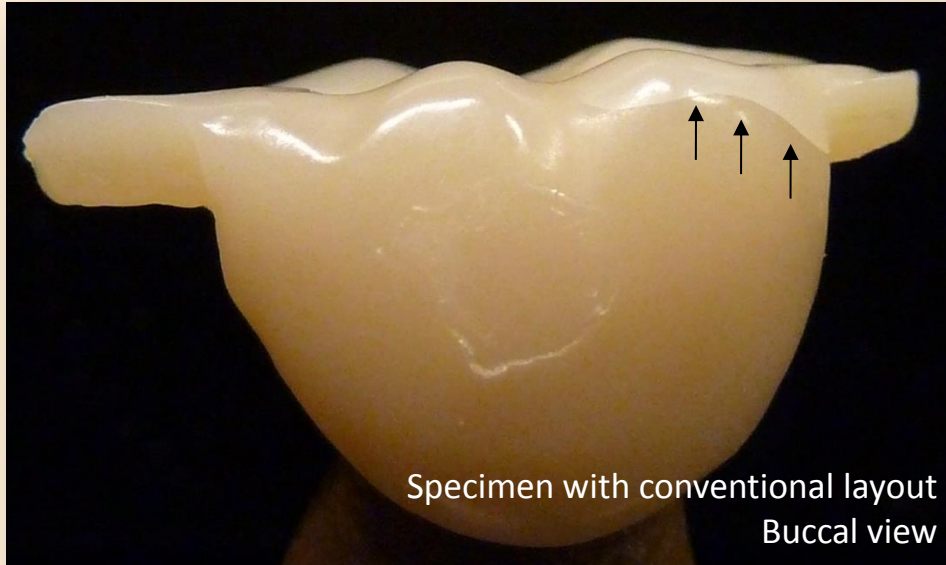
Shi, L. and A.S.L. Fok, Dental Materials, 2009. 25(6): p. 791-801.

Mechanical testing



Loaded to 400 N

Visual inspection



Cracking

Location

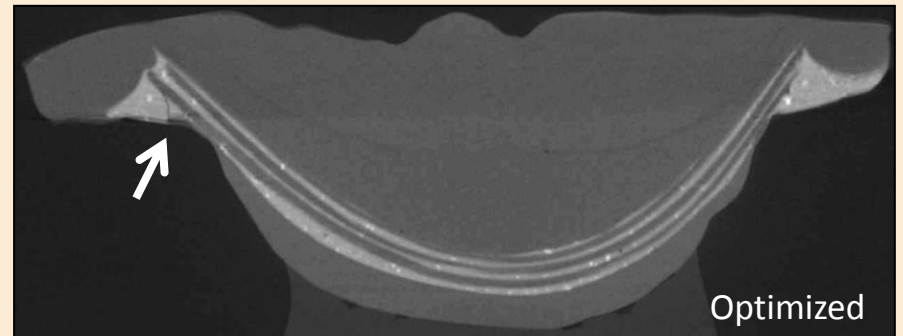
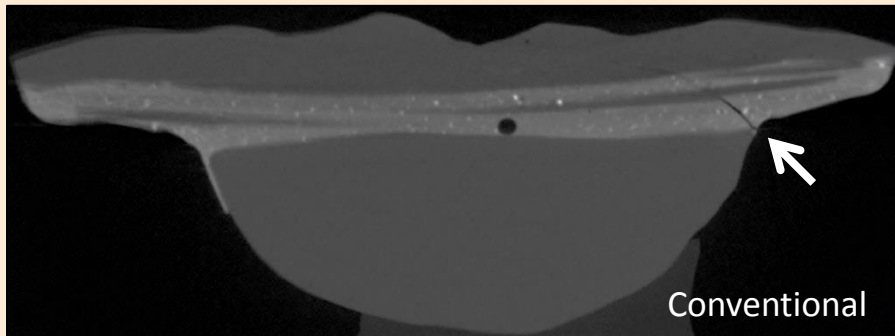
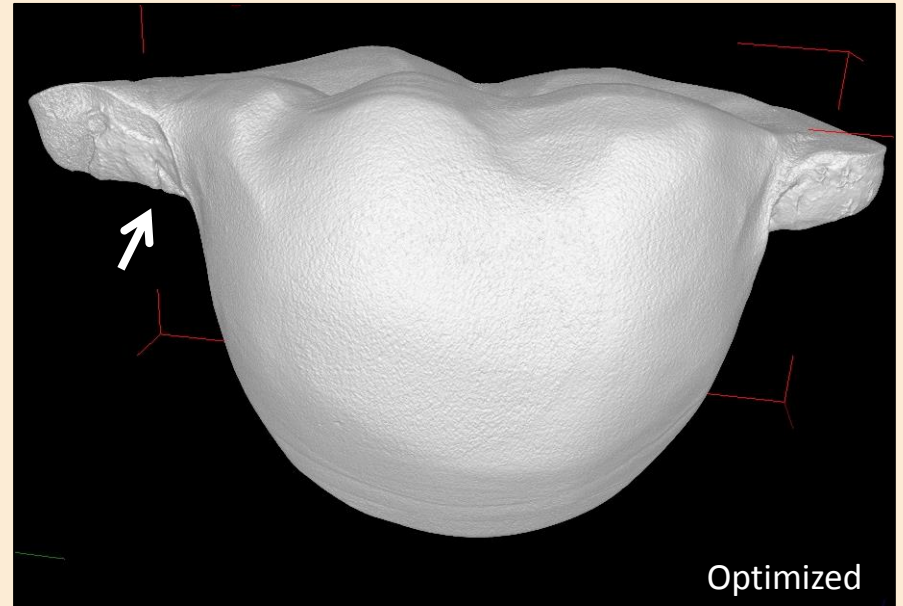
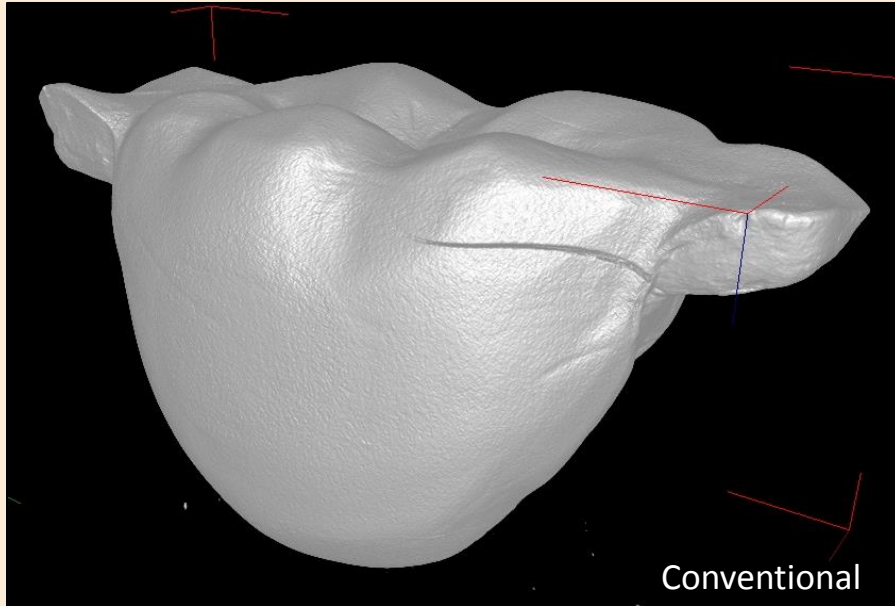
- buccal surface
- lingual surface
- loading point

Percentage of failure

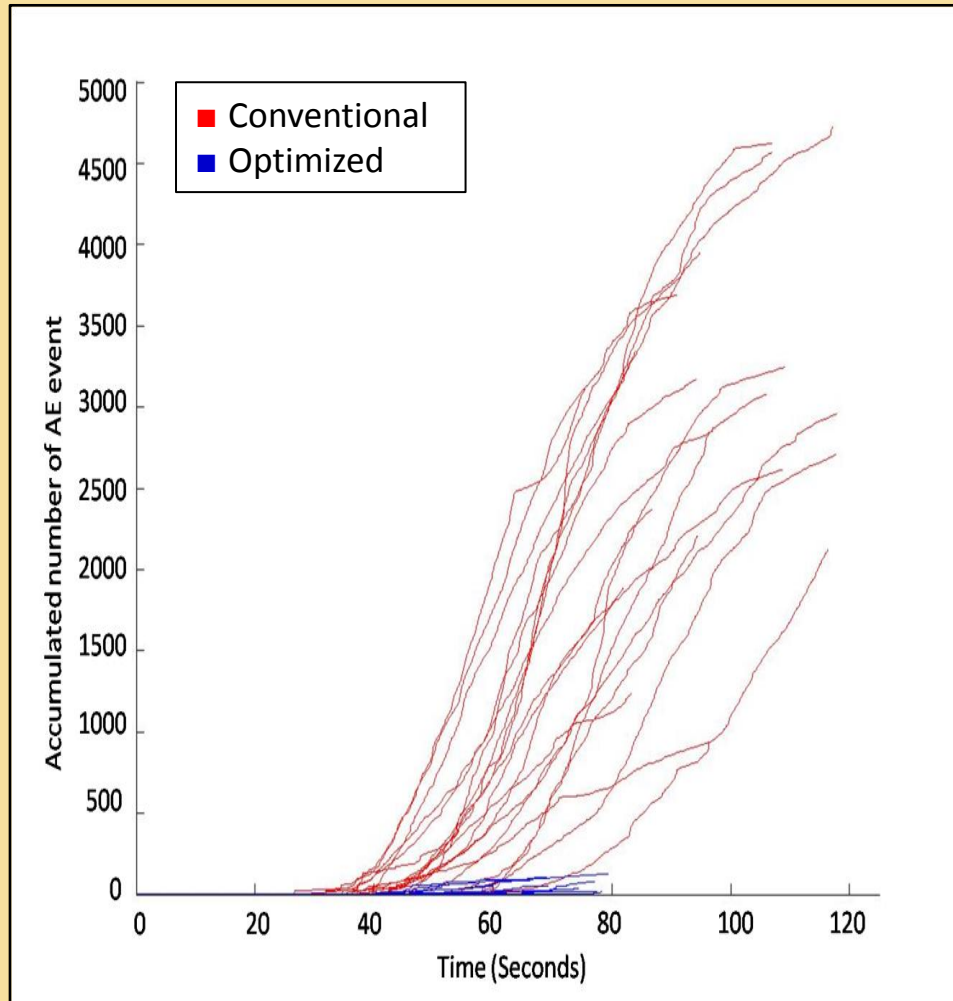
- Conventional layout
→ **100 % (20/20)**
- Optimized layout
→ **28.5 % (6/21)**



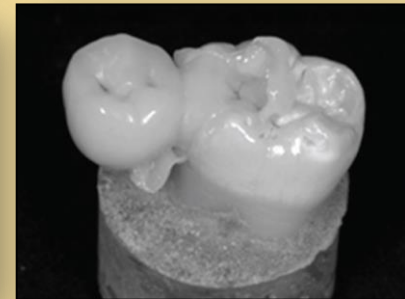
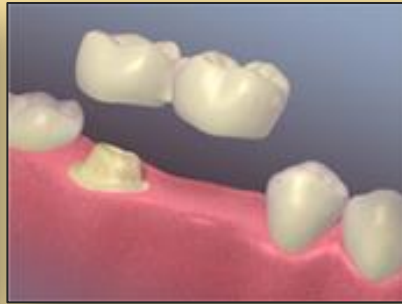
Micro-CT



Acoustic emission



Two-unit cantilever bridge



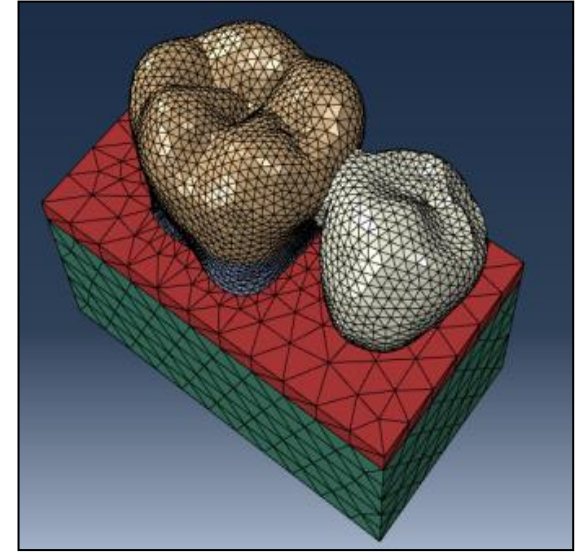
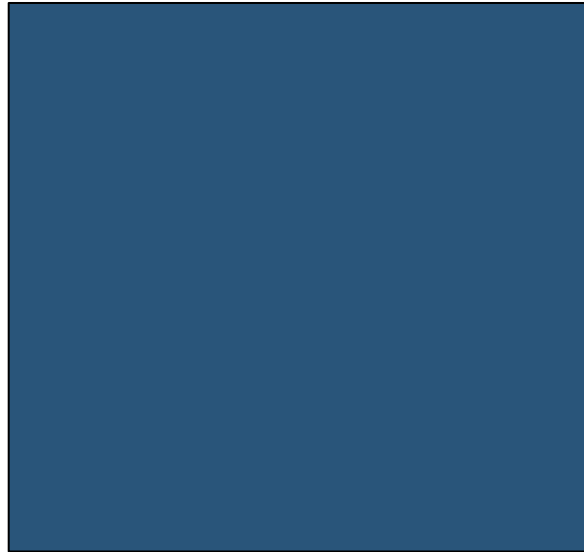
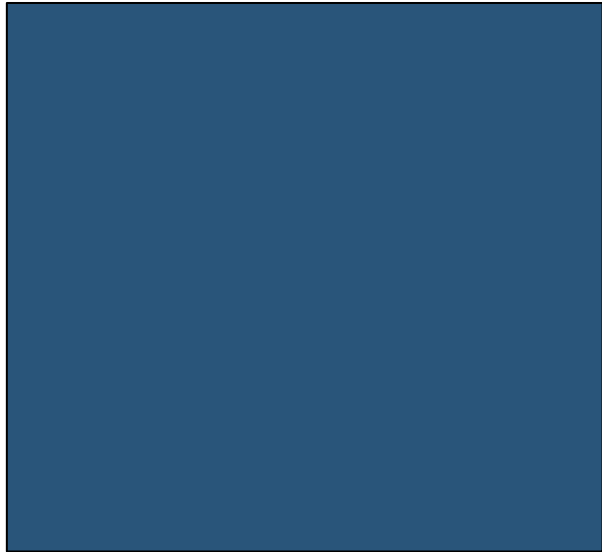
- Advantages:

- Less tooth tissue removal

- Easier to clean

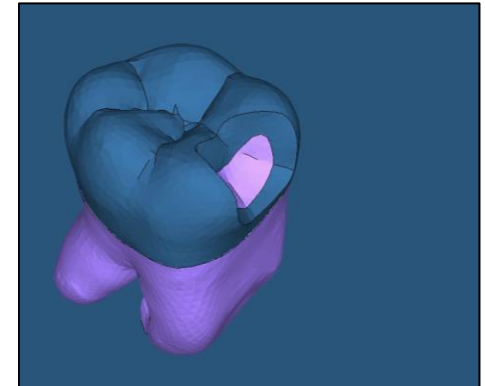
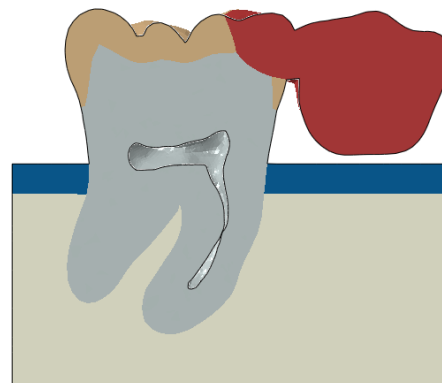
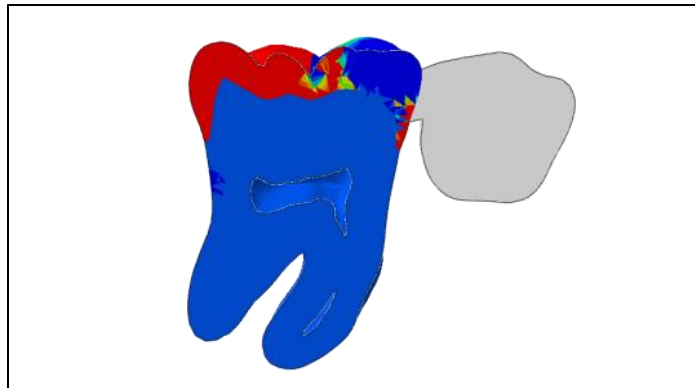
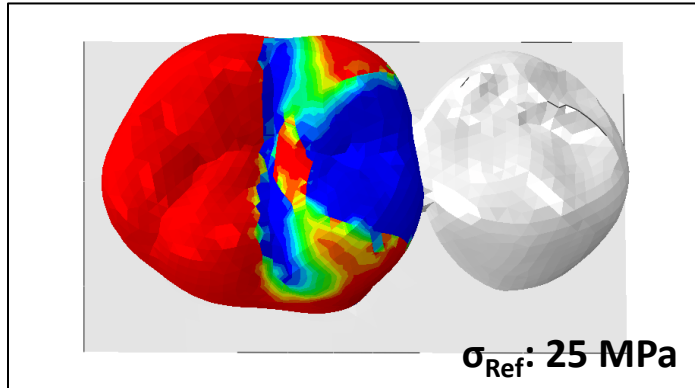
- Less expensive

Materials & Methods



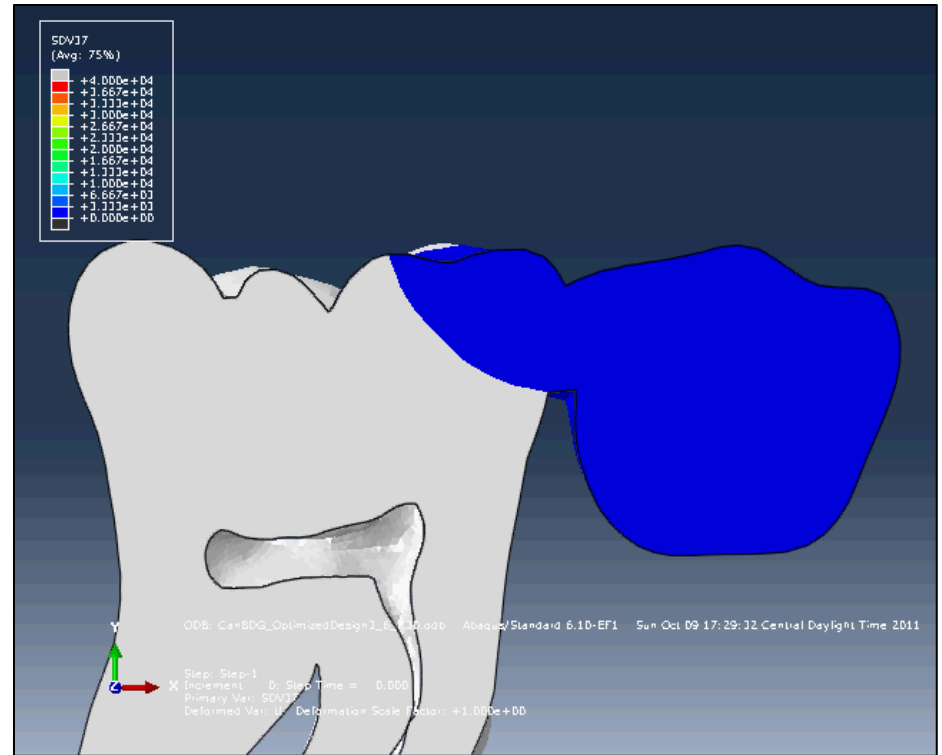
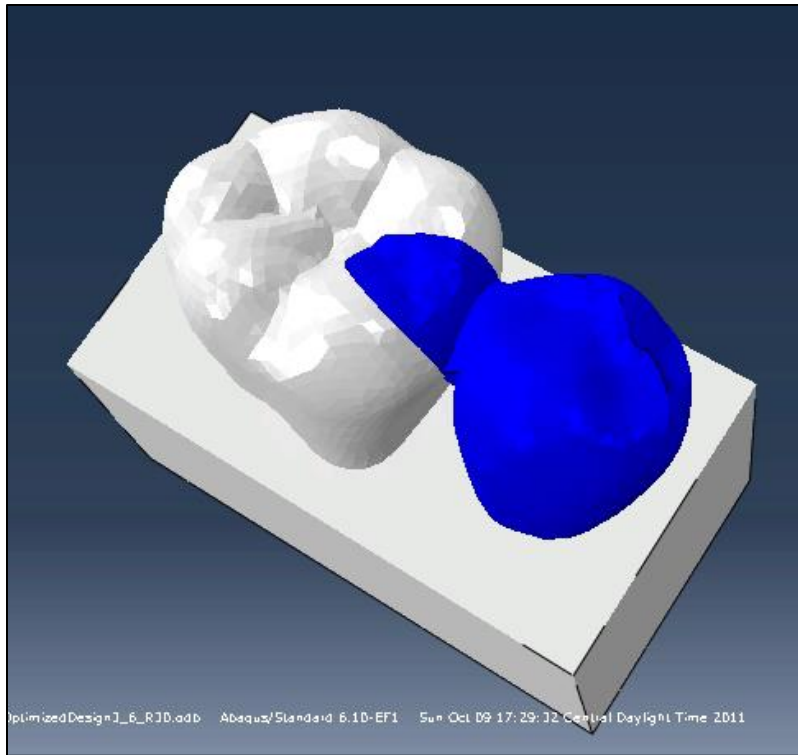
Two-step optimization

1st STEP: Using isotropic SMT UMAT to obtain the cavity design

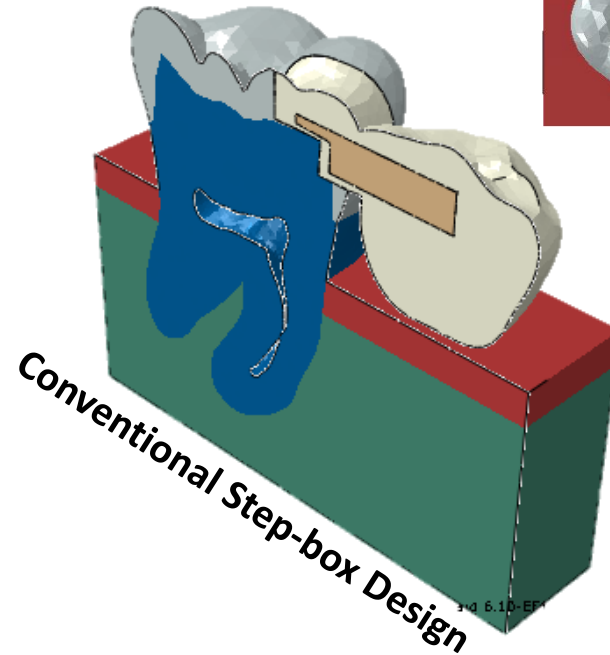
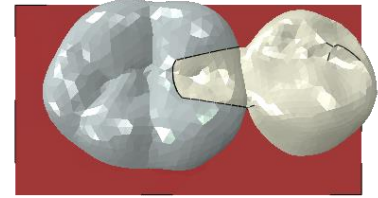
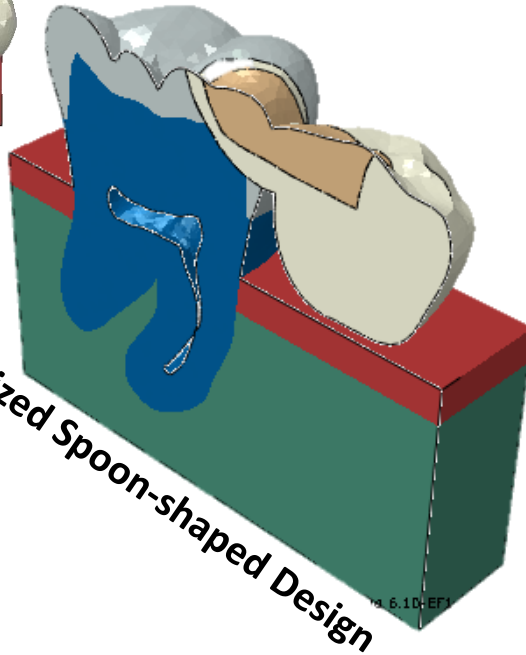
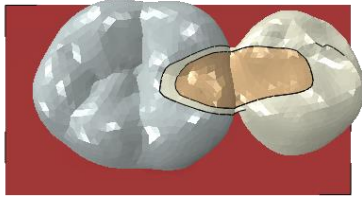


Two-step optimization

2nd STEP: Using orthotropic SMT UMAT to obtain the fiber layout



Optimized vs conventional designs

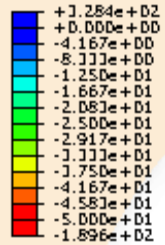


Design	Optimized	Conventional
Bonding surface area	31.314	37.980
Retainer's volume	26.122	26.226

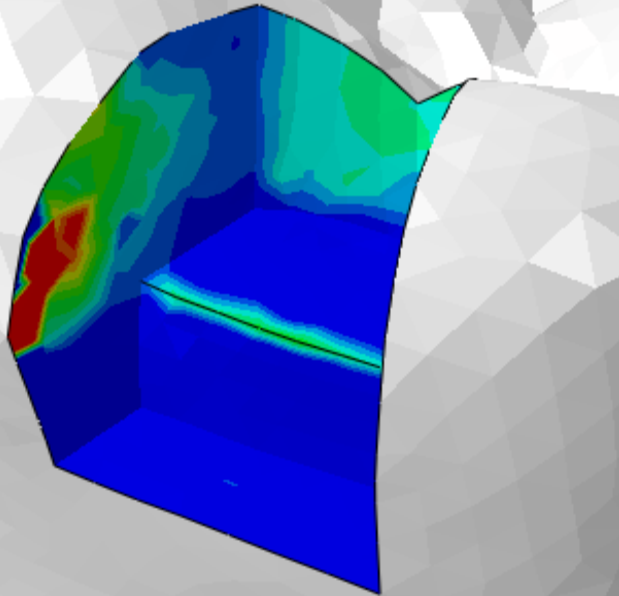
Interfacial stress distribution

Viewport: 1 ODB: J:/Temp/CanBDG_ConventionalDesign.odb

CPRESS

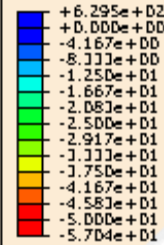


Conventional Step-box Design

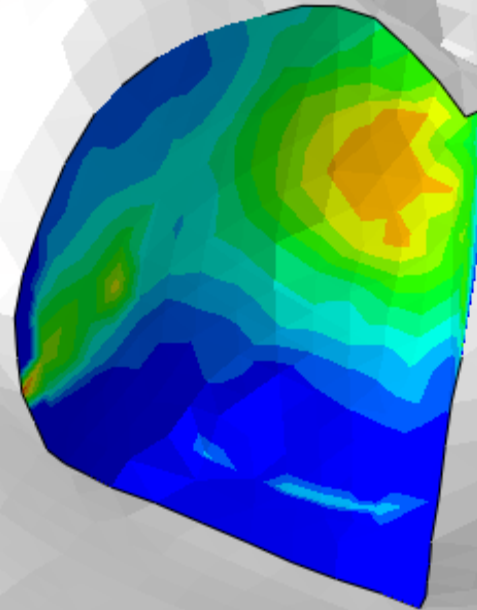


Viewport: 2 ODB: J:/Temp/CanBDG_ModifiedOptimizedDesign3.odb

CPRESS



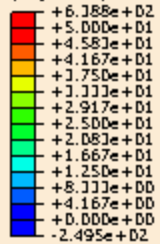
Optimized Spoon-shaped Design



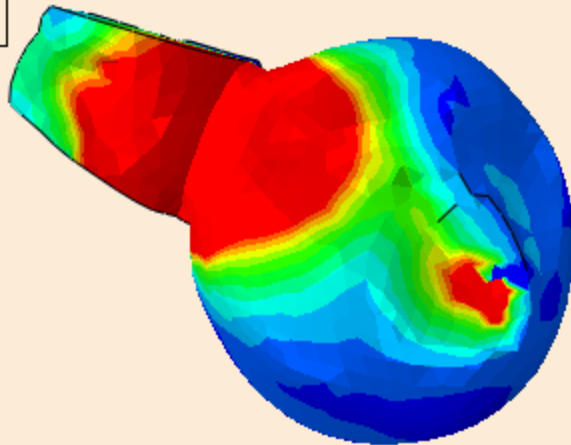
Structural stress distribution

Viewport: 1 ODB: C:/Users/YungChung/Desktop/...entionalDesignContact.odb

S, Max. Principal
(Avg: 75%)



Conventional Step-box Design

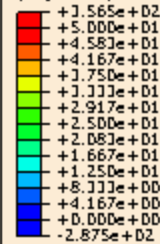


ODB: CanBDG_ConventionalDesignContact.odb Abaqus/Standard 6.10-EP1 Tue Oct 04 10:

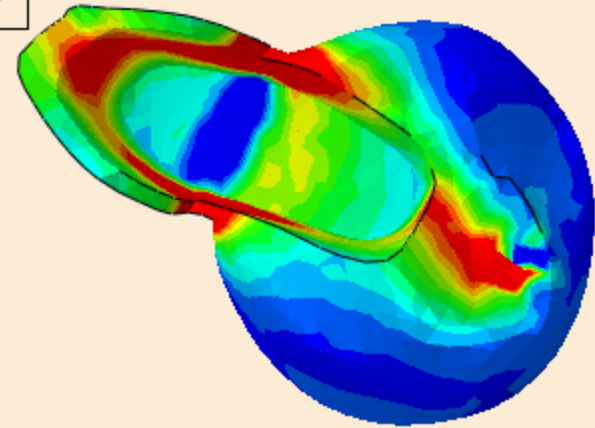
Step: Step-1
Increment: 1; Step Time = 1.000
Primary Var: S, Max. Principal
Deformed Var: U Deformation Scale Factor: +1.000e+00

Viewport: 7 ODB: C:/Users/YungChung/Desktop/...ifiedOptimizedDesign3.odb

S, Max. Principal
(Avg: 75%)



Optimized Spoon-shaped Design



ODB: CanBDG_ModifiedOptimizedDesign3.odb Abaqus/Standard 6.10-EP1 Sat Oct 08 21:2

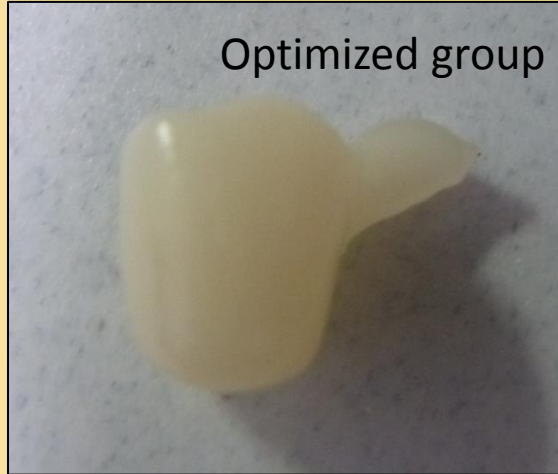
Step: Step-1
Increment: 1; Step Time = 1.000
Primary Var: S, Max. Principal
Deformed Var: U Deformation Scale Factor: +1.000e+00

Mechanical testing

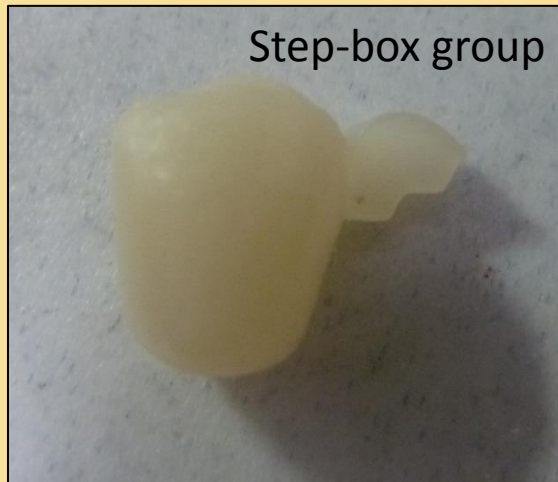
Abutment



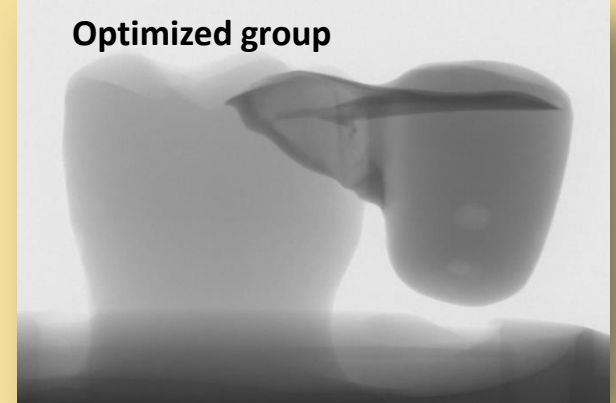
Optimized group



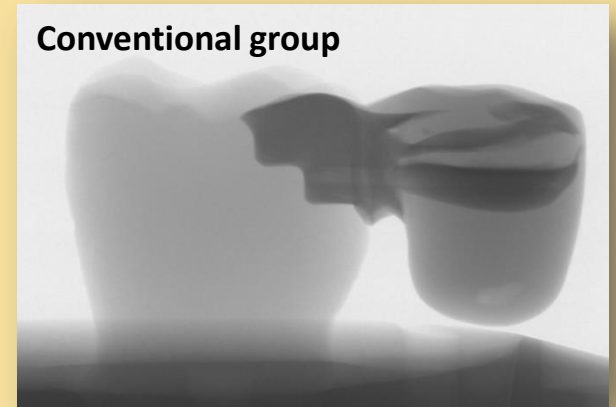
Step-box group



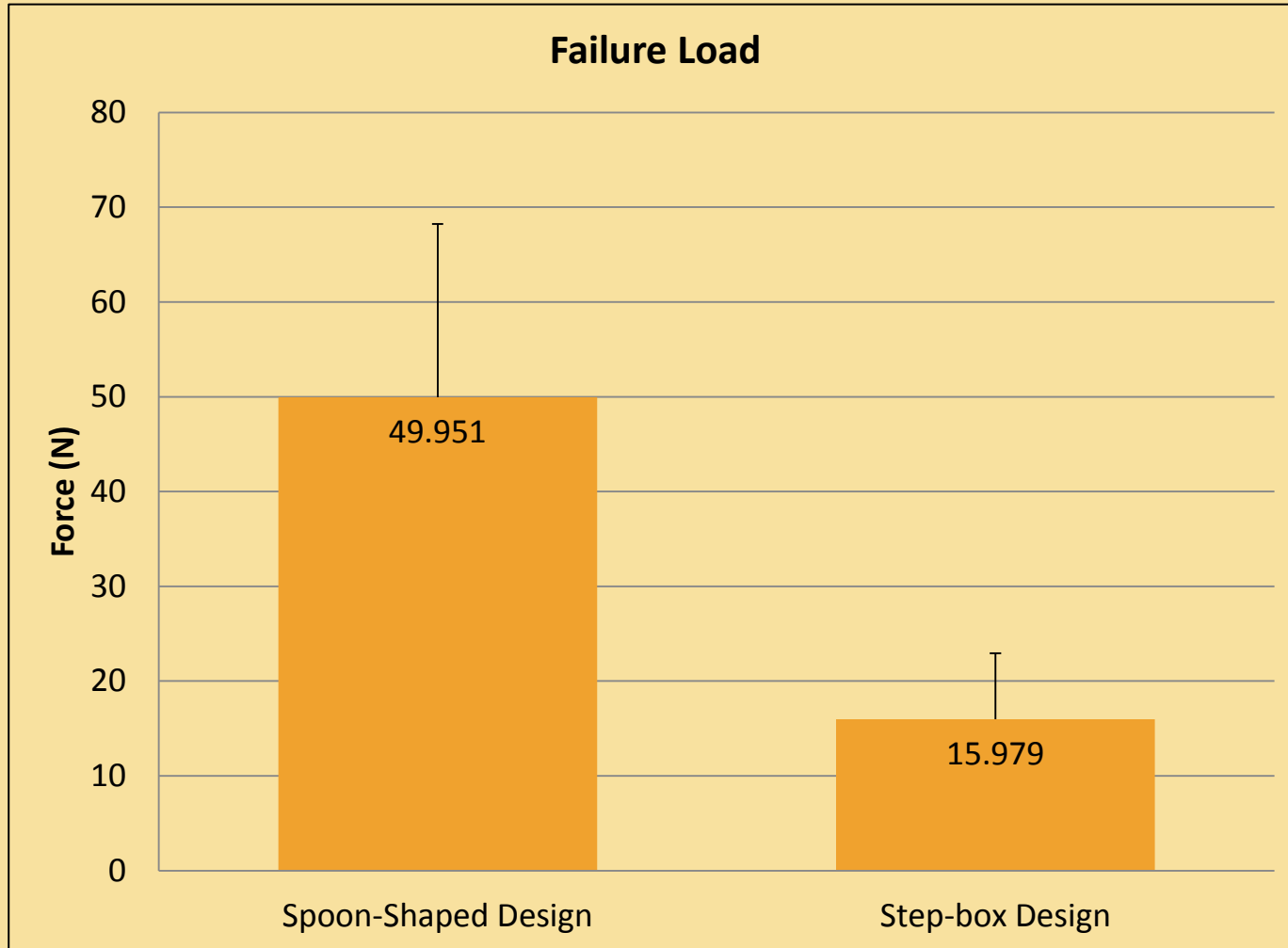
Optimized group



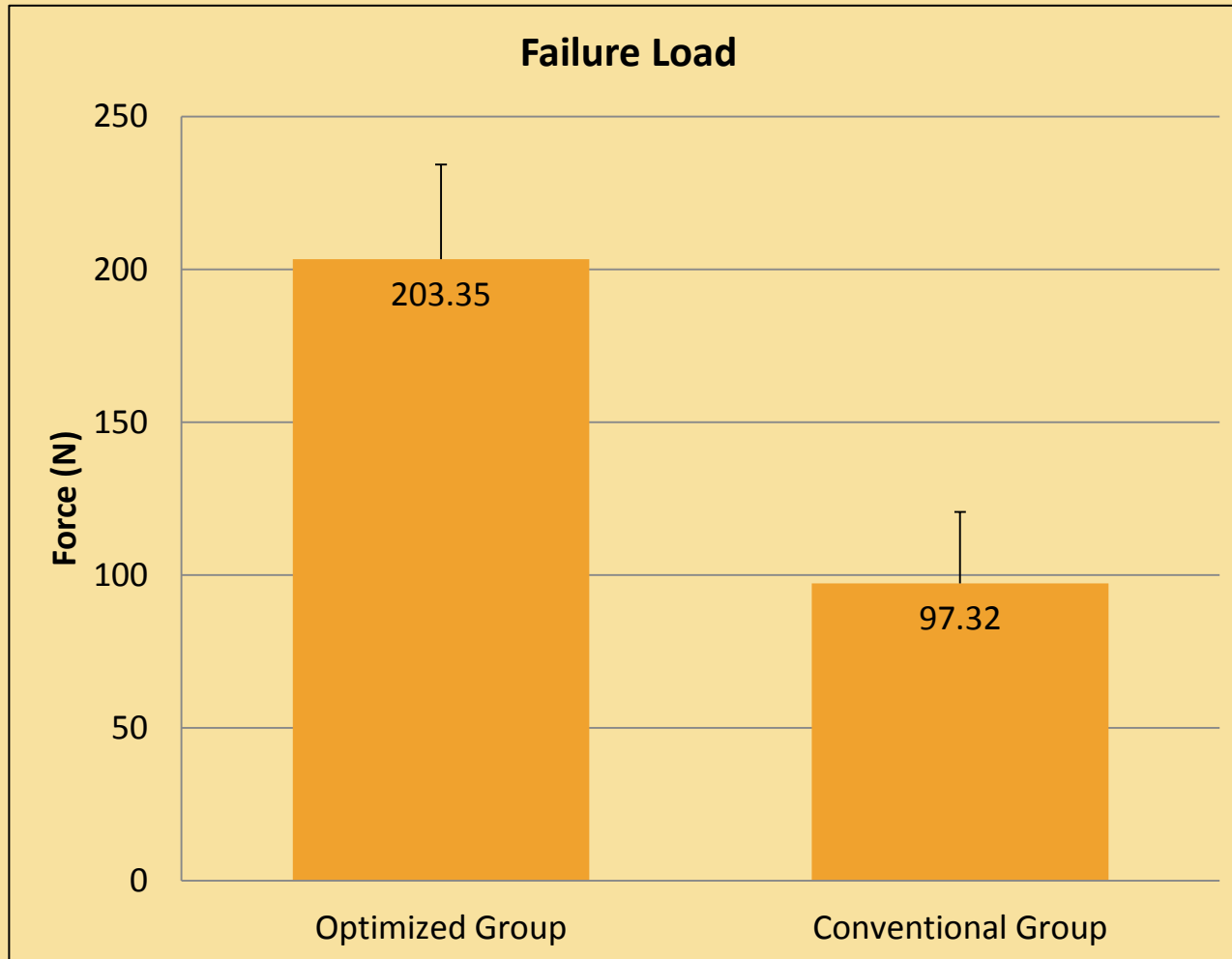
Conventional group



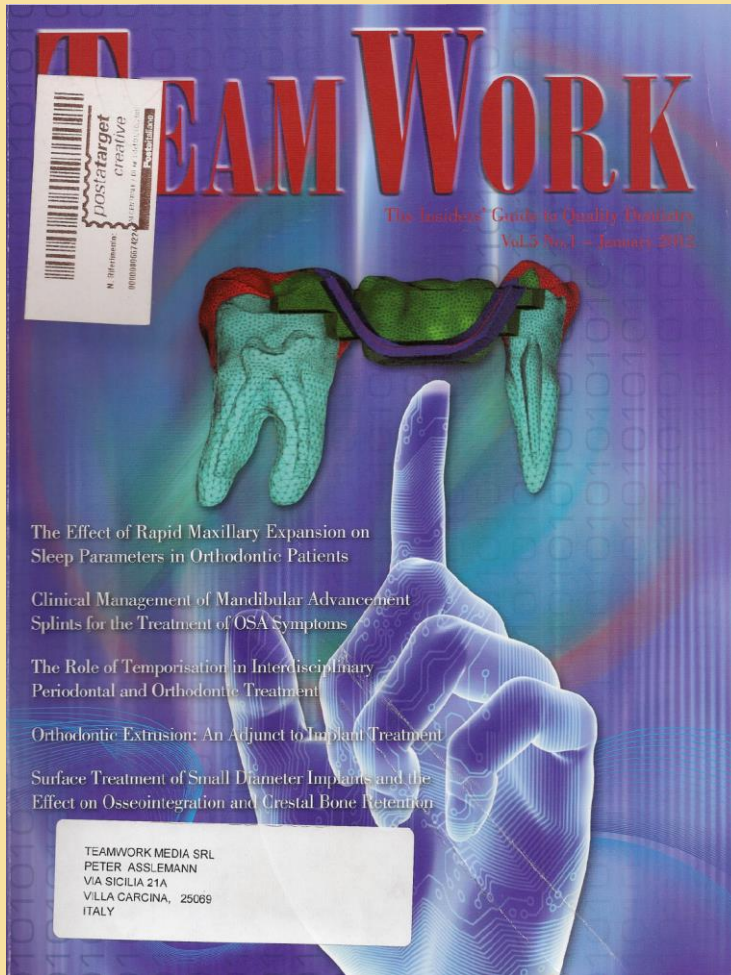
Performance without fiber reinforcement



Performance with fiber reinforcement



Translation to clinical practice



Courtesy of Gerardo Sacco, Bari, Italy



Isambard Kingdom Brunel



Clifton suspension bridge

