Bonding to alloys and ceramics in adhesive prosthodontics

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Science of Adhesive Cementation

- Advantages of adhesive cementation
- How successfully bonding to metal- and all-ceramic restorations
- Clinical outcome of all-ceramic restorations
- Future developments

Chemistry of conventional acid-based cements

- Zinc oxide eugenol
- Zinc phosphate
- Eugenol
- Carboxylate
- Zinc oxide
- Diluted phosphoric acid
- Silicate
- Aluminum silicate glass
- Glass ionomer
Retention of cemented crowns in relation to convergence angle of the preparation

Retention [in g/mm²]

Convergence angle [in degrees]

0 5 10 15 20 25 30 35 40 45 50

Smooth surface • Rough surface

Retention [in kg]

0,2 0,4 0,6 0,8 1

Fracture strength of all-ceramic table tops luted with Variolink II after chewing simulation

Fracture strength [N]

0 500 1000 1500 2000 2500 3000 3500 4000

Empress Esthetic e.max Press

**Bonding versus Conventional Cementation**

- **Pro Bonding**
  - No or limited mechanical retention
    - e.g. resin-bonded retainer
  - Moisture control ensured
  - Restoration margins visible or risk of visibility in the future
  - Time and costs of less concern

- **Pro Cementation**
  - Adequate mechanical retention
    - e.g. full crown
  - Moisture control compromised
  - Restoration margins not visible and no risk of visibility in the future
  - Time and costs of concern

**Adhesive Cementation**

**Advantages**
- Minimal invasive techniques
  - often only minimal abutment preparation needed
- Improved esthetics
  - bonding ceramics without visible cementation line
- Stabilization of the tooth structure & restoration
  - strengthening of the restored tooth through a strong bond between the restoration and the tooth structure
- Less secondary caries
  - gap-free restoration margins

**Fracture strength of crowns (incisors)** (cemented or resin-bonded)

![Graph showing fracture strength in N for different materials and studies.](image)
Fracture strength of crowns (incisors) (cemented or resin-bonded)

Mirage ceramic premolar crowns axially loaded

- Zinc phosphate cement
- Composite resin
- Composite resin + dentin adhesive
- Composite resin + dentin adhesive; ceramic silanated

Burke 1995, Quintessence Int 26:293.

Mechanical retention versus bonded sealing

Havard Cement


Mechanical retention versus bonded sealing

Microleakage of all-ceramic crowns after chewing simulation

Microleakage Scores

Havard Cement Dyract Cem Panavia F

Tooth/Cem. Rest./Cem.


Microleakage of all-ceramic crowns after thermal cycling

Microleakage Scores

Havard Cement Dyract Cem Panavia F


Resin bonding all-ceramic restorations

Problems:

- Limited indications
- Higher treatment costs
- Handling highly technique sensitive
- Long-term prognosis of new bonding systems uncertain until scientific data is available
### In vivo factors influencing adhesive bonds negatively

- Mechanical loading
- Water sorption of the resins
- Temperature changes (thermal cycling)

![In-vitro testing diagram](image)

- Thermocycling
- Tensile test after 3 days

### Acid-etch technique

_Buonocore, M.G._:

A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces.

*J Dent Res 34, 849-853 (1955).*
Resin bond strength to human enamel

= golden standard


Panavia 21

Panavia EXTwinlock

Tensile test

1 d/0 TC

150 d/37.500 TC

Resin bond strength to tooth structure

Enamel (acid-etching)

Dentin (ED Primer)

Panavia F

Panavia (auto)

Panavia (dual)

Panavia 21

Dentin (ED Primer)

3 d/0 TC

150 d/37.500 TC


Resin bond strength to tooth structure

– self-etching resin

Enamel

Dentin

Acid-etch Panavia 21

Self-etch X (auto)

Self-etch X (dual)

Self-etch Panavia 21

ED Primer X (auto)

ED Primer X (dual)

Kern et al. 2003, unpublished data.
Resin bond strength to human regional dentin

Microtensile test after 1-3 days

![Graph showing resin bond strength to different dentin layers](image)


Hybrid layer of various luting resins


![Images of various luting resins](image)

Bonding to dentin with a so-called self-adhesive luting resin

Tensile test

![Graph showing tensile strength of luting resins under different conditions](image)

Resin-bonding to metals

Macro-mechanical
- retentions of various kinds

Micro-mechanical
- sandblasting
- electrolytical & chemical etching

Mechano-chemical (sandblasting always 1st step)
- silica coating & silanating
- tin plating
- adhesive monomers
- acrylizing

Mechano-chemical bonding methods to metals

- Silica coating
  + Silicoater / Silicoater MD / Siloc
  + Rocatec
- Tin plating
  + OVS system
  + Kura Ace
- Adhesive monomers
  + Phosphate monomer
  + Metal primers
- Acrylizing
  – Kevloc

Resin bond strength to base alloys
(NiCr, Wiron 99, Bego, Bremen)

![Graph showing resin bond strength to base alloys](image)
Monobond Plus vs Alloy Primer


Recommended methods

<table>
<thead>
<tr>
<th>Functional steps</th>
<th>Noble alloys</th>
<th>Base alloys</th>
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<tbody>
<tr>
<td>Cleaning, chemical activation &amp; rouhening</td>
<td>Sandblasting 50-110 µm at 2.5 MPa, i.e. 36 PSI</td>
<td>Sandblasting 50-110 µm at 2.5 bar, i.e. 36 PSI</td>
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<tr>
<td>Chemical bonding</td>
<td>Silica coating &amp; silanating or Priming (e.g. Monobond Plus)</td>
<td>Phosphate monomer containing primers or luting resins (e.g. Monobond Plus or Panavia)</td>
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<td>Luting</td>
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Composition of dental silicate ceramics

<table>
<thead>
<tr>
<th></th>
<th>Feldspatic ceramic</th>
<th>Dicor</th>
<th>Empress</th>
<th>Optec HSP</th>
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<td>SiO₂</td>
<td>58-73</td>
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<td>Al₂O₃</td>
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<td>10-14</td>
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<td>MgO</td>
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## Composition of dental silicate ceramics

<table>
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<tr>
<th></th>
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<th>In-Ceram Alumina</th>
<th>Procera Al-Cubes</th>
<th>Cerapost Cosmopost DCS</th>
<th>Zirkon Lava</th>
<th>e.max ZirCAD</th>
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<td>Al$_2$O$_3$</td>
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<td>99.9</td>
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## Resin-bond to dental ceramics

### Silicate ceramics
- Etching with hydrofluoric acid (or sandblasting)
- Silanating

![Silicate ceramics bonding](image)

**Resin bond to dental ceramics**

### High-strength oxide ceramics
- Not etchable with hydrofluoric acid
- Silane does not bond to oxides other than silica

![High-strength oxide ceramics bonding](image)
Resin-bond to dental ceramics

High-strength oxide ceramics
- Sandblasting
- Adhesive monomers (or silica coating & silanating)

Resin bond strength to sandblasted zirconia ceramic

Resin bond strength to the alumina ceramic with various surface treatments (Procera)
Influence of primers and air-abrasion on the resin bond strength zirconia ceramic

![Graph showing influence of primers and air-abrasion on resin bond strength zirconia ceramic.](image)

Surface roughness through air-abrasion

![Graph showing surface roughness through air-abrasion.](image)

Resin bond strength of Multilink Automix to ceramics

![Graph showing resin bond strength of Multilink Automix to ceramics.](image)
Bonding to air-abraded zirconia ceramic (e.max ZirCAD) using different conditioning methods

<table>
<thead>
<tr>
<th>Tensile bond strength of Multilink Automix</th>
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<tbody>
<tr>
<td>Gained by airblasting</td>
<td>Cleaned ultrasonically in alcohol</td>
<td>Cleaned by airblasting</td>
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Bonding to dental ceramics

Recommended methods

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<th>Functional steps</th>
<th>Silicate ceramics</th>
<th>High-strength oxide ceramics</th>
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<td>Cleaning</td>
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<td>Chemical activation &amp; rouhening</td>
<td>Hydrofluoric acid etching</td>
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<td>Chemical bonding</td>
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<td>Phosphate monomer containing primer or luting resin (e.g. Monobond Plus or Panavia)</td>
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<tr>
<td>Luting</td>
<td>Any luting resin</td>
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Cleaning of acid-etched lithium disilicate ceramic (e.max Press) after contamination with saliva & silicone

<table>
<thead>
<tr>
<th>Tensile bond strength of Monobond S/Multilink Automix</th>
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<tbody>
<tr>
<td>Alcohol</td>
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<td>MPa 30</td>
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Cleaning of air-abraded zirconia ceramic after contamination with fit checker/saliva

Tensile bond strength of Panavia F 2.0

Tensile bond strength of Panavia 21

Failure rates of glass-ceramic crowns in relation to location and cementation

<table>
<thead>
<tr>
<th>First author</th>
<th>N</th>
<th>Ceramic</th>
<th>Time (months)</th>
<th>Failure rates in %</th>
<th>Cement</th>
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<tr>
<td>Hankinsson 1994</td>
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<td>110</td>
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<td>36</td>
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</table>

*8.8% veneering ceramic chipping **replaced because of core fracture or chipping
Failure rates of crowns made from alumina based ceramics

<table>
<thead>
<tr>
<th>First author</th>
<th>N</th>
<th>Ceramic</th>
<th>Time (months)</th>
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<td>Odén 1998</td>
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<td>Walter 2008</td>
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<td>24</td>
<td>-</td>
<td>9</td>
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Failure rates of crowns made from zirconia ceramics

<table>
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<th>First author</th>
<th>N</th>
<th>Ceramic</th>
<th>Time (months)</th>
<th>Failure rates in %</th>
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<td>205</td>
<td>Lava/Procera</td>
<td>60</td>
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Only few framework fractures, 5% - 25% chipping of the veneering ceramic.

*Feather-edged marginal preparation

Fatigue fracture resistance of all-ceramic fixed dental prostheses

- Decreasing after dynamic loading
- Lower with lower fracture toughness
- Often only 50% of the initial fracture resistance (static fracture strength)
- Decreasing with increasing abutment mobility
### Failure rates of crown-retained all-ceramic FDPs

#### In-Ceram alumina and Empress 2

<table>
<thead>
<tr>
<th>First author</th>
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(C = conventional cementation, A = adhesive cementation. Additional fractured veneers (repairable). Recommended connector dimensions not always obtained)

### Failure rates of crown-retained all-ceramic FDPs

#### In-Ceram zirconia, zirconia ceramics and e.max Press

<table>
<thead>
<tr>
<th>First author</th>
<th>N</th>
<th>Ceramic</th>
<th>Time (months)</th>
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<td>Cercon</td>
<td>40</td>
<td>-</td>
<td>9.5</td>
</tr>
<tr>
<td>Uschbach 2009</td>
<td>85</td>
<td>In-Ceram Z</td>
<td>54</td>
<td>-</td>
<td>3.1</td>
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<tr>
<td>Sommer 2008</td>
<td>45</td>
<td>Procera Z</td>
<td>72</td>
<td>-</td>
<td>0</td>
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<tr>
<td>Sax 2011</td>
<td>41</td>
<td>DCM</td>
<td>128</td>
<td>-</td>
<td>33.8</td>
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<tr>
<td>Naugel 2012</td>
<td>15</td>
<td>Lava</td>
<td>60</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Schmidt 2012</td>
<td>25</td>
<td>Lava</td>
<td>60</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Kim 2012</td>
<td>30</td>
<td>e.max Press</td>
<td>120</td>
<td>0</td>
<td>12.1</td>
</tr>
<tr>
<td>Rink 2013</td>
<td>30</td>
<td>Cercon</td>
<td>84</td>
<td>-</td>
<td>16</td>
</tr>
</tbody>
</table>

(C = conventional cementation, A = adhesive cementation. 5% - 25% chipping of the veneering ceramic. 20% - 5% failures related to framework fracture)

## Worldwide first clinical study reporting long-term outcome of zirconia ceramic FDPs after 10 years

**Sax, C., Hämmerle, C.H.F., Sailer, I.:**

10-year clinical outcomes of fixed dental prostheses with zirconia framework.

Prospective clinical study at Kiel University with all-ceramic fixed dental prostheses (FDPs)

- **36 fixed dental prostheses**
  - 6 anterior FDPs
  - 30 posterior FDPs
  - Full crown abutments
  - Experimental lithium disilicate glass-ceramic (e.max press, Ivoclar-Vivadent)

- **Patient acquirement**
  - Start in 2/2000
  - End in 1/2001
  - Status 4/2011


---

Prospective clinical study at Kiel University with all-ceramic fixed dental prostheses (FDPs)

- **Preparation**
  - 0.8 mm circumferential reduction
  - 1.5 mm occlusal reduction
  - Chamfer or shoulder preparation

- **Connector dimensions**
  - Anterior 4 mm in height and 3 mm in width (12 mm²)
  - Posterior 4 mm in height and 4 mm in width (16 mm²)

- **Staining technique**

---

Prospective clinical study at Kiel University with all-ceramic fixed dental prostheses (FDPs)

- **Cementation**
  - 19 conventionally with glass-ionomer cement
  - 17 adhesively with composite resin (Syntac classic/Variolink II)
Prospective clinical study at Kiel University with all-ceramic fixed dental prostheses (FDPs)

**Results**
- Service time 79-133 months
- 2 connector fractures in 7th year, 1 fracture in 10th year (fracture rate 8.3%)
- Ceramic chipping in 5 restorations
- Loss of retention in 3 restorations, which were re-cemented
- Endodontic treatment in 2 cases

---

Survival rate according to Kaplan-Meier

- Failure due to ceramic fracture
- All failures
- DCM-Zirkon (Sax et al. 2011)
**Prospective clinical study at Kiel University with all-ceramic fixed dental prostheses (FDPs)**

**Complications according to Kaplan-Meier**

![Graph showing Kaplan-Meier survival analysis](image)


**Failure rates of all-ceramic FDPs retained by resin-bonded retainer wings or inlays**

<table>
<thead>
<tr>
<th>First author</th>
<th>Retainer</th>
<th>N</th>
<th>Ceramic</th>
<th>Time (months)</th>
<th>Failure rates in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunsfahrt 1995</td>
<td>2 wings</td>
<td>19</td>
<td>Optec HSP</td>
<td>34</td>
<td>5.3</td>
</tr>
<tr>
<td>Edelhoff 2002</td>
<td>2 wings</td>
<td>15</td>
<td>Empress 2</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>Ries 2006</td>
<td>2 wings</td>
<td>17</td>
<td>Empress 2 or e.max press</td>
<td>21</td>
<td>59.7</td>
</tr>
<tr>
<td>Ries 2006</td>
<td>1 wing</td>
<td>21</td>
<td>e.max press</td>
<td>15</td>
<td>9.1</td>
</tr>
<tr>
<td>Ohmann 2008</td>
<td>2 inlays or inlay &amp; crown</td>
<td>30</td>
<td>e.maxZirCAD</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Harder 2010</td>
<td>2 inlays</td>
<td>10</td>
<td>e.max press</td>
<td>70</td>
<td>55.6</td>
</tr>
<tr>
<td>Abou Tara 2011</td>
<td>2 inlays with add. wings</td>
<td>23</td>
<td>In-Ceram YZ</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Kern 2011</td>
<td>2 wings</td>
<td>10</td>
<td>In-Ceram Al or e.max press</td>
<td>120</td>
<td>26.1</td>
</tr>
<tr>
<td>Kern 2011</td>
<td>1 wing</td>
<td>21</td>
<td>In-Ceram Zr</td>
<td>100</td>
<td>5.5</td>
</tr>
<tr>
<td>Loeske 2012</td>
<td>1 wing</td>
<td>30</td>
<td>e.max ZirCAD</td>
<td>42</td>
<td>0</td>
</tr>
</tbody>
</table>

**Prospective clinical study at Kiel University with inlay-retained fixed dental prostheses (FDPs)**

- 45 inlay-retained FDPs
  - Posterior FDPs
  - Lithiumdisilicate glass-ceramic (E.max press, Ivoclar-Vivadent) made in full press & staining technique

**Results**

- Service time 20-120 months
- 25 total failures (55.6% failures)
  - 17x fractures
  - 6x loss of retention
  - 2x combinations
- 1 pulpitis, restoration retained

Survival rate (Kaplan-Meier)

Conclusion:
In adequate method!

Modified design of inlay-retained FDPs
Zirconia ceramics with small retainer wings

Prospective clinical study at Kiel University with inlay-retained fixed dental prostheses (FDPs)

● Survival rate (Kaplan-Meier)

Conclusion:
In adequate method!

Modified design of inlay-retained FDPs
Zirconia ceramics with small retainer wings

Prospective clinical study at Kiel University with inlay-retained FDPs in the new design

● 23 inlay-retained posterior FDPs with add. retainer wings
  – 18 replaced molars
  – 5 replaced premolars
  – Zirconia ceramic (In-Ceram YZ-Cubes, Vita)
  – Luted adhesively (Panavia 21 TC)

● Results (Status 3/2010)
  – Mean service time 20 months
  – No major failures
  – 1 x loss of retention
  – 2 x chipping of the veneering ceramic
  – No biological failures

**Maryland type all-ceramic FDPs**

**Advantages**
- No greyish shine-through of the metal framework
- Visible framework parts might be esthetically acceptable
- Transparent, tooth-colored luting resins may be used
- Rigidity of the framework

**Resin-bonded all-ceramic FDPs**
- one retainer design

**Advantages**
- Minimal invasive
- No parallel preparation needed
- Physiological tooth mobility

**Disadvantages**
- Limited fracture strength
- Possibility of abutment tooth migration
- Long-term clinical outcome?

**Survival rate of In-Ceram resin-bonded Maryland type FDPs**

Criterion: Restoration in situ and no fracture

![Survival Rate Graph](image)
Survival rate of In-Ceram resin-bonded Maryland type FDPs

Criterion: Restoration in situ (in part with unilateral fracture)

<table>
<thead>
<tr>
<th>Observation time [months]</th>
<th>Survival rate</th>
<th>two retainers (N=16)</th>
<th>one retainer (N=22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>100%</td>
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<tr>
<td>48</td>
<td>80%</td>
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</tr>
<tr>
<td>72</td>
<td>60%</td>
<td></td>
<td></td>
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<tr>
<td>96</td>
<td>40%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>20%</td>
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<td></td>
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<tr>
<td>144</td>
<td>0%</td>
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<td>168</td>
<td>0%</td>
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<tr>
<td>192</td>
<td>0%</td>
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<td></td>
</tr>
<tr>
<td>216</td>
<td>0%</td>
<td></td>
<td></td>
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<tr>
<td>240</td>
<td>0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Survival rate of InCeram resin-bonded Maryland type FDPs

Fracture strength of all-ceramic resin-bonded FDPs

Study design

- Caries-free abutment teeth with artificial periodontal membrane
- Fabrication with Celay copy-milling technique
  - Pontic width in maxilla: 8.5 mm
  - Pontic width in mandible: 5.5 mm
  - Height of the connector: 3.0 mm
  - Diameter of the connector: 1.5 mm
  - Thickness of the retainer wing: 0.5 mm
- Evaluation of influence of the retainer number

Fracture strength of all-ceramic resin-bonded FDPs

![Fracture strength graph](image)
Preparation for retainer wings

Metal ceramic
- C – Chamfer
- G – Grove
- P – Pinhole
- S – Shoulder

All-ceramic
- C – Chamfer
- B – Box
- P – Pinhole
- S – Shoulder


Preparation for retainer wings

30 single retainer resin-bonded FDPs
- Maxilla (N=19)
  - 15 lateral incisivi
  - 4 central incisivi
- Mandible (N=11)
  - 4 laterale incisivi
  - 7 central incisivi
- Connector size
  - 3 mm height and 2 mm width
- Bonding systems (randomization)
  - Multilink Automix/Metal Zirconia Primer (N=14)
  - Panavia 21 TC (N=16)

Results
- Mean service time: 41.7 months (Update 12-2012: 51.9 months)
- One debonding caused by trauma in each group


Prospective clinical study at Kiel University with zirconia ceramic RBFDPs
<table>
<thead>
<tr>
<th>Future developments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Restorative goals</strong></td>
</tr>
<tr>
<td>▪ Minimal invasive</td>
</tr>
<tr>
<td>▪ Highly esthetic</td>
</tr>
<tr>
<td>▪ Biocompatible</td>
</tr>
<tr>
<td>▪ Cost reduction</td>
</tr>
<tr>
<td>▪ Proven longevity</td>
</tr>
</tbody>
</table>