Bonding to alloys and ceramics in adhesive prosthodontics

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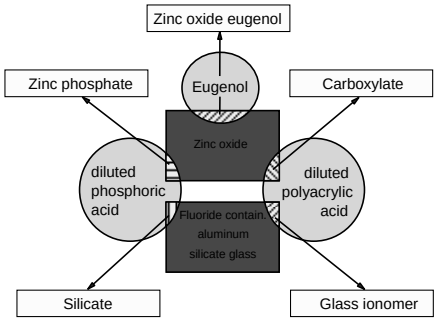
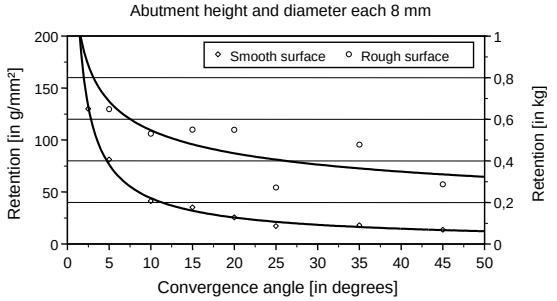
Science of Adhesive Cementation

- **A**dvantages of adhesive cementation
- **H**ow successfully bonding to metal- and all-ceramic restorations
- **C**linical outcome of all-ceramic restorations
- **F**uture developments

Chemistry of conventional acid-based cements

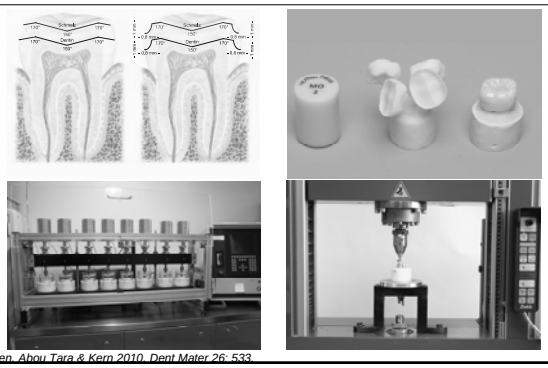


Retention of cemented crowns in relation to convergence angle of the preparation



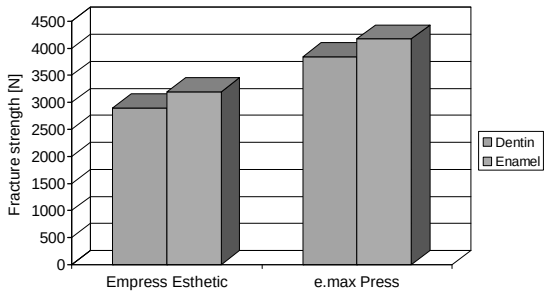
Jørgensen 1955,
Acta Odontol Scand 13:35.

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



Clausen, Abou Tara & Kern 2010, Dent Mater 26: 533.

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



Clausen, Abou Tara & Kern 2010, Dent Mater 26: 533.

Bonding versus Conventional Cementation

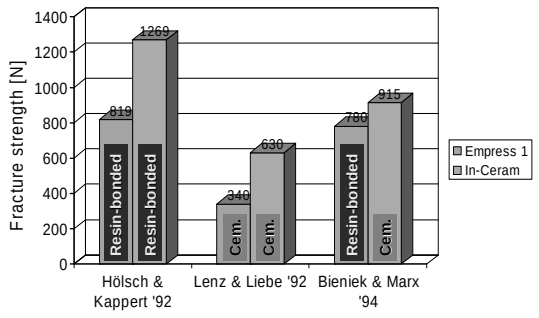
- Pro Bonding
  - No or limited mechanical retention
    - e.g. resin-bonded retainer
  - Moisture control ensured
  - Restoration margins visible or risk of visibility in the future
  - Time and costs of less concern
- Pro Cementation
  - Adequate mechanical retention
    - e.g. full crown
  - Moisture control compromised
  - Restoration margins not visible and no risk of visibility in the future
  - Time and costs of concern

Adhesive Cementation

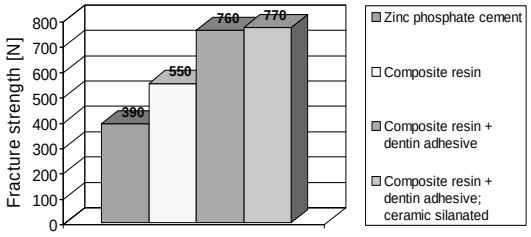
Advantages

- 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)

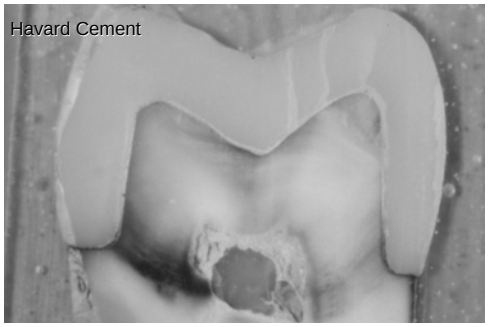


Fracture strength of crowns (incisors) (cemented or resin-bonded)



Burke 1995, Quintessence Int 26:293.

Mechanical retention versus bonded sealing

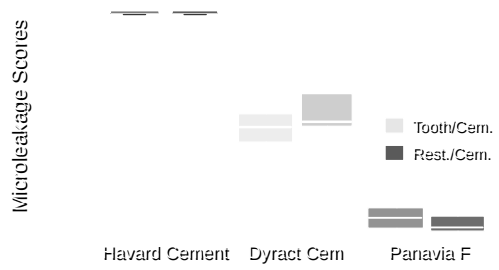


Gu & Kern 2003, Int J Prosthodont 16:109.

Mechanical retention versus bonded sealing

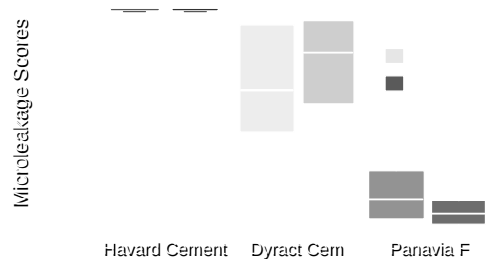
Gu & Kern 2003, Int J Prosthodont 16:109.

Microleakage of all-ceramic crowns after chewing simulation



Gu & Kern 2003, Int J Prosthodont 16:109.

Microleakage of all-ceramic crowns after thermal cycling



Gu & Kern 2003, Int J Prosthodont 16:109.

Resin bonding all-ceramic restorations

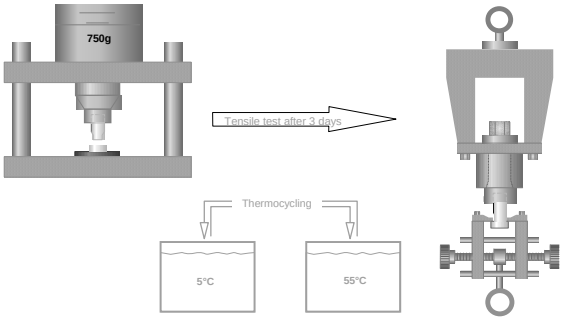
Problems:

- ➔ 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



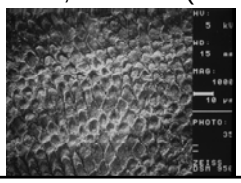
Kern & Thompson 1993, Dtsch Zahnärztl Z 48:769.

Acid-etch technique

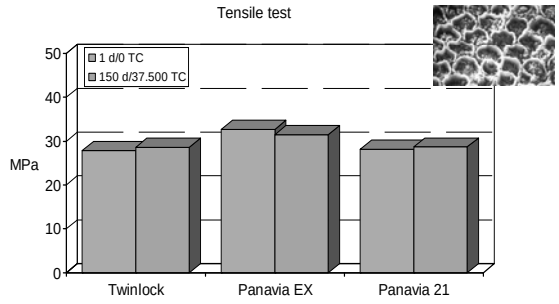
Buonocore, M.G.:

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

J Dent Res 34, 849-853 (1955).

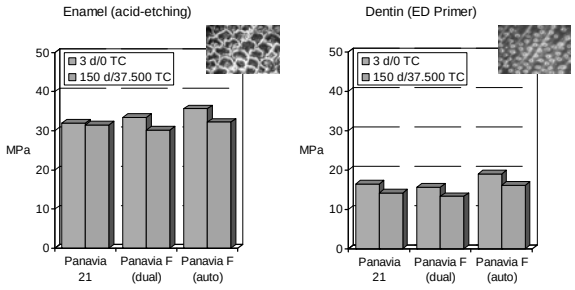


Resin bond strength to human enamel = golden standard



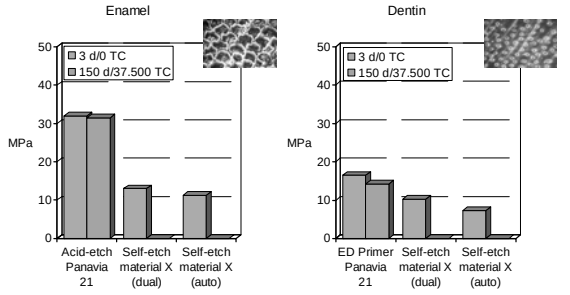
Kern 1994.

Resin bond strength to tooth structure



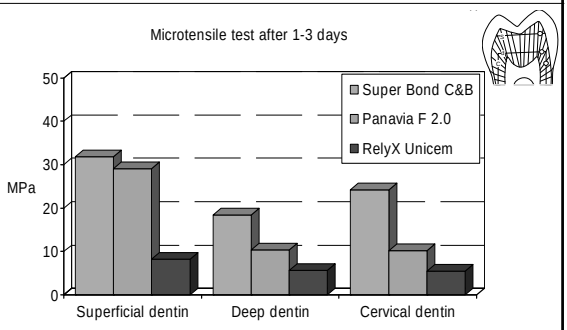
Frenzel & Kern 2001, J Dent Res 80:706.

Resin bond strength to tooth structure – self-etching resin



Kern et al. 2003, unpublished data.

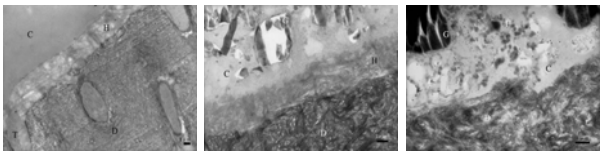
Resin bond strength to human regional dentin



Yang, Ludwig, Adelung & Kern 2006, Dent Mater 22:45.

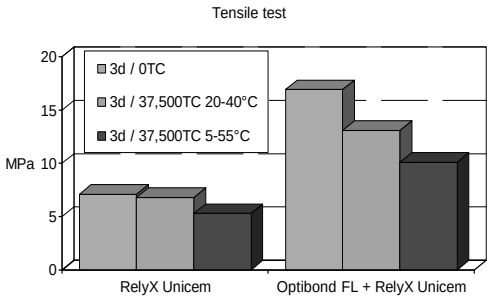
Hybrid layer of various luting resins

Yang, B., Ludwig, K., Adelung, R., Kern, M.:
Micro-tensile bond strength of three luting resins to human regional dentine.
Dent Mater 22, 45-56 (2006).



Super Bond C&B | Panavia F 2.0 | RelyX Unicem

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

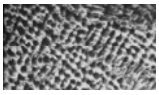


Brunzel, Yang, Wolfart & Kern 2010, J Adhes Dent 12:143.

Resin-bonding to metals

Macro-mechanical
- retentions of various kinds

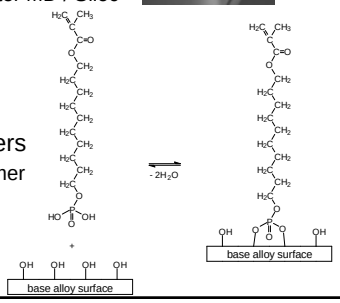
Micro-mechanical
- sandblasting
- electrolytical & chemical etching



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

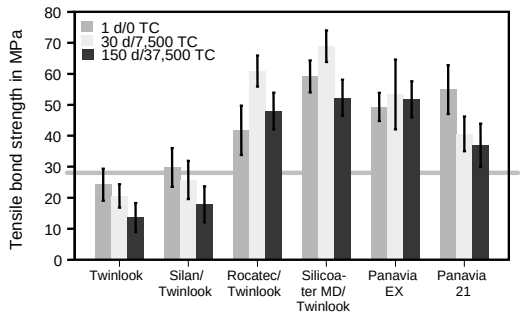
Mechano-chemical bonding methods to metals

- 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)



Kern & Thompson 1994, Dent Mater 10:19.

Resin bond strength to base alloys

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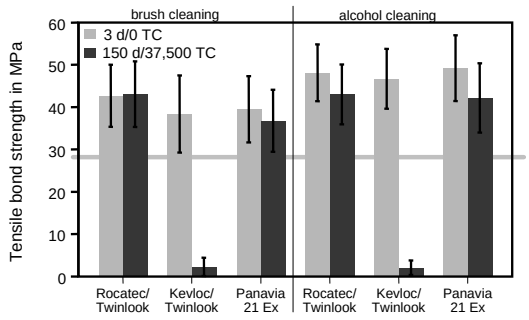
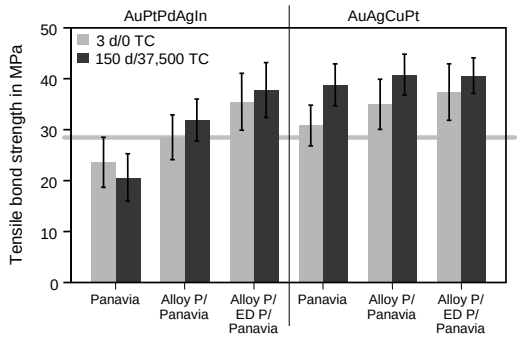


Ouaas et al. 2005, Dent Mater 21:192.

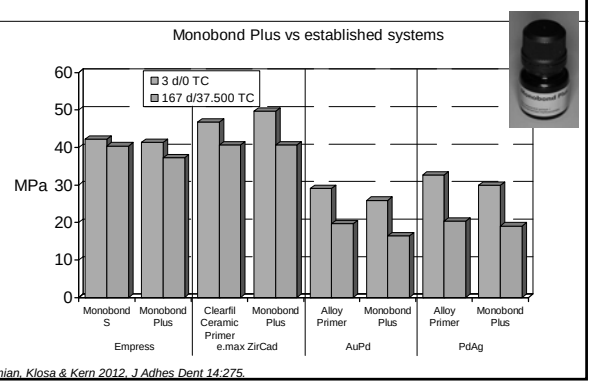
Resin bond strength to noble alloys

(Herador NH & BioMaingold SG, Heraeus Kulzer, Hanau)



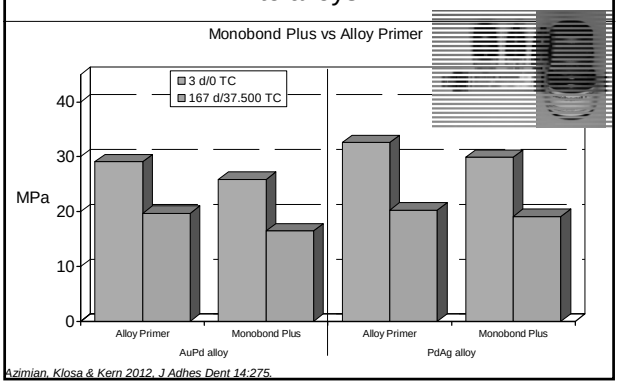
Antoniadou, Kern et al. 2000, J Prosthet Dent 84:554.

Resin bond strength of Multilink Automix to alloys



Azimian, Klosa & Kern 2012, J Adhes Dent 14:275.

Resin bond strength of Multilink Automix to alloys



Azimian, Klosa & Kern 2012, J Adhes Dent 14:275.

Bonding to dental alloys

Recommended methods

Functional steps	Noble alloys	Base alloys
Cleaning, chemical activation & rouhening	Sandblasting 50-110 µm at 2.5 MPa, i.e. 36 PSI	Sandblasting 50-110 µm at 2.5 bar, i.e. 36 PSI
Chemical bonding	Silica coating & silanating *or* Priming (e.g. Monobond Plus)	Phosphate monomer containing primers or luting resins (e.g. Monobond Plus or Panavia)
Luting	Any luting resin	

Kern 2012.

Composition of dental silicate ceramics

in wt%

	Feldspathic ceramic	Dicor	Empress	Optec HSP	e.max Press
SiO_2	58-73	55-65	59-63	55-65	57-80
Al_2O_3	11-17	0-2	19-23	16-20	0-5
NaO	2-10	-	3-7	-	-
K_2O	6-20	-	10-14	12-20	0-13
MgO	0-2	14-19	0	0.5-5	0-5
Li_2O	0-5	0	0	1-5	11-19
others	0-3	0-7	0-4	0-4	0-11

Various sources

Composition of dental silicate ceramics

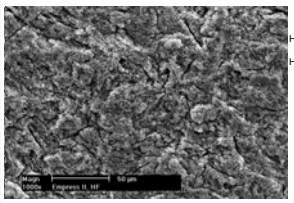
in wt%

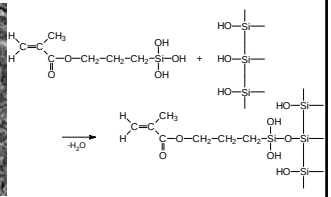
	In-Ceram Alumina	In-Ceram Alumina	Procera Al-Cubes	Cerapost Cosmopost DCSZirkon	e.max ZirCAD Lava …
SiO_2	4-5	3-4	-	-	-
Al_2O_3	82	57	99.9	-	-
ZrO_2	-	26	-	95-96	95-97
Y_2O_3	-	-	-	3-5	3-5
La_2O_3	12	7	-	-	-
others	1-2	6-7	0.1	<0.005	<0.005

Various sources

Resin-bond to dental ceramics

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

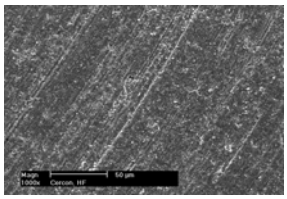


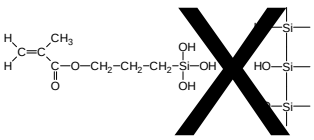


Kern 2009, J Adhes Sci Technol 23:1097.

Resin-bond to dental ceramics

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

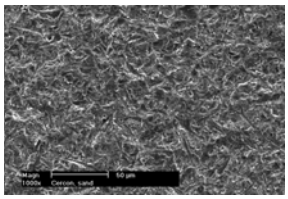


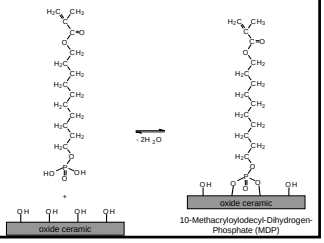


Kern 2009, J Adhes Sci Technol 23:1097.

Resin-bond to dental ceramics

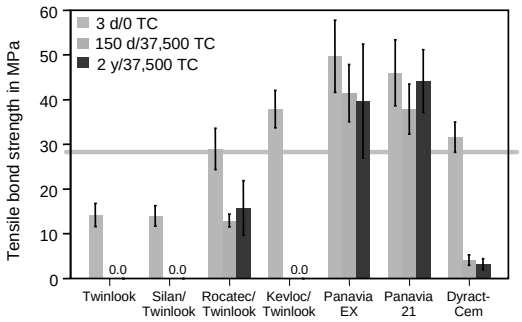
High-strength oxide ceramics
- Sandblasting
- Adhesive monomers (or silica coating & silanating)





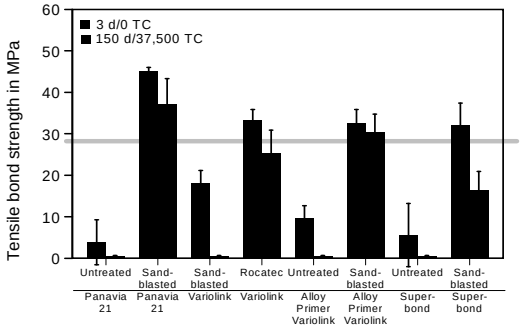
Kern 2009, J Adhes Sci Technol 23:1097.

Resin bond strength to sandblasted zirconia ceramic



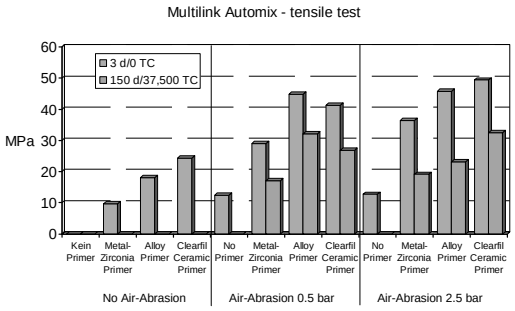
Kern & Wegner 1998, Dent Mater 14:64; Wegner & Kern 2000, J Adhes Dent 2:139.

Resin bond strength to the alumina ceramic with various surface treatments (Procera)



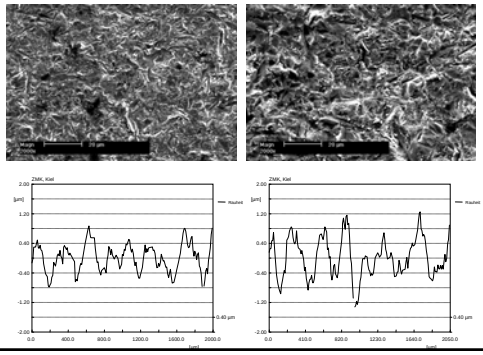
Hummel & Kern 2004, Dent Mater 20: 498.

Influence of primers and air-abrasion on the resin bond strength zirconia ceramic

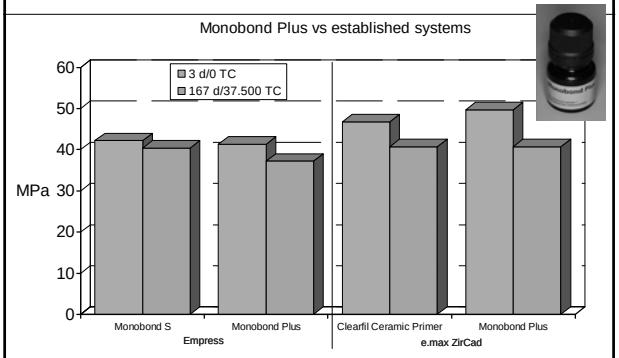


Kern, Barloi & Yang 2009, J Dent Res 88:817.

Surface roughness through air-abrasion



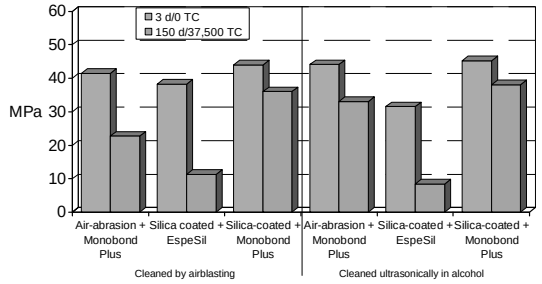
Resin bond strength of Multilink Automix to ceramics



Azimian, Klosa & Kern 2012, J Adhes Dent 14:275.

Bonding to air-abraded zirconia ceramic
(e.max ZirCAD) using different conditioning methods

Tensile bond strength of Multilink Automix



Attia & Kern 2011, J Prosthet Dent 106:319.

Bonding to dental ceramics

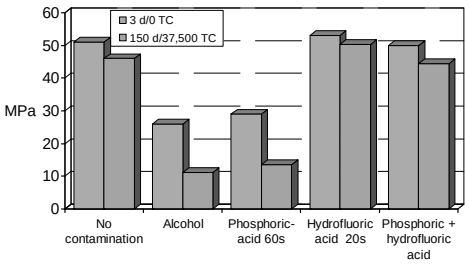
Recommended methods

Functional steps	Silicate ceramics	High-strength oxide ceramics
Cleaning	(Phosphoric acid etching)	Sandblasting 50-110 µm at 0.5 - 2.5 bar, i.e. 7.2 - 36 PSI
Chemical activation & rouhening	Hydrofluoric acid etching	
Chemical bonding	Silanating	Phosphate monomer containing primer or luting resin (e.g. Monobond Plus or Panavia)
Luting	Any luting resin	

Kern 2009, J Adhes Sci Technol 23:1097.

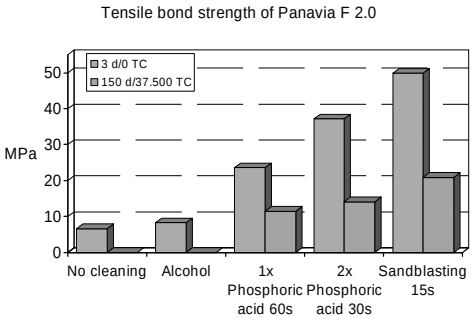
Cleaning of acid-etched lithium disilicate ceramic
(e.max Press) after contamination with saliva & silicone

Tensile bond strength of Monobond S/Multilink Automix



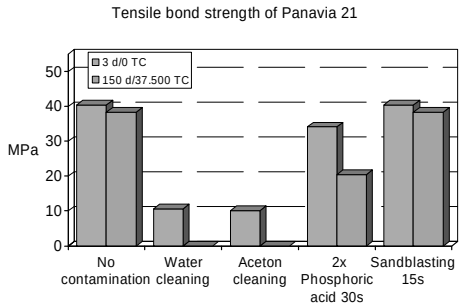
Klosa, Wolfart, Lehmann, Wenz & Kern 2009, J Adhes Dent 11:127.

Cleaning of air-abraded zirconia ceramic after contamination with fit checker/saliva



Ouaas, Yang & Kern 2007, Dent Mater 23: 506.

Cleaning of air-abraded zirconia ceramic after contamination with fit checker/saliva



Yang, Wolfart, Scharnberg, Ludwig, Adelung & Kern 2007, J Dent Res 86:749.

Failure rates of glass-ceramic crowns

in relation to location and cementation

First author	N	Ceramic	Time (months)	Failure rates in %			Cement
				Ant.	PM	M	
Hankinson 1994	95	Optec	30	0	2.3	24.0	A
Lehner 1998	138	Empress 1	73	15.6	5.4	10.8	A
Malament 1999	1044	Dicor	168	5.8	10,8	29.0	A
Sjogren 1999	110	Empress 1	43	2.7	7.0	12.0	A
Fradeani 2002	125	Empress 1	132	1.1	15.6		A
Zimmer 2004	27	Empress 2	38	-	0	0	A
Kinnen 2006*	102	Empress 2	60	1.0			C/A
Böning 2006	39	e.max Press	36	0	0	7.7	C
Valenti 2009**	261	Empress 2	120	5.6	4.2		A
Fasbinder 2010	62	e.max CAD	24	0	0	0	A
Reich 2011	41	e.max CAD	36	-	2.5		A

*8.8% veneering ceramic chipping **replaced because of core fracture or chipping

Failure rates of crowns made from alumina based ceramics

in relation to location and cementation

First author	N	Ceramic	Time (months)	Failure rates in %			Cement
				Ant.	PM	M	
Pröbster 1996	95	In-Ceram A	30	0	1.5		C
Rinke 1997	457	In-Ceram A	72	5.0			C
Odén 1998	100	Procera	60	0	3.6	7.3	C
McLaren 2000	223	In-Ceram A	36	2.1	6.5	6.2	C
Haselton 2000	80	In-Ceram A	48	7.7			C
Odman 2001	87	Procera A	120	6.5			C
Segal 2001	546	In-Ceram A	12-70	1.1	0.8		C
Fradeani 2002	40	In-Ceram S	50	2.5	-		C
Bindl 2002	43	In-Ceram A/S	39	-	0	5.4	C
Fradeani 2005	205	Procera A	60	0	4.8		C
Galindo 2006	155	Procera A	55	0	1.2		C
Walter 2006	107	Procera A	72	3.3	8.7		C
Çehreli 2009	20	In-Ceram Zr	24	-	0		C

*6.7% veneering ceramic chipping

Failure rates of crowns made from zirconia ceramics

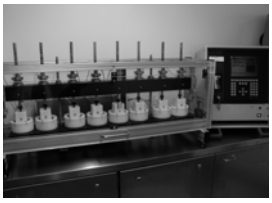
in relation to location and cementation

First author	N	Ceramic	Time (months)	Failure rates in %			Cement
				Ant.	Pm	M	
Kerschbaum 2009	815	Cercon	60	7.0			C/A
Çehreli 2009	20	Cercon	24	-	6.7		C
Barnes 2010	72	Cercon	48	9.7			C/A
Groten 2010	54	Cercon	24	2.0			c/A
Schmitt 2010*	19	Lava	39	0	-	-	C
Örtop 2012	205	NobleProcera	60	11.2			C/A

Only few framework fractures, 5 % - 25% chipping of the veneering ceramic.
*feather-edged marginal preparation

Fatique 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

in relation to location and cementation

First author	N	Ceramic	Time (months)	Failure rates in %			Cement
				Ant.	Pm	M	
Hüls 1995	44	In-Ceram Al	36-72	0	19.0		C
Sorensen 1998	61	In-Ceram Al	36	0	11	24	C
Tinschert 1999	18	In-Ceram Al	42	5.6	-	-	C
Pospiech 2000	51	Empress 2	24	0	9,1	25	A
Vult v. Steyern 2001	20	In-Ceram Al	60	-	0	22.2	C
Olsson 2003	42	In-Ceram Al	76	12			C
Zimmer 2004	31	Empress 2	38	27.6	-		A
Edelhoff 2005	43	Empress 2	52	27.2*°			C/A
Marquardt 2006	31	Empress 2	50	30*	-		A
Kinnen 2007	21	Empress 2	60	6.7			C/A
Makarouna 2011	18	Empress 2	72	37			C
Solá-Ruiz 2013	21	Empress 2	120	28.6		-	A

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

in relation to location and cementation

First author	N	Ceramic	Time (months)	Failure rates in %			Cement
				Ant.	Pm	M	
Edelhoff 2008	22	DigiZon	39	0*	0*	0*	C/A
Pospiech 2008	35	Lava	60	-	-	0*	C
Tinschert 2008	65	DCS	37	0*	0*		C/A
Wolfart 2008	24	Cercon	45	-	4*		C
Wolfart 2008	37	Cercon cantil.	46	-	8.1*°		C
Beuer 2009	21	Cercon	40	-	9.5		C
Eschbach 2009	65	In-Ceram Zr	54	-	-	3.1*	C
Sorrentino 2011	48	Procera Zr	72	-	0*		A
⇨ Sax 2011	41	DCM	128	-	33.0*°		A
Raigrodski 2012	20	Lava	60	-	10*		C
Schmitt 2012	25	Lava	60	-	8*		C
⇨ Kern 2012	36	e.max Press	121	0*	12.1*		C/A
Rinke 2013	99	Cercon	84	-	16.6*°		C

C=conventional cementation, A=adhesive cementation
*5 % - 25% chipping of the veneering ceramic °2.2 – 8.5 % 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.

Int J Comp Dent 14, 183-202 (2011).

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

Kern, Sasse & Wolfart 2012, J Am Dent Assoc 143: 234.

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)

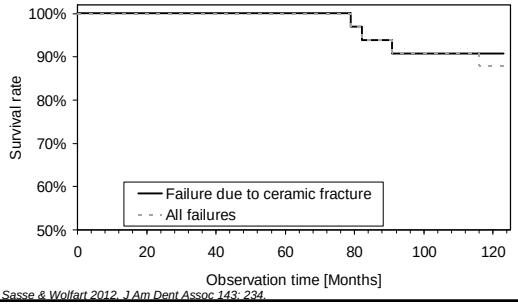
Prospective clinical study at Kiel University with all-ceramic fixed dental prostheses (FDPs)

- 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

Kern, Sasse & Wolfart 2012, J Am Dent Assoc 143: 234.

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

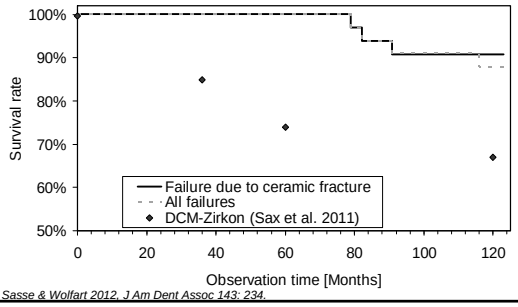
- Survival rate according to Kaplan-Meier



Kern, Sasse & Wolfart 2012, J Am Dent Assoc 143: 234.

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

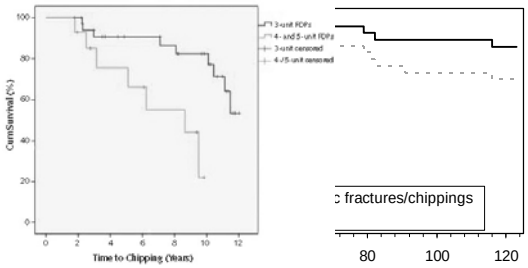
- Survival rate according to Kaplan-Meier



Kern, Sasse & Wolfart 2012, J Am Dent Assoc 143: 234.

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

- Complications according to Kaplan-Meier



Kern, Sasse & Wolfart 2012, J Am Dent Assoc 143: 234.

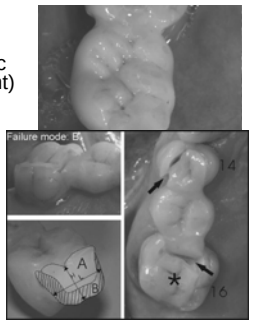
Failure rates of all-ceramic FDPs retained by resin-bonded retainer wings or inlays

in relation to their location

First author	Retainer	N	Ceramic	Time (months)	Failure rates in %		
					Ant.	PM	M
Dumfahrt 1995	2 wings	19	Optec HSP	34	5.3	-	-
Edelhoff 2002	2 wings or 2 inlays	15	Empress 2	26	0	18.2	-
Ries 2006	2 wings	17	Empress 2 or e.max press	21	39.7	-	-
Ries 2006	1 wing	21		15	9.1	-	-
Ohlmann 2008	2 inlays or inlay & crown	30	e.maxZirCAD	12	-	-	10
⇨ Harder 2010	2 inlays	45	e.max press	70	-	55.6	
⇨ Abou Tara 2011	2 inlays with add. wings	23	In-Ceram YZ	20	-	0	
⇨ Kern 2011	2 wings	16	In-Ceram Al or In-Ceram Zr	120	26.1	-	-
⇨ Kern 2011	1 wing	21		120	5.6	-	-
⇨ Sasse 2012	1 wing	30	e.max ZirCAD	42	0	-	-

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

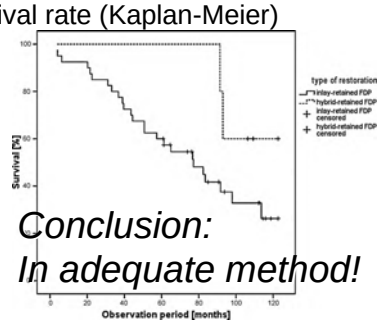


- Results
  - Service time 20-120 months
  - 25 total failures (55.6% failures)
    - 17x fractures
    - 6x loss of retention
    - 2x combinations
  - 1 pulpitis, restoration retained

Harder, Wolfart, Eschbach & Kern 2010, J Dent 38:875.

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

- Survival rate (Kaplan-Meier)

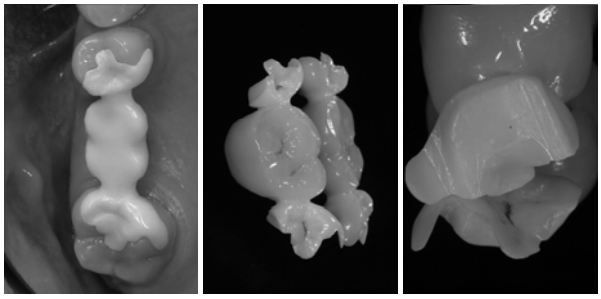


Conclusion:
In adequate method!

Harder, Wolfart, Eschbach & Kern 2010, J Dent 38:875.

Modified design of inlay-retained FDPs

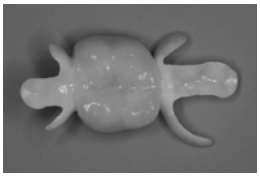
Zirconia ceramics with small retainer wings

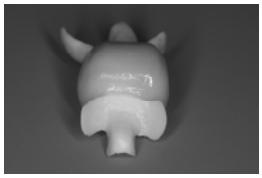


Wolfart & Kern 2006, Quintessence Int 37:27.

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





Abou Tara, Eschbach, Wolfart & Kern 2011, J Dent 39:208.

Maryland type all-ceramic FDPs

Advantages

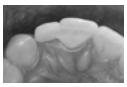
- No greyish shine-through of the metal framework
- Visible framework parts might be esthetically acceptable
- Transparent, tooth-colored luting resins may be used
- Rigidity of the framework

Kern et al. 1991, Quintessence Int 22:257.

Resin-bonded all-ceramic FDPs
- one retainer design

Advantages

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

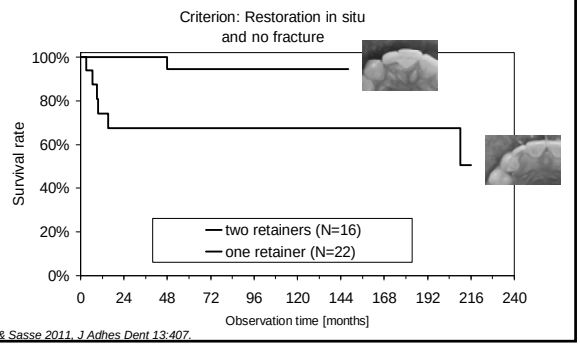


Disadvantages

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

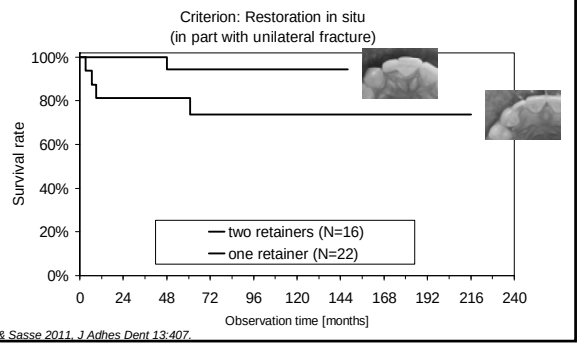
Kern & Gläser 1997, J Esthet Dent 9:255.

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



Kern & Sasse 2011, J Adhes Dent 13:407.

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



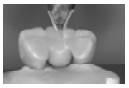
Kern & Sasse 2011, J Adhes Dent 13:407.

Fracture stength of all-ceramic resin-bonded FDPs

Study design

- Caries-free abutment teeth with artificial periodontal membrane

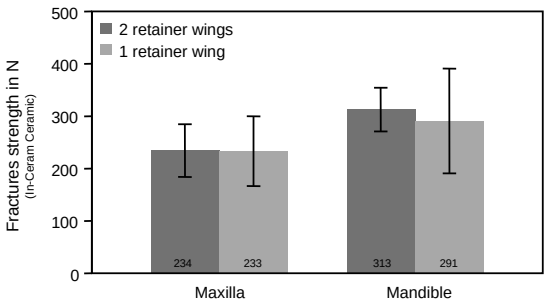
- Fabrication with Celay copy-milling technic
  - Pontic width in maxilla: 8.5 mm
  - Pontic width in mandible: 5.5 mm
  - Height of the connector: 3.0 mm
  - Diameter of the connector: 1.5 mm
  - Thickness of the retainer wing: 0.5 mm



- Evaluation of influence of the retainer number

Koutayas et al. 2000, J Prosthet Dent 83:540.
Koutayas et al. 2002, Int J Prosthodont 15:223.

Fracture stength of all-ceramic resin-bonded FDPs

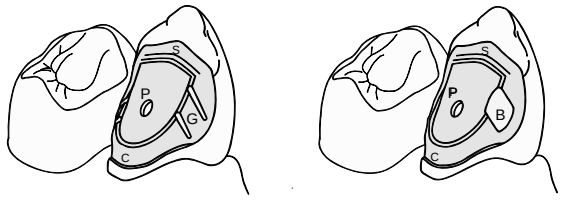


Koutayas et al. 2000, J Prosthet Dent 83:540.
Koutayas et al. 2002, Int J Prosthodont 15:223.

Preparation for retainer wings

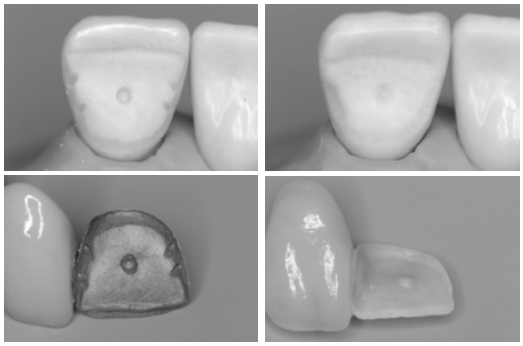
Metal ceramic
C – Chamfer
G – Grove
P – Pinhole
S – Shoulder

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



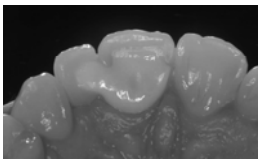
Kern & Gläser 1997, J Esthet Dent 9:255.

Preparation for retainer wings



Prospective clinical study at Kiel University with zirconia ceramic RBFDPs

- 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



Sasse, Eschbach & Kern 2012, J Dent 40:783.

Future developments

Restorative goals

- Minimal invasive
- Highly esthetic
- Biocompatible
- Cost reduction
- Proven longevity