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Bone cement with reduced proportion of monomer in total hip arthroplasty

Preclinical evaluation and randomized study of 47 cases with 5 years' follow up

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ABSTRACT – Bone cement with reduced amount of monomer and low curing temperature may improve implant fixation due to reduced toxicity. We analyzed the mechanical, chemical and thermal properties of such a cement (Cemex Rx) using Palacos R as control. The in vivo performance of the 2 cements was also evaluated in a prospective randomized study of 47 hips, where either of the cement types were used to fixate Lubinus SP2 prostheses with the stem component made of titanium alloy.

Cemex Rx had a reduced tensile strength, probably because this cement was manually mixed as recommended by the manufacturer. A standardized laboratory test showed lower curing temperature for Cemex, but measurements at 37° and with prechilled Palacos R and Cemex Rx, as in the clinical work, showed no difference.

In the clinical study radiostereometric measurements of cup and stem migration showed similar values in the 2 groups up to 5 years after the operation. The cement mantle was stable in both groups, but the stems migrated similarly inside the cement mantle regardless of the type of cement used. Proximal wear was low (0.04 - 0.05mm/year) and tended to be lower in the Cemex group (p=0.02). Aluminum and vanadium levels in serum increased 5 years after the operation, but no difference was noted between the 2 groups. Collagen markers (PICP, ICTP) showed similar increases in bone turnover 6 weeks and 6 months after operation in both groups.

During the last 15 years, changes of the cementing technique have been the main reason for improved outcome after cemented hip arthroplasty (Önsten et al. 1994, Herberts and Malchau 1997). According to Smith et al. (1998), this observation especially concerns the femoral component. More careful preparation of the bone bed and better methods in making a reproducible cement mantle have proved beneficial. The value of more recent details in cementing technique, such as vacuum-mixing and precoating of the stem with mwthylmethacrylate, remains to be shown or they may even affect the results negatively (Malchau and Herberts 1998, Sporer et al. 1998). Changes in the cement, such as the introduction of low-viscosity cement to improve cement penetration or increase its elasticity by changes in the polymer component, have been less successful (Mjöberg et al 1990, Havelin et al. 1995, Suominen 1995, Thanner et al. 1995).

Mjöberg (1986) studied bone cement having particles of different sizes in the powder component. This bone cement needed less monomer to wet the powder. The aim was to reduce the curing temperature and thereby the risk of bone necrosis and long-term clinical loosening. In a short-term clinical trial using radiostereometry the early results were promising, but long-term results unfortunately are not available.

Later, two cements with low curing temperature became commercially available. One of them, Boneloc, turned out to be a large-scale clinical failure, because of poor mechanical

Table 1. Composition of the two bone cements

	Cemex Rx/ Cemex System		Palacos R	
Liquid				
Monomer	Methylmethacrylate	99.1 (98.2)%	methylmetliacrylate	97.8%
Accelerator	N,N-dimetyl-p-tolouidin	0.9 (1.8)%	N,N-dimetyl-p-tolouidin	2.1 %
Stabilizing agent	hydroquinone	75 (75) ppm	hydrokinon	65 ppm
Color	-		chlorophyll	
Powder				
Polymer	polymetylmhacrylate	88.3 (85.0) %	Methylmethacrylate- methylacrylate	84.5%
Contrast medium	barium sulphate	9 (12) %	zirconium oxide	15%
Initiator	benzoyl peroxide	2.7 (3.0) %	bensoylperoxid	0.5%
Color	-		chlorophyll	0.05%
Liquid/powder ratio		25/75 (27/73)		31/69

properties and a low glass transition temperature (Thanner et al. 1995)-i.e., the cured cement becomes softer, especially when saturated with water at body temperature (Kuhn 2000). An increase in stem migration inside the mantle facilitates abrasive wear and penetration of the mantle and causes osteolysis and clinical failure (Havelin et al. 1995, Furnes et al. 1997). In the second type of cement, the curing temperature was reduced by removing the smallest particles in the powder (Cemex RX and Cemex System, Tecres, S.p.A., Italy). When this cement became available on the Swedish market in 1992, we started a prospective randomized trial of patients who were to undergo a total hip arthroplasty. In addition, some of the mechanical and chemical properties of this cement were studied to validate data obtained from the manufacturer. Palacos R cement (Schering Plough, Labo n.v., Belgium) was used as control.

Material and Methods

Laboratory tests of cement samples

Both types of cement (Table 1) were hand-mixed to determine the curing temperature. In the other experiments Palacos R (P) was mixed under reduced pressure (0.85 bar). Cemex Rx (C) was hand-mixed in a ventilated enclosure to mimic the clinical situation as much as possible.

We studied the tensile strength, elastic modulus, shear strength cement/metal, curing temperature, glass transition temperature and amount of monomer that remained after curing. The equipment and methodology used in this preclinical test have been presented elsewhere (Thanner et al. 1995).

Curing temperature during clinical conditions

To obtain more clinically relevant curing temperatures, 10 Lubinus stems made of-cobalt-chromium alloy (Waldemar Link, Germany) were cemented into composite femurs (Sawbones, Europe AB, Malmö, Sweden). The femora were prepared using our ordinary instruments for SP2 prostheses. Cemex Rx and Palacos R cements were mixed in vacuum chambers (Optivac®, Scandimed, Sweden). The Cemex Rx cement was kept at room temperature and mixed without vacuum. The Palacos cement was stored at +8° and mixed using a vacuum. The specimens were placed in water at 37° before preparation and during curing of the cement. Before cementing, one thermocouple (NiCr-Ni, ZA 9020-FS, Alemo, Ahlborn, Germany) was inserted via a canal drilled through the greater trochanter (5 cm distal to its tip) and another one at the tip of the prosthesis (Figure 1). The thermocouples were placed at the "endocortex" to record the temperature at the cement/sawbone interface. The temperature was registered at intervals of 10 s using a data-logger (Alemo 2290-8). Readings were done for 7-12 minutes or at least during 2.5 minutes after the maximum value had been recorded.

Clinical study

44 patients (47 hips) with primary arthrosis of the hip and scheduled for a THR were randomised to fixation with either Cemex Rx or Palacos R cement of both components (Table 2). None of the bilaterally operated patients received the same cement on both sides. One female patient (P) was excluded because of a deep infection, which developed during treatment of a malignant disease.

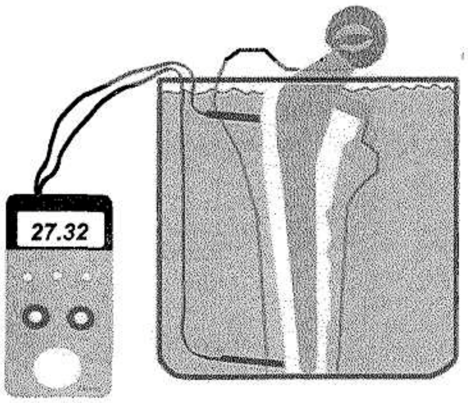

Figure 1. The thermocouples were placed at the cement/sawbone interface in the greater trochanter and at the tip of the prosthesis. The bones were placed in tempered water (37°C).

The operations were done by 2 of the authors (BN, JK). A posterior approach and third generation cementing technique (brushing of the bone, high-pressure lavage, distal plugging of the femoral canal, tamponades soaked in adrenaline solution, retrograde injection of cement into the femur, cement pressurization) were used. The Cemex Rx cement was kept at room temperature and when used the acetabular component, it was mixed without reducing the air pressure in a bowl, placed in a closed and ventilated environment. The cement for the femoral component was mixed in a closed system (Cemex System) in which the powder and liquid components are kept in separate compartments of a large syringe. By screwing the piston into the syringe a glass container with monomer releases its content into the powder. After mixing, a nipple is attached to the syringe to permit retrograde injection of cement into the femoral canal. The Palacos R cement was taken from the refrigerator (6-8° C) immediately before use and was mixed in a vacuum chamber (Scandimed, Sjöbo, Sweden). All patients received Lubinus SP2 stems made of titanium alloy and with a CCD angle of 135° (Waldemar Link, Germany). According to the manufacturer this stem has a surface roughness of 1 µm. The acetabular component was the eccentric version of the Lubinus cup. We used 28 mm femoral heads made of aluminum oxide were used in all cases.

5-7 tantalum markers (∅=0.8mm) were inserted into the polyethylene cup. The manufacturer had supplied the femoral stem with 6 tantalum markers of the same diameter.

Table 2. Patient data and Harris hip and pain scores. Median *range*. One patient, who became infected is excluded. There were no significant differences between the groups (p>0.12, Mann Whitney U-test)

	Cemex	Palacos
Male/Female	9/14	9/14
Age	70 (51-81)	65 (51-76)
Charnley group (A/B/C)	13/10/0	11/10/2
Weight (kg)	70 (53-95)	68 (53-96)
Harris hip score		
Total		
Preop.	48 (17-64)	47 (29-71)
2 years	98 (58-100)	96 (78-100)
5 years	94 (54-100)	97 (77-100)
Difference 0-5 years	46 (-10-71)	45 (14-71)
Pain		
Preop.	10 (0-20)	10 (10-30)
2 years	44 (20-44)	44 (30-44)
5 years	44 (20-44)	44 (30-40)
Difference 0-5 years	24 (0-40)	30 (10-34)

In the evaluation of migration, the femoral head center was included into the femoral segment. It was also used to measure the penetration of the head into the polyethylene (here called wear). Other markers were inserted into the acetabulum and the proximal femur. Tantalum spheres were also inserted into the cement for evaluationss of micromotions of the femoral component inside the cement mantle.

The patients were mobilized the day after the operation and were allowed as much weight bearing as tolerated.

Radiostereometry

Radiostereometric examinations were done with the patient supine postoperatively, after 6 months, 1, 2 and 5 years. Uniplanar technique with the calibration cage placed below the examination table was used (Kärrholm et al. 1997). The migration of the cup was measured as rotations about the three cardinal axes and translations of the cup center. The rotations of the stems were measured in relation to the same axes. Subsidence of the gravitational center of the segment, defined by the stem markers and the center of the femoral head, was chosen to represent proximal-distal translations of the stem.

Migration of the femoral stem in relation to the cement markers and of the cement mantle in relation to the bone was only studied in terms of subsidence. To maintain the precision of the measurements this analysis was done only if at least 3 well-defined markers could be identified.

Table 3. Precision based on 55 .double examinations. The table presents motion values which can be considered as real with 99%

probability in the individual case (absolute mean value of the difference + 2.7 SD).

Type of motion	Wear	Migration		
		Cup	Stem	Cement-mantle[a]
Translations, mm				
Transverse axis	0.12	0.20	-	
Longitudinal axis	0.14	0.16	0.18	0.16
Sagittal axis	0.20	0.41	-	
3D		0.43		
Rotations, degrees				
Transverse axis	0.90	-	0.41	
Longitudinal axis	0.63	-	1.62	
Sagittal axis	0.30	-	0.21	

[a] n 43

These should have an acceptable configuration (condition number <130, Söderqvist and Wedin 1993) and stability (mean error of rigid body fitting <=0.3, Selvik 1974,1989). 28 such hips followed for 5 years were available (17 C, 11 P). The precision of the measurements was evaluated from 55 double examinations. We calculated the absolute mean value + 2.7 SD of the differences between 2 subsequent radiostereometric examinations with an interval of about 15 minutes (Table 3).

3 patients did not attend the 2-year and 5 others did not attend the 5-year follow-ups. In 4 cases this was because of severe diseases not related to their operated hip (2 C, 2 P). 4 had deceased (2 C, 2 P). 1 hip, mentioned above, was excluded because of a deep infection (P).

Laboratory tests

Preoperatively, 6 weeks and 6 months after the operation, serum concentrations of type I procollagen carboxyterminal propeptide (PICP) and carboxyterminal cross-linked telopeptide of type I collagen (ICTP) were determined using radioimmunoassay (Taubman et al. 1974, Elomaa et al. 1992, Risteli et al. 1993) obtained from Orion Diagnostica, Finland. The intra- and inter-assay coefficients of variation for these assays are 3 and 5 % (PICP) and 5 and 7%, respectively (Elomaa et al. 1992). PICP reflects deposition of collagen during bone formation, while ICTP circulates in serum when bone is bresorbed. Only patients with unilateral stems were included.

At the 5 years follow up titanium, aluminum and vanadium levels in serum were analyzed in 30 patients (16 P, 14 C) and 5 controls without an implant. 3 patients with SP2 prostheses made of titanium alloy on the opposite side (not included in the study) were evaluated separately. The analyses were done at SGAB Analytica, Luleå University, Sweden, using inductively-coupled plasma sector mass spectrometry (ICP-SMS) (Rodushkin et al. 1999). The detection limits (3 SD) of the three elements (Ti, Al, V) were 0.2. 2.0 and 0.1 ng/ml, respectively.

Conventional radiography

Conventional radiography including AP, lateral and pelvic views was taken postoperatively and after 2 and 5 years. Measurements on radiographs were made on a digitizing tablet (Ortho-Graphics Inc., Salt Lake City, UT) connected to a personal computer. The location of any radiolucent line was classified according to DeLee and Charley (1976) and Gruen et al. (1979). The extent of these lines in each region was graded: no lucency, <50%, 50-99% and 100 %. The entire length of the radiolucent lines on the AP view of the femur was related to the femoral stem length or, as regards the socket, to the calculated circumference of the acetabular cement mantle (Kärrholm and Snorrason 1992,1993).

Clinical evaluation

The Harris hip score was used.

Statistics

The findings were evaluated only if at least 5 observations were available in one group. The statistical analysis of the radiostereometric results was done on signed values, using repeated measures ANOVA. Data from the 1-year follow up were excluded from this analysis because 3 patients did not attend this examination although they were seen at the follow-ups at 6 months, 2 and 5 years. In addition a separate evaluation was done at 6 months using Mann-Whitney U-test. All other comparisons between the two groups were done with non-parametric tests. Median values (range) are shown in the text. On the basis of the scatter of the data, the study design (20 observations in each group up to 5 years) would detect a mean difference of proximal cup migration

Table 4. Characterization of the cement and temperature at the cement — foam bone interface.

	Cemex Rx n		Palacos R n	
Laboratory tests				
Tensile strength at break (MPa) [a]	4	21 (*10-23*) [d]	8	34 (*21- 41*) [d]
E-modulus (MPa) [a]	4	1207 (*1044-1401*)	8	1351 (*1159-1522*)
Fracture strain (%) [a]	4	2.4 (*1.8-2.9*)	8	3.0 (*2.2-3.5*)
Shear strength cement/metal [b]	2	7.6 *0.2*	2	5.8 *0.2*
Curing temperature °C [b]	2	67 *1*	2	73 *5*
Glass transition temperature °C [c]	3	108	3	110
Weight loss 21 days in PBS (%)	2	0.5	2	0.4
Weight loss 21 days in methanol (%)	2	5.0 *0.4*	2	3.8 *0.1*
MMA in methanol after 24 hours (%)	1	0.03	1	0.01
MMA in methanol after 21 days (%)	1	0.08	1	0.12
Cementing in foam bone [c]				
Curing temperature °C				
Trochanter	5	56 (*44 – 76*)	5	54 (*48 – 72*)
Tip	5	63 (*55 – 88*)	5	*70 (68 – 74)*
Time to max. temperature (sec.)				
Trochanter	5	290 *(280-360)*	5	360 (*340 – 400*)
Tip	5	370 (*270 – 430*)	5	420 (*390 –470*)

[a] Median, (range)
[b] Mean, SD
[c] Maximum value
[d] p <0.01, Mann-Whitney test

or stem subsidence of 0.18 mm with more than 80% probability. In 1991-1992 when this study was planned the local ethics committee claimed that no specific permission was required. Thus, the patients were recruited on the basis of informed consent. We presented our study to the local ethics committee again in 1998. At that time they stated that they had no objections against the study design.

Our approach to evaluation of a new cement was that any beneficial effects should be proven with a high degree of probability. Because of this and the large number of comparisons done, we decided that p-value less than 0.025 represented differences, which could be regarded as established with a reasonably high degree of probability.

Results

Characterisation of the cement

Manually-mixed Cemex Rx cement had a lower tensile strength then vacuum-mixed Palacos R. The E-modulus, fracture strain and curing temperature were lower, but the shear strength metal/cement tended to be higher (Table 4). When Lubinus stems were cemented into sawbones the maximum temperature at the greater trochanter and the tip of the stem did not differ between the two bone cements (p=0.9 and 0.3, Table 4).

Radiostereometry — migration of the cup

In both groups, mean translation of the cup center in the lateral direction at 6 months, and it showed little change up to 5 years (Table 5). Proximal migrations of 0.15 and 0.12 mm occurred at 6 months (C/P) and increased to 0.29 and 0.27 mm, respectively after 5 years. Small anterior-posterior translations were observed throughout the period of observation (mean values between - 0.05 and 0.02 mm).

On average, the sockets displayed minimum (about 0.1°) rotations around the transverse and longitudinal axes (anterior/posterior tilting or ante/retroversion) up to 5 years. In both groups, the inclination of the socket tended to increase slightly more. The small differences in translations and rotations were not statistical significant in any comparison.

Table 5. Cup migration at the 5 years follow up.

		Mean value (signed)	95% confidence Limits of The mean [a]	Range	P-value [a]
Cup translations (mm)					
Medial (+)/Lateral (-)	Cemex	-0.02	-0.10 - 0.07	-0.25 - 0.57	0.3
	Palacos	-0.13	-0.32 - 0.07	-1.13 - 0.51	
Proximal (+)/Distal (-)	Cemex	0,29	0.16 - 0.41	-0.09 - 0.92	0.5
	Palacos	0.27	0.14 - 0.40	-0.08 - 0.81	
Anterior (+)/Posterior (-)	Cemex	-0.05	-0.15 - 0.05	-0.43 - 0.54	0.5
	Palacos	0.02	-0.16 - 0.21	-0.71 - 1.15	
Cup rotations (degrees)					
Anterior (+)-Posterior (-) tilt	Cemex	-0.11	-0.46 - 0.23	-1.80 - 1.99	0.4
	Palacos	0.09	-0.21 - 0.38	-1.22 - 1.39	
Ante- (-)/Retroversion (+)	Cemex	0.09	-0.14 - 0.32	-0.54 - 0.99	0.6
	Palacos	-0.14	-0.46 - 0.18	-1.66 - 1.29	
Increase (+)/Decrease (-) in the inclination	Cemex	0.16	-0.07 - 0.40	-0.97 - 1.34	0.5
	Palacos	0.43	-0.01 - 0.89	-0.98 - 2.09	

[a] Repeated measure ANOVA including values at 6 months 2 and 5 years

Table 6. Stem migration in relation to bone at the 5-year follow-up

		Mean value (signed)	95% confidence Limits of The mean [a]	Range	P-value [a]
Stem translations (mm)					
Proximal (+)/Distal (-)	Cemex	-0.17	-0.26 - -0.01	-0.46 - 0.14	0.3
	Palacos	-0.22	-0.36 - -0.09	-0.76 - 0.48	
Stem rotations (degrees)'					
Anterior (+)-Posterior (-) tilt	Cemex	-0.13	-0.23 - -0.03	-0.44 - 0.39	0.9
	Palacos	-0.10	-0.39 - 0.19	-1.72 - 0.80	
Ante- (-)/Retroversion (+)	Cemex	0.65	0.29 - 1.00	-0.43 - 2.14	0.4
	Palacos	0.83	0.53 - 1.13	-0.10 - 2.04	
Valgus (+)/Varus (-) tilt	Cemex	-0.11	-0.25 - 0.02	-0.69 - 0.37	0.7
	Palacos	-0.17	-0.33 - -0.01	-0.70 - 0.53	

[a] Repeated measure ANOVA including values at 6 months 2 and 5 years

Radiostereometry - migration of the stem

At the 6-month follow-up stems cemented with Cemex had subsided - 0.02 mm, but the subsidence reached - 0.11 mm in the Palacos group (p=0.04, Mann-Whitney U-test). At 5 years the distal migration was nearly the same (- 0.17 and - 0.22 mm. p=0.3, *repeated measure ANOVA,* Table 6).

In 28 cases (17 C, 11 P), where subsidence of the cement mantle could be studied, distal migration of the stem was mainly due to motions between the stem and cement (Figure 2). In 2 (2 C) of 16 cases (10 C, 11 P), where the stem subsidence relative bone exceeded -0.18 mm, less than 50% of this motion occurred inside the mantle. In 7 cases each 50-99% (3 C, 4 P) and 100% (4 C, 3P) of the subsidence occurred inside the mantle. Four of the 28 cases (2 C, 2P) showed distal migration of the cement mantle exceeding our detection limit for individual cases (-0.16 mm, range: -0.17 to - 0.37 mm).

Only slight rotations of the stem component occurred (mean values of 0.8° or less). In both groups, a small posterior tilt of about 0.1° (rotation around the transverse axis) was seen, which did not change after 6 months, and rotation into increased retroversion and varus tilt. These types of migration increased slightly in the control group (6 months to 5 years-retroversion: p=0.001; varus tilt: p=0.02, *Wilcoxon signed rank test),* but not significantly in the group cemented with Cemex RX (p=0.06 and 0.2). *ANOVA).*

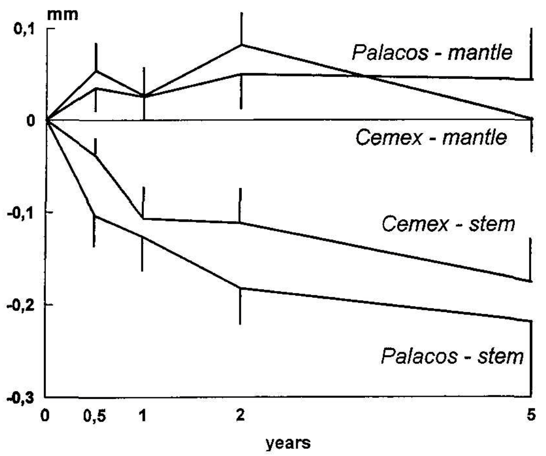

Figure 2. Subsidence of the cement mantle and the stem in relation to bone in 28 cases (17 C, 11 P),where also subsidence of the cement mantle could be studied, (mean, SE)

This seeming increase in instability in the control group was not statistical significance in the overall comparison of the 2 groups (p= 0.4 and 0.7, *repeated measure*

Radiostereometry - penetration of the femoral head

The mean medial/lateral penetration was close to zero (C *vs.* P: p=0.7) during the observation period, but ranged between -0.4 and 0.8 mm at 5 years (Table 7). The penetration in the proximal direction was slightly higher in the Palacos than in the Cemex Rx group (p=0.02). Thus, the corresponding mean and maximum annual proximal penetration rates were about 42 and 50 and 100 and 110 microns/year, respectively. Both groups showed posterior penetration of the femoral head (5 years: -0.10 and -0.14 mm, p = 0.3). The vector length of the penetration (total penetration) reached 0.35 and 0.39 mm (p= 0.8).

Laboratory tests

The preoperative values of PICP and ICTP in µg/L were about the same in the Cemex/Palacos groups (PICP: 105 (82 – 159)/98 (69 – 158); ICTP: 3.2 (2.0 - 4.7)/ 3.6 (2.1 - 7.3), p > 0.7). At 6 weeks the PICP concentration had increased with 33 and 37 % in the two groups (Figure 3). A relative reduction occurred at 6 months, but not to the preoperative level. A similar pattern in ICTP was observed, but the relative increase was higher. The type of cement had no obvious effect on the concentrations of these markers of bone turnover (p>0.4).

At 5 years the concentrations of metal in the serum were about the same in the two groups with unilateral prostheses (Table 8). Compared to normals both these groups displayed increased levels of aluminum and vanadium (p<0.003), but not of titanium (C vs. N: p=0.04; P vs. N: p=0.07). The 3 patients with bilateral prostheses tended to have still higher values of titanium and aluminum, but the difference was not significant (all patients with uni- vs. bilateral prostheses: p=0.03, 0.04).

Table 7. Wear at the 5-year follow-up

Wear (mm)		Mean value (signed)	95% confidence limits of the mean a	Range	P-value [a]
Medial (+)/Lateral (-)	Cemex	0.03	-0.08 - 0.14	-0.35 - 0.79	0.7
	Palacos	-0.13	-6.09 - 0.08	-0.42 - 0.26	
Proximal (+)/Distal (-)	Cemex	0.21	0.15 - 0.27	-0.05 - 0.48	0.02
	Palacos	0.25	0.17 - 0.33	-0.01 - 0.56	
Anterior (+)/Posterior (-)	Cemex	-0.10	-0.20 - 0.01	-0.69 - 0.35	0.3
	Palacos	-0.14	-0.26 - -0.03	-0.57 - 0.19	
Three-dimensional	Cemex	0.35	0.23 - 0.46	0.09 - 1.14	0.8
	Palacos	0.39	0.30 - 0.48	0.11 - 0.70	

[a] Repeated measure ANOVA including values at 6 months 2 and 5 years

Number of observations (PICP/ICTP)

Cemex 15/16 16/18

Palacos 15/16 17/17

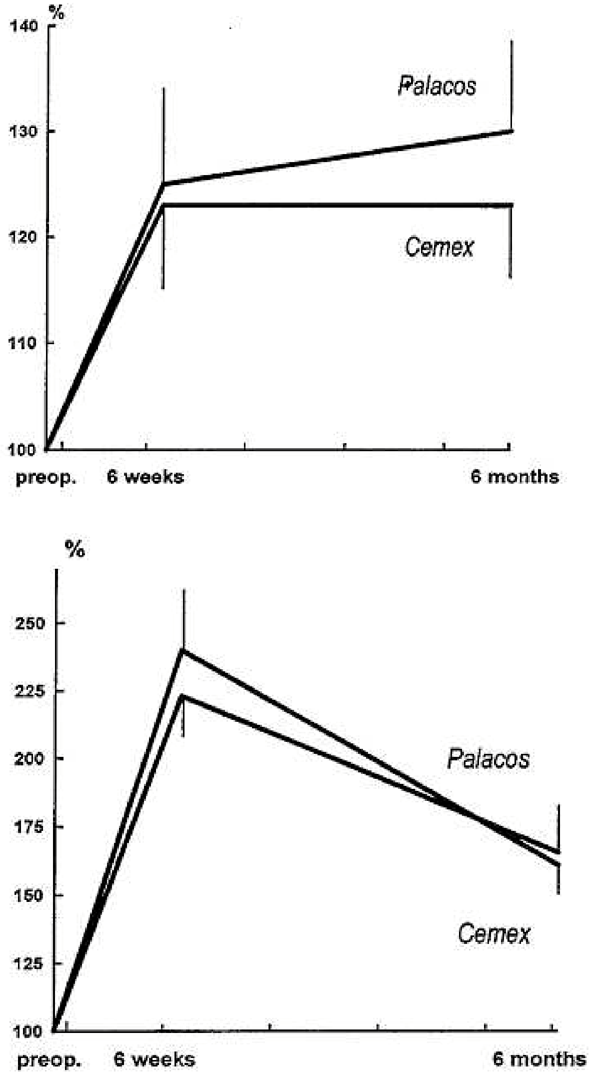

Figure 3. Relative change of type I procollagen carboxyterminal propeptide (PICP- top) and carboxyterminal cross-linked telopeptide of type I collagen (ICTP - bottom) 6 weeks and 6 months after the operation (mean, SD).

In the patient group, there was a positive correlation between the concentrations of titanium and aluminum in serum (r=0.56, p=0.001). The corresponding r-value in normals was -0.66 (p=0.2). We found no correlation between the levels of metal in serum and any of the parameters describing the migration of the stem or wear at the 5-year follow-up.

Radiography

The postoperative radiolucent lines surrounding the cup were the same in the 2 groups (Table 9). The extent of these lines increased in both groups up to 2 years (C: p=0.008; P=0.001). Thereafter, they seemed to be stationary (2 vs. 5 years: p=0.06, 0.46).

The minimum median width of the cement mantle surrounding the stem (AP-view only) varied between 2.7 and 3.5 mm proximally. Distally and laterally it was slightly thinner (C/P: 1.7/1.1 mm). There were more lines surrounding Cemex than Palacos cement immediately after the operation. In the Cemex group these lines tended to increase during the follow-up (0 vs. 2 years, 2 vs. 5 years: p=0.03, 0.03). In the Palacos group no significant increase was noted until after the 2-year follow-up (0 vs. 2 years, 2 vs. 5 years: p=0.46, 0.001). Thus, postoperatively 3 stems cemented with Cemex displayed radiolucent lines exceeding 10 % (10-41) of the interface, but the maximum length in the Palacos group was 7 %. At 5 years 9 and 7 had radiolucent lines of a minimum length of 10 % in the 2 groups, respectively. On the lateral view, the corresponding numbers were 10 and 4. When present, the radiolucent lines were mainly located in the 2 proximal Gruen regions on either side of the stem (Figure 4).

Table 8. concentrations of metal In serum at 5 years (ng/mL). All operated hips had a SP2 prosthesis made of titanium alloy. Median range

	N	Titanium	Aluminum	Vanadium
Normal	5	0.36 (0.13 - 1.87)	2.65 (1.81 - 3.96)	0.02 (0.02 - 0.06)
Unilateral THA				
Cemex	14	0.63 (0.39 - 13.10)	6.36 (2.98 - 16.50)	0.07 (0.04 - 0.18)
Palacos	13	0.78 (0.35 - 3.27)	6.01 (2.00 - 13.20)	0.09 (0.04 - 1.19)
Bilateral THA				
Palacos or both [a]	3	1.39 (1.29 - 1.79)	16.10 (7.39 - 17.90)	0.14 (0.05 - 1.09)

a 2 patients with Cemex on one side and Palacos on the other, 1 patient with Palacos on both sides (1 hip is included in the study)

Table 9. Results of the radiographic evaluation. Median, range

	Cemex	Palacos	P-value [a]
Cup			
Inclination (degrees)	50 (38 - 59)	45 (27 - 68)	0.05
Radio lucent lines [b]			
in % of interface			
Postop	10 (0 - 30)	5 (0 - 38)	0.5
2 years	10 (0 - 50)	10 (0 - 30)	0.4
5 years	5 (0 - 66)	11 (0 - 30)	0.2
localisation [c]			
proximal-lateral	7/11/2/0	7/7/5/1	0.4
central	16/6/0/0	15/5/0/0	0.9
medial-distal	17/4/0/1	9/9/2/0	0.04
Stem			
Varus angle of stem (degrees)	-0.8 (-4.1 - 1.7)	-0.7 (-2.6 - 0.5)	0.07
Width of cement mantle (mm)			
proximal-medial	2.7 (0.7 - 5.8)	2.7 (1.5 - 6.1)	0.6
proximal-lateral	3.5 (0.7 - 5.6)	3.3 (1.2 - 7.2)	0.2
distal-medial	3.6 (1.4 - 5.6)	3.0 (0.8 - 6.9)	0.6
distal-lateral	1.7 (0.7 - 5.8)	1.1 (0.3 - 5.3)	0.06
Cement quality stem (A/B/C) [d]	10/1/9	14/0/6	0.3
Radio lucent line in %			
of interface - AP view			
Post op	2 (0 - 41)	0 (0 - 7)	0.001
2 years	8 (0 - 50)	0 (0 - 10)	0.005
5 years	8 (0 - 50)	6 (0 - 39)	0.7
Lateral view [e]			
5 years	11 (0 - 52)	0 (0 - 49)	0.1 [e]

[a] Mann-Whitney test
[b] AP view only, > 1 mm wide in % of the interface
[c] Evaluated at 5 years in 4 classes (DeLee and Charnley) 0%, 1-49%, 50-99%,100%
[d] Barrack et al. 1992
[e] 2 cases in each group due to poor radiographic quality or missing radiographs

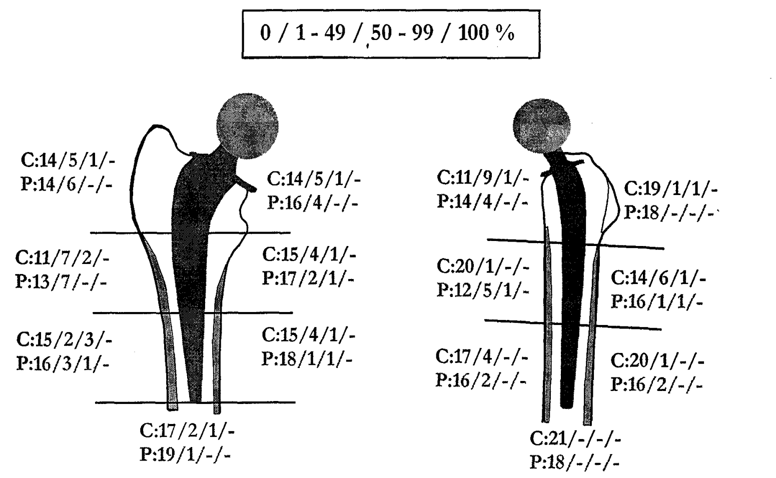

Figure 4. Distribution of radiolucent lines (0 /1-49 / 50-99 /100 %) in the different Gruen regions at 5 years. Left: AP view, Right: lateral view. C = Cemex Rx P = Palacos R. One AP view missing (C) and two laterals (2P) could not be evaluated.

Clinical results

The hip and pain scores and the change of these scores between the postoperative and 5-year follow-up examinations were similar in the 2 groups (Table 2).

Discussion

Previous studies of the mechanical properties of Cemex Rx cement have shown that it fulfils the conditions set by the ISO standards. Spierings et al. (1992) compared CMW3 and Sulfix-6 with Cemex Rx and noted that the latter had slightly less tensile strength which they attributed to insufficient mixing cement that had not been homogeneously cured, because of inadequate wetting. In a later study of fatigue strength (Have et al. 1997) the two types of Cemex cements used in this study (Cemex RX and Cemex System) proved to have longer lifetime than 2 high- (CMW1 and Cemex Isoplastic) and one type of low-viscosity cement (CMW3). Four of the cements were hand mixed except from Cemex System. Later studies of vacuum mixed Cemex Rx have shown that this procedure increases its strength, but also causes greater variations in the results due to an unpredictable presence of large pores in the cement (Prendergast and Murphy 1998).

From a scientific point of view, it would be more appropriate to vacuum-mix the Cemex cement. When we began our study, the manufacturers objected strongly to this method. Later on they held that vacuum mixing could be accepted.

Today we do not recommend hand-mixing, even if when is done in a ventilated enclosure. Cement should be mixed in a closed system as used for the femoral component, not least for environmental reasons. The use of reduced aerial pressure may be beneficial, but this remains to be shown in patients.

We wanted to make our laboratory study comparable to our clinical study as possible and did not use vacuum for the Cemex cement. Sawbones could partly be expected to mimic the geometry of the cement mantle. Nonetheless, this model may not have been optimal, because sawbones do not have the same heat-transferring capacity as vascularized bone tissue.

As expected Cemex Rx had reduced mechanical strength probably because it had been mixed under aerial pressure. So far no clinical study has demonstrated that vacuum mixing will reduce the frequency of loosening. In the Swedish National Registry vacuum mixing has been found to even increase the number of early revisions (Malchau and Herberts 1998). This finding could reflect handling problems related to one or more of the mixing systems on the Swedish market. It could also be that mixing under aerial pressure really is advantageous. One theory is that air inclusions will expand during curing, which can largely compensate for shrinkage in the later phase of curing (De Wijn et al. 1975). Then , the use of less monomer in Cemex cement can also reduce the amount of shrinkage. In our study, less cement shrinkage or an increase in friction between the stem and the cement, as suggested from the laboratory test, might have caused the slightly smaller subsidence of the stem at 6 months. The equalization of the subsidence between the two groups during the following 4.5 years might be an effect of less resistance to creep in the Cemex group (Verdonschot and Huiskes 1999). Factors other than cement shrinkage could also have influenced the motions between the stem and the cement. In a laboratory study, Liden et al. (1998) noted that the cement-stem interface differed between Palacos R and Cemex cement with Fluoride when used with the Spectron EF stem. The specimens cemented with Palacos had a more porous interface, which might be more brittle and susceptible to microfractures and a slight early subsidence.

Other factors which can influence the motion of the stem inside the mantle are the geometry of the stem, material and surface finish (Huiskes and Verdonschot 1998, Verdonschot and Huiskes 1998,Alfaro-Adrian et al. 1999). In a previous study of Lubinus SP2 stems made of cobalt chromium alloy, the same technique including Palacos cement we found a considerably smaller median subsidence after 2 years (-0.08 mm) than in the implants with Palacos cement in the present study (-0.18 mm). Increased flexibility and a smoother surface finish (Ra=1.0 instead of 1.5 µm) of the titanium alloy version of the SP2 stem can probably explain this difference (Nivbrant et al. 1999).

In a previous study of cemented stems made of titanium alloy and with a rougher surface finish than the SP2 stem, we noted that the levels of aluminum and vanadium increased in blood between the 2- and 5-year follow-up (Kärrholm et al. 1998). Clinical fixation failure and femoral osteolysis were observed in some of these cases. In the present study and despite absence of any signs of clinical failures, patients with prostheses had elevated levels of metals. This finding and those in our earlier study suggest that motions of the stem inside the mantel may have clinical consequences. The tendency to increase further in the 3 cases with bilateral stems made of titanium raise concerns about systemic effects in the long-term.

One previous radiostereometric study of femoral head penetration showed three-dimensional wear of 0.5 - 0.6 mm in the Lubinus SP1 design with 32 mm heads after 5-6 years (Kärrholm et al. 1997). Önsten et al. (1994) reported lower values with the Charnley prosthesis after about the same observation period. The values recorded for the Lubinus SP2 design with aluminum heads in our study were still lower when the comparison was restricted to linear wear. The choice of head material, however, seems to be of minor importance in the short perspective. Lubinus SP2 prostheses with 28 mm heads of cobalt chromium have shown the same amount of three-dimensional wear as in the present study after 2 years of follow-up (Nivbrant et al. 1999).

Sakobar et al. (1997) found that particles of Barium Sulfate induced a more intense inflammation response than did particles of Zirconium Oxide. This observation has been questioned (Ingham et al. 1999). We noted that patients cemented with Cemex had less proximal wear than the control group. This difference was small, but we have observed a similar tendency in another prospective and randomized study where Cemex with Fluoride is compared with Palacos (Kärrholm et al. 2000). The reasons for these differences are not clear, but it may be that particles of barium sulfate causes slightly less third body wear than particles from cement containing zirconium or that more particles are generated from the Palacos - stem interface.

Polymethylmethacrylate cement may cause thermal damage to the bone tissue by a high curing temperature and release of monomers during polymerization (Mjöberg 1986, Leeson and Lippit 1993, Stürup et al. 1994). According to De Bastiani et al (1990) new bone formation appeared earlier in the rabbit femur after Cemex than after CMW 1 cement. We did not measure monomer release during curing, but found no obvious difference between Palacos and Cemex Rx regarding monomer release when cured cement specimens were studied. The theoretical advantage of a lower curing temperature in the study group was in practice neutralized by using prechilled Palacos R as recommended by the manufacturer. The similar pattern of migration and changes in bone specific collagen markers suggest that the damage to the bone is about the same for the two types of cement in the clinical work.

The increased length of postoperative radiolucent lines in the Cemex group suggests that we had difficulties in obtaining a sufficient pressure to achieve an optimum interface. The lower viscosity of the cement combined with less clinical routine may also have been important. The reason for the dissimilar pattern of progression of the radiolucent lines in the 2 groups of cement is unclear. Differences between biomechanics of hand- and vacuum-mixed cements or in the long-term interaction between the bone tissue and the two types of cements studied are possible explanations. The accelerated progression in the Palacos group could be an effect of the increased number of particles or more abrasive particles, as suggested by the increased proximal wear in this group.

In the choice between various type of cements, optimum long-term performance has the highest priority. Secondly factors like handling characteristics, time-to-curing and need for prechilling must be considered. Compared to Palacos R, Cemex Rx has lower viscosity, sshorter time-to-curing at about 20 degrees Celsius and should not be prechilled. When used according to the instructions of the manufacturer it also differed significantly from Palacos R in the laboratory tests. In the clinical work, these differences seemed to be less important. Measurements of postoperative bone turnover, metal release and implant migration up to 5 years after the operation showed no significant differences. However, our study was done by surgeons with a special interest in total hip surgery. Moreover, it is not known to what extent our findings can be generalized to other stem designs and surface finishes. Therefore, further multicenter trials are needed to evaluate wheter this cement still performs in a reproducible way with different implants and by many surgeons use variations of the surgical technique.

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