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## Osteoporotic distal radius curettage–filling with an injectable calcium phosphate cement. A cadaveric study

Received: 26 June 2004 / Accepted: 21 August 2004 / Published online: 16 October 2004  
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**Abstract** Osteoporotic distal radius fractures are a public health problem that medical osteoporosis treatment is unable to check. We have described a bone substitute method to improve mechanical properties in bone. Our current study aims at improving the technique by maximising the filling of the distal radius. Cavities were created by curettage in the distal radius using a styloid process approach in ten randomly selected wrists from the sample population of ten cadavers. All radii were injected percutaneously with calcium phosphate cement. Cement quantities injected were calculated and corrected for observed cement leakage. Our results show that distal radius curettage before cementoplasty can double the amount of calcium phosphate cement injected. Prevention of osteoporotic distal radius fractures by cementoplasty seems a promising technique. Slowly absorbed micro-porous biomaterial use is preferable in long-term preventive treatment. Nevertheless, in the future, this technique should apply in specific cases, such as medical osteoporosis treatment failure with contralateral wrist fracture.

**Keywords** Bone substitute · Calcium phosphate cement · Distal radius · Hydroxyapatite · Osteoporosis

### Injection d'hydroxyapatite dans l'extrémité distale du radius

**Résumé** Les fractures du poignet ostéoporotique sont un problème majeur de santé publique. En effet, le traitement médical de l'ostéoporose ne parvient pas à enrayer la progression de cette épidémie. Dans ce contexte, nous avons mis au point une technique de cimentoplastie préventive du radius distal lors d'un précédent travail expérimental. Le but de la présente étude est d'améliorer

cette technique d'injection percutanée perosseuse d'un ciment phosphocalcique pour obtenir un remplissage maximum de la cavité médullaire du radius distal. Les vingt poignets de dix sujets anatomiques ont été préparés à l'École de Chirurgie de l'Assistance Publique-Hôpitaux de Paris. Dans dix poignets tirés au sort, une cavité a été réalisée par curetage dans le radius distal par voie styloïdienne punctiforme. Puis les vingt radius ont été injectés en percutané perosseux sous fluoroscope par un ciment phosphocalcique. Les moyennes de remplissage de ciment en mm<sup>3</sup> des vingt poignets ont été calculées, avant et après correction en fonction des fuites de ciment constatées. Nos résultats démontrent que la préparation initiale du radius distal par curetage avant cimentoplastie double la quantité de ciment phosphocalcique injecté. La prévention des fractures du radius distal ostéoporotique par cimentoplastie percutanée perosseuse au ciment phosphocalcique injectable nous paraît être une voie intéressante à explorer. L'utilisation d'un biomatériau microporeux à résorption lente est indispensable dans un traitement préventif fait pour durer. Cette technique devra néanmoins s'appliquer à des indications ciblées telles contraindication ou échec de traitement médical de l'ostéoporose, fracture du poignet controlatéral.

**Mots clés** Ciment phospho-calcique · Hydroxyapatite · Ostéoporose · Radius distal · Substitut osseux

### Introduction

Osteoporotic wrist fractures represent an ever-increasing proportion of health care administered in developed countries, due notably to increased life expectancy. These fractures are often indicators of osteoporotic disease, and their appearance should systematically lead to a diagnostic assessment [6]. However, even when osteoporosis is diagnosed, treatment is limited to, at best, improving bone mineralisation and, at worst,

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preventing its reduction [12] without acting directly on bone resistance that is not proportional to the degree of mineralisation [24]. The treatment of osteoporosis relies on the use of various therapeutic agents where the ratio of effectiveness to side effects does not allow reliable reproducible results. Although bisphosphonates have an overall effectiveness of 50% [3], the principle of hormone replacement therapy in menopausal women has been called into question due to the risk of cancer [2].

In this context, during an anatomical trial [13], we suggested the basis for a preventive surgical treatment of osteoporotic fractures of the distal radius. The objective was to increase bone resistance and, therefore, raise the threshold of resistance to fracture by percutaneous injection of calcium phosphate cement. In this study, we found that the centro-medullary filling of the distal radius with the calcium phosphate cement was uneven. This depended notably on the trajectory imposed on the injection stylet, the degree of mineralisation, the microarchitecture and the initial bone strength. The lower the initial mechanical bone strength, the greater the degree of filling with calcium phosphate cement. After cementoplasty, the mechanical strength measured with peripheral quantitative computed tomography was proportional to the degree of filling seen on the fluoroscope. The space occupied by the injected cement spread most often to the edge of the cone scooped out by the removal of the stylet, without reaching either the shaft or the sub-chondral area of the distal radius [15].

The objective of the current study is to improve this calcium phosphate cement injection technique by maximising the filling of the distal radius medullary cavity, from the subchondral bone to the metaphyseal–diaphyseal area. As the technique was designed for eventual clinical application in humans, it appears essential to develop a reliable, reproducible and minimally invasive technique as soon as possible. The principle of single percutaneous cement injection through the bone satisfies the last criterion. In order to deal with the other criteria in the specification, we sought to standardise our technique by preparation of the distal radius by curettage in order to obtain a homogeneous cavity ready for filling.

The calcium phosphate cement Cémentek LV (TEKNIMED) was chosen from among the injectable bone substitutes available because of its interesting physicochemical properties [11]. This particular synthetic bone substitute has a calcium–phosphate ratio of 1.63, approaching that of natural bone. The crystallisation process that characterises it leads to a chemically non-stoichiometric stable hydroxyapatite, meaning that ionic exchanges between the crystal surfaces and the extra-cellular environment are high [17]. Its microporosity explains its relatively slow biodegradation rate [14] whereas the absence of macro-porosity provides a resistance to compression rupture of the order of 20 Mpa, placing it between that for trabecular and cortical bone.

## Methods

A preliminary study was undertaken on two separate anatomical subjects in order to determine the ideal entry point for the injection stylet (Fig. 1). To artificially form the best possible intrabone cavity in the distal radius, from the subchondral bone to the metaphyseal–diaphyseal junction, we made a special tool using a hand-shaped, double-curved number 18 Kirschner wire manipulated with a removable handle. The curve and counter-curve were adapted to the shape of the distal radius.

In one case (Fig. 1a), the entry point was proximal metaphyseal–diaphyseal and in the other, distal, the trocar point therefore being penetrated by the tip of the radial stylus (Fig. 1b). In both cases, the rectilinear, trocar-tipped stylet was pushed from the lateral to the medial edge of the radius, descending when the point of entry was proximal and ascending when the point of entry was distal. It was then replaced by the double-curved wire manipulated simultaneously in three dimensions—in rotation, backwards and forwards—to collapse the remaining bone honeycombs and obtain the largest possible injectable cavity.

It became obvious from reading the fluoroscope images (Fig. 1) that preparation at the proximal entry point did not allow us to collapse all the space occupied by the trabecular bone in the distal radius. It proved impossible to reach the styloid area and difficult to reach the medial area with regard to the distal radio-ulnar (Fig. 1a). On the other hand, preparation at the distal entry point allowed easy access to the centro-medullary distal radius area (Fig. 1b). The probable reason is that the trocar-tipped stylet and the double-curved wire in the upward direction could be moved to trace a cone at the styloid tip. On the other hand, when the point of entry was proximal, the only direction possible for the



**Fig. 1** Percutaneous distal radius hollowing by the proximal (a) and distal (b) route

stylet and the double-curved pin was rectilinear, oblique at the bottom and inward. As a result, we decided to use only the styloid entry for the study.

## Subjects

Ten Caucasian anatomical subjects, five men and five women, were prepared by the Ecole de Chirurgie de l'Assistance Publique-Hôpitaux de Paris (Table 1). The average age at death was 86.7 years (73–95). No wrist from any of the subjects, 20 wrists in total, presented any previous consolidated fracture lesions of the distal radius.

## Technique

The author carried out the anatomical procedure on the 20 wrists. A percutaneous orifice was created across the tip of the radial styloid using a 10-cm-long number 11 trocar-tipped stylet pushed along its bisectrix until it reached the medial cortical of the radius without perforating it. In two cases where the resistance of the bone was particularly weak, an un-wanted perforation of the cortical was noted while pushing the stylet.

Two groups were subsequently defined. In group 1, calcium phosphate cement injection was carried out after preparation of the cavity, as described above. In group 2, calcium phosphate cement injection was carried out without any special preparation. It was decided that the two wrists from each subject should be allocated to a different group in order to obtain a matched series. To avoid bias due to manual dominance, the side chosen for preparation was selected at random.

For both groups, a 20-mg dose of Cementek LV was hand mixed to obtain a malleable homogenous paste and introduced into a BoC system (Grifols) injection syringe to which the stylet had been adapted. The injection was subsequently carried out using a BVgold (Philipps) fluoroscope to check the progress of the cementoplasty. The cementoplasty of the distal radius was stopped either when cement leakage was seen or when the operator judged the filling to be satisfactory. Leaks appeared either because of the medial cortical perforation caused by the thrust of the trocar point or at the entry hole for the injection stylet. The torsion-torque resistance of the syringe was 1,000 psi, the syringe automatically breaking when this value was exceeded.

## Measurement method

We used a BoC system syringe graduated in millimetres cubed to measure the quantity of cement injected. To avoid measurement errors, the syringe was flushed before each injection. Extra-osteal leakage obviously increased the measured volume of cement injected into the distal radius. The measured injected volume in millimetres cubed was corrected for leaks by subtracting the leak volume estimated using the fluoroscope.

The average cement fill volumes in millimetres cubed were calculated both before and after observed leakage correction for both groups.

## Data analysis

The average volumes and the standard deviations were calculated for three variables: injected volume, leakage

**Table 1** Ten anatomical subjects. Result of phosphate calcium cement injection in distal radius. *F* female, *M* male, *R* right, *L* left

Subjects ( <i>n</i> = 10)	Age (years)	Gender	Side	Injected volume (mm <sup>3</sup> )	Leak volume (mm <sup>3</sup> )	Corrected volume (mm <sup>3</sup> )
Group 1: after preparation						
1518	79	F	L	30	0	30
1510	93	F	L	25	0	25
1490	94	M	R	30	0	30
1485	75	M	R	20	5 <sup>a</sup>	15
1546	95	F	L	25	4 <sup>a</sup>	21
1489	73	M	L	23	3 <sup>a</sup>	10
1509	95	F	R	63	2 <sup>a</sup>	61
1572	82	M	L	85	0	85
1528	91	F	R	45	0	45
1570	90	F	r	45	6 <sup>b</sup>	39
Mean	86.7			39.1	2	36.1
Group 2: without preparation						
1518	79	F	R	21	3 <sup>a</sup>	18
1510	93	F	R	20	0	20
1490	94	M	L	19	0	19
1485	75	M	L	16	3 <sup>a</sup>	13
1546	95	F	R	25	10 <sup>b</sup>	15
1489	73	M	R	20	0	20
1509	95	F	L	15	1 <sup>a</sup>	14
1572	82	M	R	18	0	18
1528	91	F	L	27	0	27
1570	90	F	L	15	1 <sup>a</sup>	14
Mean	86.7			19.6	1.8	17.8

<sup>a</sup>Leak at the tip of the radial stylus

<sup>b</sup>Leak at the medial cortical of the radius

volume and corrected volume for both groups. The Shapiro-Wilk test for normality was applied to the distribution for the difference in results between the two groups. If normality was refused, the Wilcoxon matched-pair test was applied to the difference or, failing that, Student's pair test was used. A value of  $p < 0.05$  was considered significant.

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## Results

Age and gender characteristics for the ten subjects in groups 1 and 2 are shown in Table 1 along with the results for the volume of cement injected, the cement leakage volumes and the corrected volumes of cement after subtraction of the leaks following cementoplasty of the distal radius. Fluoroscopy images examples in groups 1 and 2 are shown in Fig. 2. Statistical analysis results are shown in Table 2.

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## Discussion

Our results clearly show that pre-preparation of the distal radius by curettage before calcium phosphate cement injection doubles the quantity of cement injected whether leaks are taken into account or not (Table 2). Although the cement leakage volumes were estimated rather than measured, extrapolation was allowable, as the total leakage volume differences between the two groups were not statistically significant. In qualitative terms, the distribution of the cement injected followed the path of the stylet in group 2 whereas in group 1, it tended to be evenly distributed from the sub-chondral bone to the metaphyseal–diaphyseal area. Nevertheless, our method is not dedicated to modify the evolution of the osteoporosis disease itself, even at the metaphyseal–diaphyseal area.

Certain authors consider that displaced radial fractures in elderly or dependent persons, particularly when they present with osteoporosis, should undergo conservative treatment [4, 23]. The argument put forward is that any attempt to reduce these fractures, regardless of the treatment applied, leads, in most cases, to a fresh displacement [16]. It is because of the unfortunate risk of displacement recurrence that these authors have abandoned surgical treatment of such fractures rather than a question of poor tolerance.

In this context, the prevention of such fractures by percutaneous transosseous cementoplasty with injectable calcium phosphate cement seems to us to be an interesting route worth exploring. The extrapolation of this technique to human clinical practice should, nevertheless, depend on specific indicators. In the first place, it appears logical to offer it to osteoporotic menopausal women presenting certain pre-existing conditions from among the following: cancer contra-indicating the use of hormone replacement therapy, failure of a properly run course of medical treatment (vitamin and calcium supplementation, bisphosphonates, raloxifene) or contralateral wrist fracture.

The use of biomaterials to strengthen the distal radius is not new, and methylmethacrylate has already been used in elderly patients with acceptable results [9]. However, the long-term fate of acrylic cement is detachment due to the total absence of bioactivity at the surface without any bone rehabilitation. On the other hand, bone substitutes are bioactive and usually allow effective osteointegration. Their rapid re-absorption, varying from a few weeks to a few months, depending on the case, is a disadvantage for preventive treatment designed to last. But the calcium phosphate cement used in this study is strictly micro-porous, which allows re-absorption over several years [14] theoretically only requiring a top-up injection every 10 years.

This type of curettage followed by the filling of the space contained within the cortical bone circumscribing the distal radius, could be suspected of inducing complications, particularly vascular and/or mechanical complications. However, the preparation of the distal radius for the implantation of complete wrist prostheses,

**Fig. 2** Cementoplasty of the distal radius without (a) and with (b) preparation



**Table 2** Results of statistical analysis. Mean comparison between groups 1 and 2

Variable	Group	Number	Mean (mm <sup>3</sup> )	<i>p</i> value	Factor
Injected volume	12	1010	39.119.6	0.009152*	1.99
Corrected volume	12	1010	36.117.8	0.03251*	2.03
Leak volume	12	1010	21.8	0.8402 <sup>NS</sup>	1.11

\* when  $p < 0.05$  et NS when  $p > 0.05$

a clinical model equivalent to our curettage filling, did not lead to any bone necrosis or metaphyseal–diaphyseal fractures after 4 years in 72 cases of porotic bone in rheumatoid polyarthritis [5]. The major problem with these prostheses is detachment at the interface between the acrylic cement and the prosthesis whereas the interface between the calcium phosphate cement and the bone tissue showed successful osteointegration in living subjects [1]. Another feature is that the calcium phosphate cement used here crystallises following a succession of non-exothermic chemical reactions [25], as opposed to acrylic cements that harden by exothermic polymerisation and which could be accused of causing burn lesions through heating of the osteogenic cells [19]. Finally, the vascularisation of the distal radius, coming essentially from the periosteal arteries that penetrate the cortical bone [7, 18], is not affected by a centro-medullary curettage.

The styloid piecing route first used is considerably less abrading than the distal radius preparation required for the implantation of a complete wrist prosthesis. Even in this case, fat embolisms, described in cases of long-bone reaming with pressure-injected acrylic cement, appear in a totally different context and have not been found in the literature concerning the distal radius. As far as cement embolisms are concerned, they have not been described with calcium phosphate cement, as the injection pressure is less than 1,000 psi, a pressure above which the injection syringe is designed to break. The curettage may even be beneficial, as the collapsing of the remaining trabecular honeycombs, even in porotic bone, may liberate osteogenic factors likely to reinforce cortical bone solidity, the product of the curettage being effectively automatically forced against the deep cortical face during the manoeuvres associated with the curettage and the calcium phosphate injection.

The question of the stylet penetration point was discussed in the “Methods” section. We consider that we have demonstrated that the radial styloid choice was better than the metaphyseal–diaphyseal area. We have not studied a third possible entry point that has, nevertheless, been regularly used in the literature [8, 10]—the middle metaphyseal area, the usual source of the horizontal line in distal radius fractures. We have already stressed the disadvantages of this (pre) fracturing route [15]. It is a classically fragile area where the posterior cortical of the radius risks being made even more fragile by the reciprocating and rotary movements of the stylet necessary to obtain the best-possible filling.

If, on the face of it, the curettage is not harmful to the mechanical properties of the distal radius, the geometric distribution of the calcium phosphate cement injected into the distal radius is important. In this study, we tried to fill the distal radius as far as possible, from the subchondral bone to the epiphyseal–metaphyseal area, as a completely filled volume. We have shown in a previous study that, although the measured mechanical strength of the distal radius is greater after percutaneous injection of a bone substitute, this increase is enhanced when the distribution of the cement is concentrated at the periphery [15]. Moreover, for an identical bone mass for a given volume, a normal bone of small section with thick cortical layers is stronger than a porotic bone of much greater section but with thinner cortical layers [22]. The porotic bone behaves as though its cortical layers have become thinner relative to the trabecular bone [21, 26]. Thus, hormone replacement therapy acts on the mineral distribution between cortical and trabecular bone by moving the interface between trabecular and cortical bone towards the cortical bone rather than acting to increase bone mineral density [20]. It would, therefore, be advisable during a future study to further improve the technique by leaving a central void within the distal radius, concentrating the distribution of the calcium phosphate cement around the periphery in contact with the cortical layer and then measuring the impact of this modification in terms of the mechanical strength of the bone.

In conclusion, we think there is a place for a prolonged action, preventive, therapeutic treatment for porotic bone fractures using a minimally invasive surgical technique aimed at areas of the skeleton at risk, the target of which is improved mechanical bone strength. From this point of view, the objective of our work was to develop a reliable, reproducible and minimally invasive technique for curettage filling of the distal radius by percutaneous transosseous calcium phosphate cement injection.

**Acknowledgements** Our grateful thanks are due to the following people and organisations for technical assistance during the study: Statistical analysis by Nicolas Molinari, Laboratoire de Biostatistiques, IURC, 641 avenue Gaston Giraud, 34093 Montpellier, France; anatomical subjects provided by the Laboratoire d’Anatomie de l’Ecole de Chirurgie du Fer à Moulin, Paris, France; calcium phosphate cement supplied by Société Teknimed, Vic-en-Bigorre, France. This study was supported financially by GRETO, Groupe de recherche et d’Etudes en Traumatologie de l’Ostéoporse.

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