Failure of fixation is a common problem in the treatment of osteoporotic fractures around the hip. The reinforcement of bone stock or of fixation of the implant may be a solution. Our study assesses the existing evidence for the use of bone substitutes in the management of these fractures in osteoporotic patients. Relevant publications were retrieved through Medline research and further scrutinised. Of 411 studies identified, 22 met the inclusion criteria, comprising 12 experimental and ten clinical reports. The clinical studies were evaluated with regard to their level of evidence. Only four were prospective and randomised.

Polymethylmethacrylate and calcium-phosphate cements increased the primary stability of the implant-bone construct in all experimental and clinical studies, although there was considerable variation in the design of the studies. In randomised, controlled studies, augmentation of intracapsular fractures of the neck of the femur with calcium-phosphate cement was associated with poor long-term results. There was a lack of data on the long-term outcome for trochanteric fractures. Because there were only a few, randomised, controlled studies, there is currently poor evidence for the use of bone cement in the treatment of fractures of the hip.

With the steadily increasing proportion of elderly people in the population, osteoporosis, a disease process characterised by compromised bone strength predisposing to an increased risk of fracture, will become epidemic. By 2012, 25% of people living in Europe will be older than 65 years and more than 40% of women and 14% of men over the age of 50 years will sustain osteoporotic fractures. Common sites affected by osteoporotic fractures include the wrist, spine, ribs, humerus and the proximal femur.

The major problem in the management of osteoporotic fractures which are characterised by poor bone stock with decreased pull-out strength of implants and reduced bone regenerative capacity, is to achieve stable fixation which will allow early mobilisation and sound healing of the fracture. It is not surprising therefore that despite achieving perfect reduction and optimal positioning of the implant, failure rates for the implant, especially in the treatment of unstable trochanteric osteoporotic fractures, are higher than those in normal bone. In order to address this problem, new implants more applicable for fixation in osteoporotic bone have been developed. Another option, however, to avoid failure of fixation is to augment the bone stock or to enhance the implant-bone interface and thus the primary stability.

In this context, the use of autograft is still the method of choice for bone grafting because of its biological characteristics, but in the osteoporotic environment it is not suitable due to its poor mechanical properties. Furthermore, its availability is limited and donor-site morbidity is an issue. For these reasons, the need for alternative solutions has led to the development of bone-graft substitutes.

Our aim was to evaluate the existing evidence for the use of bone substitutes in the management of hip fractures in osteoporotic patients.

Materials and Methods
Publications dealing with this subject were retrieved through research on Medline using search date parameters such as hip fracture, fractured neck of the femur, trochanteric fracture and augmentation, bone (graft) substitutes or bone cement and osteoporosis.

Inclusion criteria were all studies published in English or German including both experimental and clinical studies. With regard to clinical studies, prospective and retrospective
Shaft and the posteromedial corner of the proximal femur were ported by cement in others only the region of the screw head was supplemented. Additionally the study settings differed in terms of the characteristics of the fractures, the implants used, the method of testing, the time of follow-up and the outcome.

Clinical studies retrieved were further evaluated regarding their level of evidence according to the Oxford Centre for Evidence-based Medicine Levels of Evidence.47

Results

Of 411 studies subjected to critical analysis, 22 met the inclusion criteria.48-69 They were divided into in vitro52-63 and in vivo studies (Tables I and II).48-51,64-69

In vitro (experimental) studies. A total of 12 experimental studies were identified, 11 of these were cadaver models. There were nine fracture models (two of a fracture of the neck of the femur and seven of a trochanteric fracture) and three non-fracture models (Table I). In vitro studies almost always concentrated on the use of bone cement for augmentation of fixation of the implant or bone stock.53-65,58-63 Two different cements were examined, namely, polymethylmethacrylate (PMMA) cement56,58,59,61-63 and calcium-phosphate degradable cement.55,56,60,62 Only one study used a composite.72 Additionally the study settings differed in terms of the characteristics of the fracture, the implants used, the technique and the location of application of cement (Fig. 1).

Most studies focused on the implant-bone interface in order to enhance fixation.53-56,58-60,62 Whereas in some studies only the region around the screw head was supported by cement53,54,58,59 in others only the region of the shaft and the posteromedial corner of the proximal femur were augmented (Fig. 1). In only one fracture model was augmentation of the bone stock itself carried out in a region superior to the screw61 (Fig. 1). In all studies the stability of the fixation was enhanced.58-61 (Table I).

Only two studies directly compared the two substitutes. Whereas that of Moore et al56 found no substantial differences between both cements, that of Eriksson et al62 showed better biomechanical properties for PMMA in the augmentation of various implants for the femoral neck. These latter authors also reported that during the pull-out test Norian SRS calcium-phosphate cement (Norian Inc., Cupertino, California) failed by shear through the cement at the periphery of the screw threads whereas PMMA failed at the cement-bone interface.62

In vivo (clinical) studies. Ten clinical studies were carried out using three different agents (PMMA, bisphenol-a-glycidyl dimethacrylate cement, calcium-phosphate degradable cement).48-51,64-69 Only four of them were prospective randomised, clinical trials.64,65,67,68 The studies included a total of 701 patients (Table II).

Polymethylmethacrylate cement. This was used only in three case series48-50 and in one retrospective comparative study51 which reported a lower rate of failure in the augmented group (Table II). Although larger amounts of PMMA were used, these were not significant rates of osteonecrosis.

Bisphenol-a-glycidyl dimethacrylate cement. Two case series used this for augmentation.66,69 It is a partial polymer substitute (Tables II and III). Although only approved in a small number of patients in one study, the authors emphasised its advantage over PMMA in hardening at lower temperatures.69 Unfortunately, a second study66 showed that more than half of the patients (n = 11) had to undergo further surgery within 24 months because of complications related to healing (five re-displacement, four nonunion, two avascular necrosis) discrediting this bone-graft substitute for biomechanical and biological reasons.

Calcium-phosphate degradable cement. In prospective, randomised trials investigating the augmentation of fractures of the neck of femur,44,65 calcium-phosphate cement was shown to improve the stability of the fixation in the early post-operative phase (up to six weeks) In the first study,64 after one week, augmented fractures had moved (described as the total displacement in three dimensions) a mean of 1.9 mm (SD 1.0) compared with 5.5 mm (SD 3.4) in the control group (Mann-Whitney test, p < 0.0001). Six weeks after surgery the mean total movement was 6.9 mm (SD 2.9) and 10.9 mm (SD 5.1), respectively (Mann-Whitney test, p < 0.005). Varus angulation occurred in both groups, but was significantly less in the augmented fractures (Mann-Whitney test, p < 0.007 after one week and p < 0.03 after six weeks).64 In the second study the same authors published the follow-up results up to 24 months after surgery of patients following the same design of study (Table I).65 Mobilisation of augmented patients was easier during the first six post-operative weeks. However, there was a higher overall rate of re-operation in the augmented group. There was a non-significant change in the cause for re-operation from early loss of reduction among the control group (after six months) to re-operations due to nonunion or avascular necrosis in the augmented group after 24 months. Of 118 patients, 34 required further surgery and underwent total hip replacement (20 in the augmented group and 14 in the control group; Table II).

In another prospective, randomised study, augmentation of unstable fractures in the trochanteric region was found to improve the stability of fixation.67 After one week augmented fractures had moved a mean of 1.9 mm (SD 1.7)
<table>
<thead>
<tr>
<th>Fracture model</th>
<th>Study</th>
<th>Bone substitute(s)/implant(s)</th>
<th>Site of application</th>
<th>Design</th>
<th>Evaluation/Results</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable fractures of the neck of femur</td>
<td>Stankewich et al</td>
<td>Calcium-phosphate cement</td>
<td>Threaded part of screw and shaft</td>
<td>Pairs of human cadaver proximal femora (n = 16)</td>
<td>Biomechanical testing</td>
<td>CPC augmentation gives significantly higher failure load</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cannulated screws (3)</td>
<td>Cannulated screws cement</td>
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<tr>
<td></td>
<td>von der Linden et al</td>
<td>PMMA* (Vertecem biomimetic bone cement; Synthes Inc, West Chester, Pennsylvania)</td>
<td>Threaded part of screw</td>
<td>Pairs of human cadaver proximal femora (n = 8)</td>
<td>Biomechanical testing</td>
<td>Irrigation/augmentation of drilling hole enhances implant anchorage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hip screw</td>
<td>Hip screw cement</td>
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<tr>
<td>Unstable trochanteric fractures</td>
<td>Choueka et al</td>
<td>Bone cement (no further specification) Gliding hip screw/plate, Lag screw/plate, Dome plunger/plate</td>
<td>Around dome plunger (efflux holes)</td>
<td>Human cadaver femora (n = 18) (n = 6 in each of the groups)</td>
<td>Biomechanical testing</td>
<td>Dome plunger with cement augmentation biomechanically superior and minimises risk of superior screw cut-out</td>
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<td></td>
<td>Gliding hip screw/plate vs lag screw/plate vs dome plunger/plate + cement</td>
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<tr>
<td></td>
<td>Choueka et al</td>
<td>Bone cement (no further specification)</td>
<td>Proximal screw track/dome plunger (efflux holes)</td>
<td>Human cadaver femora (n = 24)</td>
<td>Biomechanical testing</td>
<td>Failure may be minimised by an appropriate choice of device (dome plunger) or cement augmentation, or both</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lag screw/plate, Dome plunger/plate</td>
<td>Lag screw ± cement vs dome plunger ± cement (n = 6 in each group)</td>
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<tr>
<td></td>
<td>Moore et al</td>
<td>PMMA (Surgical Simplex, Howmedica Inc, Rutherford, New Jersey) or calcium-phosphate cement</td>
<td>Screw track</td>
<td>Pairs of human cadaver proximal femora (n = 10)</td>
<td>Biomechanical testing</td>
<td>Although biomechanically slightly inferior, CPC may have promise as substitute for PMMA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compression hip screws + PMMA or calcium-phosphate cement</td>
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<tr>
<td></td>
<td>Elder et al</td>
<td>Calcium-phosphate cement (Norian SRS; Synthes, West Chester, Pennsylvania)</td>
<td>Prox. screw track + posteromedial defect</td>
<td>Pairs of osteoporotic human cadaver proximal femora (n = 10)</td>
<td>Biomechanical testing</td>
<td>Augmentation decreased both shortening of the proximal femur and stress on the sliding hip screw</td>
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<td></td>
<td></td>
<td>Hip screw/plate</td>
<td>Hip screw/plate ± cement</td>
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<tr>
<td></td>
<td>Augat et al</td>
<td>PMMA (Duracem 3, Sulzer Orthopedics, of modified screw Winterthur)</td>
<td>Around threaded part</td>
<td>Pairs of human cadaver femora (n = 9)</td>
<td>Biomechanical testing</td>
<td>Modified/augmented hip screw significantly enhanced the initial fixation, especially in the most osteoporotic bones</td>
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<tr>
<td></td>
<td></td>
<td>Conventional hip screw, modified hip screw with efflux holes</td>
<td>Conventional vs modified hip screw + cement</td>
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</table>
while movement in the control group was 4.0 mm (SD 2.4) (Mann-Whitney test, $p < 0.05$). After six months the mean total movement was 7.8 mm (SD 6.2) for the augmented fractures and 13.2 mm (SD 4.3) for the control group (Mann-Whitney test, $p < 0.05$). Augmented fractures showed less varus angulation compared with the control group at all time points.\(^6\)

In a second study, the same authors also describe a better clinical outcome after six weeks (lower global and functional pain scores (chi-squared test, $p < 0.003$)), less pain after walking 50 feet (chi-squared test, $p < 0.01$) and a better return to the activities of daily living (chi-squared test, $p < 0.05$) in augmented patients and a significant improvement in the SF-36 score in the augmented group at six months.\(^6\) Two cases of delayed union which healed by nine months and two of loosening of the plate occurred in the augmented group after six months. There were no cut-outs in either group (Table II).

**Discussion**

Because of higher rates of re-intervention after fixation of osteoporotic hip fractures, clinicians have been seeking a holistic approach to improve the healing of these fractures. In addition to the development of newer implants,\(^1\), bone substitutes may be beneficial for the augmentation of implant stability in these fractures. Studies on the

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**Table I. continued**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Material</th>
<th>Implant Procedure</th>
<th>Implant Design</th>
<th>Outcome</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yetkinler et al(^6)</td>
<td>Calcium-phosphate cement (Norian SRS, Synhes)</td>
<td>Hip screw/plate</td>
<td>Along the shaft of lag screw and calcar</td>
<td>Biomechanical testing</td>
<td>Augmentation of fixation in regions addressed offered more stability (less shortening, higher failure load)</td>
</tr>
<tr>
<td>Stoffel et al(^6) (Fig. 1)</td>
<td>PMMA (Osteofirm; William Cook, Brisbane, Australia)</td>
<td>Hip screw/plate</td>
<td>Superior to threaded part of hip screw</td>
<td>Biomechanical testing</td>
<td>Higher cut-out strength after augmentation</td>
</tr>
<tr>
<td>No fracture model</td>
<td>Witschger et al(^6)</td>
<td>PMMA or polypropylene fumarate composite</td>
<td>Screw track</td>
<td>Biomechanical testing</td>
<td>Biomechanical results comparable</td>
</tr>
<tr>
<td>Eriksson et al(^6)</td>
<td>PMMA (Palacos, Schering-Plough, Stockholm, Sweden) or calcium-phosphate cement (Norian SRS, Norian Inc)</td>
<td>Hip screw</td>
<td>Foam blocks of 3 different densities (normal bone, slight and severe osteoporosis)</td>
<td>Biomechanical testing</td>
<td>PMMA better at increasing holding power and more resistant to shear forces</td>
</tr>
<tr>
<td>Heini et al(^6)</td>
<td>PMMA (Palacos LV-40 + Gentamicin, Essex Chemie, Luzern, Switzerland)</td>
<td>No implant</td>
<td>Proximal femoroplasty</td>
<td>Biomechanical testing</td>
<td>Prophylactic reinforcement of femora increased energy absorption</td>
</tr>
</tbody>
</table>

\(^*\) PMMA, polymethylmethacrylate cement + with or without 
\(^†\) CPC, calcium-phosphate cement +, with
Table II. Details of *in vivo* (clinical) studies

<table>
<thead>
<tr>
<th>Fracture model</th>
<th>Study</th>
<th>Level of evidence</th>
<th>Bone substitute/implant(s)</th>
<th>Application site</th>
<th>Design</th>
<th>Evaluation</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displaced femoral neck fractures</td>
<td>Mattsson and Larsson\textsuperscript{64}</td>
<td>I</td>
<td>Calcium-phosphate cement</td>
<td>Screw holes before screw insertion and into fracture void</td>
<td>Prospective, randomised study (n = 40)</td>
<td>Radiostereometry</td>
<td>Improved stability of fixed femoral neck fractures during the first six weeks after surgery</td>
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<td>Cannulated screws (2)</td>
<td>Cannulated screws (n = 20) vs screws + cement (n = 20)</td>
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<tr>
<td></td>
<td>Mattson and Larsson\textsuperscript{65}</td>
<td>I</td>
<td>Calcium-phosphate cement</td>
<td>Screw holes before screw insertion and into fracture void</td>
<td>Prospective, randomised (multicentre study (n = 118)</td>
<td>Clinical and radiological</td>
<td>Trend towards more re-operations in the augmented group</td>
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<td>Cannulated screws (2)</td>
<td>Cannulated screws (n = 60) vs cannulated screws + cement (n = 58)</td>
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<tr>
<td></td>
<td>Frihagen et al\textsuperscript{66}</td>
<td>IV</td>
<td>Bisphenol-a-glycidyl dimethacrylate (Cortoss; Orthovita, Malvern, Pennsylvania)</td>
<td>Composite was delivered around the screw threads</td>
<td>Case series, no control (n = 21)</td>
<td>Clinical and radiological</td>
<td>High failure rate (n = 11)</td>
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<tr>
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<td></td>
<td>Cannulated screws (2)</td>
<td>Histology follow-up 24 months</td>
<td></td>
<td>Fragmentation of composite with foreign-body response and low grade inflammation</td>
</tr>
<tr>
<td>Unstable trochanteric fracture</td>
<td>Harrington\textsuperscript{48}</td>
<td>IV</td>
<td>PMMA*</td>
<td>Fracture site</td>
<td>Case series, no control (n = 42)</td>
<td>Clinical and radiological</td>
<td>37 fractures healed without any loss of position</td>
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<td></td>
<td>Fixed nail-plate or compression screw/plate</td>
<td>38 patients followed up</td>
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<tr>
<td></td>
<td>Schatzker et al\textsuperscript{49}</td>
<td>IV</td>
<td>PMMA*</td>
<td>Fracture site</td>
<td>Case series, no control (n = 28)</td>
<td>Clinical and radiological</td>
<td>3 failures (1 nonunion)</td>
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<td></td>
<td></td>
<td>Fixed blade plate</td>
<td>10 patients (11 fractures) followed up</td>
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<td>Cement did not interfere with bone union</td>
</tr>
<tr>
<td></td>
<td>Muhr et al\textsuperscript{50}</td>
<td>IV</td>
<td>PMMA*</td>
<td>Fracture site</td>
<td>Case series, no control (n = 231)</td>
<td>Clinical and radiological</td>
<td>No femoral head necrosis, no nonunion</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>Fixed blade plate</td>
<td>106 patients followed up</td>
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<tr>
<td></td>
<td>Mattson and Larsson\textsuperscript{67}</td>
<td>I</td>
<td>Calcium-phosphate cement (Norian SRS, Norian Inc)</td>
<td>Posteromedial defect and proximal screw hole of sliding hip compression screw plate</td>
<td>Prospective, randomised study (n = 21)</td>
<td>Radiostereometry</td>
<td>Improved stability in augmented fractures pronounced for varus angulation</td>
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<td></td>
<td>Sliding hip compression screw</td>
<td>Compression screw (n = 10) vs compression + cement (n = 11)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Mattson et al\textsuperscript{68}</td>
<td>I</td>
<td>Calcium-phosphate cement</td>
<td>Posteromedial defect and proximal screw hole of DHS plate</td>
<td>Prospective, randomised (multicentre) study (n = 112)</td>
<td>Clinical and radiological</td>
<td>Augmentation provides modest reduction in pain</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>Sliding hip compression screw</td>
<td>Compression screw (n = 57) vs compression + cement (n = 55)</td>
<td></td>
<td>Slight improvement in quality of life</td>
</tr>
</tbody>
</table>
The reinforcement of hip fractures with underlying osteoporosis have focused on the use of bone cements. However, before any conclusions can be made there are several issues to be considered when cements are implanted in general and in patients with hip fractures in particular. First, the decision should be made which cement to use since they differ in terms of biomechanical properties (Table III). These are of utmost importance since their ability to offer sufficient primary stability allows immediate mobilisation and load-bearing on the affected limb. Earlier studies have pointed out that PMMA increases the resistance to the pull-out of screws in osteoporotic bone. Calcium-phosphate cements also have been shown to complement the fixation of hardware. They seem to develop compressive strength midway between cancellous and cortical bone, but there are concerns about their resistance to shear and tension. All cements examined in the recent studies were shown to increase the primary stability of the implant-bone construct. This was a consistent finding in both in vitro and in vivo studies and in fractures of the osteoporotic femoral neck and trochanter and was independent of the implants used and the site of application. Eriksson et al confirmed the susceptibility of Norian SRS to shear forces when directly compared with PMMA in the reinforcement of a variety of implants for fixation of the femoral neck. During the pull-out test Norian SRS failed through the cement at the periphery of the screw threads whereas PMMA failed at the cement-bone interface. Reinforcement by calcium-phosphate cement gave results which were inferior to the normal fixation by screws which were implanted without pre-drilling such as the Olmed (DePuy, Uppsala, Sweden) and Hansson (Swemae, Linköping, Sweden) screw which therefore compress the surrounding bone during insertion. This in particular was evident in the less osteoporotic bone substance because the use of bone cement requires a hole to be drilled for the application of cement before the insertion of the screw.

*T PMMA, polymethylmethacrylate cement + with*
Secondly, bone cements also vary in biological properties (Table III). In contrast to PMMA, calcium-phosphate cements are injectable, osteoconductive and are remodelled and replaced by bone \textit{in vivo}. In a rabbit model morphological analysis showed a sequential loss of Norian SRS and subsequent bone ingrowth over a testing period of up to 30 weeks. At this stage resorption of the bone cement was complete in only one rabbit. However, there has been no study of this in human patients which has examined the exact rate of resorption of calcium-phosphate cements. Non-biodegradable cements may complicate revision surgery since more complex peri-prosthetic fracture patterns may arise during subsequent trauma, repair of which is much more challenging. Higher temperatures occurring during polymerisation of cement may cause heat-induced osteonecrosis or impairment of fracture healing since they can damage the periosteal blood supply. This is a considerable disadvantage particularly for PMMA because calcium-phosphate cements are generally not expected to polymerise at dangerously high temperatures (Table III).

Thirdly, we need to understand the optimal site of application of these cements to achieve the best results in the different patterns of fracture and implants used. The site of application is important since it determines the modality of augmentation by the bone cement used. Bone cements can be used as a gap-filling internal fixation device to facilitate reconstruction and load transfer, but also they can be directly attached to a fixation device improving its anchorage in bone. With regard to their use as a gap-filling device, non-biodegradable cements such as PMMA administered directly at the site of a fracture can lead to nonunion. In addition to heat-induced impairment of fracture healing in the surrounding area, no formation of bone can occur where non-resorbable bone cement is placed. There are also concerns about the application of cement around the implant itself. Bone cement introduced around the shaft of a sliding device may impair its mechanism and turn it into a rigid fixation device, possibly leading to a cranial cut-out of the implant. The recently introduced technique of reinforcing bone stock above the threads of the proximal sliding screw in a sliding screw-plate device where it is most beneficial to prevent cut-out could be a reasonable alternative. This procedure can be carried out at the end of surgery. Furthermore, it also reduces the risk of penetration of the hip with the cement compared with techniques in which the cement is applied through the hole of hip screw itself, drilling of which may have already perforated the joint. The disadvantage of the procedure is that the technique described is not appropriate if a sliding screw/nail-implant is used. With regard to the reinforcement techniques of the implants themselves, controlled methods for delivering smaller quantities of cement at the level of the screw head have been reported. Modification of the design of a hip screw for the application of bone cement produced three slots which ensured a localised effluence of cement at the height of the thread, a closed tip to prevent penetration of the joint and a barrier to avoid reflux of cement in the direction of the shaft where it might impair the gliding mechanism.

Fourthly, the optimal timing and method of insertion of the cement should be considered. Von der Linden et al described the use of pulsatile irrigation to remove fat, blood and bone debris to allow better penetration of cement for the augmentation of a hip screw. In the studies retrieved, all techniques described to strengthen fixation of an implant used liquid cement. No techniques have been described which introduced hip screws into hardened cement. This aspect has been investigated by Motzkin et al. They performed axial pull-out tests of 3.5 mm and 4.5 mm AO cortical screws after these had been placed into liquid, solid (by drilling and tapping), or into curing PMMA with quarter-revolution turns every 30 seconds until the PMMA had hardened. They found no significant difference in the pull-out strengths according to screw size or in screws placed in liquid or solid PMMA. Screws placed in curing PMMA were significantly weaker. Consequently, screws should be inserted either in solid or liquid PMMA according to the circumstances and the preference of the surgeon.

In our study, the clinical results of the augmentation of proximal femoral fractures were analysed in a systematic manner. According to the results of the two randomised, controlled studies on the augmentation of displaced fractures of the femoral neck using Norian SRS only the early post-operative results were improved in terms of rehabilitation and loss of reduction. Evaluation after 24 months was discouraging since there was a tendency towards more re-operations in the augmented group because of higher rates of nonunion and avascular necrosis. The technique of augmentation used in these studies included the application of Norian SRS in the screw holes and also into the fracture void. Unfortunately, there were no further details about the failed cases and reasons were not fully addressed in the study. Therefore only speculation is possible.
Late complications were also reported by Cheng et al. who used augmentation with acrylic cement at the site of the fracture in a Dimon-Hughston medial displacement osteotomy in 38 patients with unstable trochanteric fractures. Whereas the early results were good, they found that six patients suffered from late complications, all occurring around one year after surgery, including nonunion, destruction and avascular necrosis of the femoral head. These complications were seen in cases in which excessive amounts of cement had been used, placement of the cement was inappropriate and inadequate bone formation was apparent.

Randomised, controlled studies have shown that fractures in the trochanteric region stabilised by dynamic hip screws were successfully augmented by calcium-phosphate cement when assessed six months after surgery. Late results using this technique of augmentation are not available at present but again, a drawback of the technique described may be the augmentation of the fracture site (Fig. 2), leading to long-term problems.

Using calcium-phosphate bone cement, modifications of the techniques described in the randomised, control studies in terms of location of the graft are conceivable to improve the late outcome and should be investigated in further trials. This is of special importance in the management of trochanteric fractures, since there is no routine alternative or second-line surgical option such as hip replacement in these patients. Hence, it is of paramount importance to analyse the pitfalls in the management of trochanteric fractures with underlying osteoporotic bone stock.

Finally, besides its mechanical properties, a bone substitute should ideally be osteoconductive, osteo-inductive and have an osteogenic potential. New types of cement have been introduced as carriers for osteo-inductive growth factors such as bone morphogenetic protein 2, but these have poorer mechanical properties. Further research has led to the development of composite grafts which contain osteogenic cells and osteo-inductive growth factors along with a synthetic osteoconductive matrix and therefore consist of all three of the essential properties required. Research is ongoing into scaffolds offering better bone ingrowth while maintaining the practicality of being injectable.

The performance of these new bone substitutes should be investigated in the mechanically compromised region of a hip fracture. Future research needs to consider which patients would benefit from primary reinforcement and to distinguish these patients in ways which are reasonable in the clinical setting.

Based on the results of our study the following conclusions can be made.

1) Both PMMA and calcium-phosphate cements increase the primary stability of the implant-bone construct in all experimental and clinical studies.

2) Because very few randomised, controlled studies have been carried out, there is currently poor evidence for the use of bone cement in the treatment of fractures of the hip. Further clinical studies are required to determine which bone cement to use and where to apply it for optimal results.

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References
20. Haynes RC, Poll RG, Miles AW, Weston RB.  
21. Audige L, Hanson B, Swiontkowski MF.  
22. Al-yassari G, Langstaff RJ, Jones JW, Al-Lami M.  
23. Hing KA.  
24. Parikh SN.  
25. Giannoudis PV, Dinopoulos H, Tsiridis E.  
26. Lorich DG, Geller DS, Nielson JH.  
27. Cutter CS, Mehrara BJ.  
28. Rush SM.  