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THE ACTUAL STATUS OF ACRYLIC BONE CEMENT IN TOTAL HIP REPLACEMENT

A review

by J. DE WAAL MALEFIJT, T.J.H. SLOOF and R. HUISKES

The utilization of polymethylmethacrylate to stabilize total hip replacements has tremendously increased since Charnley introduced the acrylic cement as a fixative in 1960.

Many contemporary studies and experiments have resulted in increased knowledge about cement properties and side-effects.

In this article the present status of acrylic cement in total hip replacement is contemplated, with the aid of a comprehensive and actual review of the literature, and supplemented with remarks and recommendations resulting from a longlasting experience with cemented hip arthroplasties in our clinic.

Native knowledge of mixing and handling instructions regarding the application of each separate cement is indispensable, while also the importance of practising meticulous cementing techniques in order to obtain optimal primary implant fixation, is strongly emphasized. When hip replacements are performed according to these developments, a reduction of mechanical loosening of cemented hip arthroplasties is liable to be achieved.

INTRODUCTION

A survey of the extensive literature concerning utilization of polymethylmethacrylate (PMMA) for fixation of joint implants suggests how revolutionary Charnley was in 1960 when he stabilized his first arthroplasty of the hip with acrylic cement (3).

Since then, the properties and side-effects of acrylic cement have been studied by many investigators. These studies have resulted in major and dramatic improvements in the use of PMMA heralding an entire new era of cemented arthroplasties.

Long term follow-up studies will have to demonstrate whether all changes lead to an improvement of results.

THE INTERLOCKING OF ACRYLIC CEMENT AND BONE

The durability of a cemented arthroplasty is closely related to the quality of fixation of acrylic cement to the bone, and is also dependent on the interfacial bond between cement and prosthesis.

Acrylic cement is exclusively a « filler », adapting the surface irregularities of the surrounding bone tissue to the relatively smooth surface of the inserted prosthesis (macro-interlock).

In this way the area of contact between cement and bone is increased and forces are distributed over a larger bone surface area, so that local overloading is avoided.

By pressurizing the cement during insertion, the acrylic cement penetrates into cancellous bone interstices with better mechanical interdigitation as a result (micro-interlock).

This bonding between bone and acrylic cement by interdigitation is called « primary mechanical anchorage ».
Subsequently, we may refer to the « secondary mechanical anchorage » as the steady state, which can be obtained when all biological reactions in the surrounding tissues following an arthroplasty, have become stationary.

PRIMARY MECHANICAL ANCHORAGE

The quality of the primary mechanical stability of the cemented prosthesis mainly depends on:
- the viscosity of the acrylic cement,
- cement pressurization,
- blood pressure,
- structure of the surrounding bone tissue,
- cleanliness of the bone tissue,
- implant design,
- implant insertion technique,
- dimensional changes of the cement.

In the past, several acrylic cements have been developed which produce different viscosity during the « mixing » and « handling » phases in the polymerization process. A number of experiments, including our own, have shown that there are no significant differences between these cements as far as mechanical properties are concerned, if the mixing technique is properly standardized (7).

Low viscosity cement penetrates easier in trabecular bone. Noble and Swarts (22) (1983) performed an in vitro study, in which they demonstrated a clear correlation between the viscosity of cement and final penetration depth (22).

The depth of penetration also depends on the size of the interstitial cavities in cancellous bone. It is impossible to obtain adequate primary anchorage in a sclerotic bone cavity. Furthermore, the time at which the cement is pressurized within the prepared bone is of critical importance in achieving the desired mechanical interdigitation (20).

Only if the cancellous bone has been thoroughly cleaned with a lavage system (waterpick), and subsequently dried, the bony structure can be optimally utilized (16). Huiskes and Slooff have shown, that thermal damage to the bone is likely to occur with a cement penetration of 5 mm or more (15). Walker et al. (31) (1984) found, that there seems to be a correlation between an increase of the strength of the cement-bone composite and the depth of penetration under similar conditions of bone preparation.

From their study they also suggested, that the ideal penetration depth amounts 3 to 4 mm. Other researchers have proposed a penetration depth of 5-10 mm (16). Considering all these factors, it is extremely difficult to develop a standardized technique which guarantees a certain penetration depth in the clinical situation. Although the viscosity of the cement should be low in order to obtain adequate cement penetration, a sufficiently high viscosity is needed to enable pressurization (22). In this respect, exact knowledge of the mixing conditions for PMMA bone cements is indispensable. Preferably, the pressure exerted on the bone tissue by the cement dough is maintained at a level substantially above the bleeding pressure, until the viscosity of the dough is high enough to resist the occurrence of a hematoma between cement and bone, which will compromise the strength of the interface (13).

The distribution of the cement and the direction in which the acrylic flows during prosthetic insertion, also depends on the geometry of the bone cavity as well as the design of the implant. During insertion into the cement, a prosthesis should only be moved in one direction; the contact force must be applied statically and must be maintained until polymerization is complete. Any movements of the pressing aid by the surgeon in this stage, always leads to undesirable migration of the cement and often to disruption of the integrity of the cement mantle.

During and after the polymerization process, the cement dough undergoes dimensional changes. In the literature, an overall expansion of 2 to 5 volume percent has been mentioned, as a result of expansion of enclosed air and vaporized monomer bubbles, followed by thermal shrinkage (25).

The shrinkage may result in a gap between the bone and the cement mass, which may constitute a threat to primary mechanical anchorage.

SECONDARY ANCHORAGE

A large number of parameters are involved in the long-term quality of the bone-cement bonding:
- the initial damage to the bone as a result of the operation,
- side-effects of acrylic cement,
- positioning of the prosthesis.
— the load on the artificial joint,
— general condition, age and in particular the weight of the patient,
— trauma/infections,
— ageing of the cement,
— changes in bone diameter in elderly patients (osteo­porosis).

Some of these parameters are as follows:

a) Damage to the bone, caused by cement constituents.
b) Other influences on secondary anchorage.

d- Damage to the bone, caused by cement properties or constituents.

Polymerization heat.

In nearly all publications on this subject, the heat from the polymerizing bone cement is unanimously considered to be an important causative factor of initial bone necrosis. Feith concluded from rabbit experiments that the thermal tissue damage far exceeds the necrosis which results from ischemia by the operative interference with the blood supply (6).

In a finite element model, Huiskes demonstrated a theoretical relationship between the maximum temperature, the cement layer thickness, and the amount of bone necrosis, whereby the stem of a metal femoral endoprosthesis in the cement leads to a reduction of the maximum temperature, acting as a «heat sink» (14).

He also established that geometrical conditions, a higher initial bone temperature, and the inferior thermal properties of HDPE compared to metal, attribute to a greater chance for thermal damage during acetabular cup fixation with cement than during fixation of intramedullary (metal) implants.

Furthermore, Huiskes evolved the hypothesis, that a higher temperature may have an indirect effect on tissue necrosis by increasing the cytotoxicity of residual monomer (14).

Of course the amount of bone necrosis depends on the duration of exposure to polymerization temperatures. Eriksson demonstrated, that bone develops necrosis when exposed to a temperature of 47° C or higher during one minute or more (6).

As previously stated, it remains uncertain what will be the exact effect of deep penetration of acrylic cement in trabecular bone, as a result of pressurization techniques.

As long as no definite clinical data are available on this subject, it is advisable to take all possible measures to reduce the maximal temperature (cooling the bone with a waterpick, avoiding thick cement mantles etc.).

Considerable precooling of the prosthetic components, before insertion and/or the cement constituents prior to mixing, may lead to a reduction of the temperature at the bone cement interface.

A disadvantage however is, that the setting time is prolonged, resulting in a compromise of the mechanical properties of the cement (14).

Monomer.

In the past, methylmethacrylate intoxication was considered to be the principal cause of circulatory disturbances and even cardiac arrest, during implantation of cemented joint arthroplasties, in particular in the femur.

Recent studies have now suggested, that this so called «implantation syndrome» is initiated by fat, bone marrow cells and probably entrapped air, being forced into the vascular system by the pressure under which bone cement is implanted into the medullary canal. This can be visualized using intraoperative transoesophageal two dimensional echocardiography continuously (12).

Utilization of a vent during cement insertion, but also cleaning of the trabecular structure of the bone with a lavage system, reduces the likelihood of this embolization to occur (28).

Many in vitro and in vivo studies have been designed to evaluate the cytotoxicity of monomer. Linder established that monomer, even when thermal effects and pressure on the tissue are eliminated, causes microcirculatory disturbances resulting in tissue necrosis (19).

Therefore, waiting with the introduction of cement until just prior to the setting time, has no beneficial effect with respect to the possibility of introducing less monomer to the patient (17).

Furthermore, it has been shown that the concentration of unpolymerized monomer at the interface is only high enough to cause tissue necrosis until a maximum of 4 hours after insertion of the cement dough (29).

Dimethylparatoluidine.

The catalyst NN-dimethyl-p-toluidine (DMpT) is well known to be toxic even at a low concentration
(inhibiting synthesis of proteins, carcinogenic effects).

Bösch and Lintner (2) suggested, that DMP T may be responsible for mineralization disturbances of bone, leading to osteoid formation.

By means of gaschromatographic analysis, they identified DMP T in acrylic cement even 10 years after total hip replacement (2). The clinical significance of these findings however, is yet unknown.

Other cement constituents.

The effect of additives like antibiotics, colourants and contrast media on the mechanical properties of the cement can not be neglected. Barium sulphate (Roening contrast medium) for instance, was found to be associated with necrosis of lamellar bone. However, it seems unlikely that these reactions will occur when this contrast medium is utilized within acrylic cement.

Ageing of polymethylmethacrylate.

As the age of implanted cement increases, its strength slowly reduces.

By diffusion processes leading to volume changes, and cyclic loading of the material, the acrylic turns into a more rigid substance with a decrease in resistance (9, 14).

The abrasion of particles of acrylic cement, in the presence of relative motions, may subsequently lead to aggressive granulomatous tissue reactions, which in turn will contribute to bone resorption and further loosening of the implant (33).

Improvements in implant design.

Femoral components were provided with a broad and rounded medial border, and sharp edges ("stress raisers") were eliminated. Preferably, the width of the stem is more than half the width of the medullary canal (1).

Concerns over the incidence of acetabular component loosening have motivated further research into acetabular cups. The addition of a metal backing to a polyethylene component serves to stiffen the otherwise flexible cup, and this stiffening serves much the same purpose as the subchondral bone in the natural acetabulum.

Metal backing thus tends to distribute loading around the prosthetic component more uniformly, which results in lower peak stresses in cement, subchondral bone, and trabecular bone within the acetabular region. Furthermore, metal backing probably establishes a heat-sink effect with respect to the polymerization heat generated by the acrylic cement.

The first clinical results of hip arthroplasty with the use of metal backed acetabular components are encouraging (11). Having a uniform cement mantle is considered to be advantageous in terms of stress in the cement. For that reason, spacers have been added to acetabular components, to guarantee a uniform cement mantle thickness.

Preferably, these spacers are made of PMMA, in order to have the same mechanical properties as the cement mantle.

In the past, the critical importance of the interfacial bond between a metal implant and bone cement, has been underestimated. Raab et al. demonstrated, that the implant-cement interface deteriorates over time when exposed to 37° C saline. They established...
poor static and fatigue properties of these interfaces compared to the same properties for bone cement, suggesting that failure of this interface may be a precursor as well as a major cause of cement failure and subsequent implant loosening (26). This was confirmed by Huiskes, who stated that the cement stress is dramatically increased when the implant-acrylic cement interface is loose (14). The strength of the cement-metal interface can be increased by PMMA-precoating. In this process, a thin layer of bone-cement is added to the metal surface of the prosthesis by the manufacturer.

Improvement of acrylic cement.

In orthopaedic research, many experiments have the objective to develop a new acrylic cement with reduced polymerization and enhanced mechanical properties, by alternating polymer formulations, addition of reinforcing agents and changes in the particle size distribution of the prepolymerized powder.

As hand mixed cement is a brittle material, several methods have been explored to enhance cement properties through reduction of cement porosity. These methods include centrifugation of the cement mixture, vacuum mixing techniques or mixing under ultrasonic vibrations. The fatigue life of cement can thus be increased by porosity reduction, while the implant-cement interface strength as well as the bone-cement interface strength are enhanced (7). The success of these techniques depends on the viscosity of cement during the mixing and handling phase. Vacuum-mixing can lead to a 70% reduction of cementporosity, resulting in a 20 to 40% increase of cementstrength (24). A major disadvantage of centrifugation might be, that cement constituents or additives, as a result of density differences compared to PMMA, are thrown to the periphery of the cement. Thus, the cementstrength is locally reduced. This is particularly marked in « cold » specimens, in which the viscosity has not yet increased, while the force of centrifugation also is of significant influence (30).

There is no general agreement about the benefits from ultrasonic vibration of the cement mixture (7). Cement porosity is not only dependent on the mixing technique. Noble et al. used Surgical Simplex bone cement in a laboratory study on cadaver femurs. They found that the degree and distribution of pores in the cement also depended on the cement thickness and the position of the cement in the femur, both of which are related to the prosthetic design (23).

Improvements in cementing techniques.

Several measures to improve implant fixation with acrylic cement have already been mentioned previously. The bulk shape of the bone cavity has to be meticulously prepared in such a manner, that a congruous cement mantle geometry can be obtained after insertion of the implant. Large bone defects are preferably filled with bone grafts. The use of pulsating saline lavage to mechanically debride the prepared bone surfaces and scrupulous cleaning and drying of the bone cavity before insertion of acrylic cement has significantly altered the primary quality of the bone cement interface.

Miller et al. demonstrated, that thorough cleaning of the bone surface in a cortical tube model in the dog produced a virtual doubling of the cement-bone surface shear strength (21). In terms of cement distribution, it is well established that plugging the medullary canal leads to a much stronger bone-cement interface. Insertion of the acrylic with a cement syringe, using a vent to allow air to escape, is recommended.

Knowledge of the exact mixing and handling time of the utilized cement is indispensable. In order to perform a proper cement technique one should not insert the cement until the appropriate viscosity is obtained, which enables us to pressurize the cement resulting in adequate penetration in the trabecular bone. The pressurization techniques as described by Ling, Weber and Harris deserve attention.

They introduced several methods and instruments to maintain pressure on the cement dough until it has cured (10, 18, 32).

CONCLUSION

The critical importance of an optimal primary fixation of cemented arthroplasties to improve long-term results, is now gaining wide acceptance. The little additional time which is needed to practice all new cementing techniques, can absolutely be neglected compared to the duration of the revision surgery. It is not to be expected that other fixation techniques will equal the quality of the primary anchorage as obtained with acrylic cement. Miculous surgery
and cement technique, and appropriate implant selection, have resulted in the evolution of the cemented total hip replacement procedure to its present status of predictable reliability.

RESUME

J. de WAAL MALEFIJT, T.J.H. SLOOFF et R. HUISKES. — Le point sur l'usage du ciment acrylique en arthroplastie totale de hanche.

Depuis l'introduction en 1960 par Charnley du methacrylate de méthyle pour fixer les prothèses totales de hanche, cette technique connaît un essor peu ordinaire. Nos connaissances des propriétés et des effets secondaires du ciment se sont considérablement développées grâce à de nombreuses études qui permettent une notable amélioration des techniques d'emploi de ce matériau.

Dans cet article, les auteurs font le point sur l'abondante littérature parue au sujet des techniques d'emploi du ciment acrylique. Ces données, ainsi que la très longue expérience des auteurs mènent à un certain nombre de conclusions pratiques formulées sous forme de recommandations pour l'emploi du ciment. Les auteurs soulignent l'importance d'avoir une connaissance approfondie des propriétés du ciment employé et surtout de posséder à fond une technique de cimentage précise qui permet une fixation optimale de l'implant. Une amélioration des techniques de cimentage, grâce à ces prescriptions pratiques, amènera logiquement à une réduction du nombre de désements.

SAMENVATTING

J. de WAAL MALEFIJT, T.J.H. SLOOFF en R. HUISKES. — Huidige positie bij het gebruik van acryle cement ter fixatie van totale heupprothesen.

Sinds Charnley in 1960 het polymethylmethacrylaat introduceerde ter fixatie van totale heupprothesen, is het gebruik van het acrylelement enorm toegenomen. Tegelijkertijd hebben vele studies met betrekking tot de eigenschappen en bijwerkingen van het cement, de kennis hieromtrent vergroot.

De resultaten in sterke verbeteringen in de praktische toepassing van het acrylelement bij gewrichtsvervangende operaties.

In dit artikel wordt de huidige positie en de gebruiks-methode van het acrylelement bij de totale heupprothese besproken aan de hand van een uitgebreide en actuele literatuurstudie.

Voorts zijn daarin aanbevelingen en opmerkingen verwerkt, die resulteren uit de jarenlange ervaring met geconcemeerde heupartheoplastiek evenwijdig aan de eigen kliniek.

De noodzaak van een gedegen kennis omtrent de verworkeingsschijven van het gebruikte cement en vooral ook het belang van een nauwkeurige cementering techniek voor het bereiken van een optimale primaire implantaatverandering, worden sterk benadrukt. Als heupprothesen met inachtneming van deze aspecten worden ingecementeerd, mag een afname van het aantal mechanische losrakingen worden verwacht.

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