Modification of PMMA Using NMP in a Stiffness-Adapted Bone Cement

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Introduction: Percutaneous reinforcement of vertebral bodies (vertebroplasty) using polymethylmethacrylate (PMMA) is an effective treatment option for osteoporotic vertebral fractures. Immediate pain relief is achieved in 80% to 90% of cases. To date, PMMA is the most common augmentation material used in vertebroplasty. However, PMMA has drawbacks, such as inappropriate mechanical properties. Due to its high stiffness, an increased fracture risk has been found for the adjacent vertebral bodies after reinforcement [1]. It seems reasonable to assume that the optimal mechanical properties in stiffness of the PMMA should be close to native cancellous bone (100–700 MPa in Young’s modulus, YM), while in compressive strength it must guarantee no failure in the long term (several times higher than native bone, 2–10 MPa in Yield strength, YS). Using an additive which acts as plasticizer on the dense PMMA cement to reduce the cross-link density may be one way to decrease its stiffness. 1-methyl-2-pyrrolidone (NMP) is an organic solvent which is fully miscible with the liquid monomer component of PMMA. NMP’s miscibility with water allows for a full exchange of NMP with body fluids after implantation and its biocompatibility has been previously shown together with its potentially favorable properties on bone growth [2]. Since the main complication in performing vertebroplasty is cement leakage and extravasation, a new cement design must take viscosity into account as well [3]. The goals of this study were to determine the mechanical properties of the new PMMA as a function of NMP amount and measure the viscosity during cement hardening.

Materials and Methods: The modification of the PMMA cement to less stiff material was performed by partly substituting the fluid MMA by NMP (Fluka AG, Switzerland). Cement preparation was done by manual mixing. 21 g of PMMA powder were mixed with 10 ml of liquid component. The liquid component consisted of 100% MMA in the control group and of 80%, 70%, 50% and 40% MMA with the rest substituted by NMP in the test groups. Cement samples were mixed and cast into cylindrical forms (length 12mm, diameter 6mm; ISO 5833). For each material composition, 24 samples were produced for the mechanical investigations. Materials were hardened in the mould for 2 h and removed. Subsequently, the samples were stored in PBS at 37°C for 48 h. Young’s modulus and yield strength were then measured on all samples.

Mechanical testing (Zwick 1486, Zwick, Germany) was carried out in compression by means of a 10kN load cell and a crosshead speed of 5mm/min. The determination of the Young’s modulus and yield strength was made according to ISO 5833. The viscosity of the cement during hardening was measured using a rheometer (Rheolab QC, Anton Paar, Austria) equipped with a double gap measurement system (oscillatory frequency 1 Hz, max. torsional moment 3mN) at room temperature.

Viscosity measurement as well as cement preparation was conducted at 22 ± 2°C.

Results: Measurements of the viscosity vs. time showed that NMP leads to a substantial reduction of the speed of the curing reaction. The time needed to reach a viscosity of 1100 Pas is approximately doubled when 60% of the MMA are substituted by NMP, as can be seen in figure 1.

Characterization of the stiffness and yield strength of the material with and without substitution of MMA by NMP give further insight into possible effects of the NMP on the material. Both the stiffness and the yield strength are reduced by the addition of NMP. Young’s modulus ranged from 2.3 ± 0.023 GPa to 320 ± 29 MPa and yield strength from 78 ± 0.8 MPa to 24 ± 4 MPa, when the amount of NMP was increased from 0 to 60%.

Discussion: Adjustment of the mechanical properties of PMMA is expected to reduce the fracture risk of adjacent vertebral bodies. This study shows that adding NMP to regular PMMA bone cement provides a possible solution: substitution of around 40% of the MMA content by NMP was able to yield a cement stiffness comparable to that of cancellous bone. Whether cement with a lower stiffness will result in a lower incidence of adjacent segment fracture can only be proven clinically. This method may additionally have the advantage that the maximum temperature reached within and around the cement is reduced when compared to regular cement. This effect results from less amount of MMA in the modified cement. The viscosity measurements showed a reduced speed in the curing reaction. As a practical point of view, this is a great advantage in that it gives a clinician more time for injecting the cement, as opposed to the standard cement formulation without NMP. The fatigue properties of the new cement will be analyzed in the further work.


Acknowledgements: The authors thank aap Biomaterials, Germany, for valuable discussions and input.