Impact of Thermal Reduction on the Early Mechanical Characteristics and Microstructure of Bone Cement

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INTRODUCTION:

Polymethyl methacrylate (PMMA) bone cement is widely used to achieve implant fixation in knee and hip arthroplasties. Proper cementing techniques are crucial to prevent aseptic loosening, which is a leading cause of joint replacement failure. Acrylic bone cement polymerization generates heat; therefore, irrigation of the surgical site and bone cement with saline is suggested to accelerate the cooling of the bone cement. One of the concerns regarding the use of water cooling is the risk of cement shrinkage and the formation of minimal cracks that disturb the integrity of the bone cement.

To the best of our knowledge, no previous study has investigated whether water cooling with low temperatures during bone cement polymerization affects the surface integrity of the bone cement and if this leads to any surface cracks. Since bone cement is usually used in contact with fluids such as saline and blood during the final stages of the cementing procedure, we aimed to investigate the effect of cooling the bone cement via normal saline irrigation on its bending strength and surface microstructure.

METHODS:

Bone cement samples of Simplex P and Fix 1 were prepared in a mold at room temperature. Then, the bone cement samples were divided into three groups: (1) contact with normal saline at 25°C, (2) contact with cold normal saline at 4°C, and (3) no contact with saline as the control group. After the setting time, all samples were put in phosphate-buffered saline solution (PBS) at 37 °C. Flexural strength was assessed according to ISO 5833 standards at 1 hour, 1 day, and 1 week after cement production. Scanning electron microscope (SEM) imaging was performed 2 hours and 24 hours after the polymerization of the samples.

Statistical analysis was performed using SPSS software ver. 26.0 (IBM, Armonk, NY, USA). The normal distribution of data was assessed using the Kolmogorov-Smirnov Z-test. Parametric or non-parametric tests are used depending on the result of normal distribution. One-way ANOVA and Kruskal-Wallis tests were used to compare quantitative variables between the three groups. Continuous variables were reported as mean ± SD. A p-value less than 0.05 was considered statistically significant.

RESULTS:

The flexural strength of bone cement samples of saline and cold saline groups was lower than the control group (Figure 1). However, only Simplex P bone cement in the saline and cold saline groups at 24 hours showed a significantly lower flexural strength compared to the control group ($p < 0.01$). The strength of Simplex P cement samples irrigated with cold normal saline was 11 and 18% lower compared to the normal saline group 1 and 24 hours after the cement preparation. Similarly, the flexural strength of Fix 1 cement in the cold normal saline group was 9% lower compared to the normal saline group 1 hour after the cement preparation (Table 1, Figure 1). The groups had similar flexural strength one week after their polymerization.

Analysis of the surface microstructure of the bone cement samples using SEM images demonstrated that no surface cracks were visible in any of the three groups (Figure 2, 3). Also, there were no significant differences between the three groups at 2 and 24 hours after storage concerning the microstructure of the fractured surfaces of bone cement (Figure 2, 3).

DISCUSSION AND CONCLUSION: Our findings demonstrated that the bending strengths of PMMA bone cement samples irrigated with NS and cold NS were lower than those of the control group up to 24 hours after production. However, bending strength was not significantly different between the three groups 1 week after bone cement preparation. Also, irrigation with cold NS reduced the bending strength more than the NS with 25°C. The results of this study demonstrate that irrigation of the surgical site and bone cement with saline and cold saline to reduce the polymerization temperature can decrease its bending strength 24 hours after the surgery, possibly putting the patients at risk for aseptic loosening.

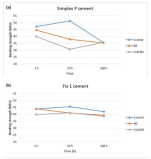

Figure 1 Changes in flexural strength of bone cement (a) Simplex P and (b) FIX 1 after different times: 1h, after 24 hours and 7 days. [Unit: h]. Storage in PBS and temperature of 37°C, in three different groups: control, exposure to normal saline at room temperature (NS) and exposure to normal cold saline (Cold NS) at the time of cement preparation. (Mean ± SD).

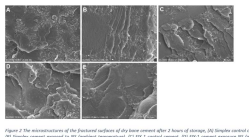

Figure 2 The microstructures of the fractured surfaces of dry bone cement after 2 hours of storage, (A) Simplex control cement, (B) Simplex cement exposed to RS (ambient temperature), (C) FIX 1 control cement, (D) FIX 1 cement exposure RS (ambient temperature), (E) FIX 1 cement exposure to cold NS.

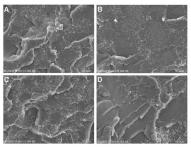

Figure 3 The microstructures of the fractured surfaces of bone cement after 24 hours of storage, (A) Simplex P control cement, (B) Simplex P cement exposure to RS (ambient temperature), (C) Simplex P cement exposure to cold NS, (D) FIX 1 cement exposure to cold NS.

Table 1. Flexural strength (MPa or N / mm2) of bone cement in different groups after one hour, 24 hours, and one week (Mean ± SD)

Cement	Group	Time		
		1 h	24 h	1 w
Simplex P	Control	47.16 ± 4.01	51.30 ± 2.89	35.63 ± 1.23
	NS	44.56 ± 4.20	37.93 ± 6.32**	35.26 ± 7.22
	Cold NS	40.31 ± 1.23	30.67 ± 3.10**	35.73 ± 6.16
Fix 1	Control	43.76 ± 1.21	45.45 ± 2.51	41.89 ± 0.74
	NS	43.91 ± 1.86	40.91 ± 2.39	39.23 ± 4.27
	Cold NS	39.70 ± 3.10	40.95 ± 3.29	38.51 ± 4.08

NS: Normal saline solution at room temperature

Cold NS: Cold normal saline solution (4 °C)

** P < 0.01, ANOVA, LSD Test, In comparison to the control group