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Mechanical Safety Study and Antibiotic-loaded Polymethylmethacrylate Spacers Threshold, Manufactured Intraoperatively, in Orthopaedic Surgery

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Abstract: *The study performed the biomechanical testing of polymethylmethacrylate (PMMA) specimens with unreinforced progressive antibiotic loading, compared to samples reinforced with Kirschner wires, by subjecting these specimens to mechanical compression forces. A difference was observed in the yield of the reinforced specimens with Kirschner wires, in which an antibiotic concentration that exceeded the usual amount was used. In this antibiotic combination of vancomycin powder and liquid gentamicin, the spacer seemed to have a superior structure compared to using only the antibiotic in liquid form. These results are superior to the usually loaded specimens (not exceeding the threshold of 4 g of antibiotic per 40 g of cement), the maximum force recorded being of 20.98 kN and the minimum of 11.54 kN. The reinforced specimens indicated higher values of force, registering differences that varied between 10 kN and approximately 19 kN, thus considering that through the reinforcement with Kirschner wires, the biomechanical qualities of the cement spacers considerably improved.*

Keywords: *polymethylmethacrylate spacers, reinforcement, antibiotic loading*

1.Introduction

In cases of positive cultures, antibiotic-loaded polymethylmethacrylate specimens in accordance with the antibiogram is the key to treating the infection of patients with septic knee prosthesis [1].

According to literature, the antibiotic loading is performed with 2 to maximum 4 g of polymethyl-methacrylate (standard value of a cement envelope) for mechanical safety reasons that interest the mechanical resistance of the polymethylmethacrylate spacer, however, no case with side effect at a higher loading has been demonstrated in literature [2,3].

In order to achieve a higher rate of success in treating PJI (periprosthetic joint infection), we conducted a study that analyzed the antibiotic loading with a larger amount of PMMA (but within limits of mechanical safety) in collaboration with the “Faculty of Mechanical Engineering and Mechatronics” at the Polytechnic University of Bucharest.

In medical application, Polymethylmethacrylate (PMMA) is an acrylic polymer formed by mixing two sterile components: a liquid methacrylate (MMA) monomer and a powered MMA-styrene co-polymer [1]. Hardened PMMA is formed after mixing the two components, the liquid monomer polymerizing around the prepolymerized powder particles. Heat is generated during the process due to the exothermic reaction [4].

Along with the presence of various additives, PMMA offers the mixture a set of physical and chemical properties [5].

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Considering that the Kirschner (K.) wired spacers lead to an increase of their mechanical resistance, in this study, we performed the biomechanical testing of PMMA specimens with unreinforced progressive antibiotic loading, compared to samples reinforced with K. wires, by subjecting these specimens to mechanical compression forces [6].

The aim of this study was to assess the threshold of mechanical safety of PMMA spacers manufactured after progressive loading with various antibiotics, in order to establish the maximum dose of antibiotic loading within mechanical safety conditions that can be used in current surgical practice.

2.Materials and methods

In order to be subjected to mechanical forces, we created 14 specimens (PMMA samples), each specimen being made of 40 g of cement, which were progressively loaded with antibiotic.

The cement used was of dual viscosity type, meaning that it had an increased resistance to other types of PMMA spacers [7].

The following antibiotics were used for loading: vancomycin powder and gentamicin vials.

Vancomycin (*Fresenius Kabi*), gentamicin (*Krka d.d Novo mesto*) and the cement (*AMINO FIX 1, Groupe Lepine*) were obtained from own funds.

7 sets of PMMA spacers (14 specimens) were made and were progressively loaded, each set containing one unreinforced specimen and one reinforced with Kirschner wires (Table 1).

Table 1. Specimens from the study group

STUDY GROUP 1	**STUDY GROUP 4**
This study group represents the control group, being cement without antibiotic loading	Vancomycin loading within limits of mechanical safety
SG1A – without reinforcement	SG4A – without reinforcement
SG1B – with reinforcement of K wires Amount of antibiotic – 0 g – **CONTROL GROUP**	SG4B – with reinforcement of K wires
STUDY GROUP 2.0	Amount of antibiotic – 2 g of vancomycin
Gentamicin loading within limits of mechanical safety	**STUDY GROUP 5**
SG01 – without reinforcement	Vancomycin and gentamicin loading while overcoming the threshold of mechanical safety
SG02 – with reinforcement of K wires	SG5A – without reinforcement
Amount of antibiotic – 2 mL of gentamicin	SG5B – with reinforcement of K wires
STUDY GROUP 2	Amount of antibiotic – 5 g of vancomycin + 5 mL of gentamicin
Gentamicin loading	**STUDY GROUP 6**
SG2A – without reinforcement	Prefabricated gentamicin loading
SG2B – with reinforcement of K wires	SG6A – without reinforcement
Amount of antibiotic – 4 mL of gentamicin	SG6B – with reinforcement of K wires
STUDY GROUP 3	Amount of antibiotic – 0.5 mL of gentamicin
Gentamicin loading	
SG3A – without reinforcement	
SG3B – with reinforcement of K wires	
Amount of antibiotic – 8 mL of gentamicin	

The maximum amount of antibiotic used to load the spacers was 8 mL of gentamicin alone and 6 ml of gentamicin combined with 5 g of vancomycin per 40 g of cement.

The reinforcement of the PMMA spacers was made with Kirschner wires.

Two specimens were made for each sample, with and without reinforcement.

4 Kirschner wires of 3.5 cm were inserted when loading each specimen, being weighed in order to calculate the weight-size gradient difference after subjecting them to compression forces.

For a correct interpretation of the results of the specimens' forces during their subjection to compression stress, we decided to correct the material by sectioning each sample. Thus, a uniform support surface resulted, avoiding the possible errors caused by an incorrect support and influenced by the uneven forces.

Two flat surfaces prepared for a correct compression resulted after cutting.

Measurement and weighing of each test specimen were performed after this process.

Elastic to plastic transition represents the value of the force at which the transition from a linear-elastic field to a plastic field occurred, with the residual deformation determined by 1st order derivative of the force-shortage curve to reduce the errors due to the operator (Figure 1). Dividing this value by the transverse surface, we could determine the compression resistance of the specimen.

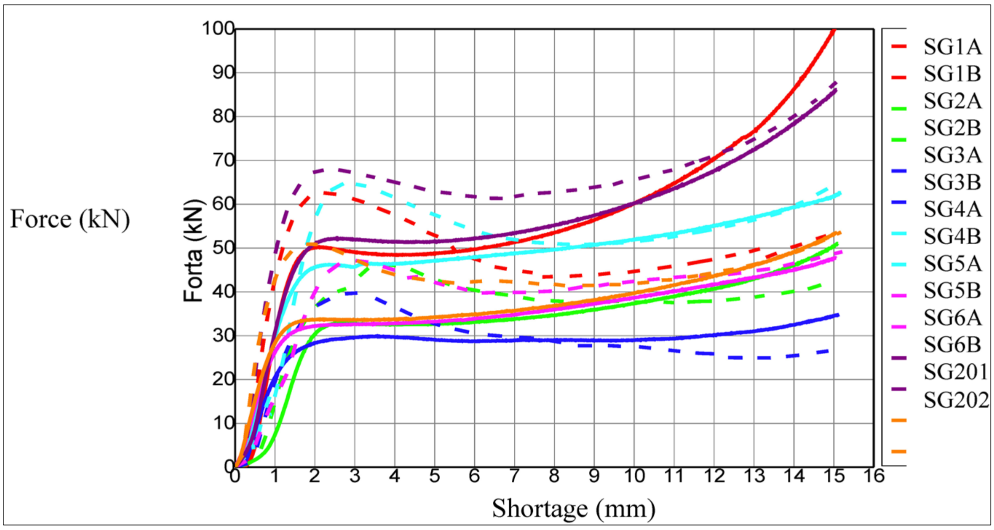

Figure 1. Stress deformation curve of the studied group

2.1.Subjection to compression forces

A Walter-Bai Ag model CH-8224 (Figure 2) device was used for subjection to compressive forces, which accurately automatically recorded the yielding of materials and the change of shape of materials with elastic structure (like in the case of methacrylate used in this study) [8].

This testing system has the ability to accurately quantify uniaxial, multiaxial and torsional stress forces.

Figure 2. Walter-Bai Ag stress device

Shape changes were recorded (being considered the initial yield point of the material) for each mechanically tested specimen, all data being recorded as graphs of material elasticity.

3.Results and discussions

3.1.Processing and interpreting values

The line indicated only elastic deformations, followed by a significant plastic flow. The subsequent increase of the force was explained by the increase of the surface.

1. The 1st derivative of the curve was made
2. The inflection point, where the curve changed its appearance, was determined

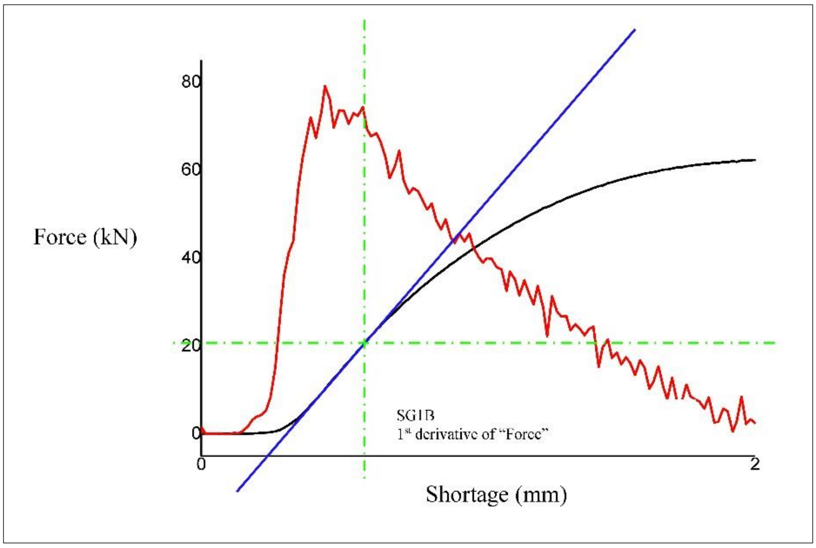

Figure 3. Determination module

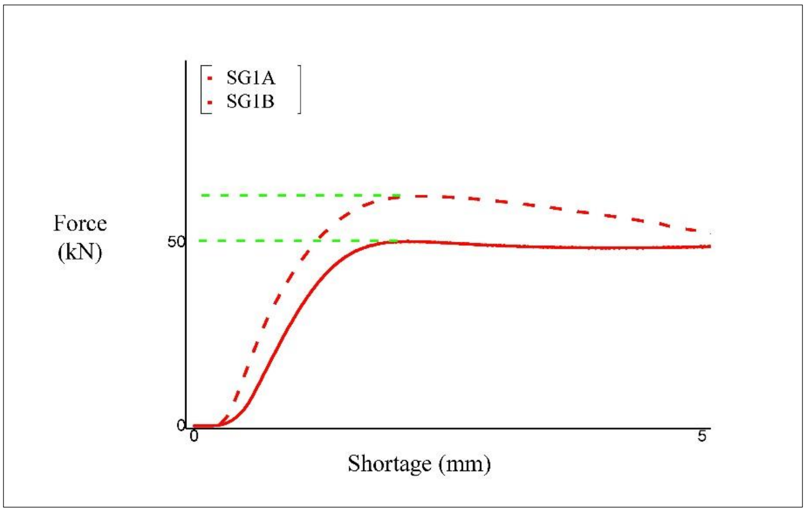

Figure 4. Maximum force value in the deformation area

According to the method of determination shown in the figure above, we could practically associate this value with the maximum force that the specimen can take until it yields.

We were able to determine the compression resistance of the specimen by dividing this value to the transverse surface.

A difference was observed in the yield of the reinforced specimens with Kirschner wires, in which an antibiotic concentration that exceeded the usual amount was used.

The spacer appeared to have a superior structure compared to using the antibiotic only in liquid form, while in this antibiotic combination of vancomycin powder and liquid gentamicin.

These results are superior to the usually loaded specimens (not exceeding the threshold of 4 g of antibiotic per 40 g of cement).

The yield threshold indicated by the change in the stress shape of the specimens from plastic to elastic is not a threshold that can be reached in joint biomechanics. In addition, we concluded that this antibiotic loading, which exceeded the usual threshold, was not accompanied by a possible mechanical complication of the joint spacer [9].

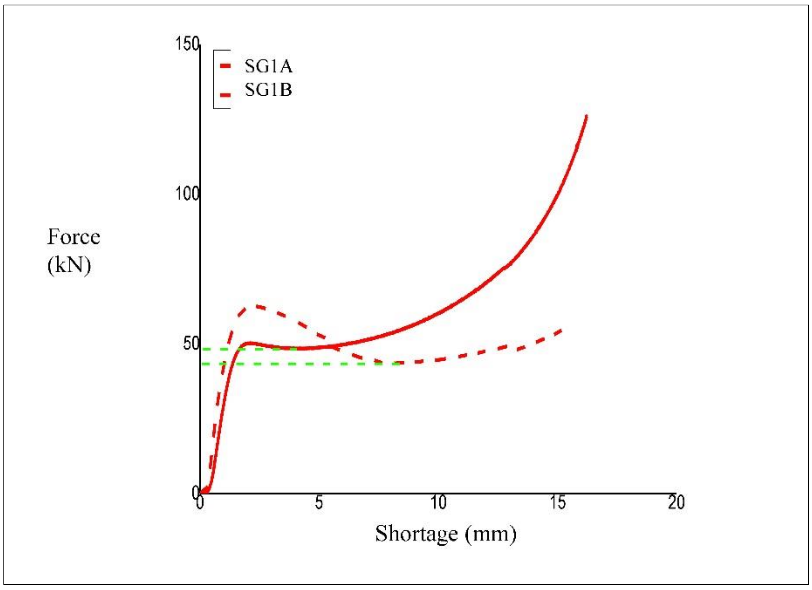

Figure 5. Bearing force value

Basically, after leaving the bearing, we considered that the specimen would have yielded, its integrity being strongly affected.

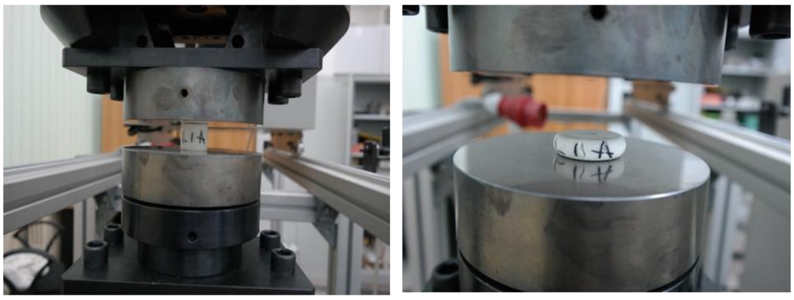

Figure 6. Before and after mechanical stress of specimens

Table 2. Value of specimens' difference to mechanical stress

Sample	Antibiotic addition [g]	Elasticity limit [km]	Maximum force in the deformation region [km]	Bearing force [km]	Maximum-bearing [km]
SG1A	0	17.5536	50.3118	48.4218	1.89
SG1B	0	20.1696	62.6268	43.569	19.0578
SG2A	4	17.3094	32.9793	32.4912	0.4881
SG2B	4	14.8419	46.4622	37.7001	8.7621
SG3A	8	12.4038	29.9673	28.9218	1.0455
SG3B	8	16.5507	39.8544	27.5427	12.3117
SG4A	2	18.2364	46.2378	46.3137	-0.0759
SG4B	2	16.3692	65.0055	50.7111	14.2944
SG5A	5	11.5398	32.5638	32.7585	-0.1947
SG5B	5	13.3671	47.2044	39.7719	7.4325
SG6A	0.5	19.9389	52.3542	51.3018	1.0524
SG6B	0.5	20.9811	68.0964	61.3104	6.786
SG201	2	14.037	33.7779	33.5898	0.1881
SG202	2	20.2719	50.9418	42.0447	8.8971
SG1A-SG1B	--	-2.616	-12.315	4.8528	--
SG2A-SG2B	--	2.4675	-13.4829	-5.2089	--
SG3A-SG3B	--	-9.1677	-9.8871	1.3791	--
SG4A-SG4B	--	1.8672	-18.7677	-4.3974	--
SG5A-SG5B	--	-1.8273	-14.6406	-7.0134	--
SG6A-SG6B	--	-1.0422	-15.7422	-10.0086	--
SG201-SG202	--	-6.2349	-17.1639	-8.4549	--

The elastic to plastic transition (indicated by the specimen's shape change in stress) was considered the yielding point of the material.

Thus, there were variations, the maximum force recorded being of 20.98 kN and the minimum of 11.54 kN, resulting an interval of 9.44 kN.

From the compared sets of specimens, the reinforced ones showed a higher force value.

The differences highlighted in the table above are of maximum 19 kN.

Transition from elastic to plastic (indicated by the changing of the specimen on stress) was considered the bending point of the material. The maximum strength force was 20.98 kN and minimum 11.54 kN. Differences observed were 6 kN (Figure 7).

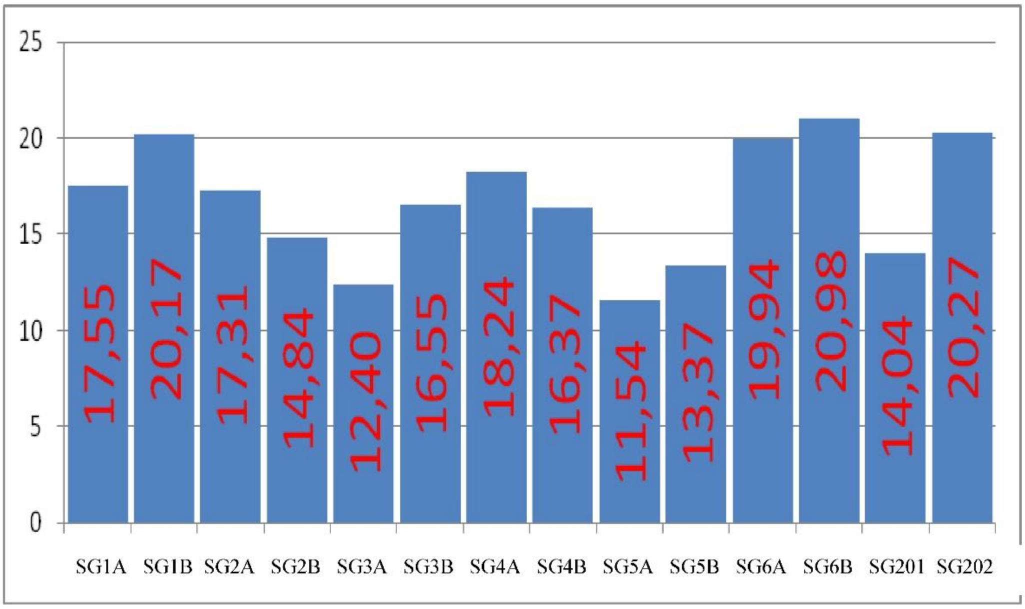

Figure 7. Elastic-plastic transition

Reinforced specimens show higher values when it comes to bending points because of the metallic wires. The differences varied between 10kN and 19kN (Figure 8).

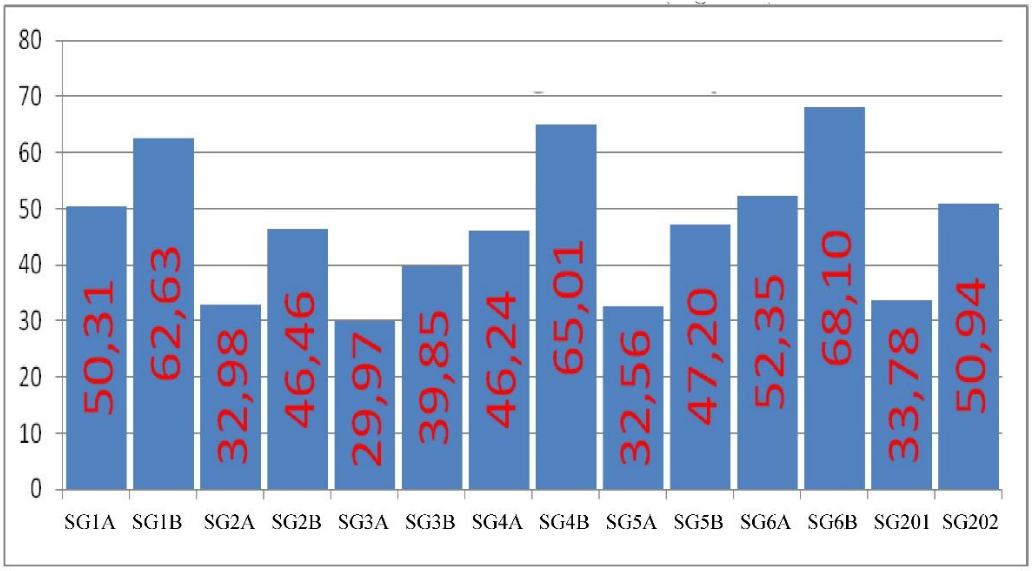

Figure 8. Maximum onset force

The maximum bearing force was registered on SG6B (61.31 kN), specimen composed of prefabricated gentamicin cement with reinforced K wires (Figure 9).

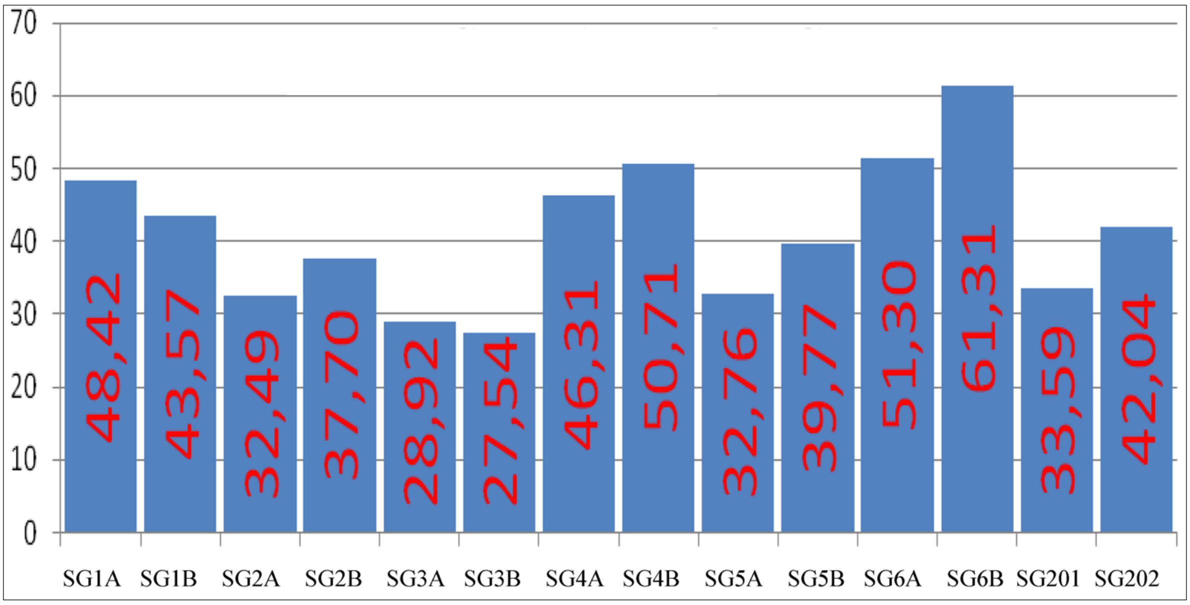

Figure 9. Maximum bearing force

According to literature, reinforced specimens showed higher force values, the influence of metal reinforcements being observed [9]. The differences varied between 10 kN and approximately 19 kN. Unreinforced spacers have a high rate of mechanical complications, in study performed by Yang et all the rate was 9.7% and led to important changes in the patient overall outcome [10].

4.Conclusions

Comparing the maximum force in the deformation region of the control group SG1A (the unreinforced specimen without antibiotic loading) which was 50.3 kN, to the reinforced specimen with Kirschner wires and loading of 5 g of antibiotic (of which 3 g of vancomycin and 2 mL of gentamicin), SG5B, which was 47.2 kN, a small difference of 3.1 kN was registered. Hence, it did not represent a significant difference that could lead to a degradation of joint dynamics.

The reinforced specimens showed higher force values, registering differences that varied between 10 kN and approximately 19 kN, thus considering that this reinforcement with K. wires considerably improved the biomechanical qualities of the cement spacers intraoperatively.

The bending threshold underlined by the specimens' shape change in stress, from plastic to elastic, does not represent a threshold that can be reached in joint biomechanics. Thus, we can conclude that this antibiotic loading, which exceeds the usual threshold, is not accompanied by a possible mechanical complication of the joint spacer.

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