Non-profit Joint-Stock Company "Karaganda Medical University"

ABSTRACT OF THE DISSERTATION

for the degree of Doctor of Philosophy (PhD) on the topic:

Application of the double cementing method in revision knee arthroplasty

Specialty: 8D10100 "Medicine"
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Relevance of the Study. Recent studies have shown an increase in the number of primary total knee arthroplasties (TKR) worldwide. The increase in the number of total knee arthroplasties over the past 13 years was 134% and is due to an increase in life expectancy and quality of life [1,2]. In some countries, the number of total knee arthroplasties is projected to increase to 3.48 million by 2030 [3].

The increase in the number of primary knee arthroplasties worldwide also leads to an increase in the number of revision interventions [1,2]. The main complications after TKR are aseptic and septic instability of the endoprosthesis components, which account for 60% of all complications associated with knee endoprostheses. The causes of these complications are improper installation of the endoprosthesis components, aseptic or septic osteolysis [2]. In case of aseptic or septic instability of the endoprosthesis components, it is necessary to resort to revision endoprosthetics, which consists of replacing the endoprosthesis with more complex models with a frequent need to replace bone defects. Modern studies show an increase in the number of revision TKA by 28.8% from 2005 to 2014 [3]. Often, as a result of instability of the endoprosthesis components, osteolysis and in the process of removing the previous endoprosthesis components, bone tissue defects are formed that require filling. Adequate replacement of bone defects during revision arthroplasty helps to avoid repeated instability of the components, the occurrence of infection and restore the function of the knee joint [4]. At the current stage of development of traumatology and orthopedics, the following methods of bone defect replacement are used in revision knee arthroplasty: cementation, cementation with screw reinforcement, factory cement spacers with augments, modular metal augments, metaphyseal sleeves with pressed porous titanium coating and structural cones made of porous tantalum, autologous bone grafting, allogenic bone grafting, impaction bone grafting, structural bone allografts, mega-endoprostheses or individual endoprostheses. Despite the wide choice of defect replacement methods, the presented methods have certain disadvantages that can lead to endoprosthesis instability [5,6].

Today, the method of choice for replacing bone defects of types 2A, 2B and 3 according to AORI are modular metal augments. Despite the fact that there are many methods for replacing bone defects of various sizes, these methods have certain disadvantages. Bone cement is applicable only to replace type 2A defects according to AORI, modular metal augments can lead to osteolysis and loosening of endoprosthesis components, and titanium cones and bushings can lead to difficulties in component extraction and bone fractures. Also, not all models of modular metal augments, titanium cones and bushings are registered in the Republic of Kazakhstan and are expensive products [6-20]. Based on all of the above, it can be argued that the existing methods for replacing bone defects are not always applicable in revision endoprosthetics, especially against the background of periprosthetic infection or at a high risk of infection. The use of new approaches to revision endoprosthetics requires the development and implementation of new methods for replacing bone defects in modern medicine. The above data confirm the relevance and need for further research in this area.

Aim of the Study

To evaluate the effectiveness of the developed Double Cementing Method for reconstruction of bone defects in revision knee arthroplasty.

Objectives of the Study

1) To develop a method for reconstructing femoral and tibial defects in revision knee arthroplasty using the Double Cementing Method;
2) To compare clinical outcomes of the Double Cementing Method with the traditional method (modular metal augments);
3) To compare radiographic characteristics of the Double Cementing Method with the traditional method;
4) To calculate the economic efficiency of the Double Cementing Method compared with the traditional method.

Scientific Novelty

1) A method for reconstructing femoral and tibial defects in revision knee arthroplasty using the Double Cementing Method has been developed for the first time and patented in the Republic of Kazakhstan (Appendix A).
2) A comparative study confirmed the effectiveness of the Double Cementing Method using clinical and radiographic assessments.
3) A knee prosthesis with a marking scale to improve augment adaptation has been developed and patented in the Republic of Kazakhstan (Appendix B).

Theses to be Defended

1) The developed Double Cementing Method allows reconstruction of femoral and tibial defects of types 2A, 2B, and 3 according to the AORI classification during revision knee arthroplasty;
2) The Double Cementing Method reduces intraoperative blood loss by 200 ml and decreases the duration of surgery by an average of 17.5 minutes;
3) The Double Cementing Method reduces the absolute number of radiolucent lines on follow-up radiographs at 6 and 12 months by 1.6 times;
4) The Double Cementing Method is economically efficient compared with modular metal augments: average costs are 88% lower. The ICER for the Knee Society Score (function) and Knee Society Score (knee) is −261,756.7 and −75,993.9 KZT per additional point, respectively. For the Oxford Knee Score, the ICER is −94,232.4 KZT per additional point. The incremental cost–utility ratio (ICUR) shows savings of −108,288.3 KZT per additional QALY.

Practical Significance

1) Implementation of the Double Cementing Method enables formation of cement augments and reconstruction of bone defects;
2) The method expands indications for bone cement to reconstruct femoral and tibial defects in revision knee arthroplasty;
3) Cement augments can be used for local antibiotic therapy in periprosthetic infection, which is not possible with metal augments.

Implementation in Clinical Practice

The Knee Society Score and Oxford Knee Score were translated into the state language and certified (Appendices C and D).

Two acts of clinical implementation were formalized: “Method for reconstruction of femoral and tibial defects during revision knee arthroplasty in the setting of periprosthetic infection using the Double Cementing Method” and “Method for reconstruction of femoral and tibial defects during revision knee arthroplasty in the setting of aseptic loosening using the Double Cementing Method” (Appendix E).

Relation of the Dissertation to Other Research Projects

The dissertation was performed within the scientific and technical program of the Ministry of Health of the Republic of Kazakhstan, project No. BR11065157 “Development and scientific substantiation of innovative technologies to improve the effectiveness of diagnosis and treatment of injuries, consequences of trauma, and diseases of the extremities, spine and pelvis.”

Author’s Personal Contribution

Analysis and statistical processing of clinical and laboratory–instrumental data in patients with bone defects undergoing revision knee arthroplasty at the National Scientific Center of Traumatology and Orthopedics named after Academician N.D. Batpenov in 2021–2024;

Jointly with the scientific supervisors and department heads, development and implementation of the Double Cementing Method for bone defect reconstruction in revision knee arthroplasty;

Participation in patient treatment during clinical data collection;

Literature review of existing methods for bone defect reconstruction in revision knee arthroplasty;

Patient enrollment for the study;

Systematization, documentation, and dissertation preparation performed personally by the author.

Approbation of the Work

The results of the research work were discussed at

- International scientific and practical conference "Horizons of modern traumatology and orthopedics" (Turkestan, 2022);
- X Congress of traumatologists-orthopedists of Uzbekistan "Priority areas for the development of traumatology and orthopedics", dedicated to the 90th anniversary of the Republican Scientific Center for Traumatology and Orthopedics (Tashkent, Uzbekistan, 2022);
- Republican scientific and practical conference "Innovations in surgery of the XXI century" with international participation, dedicated to the memory of Doctor of Medical Sciences, Professor of the Medical University of Karaganda Mamalinov Gabdulmazhit Kalievich (Karaganda, 2023);

- Scientific and practical conference of young scientists, master's and doctoral students, dedicated to the Day of Science "The world of science and youth: traditions and innovations" (Karaganda, 2023);

- International Congress "24th European Federation of National Associations of Orthopaedics and Traumatology" (Vienna, Austria 2023);

- International Eurasian Orthopedic Forum (Kazan, Russia);

- Competition of young scientists "Batpen Readings" and the XXIII Interuniversity Conference of students and young scientists with international participation on the topic "Topical issues of traumatology and orthopedics" with the support of SICOT (Astana, 2023);

- International Congress "43rd SICOT Orthopaedic World Congress" (Cairo, Egypt, 2023);

- International Congress 25th European Federation of National Associations of Orthopaedics and Traumatology" (Hamburg, Germany 2024); - Competition of young scientists "Batpen Readings" within the framework of the IV Congress of Traumatologists-Orthopedists of the Republic of Kazakhstan and the III Congress of KATO (Astana, 2024);

- International Congress "44th SICOT Orthopedic World Congress" (Belgrade, Serbia, 2024).

Publications

Based on the dissertation materials, 15 scientific papers have been published, including: 3 in scientific journals recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan:

1. Balgazarov S., Belokobylov A., Batpen A., Ramazanov Z., Rimashevskiy D., Dolgov A., Abilov R., Moroshan A., Atepilevs A., Krikliviy A. Replacement of bone defects of the femur and tibia by the double cementing method in the treatment of periprosthetic infection of the knee joint using a dynamic cement spacer. Astana Medical Journal, 2025, 125 (3) https://doi.org/10.54500/2790-1203-2025-3-125-amj004

2. Balgazarov S., Belokobylov A., Batpen A., Ramazanov Z., Rimashevskiy D., Abilov R., Moroshan A., Krikliviy A. Comparative Evaluation of the Use of the Double Cementation Method and Modular Metal Augments for the Replacement of Bone Defects in Revision Knee Arthroplasty. J CLIN MED KAZ. 2024;21(3):43-8. https://doi.org/10.23950/jcmk/14682

3. Alexandr Krikliviy, Serik Balgazarov, Alexey Belokobylov, Zhanatai Ramazanov, Alexey Dolgov, Denis Rimashevskiy, Amanzhol Balgazarov, Ruslan Abilov, Artyom Moroshan. Replacement of Defects of the Femur and Tibia in Revision Knee Arthroplasty Using Non-Biodegradable Materials. Traumatology and Orthopaedics of Kazakhstan, Volume 70. Number 4 (2023) https://doi.org/10.52889/1684-9280-2023-4-70-36-46

1 publication in the international scientific journal included in the Scopus information database:

1. Balgazarov S., Belokobylov A., Batpen A., Ramazanov Z., Dolgov A., Rimashevskiy D., Kriklivyy A. The First Stage of Knee Revision Arthroplasty in Periprosthetic Infection with Replacement of a Large Defect Double Cementing Method:

A Case Report. Int Med Case Rep J. 2023 Sep 6;16:513-520. https://doi.org/10.2147/IMCRJ.S420109

2 patents issued by the National Institute of Intellectual Property of the Republic of Kazakhstan:

1. Patent for invention No. 36510, 12/22/2023. Batpen A.N., Balgazarov S.S., Belokobylov A.A., Ramazanov Zh.K., Rimashevsky D.V., Serikbaev V.D., Abilov R.S., Dolgov A.A., Moroshan A.V., Balgazarov A.S., Kriklivy A.A., Kurmangaliev E.-D.T., Aubakirov M.G., Ali A.E., Ustazov K.A., Alzhanov E.A.. Method of revision knee arthroplasty using double cementation

2. Utility model patent No. 8705, 12/15/2023. Batpen A. N., Balgazarov S. S., Belokobylov A. A., Ramazanov Zh. K., Rimashevsky D. V., Serikbaev V. D., Abilov R. S., Dolgov A. A., Moroshan A. V., Balgazarov A. S., Kriklivy A. A., Kurmangaliev E.-D. T., Aubakirov M. G., Ali A. E., Ustazov K. A., Alzhanov E. A. Knee joint endoprosthesis.

8 in collections of international and foreign conferences, 1 methodical recommendations.

Materials and Methods

We formed 2 equal groups - the main group and the control group. Each group included 40 patients. In the main group, patients underwent surgical treatment in the volume of revision knee arthroplasty with replacement of the resulting defects of the femur and / or tibia using the double cementing method. The method was permitted and approved for use by the local ethics committee of the N.D. Batpenov National Scientific Center of Traumatology and Orthopedics (protocol No. 4 dated October 19, 2021) (Appendix G of the dissertation). In the comparison group, surgical intervention was performed in the volume of revision knee arthroplasty with replacement of the resulting defects of the femur and / or tibia using the traditional method - using modular metal augments.

Comparison of patients in both groups did not show a statistically significant difference in age, gender, body mass index and the number of revision surgeries ($p > 0.05$). The treatment of patients in the main and control groups was assessed based on complaints, general condition of the patient, wound healing, function of the operated limb and radiographic data. The treatment results were assessed 6 and 12 months after surgery.

The two study groups were compared based on the following effectiveness criteria:

- type of postoperative wound healing;
- hospitalization period;
- duration of stay in the intensive care unit;
- duration of surgery;
- intraoperative blood loss;
- radiographic stability of endoprosthesis components;
- number of periprosthetic infection cases;
- knee joint function.

The study design is presented in Figure 1.

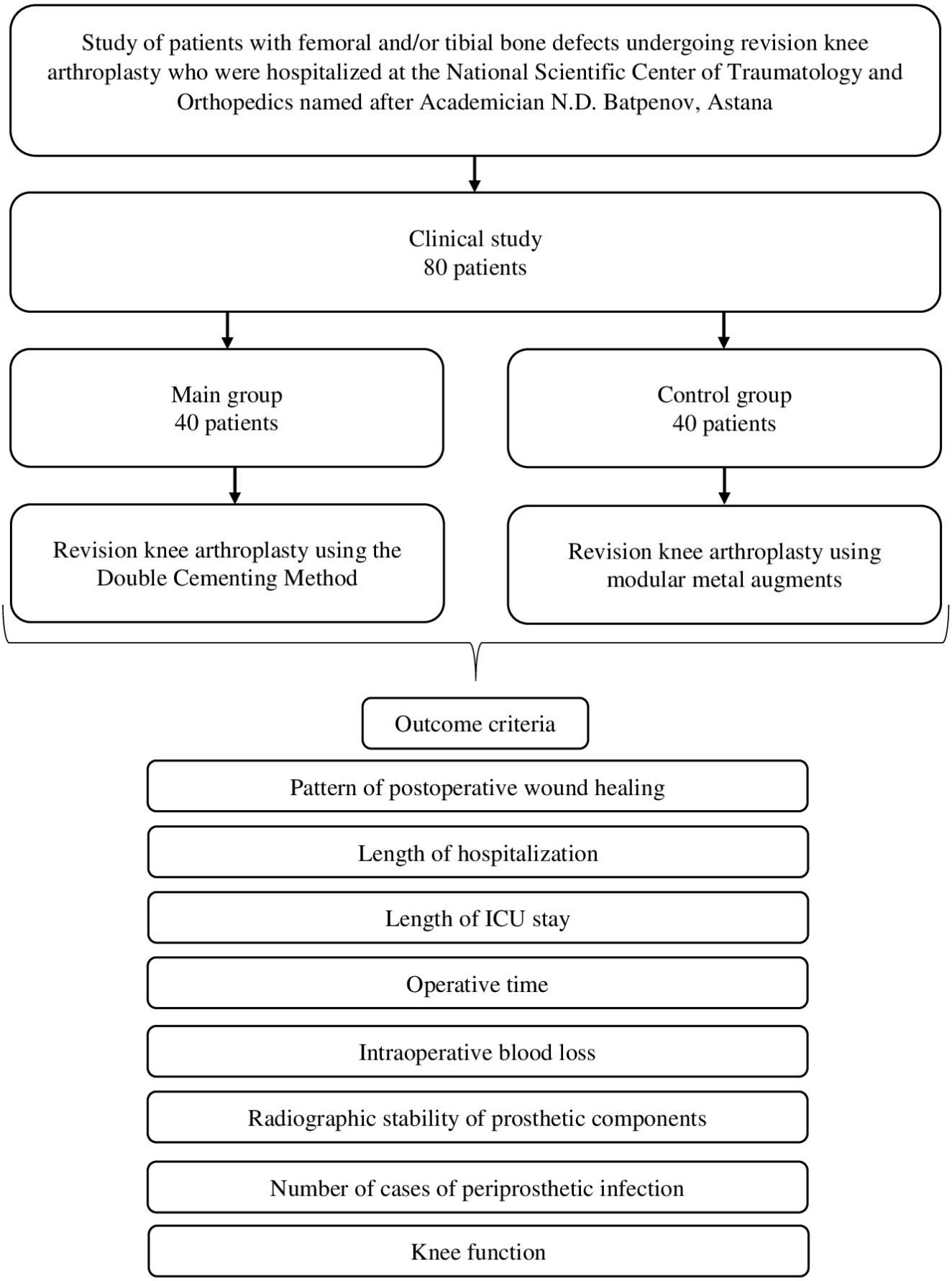

Figure 1 – Study design

Description of the method of revision knee arthroplasty using the double cementation method - the patient is given spinal anesthesia, then the patient is placed on the operating table in a supine position. The surgical field is treated with Povidone-Iodine solution four times. The surgical field is limited by sterile material. In the presence of several postoperative scars in the area of the surgical intervention, preference was given to the most lateral scar, the longest scar, the least old scar. This is necessary to prevent devascularization of the lateral skin flap. Skin incisions that are less than 1.5 cm were ignored. The skin incision was standardly made along the anterolateral surface of the knee joint along the old postoperative scar up to 25.0 cm. After making an optimal skin incision, the next step is to change the scalpel blade to a new one. Next, the subcutaneous tissue and superficial fascia are dissected at the same level as the skin. If necessary, ligatures are removed. The skin-subcutaneous-fat flaps are mobilized inwardly up to 2-3 cm, and outwardly by 1 cm. Step-by-step electrocoagulation is performed. The next step is to perform arthrotomy of the knee joint using an electric knife (the incision is made between m. vastus medialis and m. rectus femoris in the tendon part). If necessary, ligatures are removed. Then the incision continues parapatellarly, up to 5 mm from the inner edge of the patella, simultaneously opening the fibrous capsule of the knee joint. Then the incision reaches the inner edge of the tibial tuberosity. In this case, the distance inward from the ligament is about 5 mm. If necessary, cicatricial soft tissues are excised and the patella is mobilized. Then, soft tissues are mobilized in order to achieve 90 degrees of flexion in the knee joint. Using a fine chisel and a nozzle, the components of the endoprosthesis are removed one by one: first, the polyethylene liner is removed, then the femoral component is removed, and then the tibial component is removed. After the endoprosthesis components are removed, a thorough debridement is performed, pathological granulations and immobilized muscle areas are removed, corroded areas of the femur and tibia are bitten off, with the removal of bone cement residues from the bone canals. Soft and bone tissue is removed within the limits of their lesion, without damaging the patellar ligament itself and thinning the joint capsule, collateral ligaments of the knee joint. Using a drill and special reamers, the canal of the femur and tibia is processed to the required diameter. An intraoperative assessment of the size of the defects of the femur and tibia is performed according to the Anderson Orthopaedic Research Institute scale [23].

The knee joint cavity is sanitized. First, the knee joint cavity is washed abundantly with a 0.9% NaCl solution up to 10 liters. Then, exposure is carried out with a Povidone-Iodine solution or a Chlorhexidine solution for 5 minutes. If necessary, ultrasonic cavitation is carried out using the Sonoka-180 device with a 0.9% NaCl solution up to 1 liter.

After processing and exposure, the augment formation stage follows, which took place in one of two possible ways: formation of an augment of the required size according to the fitting components or formation of an augment "cast" after trying on the final components.

The formation of the required size augment using the trial components was carried out if the bone defect did not require significant edge processing. Using the trial components of the endoprosthesis, the required size of the components was selected and the size of the required femoral and tibial augments was estimated. The next step is to mix bone cement (DePuy Synthes Endurance GMV Gentamicin medium viscosity, 40g, ISO

5833-2011 standard, registration certificate RK-IMN-5№020252) with the factory antibiotic Gentamicin 1.0 g and manufacture an augment from bone cement of the required size for the tibial component of the endoprosthesis.

After polymerization of the bone augment of the tibial component, the second package of bone cement is mixed with the factory antibiotic Gentamicin 1.0 g and, if necessary, with the addition of the antibiotic Vancomycin-TF 2 g. (Figure 30), the resulting bone cement is applied to the tibial component and the previously formed augment (Figure 29). Then the tibial component is installed in the tibia, the component is centered and the rotation is corrected.

Additional pressurization of the tibial component is performed using a nozzle until the bone cement is completely polymerized. The second step is to mix the third package of bone cement with the factory antibiotic Gentamicin 1.0 g and make an augment from bone cement of the required size for the femoral component of the endoprosthesis.

After polymerization of the augment from the bone cement of the femoral component, the fourth package of bone cement is mixed with the factory antibiotic Gentamicin 1.0 g and, if necessary, with the addition of the antibiotic Vancomycin-TF 2 g, the resulting bone cement is applied to the femoral component and the previously formed augment, the component is installed in the femur, the component is centered and the rotation is corrected.

Additional pressure is applied to the femoral component using a nozzle until the bone cement is completely polymerized. Then a polyethylene insert is installed on the tibial component. The range of motion in the knee joint, lateral stability, and absence of hyperextension in the joint are assessed. If necessary, active drainage is installed in the knee joint cavity. The wound is sutured layer by layer: first, the muscles, aponeurosis, and joint capsule, then the subcutaneous fat, and then the skin. An aseptic dressing is applied. Formation of the augment with a “cast” after trying on the final components was used if the defects of the femur and tibia were irregular in shape and required significant bone processing with an oscillating saw.

After installing the try-in components and determining the need to use a "cast", preparation for the formation of augments was carried out. A tibial component of the required size was prepared. Then bone cement (DePuy Synthes Endurance GMV Gentamicin, 40g, ISO 5833-2011 standard) with the factory antibiotic Gentamicin 1.0 g was mixed. Bone cement is applied to the inner surface of the tibial component in the defect area. Then the tibial component together with bone cement is installed in the tibia in its final position. When installed, the bone cement follows the contour of the bone defect and takes the shape of the bone defect. Then the tibial component is removed and polymerization of the bone augment is expected (Figure 35, 36). The next step, after polymerization of the bone augment of the tibial component, is to mix the second package of bone cement with the factory antibiotic Gentamicin 1.0 g. and, if necessary, with the addition of the antibiotic Vancomycin-TF 2 g., the resulting bone cement is applied to the tibial component and the previously formed augment. Then the tibial component is installed in the tibia, the component is centered and the rotation is corrected. Additional pressurization of the tibial component is carried out using a nozzle until the bone cement is completely polymerized.

Preparation for the installation of the femoral component begins with mixing the third package of bone cement with the factory antibiotic Gentamicin 1.0 g. and preparing the femoral component of the endoprosthesis of the required size. Bone cement is applied to the inner surface of the femoral component, with its subsequent installation. When the femoral component is installed in the final position, the bone cement takes the shape of the bone defect. After the femoral component is removed, the bone augment is left to polymerize in the same shape. When the bone augment is completely polymerized, the fourth package of bone cement with the factory antibiotic Gentamicin 1.0 g is mixed. and, if necessary, with the addition of the antibiotic Vancomycin-TF 2 g. Upon reaching a homogeneous consistency, bone cement is applied to the femoral component and the formed augment. The femoral component is installed, the component is centered and rotation is corrected. Additional pressure is applied to the femoral component using a nozzle until the bone cement is completely polymerized. The installation of the knee joint endoprosthesis is completed.

After that, a polyethylene liner is installed on the tibial component. The range of motion in the knee joint, lateral stability, and the absence of hyperextension in the joint are assessed. If necessary, active drainage was installed in the knee joint cavity. The wound is sutured in layers: first, the muscles, aponeurosis and joint capsule, then the subcutaneous fat, and then the skin. An aseptic dressing is applied.

Cost-effectiveness analysis

Simple comparative economic analysis, Cost-Effectiveness Analysis (CEA) and Cost-Utility Analysis (CUA) were used to evaluate the cost-effectiveness of dual cementation and modular metal augments in revision knee arthroplasty.

Results and discussions

Based on the results obtained, no statistically significant difference was found between the groups ($p = 0.64$) in the healing of postoperative wounds.

The median number of hospital stays in the main group was 18 days (Q1-14; Q3-21.5), and in the comparison group - 15 days (Q1-13.5; Q3-19.5). There was no statistically significant difference between the groups in the number of hospital stays ($p = 0.17$). Although there were no statistically significant differences in the length of hospitalization between the two groups, the number of cases with a hospital stay of more than 40 days was higher in the control group.

The median number of bed-days of stay in the intensive care unit in the main group was 1 day (Q1-0; Q3-2), in the control group also 1 day (Q1-1; Q3-1). There was no statistically significant difference in the number of bed-days spent by patients in the intensive care unit ($p = 0.88$) in both groups. When comparing the time spent on surgery, the following results were obtained: in the main group, the median time of surgery was 90 minutes (Q1-80; Q3-117.5), in the comparison group, the median time was 107.5 minutes (Q1-92.5; Q3-135). A statistically significant difference in the duration of surgery in the groups was revealed; in the main group, the duration of surgery was 17.5 minutes (16.3%) less ($p = 0.034$). Evaluation of the median volume of intraoperative blood loss in the main group showed that blood loss was 400 ml (Q1-250; Q3-500), and in the control group - 600 ml (Q1-250; Q3-825). When comparing the volume of intraoperative blood loss in

both groups, it was found that in the control group there was 200 ml more blood loss than in the main group (p = 0.031) (Figure 48).

During follow-up examinations, the presence of periprosthetic infection (PPI) of the operated joint was assessed. In the main group, 2 cases (5%) of periprosthetic infection were detected during the follow-up examination, and 4 cases (10%) in the control group. The median number of knee points on the Knee Society Score scale 6 months after the operation in the main group was 80 points (Q1-77; Q3-82) and in the control group it was also 80 points (Q1-77.5; Q3-82). The analysis showed that there was no statistically significant difference in the number of knee points on the KSS scale (p = 0.75). The median number of functional points on the Knee Society Score scale 6 months after the operation in the main group was 75 points (Q1-67.5; Q3-80), in the control group it was 70 points (Q1-60; Q3-82.5). There was no statistically significant difference in the number of points between the groups (p = 0.29). The median Oxford Knee Score score 6 months after surgery in the main group was 9 points (Q1-6; Q3-11), in the control group it was 11 points (Q1-6; Q3-16). There was no statistically significant difference between the scores between the groups (p = 0.13).

The median number of knee points on the Knee Society Score scale 1 year after the operation in the main group was 83 points (Q1-83; Q3-88), in the control group it was 83 points (Q1-82; Q3-88). The analysis showed that there was no statistically significant difference in the average number of Knee points on the KSS scale (p = 0.5). The median number of functional points on the Knee Society Score scale 1 year after the operation in the main group was 80 points (Q1-75; Q3-90), in the control group it was 80 points (Q1-70; Q3-90). There was no statistically significant difference between the average number of points between the groups (p = 0.24). The median Oxford Knee Score score 1 year after surgery was 17 points (Q1-14; Q3-20) in the study group and 20 points (Q1-14.5; Q3-24) in the control group. There was no statistically significant difference between the median scores between the groups (p = 0.15). Radiographic assessment of knee prosthesis component stability was assessed on control radiographs in both groups. Six months after surgery, 5 cases of radiolucent lines at the bone cement/bone interface (12.5%) were detected in the study group and 8 cases (20%) were detected in the control group. Twelve months after surgery, 9 cases of radiolucent lines at the bone cement/bone interface (22.5%) were detected in the study group and 13 cases (32.5%) were detected in the control group. An increase in the size of radiolucent lines after 12 months compared to the control radiography 6 months after the operation in the main group was noted in 4 cases, and in the control group in 5 cases.

A simple comparative analysis of the cost-effectiveness of the dual cementation method compared to the standard method was carried out. According to the results of the analysis, a statistically significant difference was found between the average cost of augments (p = 0000001) between the groups. Thus, the cost of using the dual cementation method is on average 235,581 tenge (88%) lower than the use of modular metal augments.

The next step was a cost-effectiveness analysis of the dual cementation method compared to the use of modular metal augments. To assess the cost-effectiveness, the Incremental Cost-Effectiveness Ratio (ICER) was calculated. The Knee Society Score scale reflecting functional results 12 months after surgery, the Knee Society Score scale reflecting knee scores 12 months after surgery and the Oxofrd Knee Score scale with

results 12 months were used as the criterion of clinical effectiveness. When using the Knee Society Score scale (functional scores), the result is -261756.7 tenge for 1 additional KSS point (functional scores). When using the Knee Society Score scale (knee scores), the result is -75993.9 tenge for 1 additional KSS point (knee scores). When using the Oxford Knee Score scale (knee scores), the result is -94232.4 tenge for 1 additional OKS point. The obtained negative ICER value when calculating for all scales indicates that the use of the developed method provides not only better functional effectiveness, but is also accompanied by a significant reduction in economic costs, which confirms its high economic feasibility compared to the standard approach.

At the third stage, a quantitative assessment of the economic efficiency of the new method of bone defect replacement in revision knee arthroplasty was performed by calculating the incremental cost-utility ratio (ICUR), which shows how much it costs to obtain one additional QALY when using the studied method compared to standard treatment.

The initial data for the calculation were the average cost values per patient and the utility indicators (QALY), reflecting the quality and duration of life after the treatment. The obtained negative ICUR value indicates that the studied method not only demonstrates greater clinical and economic efficiency (higher QALY), but is also accompanied by lower costs compared to the standard approach. Thus, the developed method can be classified as a dominant strategy and is economically justified for use in the practice of revision arthroplasty.

Conclusions:

1) The developed method of double cementation allows to replace bone defects of the femur and tibia of type 2A, 2B, 3 according to the AORI classification in revision knee arthroplasty. The developed marking scale used for defects of the metaepiphyseal zone and damage to the collateral ligaments allows to replace extensive defects and restore lateral stability of the knee joint;

2) The developed method of double cementation reduces the duration of the operation by 17.5 minutes (16.3%) ($p = 0.034$), the volume of intraoperative blood loss by 200 ml ($p = 0.031$) and shows the same functional results according to the Knee Society Score (knee and functional scores) and Oxford Knee Score ($p > 0.05$) scales;

3) The use of the dual cementation method showed an absolute number of cases of the occurrence of radiographic lines of enlightenment on control radiographs 6 and 12 months after surgery by 1.6 times. However, the assessment did not reveal a statistically significant difference between the groups ($p > 0.05$); 4) The developed dual cementation method showed cost-effectiveness compared to the use of modular metal augments. The costs of using the developed method are on average 88% lower than when using the traditional method ($p = 0.0000001$). The ICER for the Knee Society Score scale (functional points) and for the Knee Society Score scale (knee points) was -261756.7 tenge and -75993.9 tenge per one additional point. The ICER for the Oxford Knee Score scale was -94232.4 tenge per one additional point. These results not only demonstrated the low cost of using the developed method, but also the economic benefit for each additional point on the Knee Society Score and Oxford Knee Score scales. Calculation of the incremental cost-utility ratio (ICUR) showed a savings of -108,288.3 tenge per one

additional QALY point, which indicates that this treatment is not only cost-effective, but also improves treatment outcomes.

Practical recommendations

In patients with aseptic or septic instability of knee endoprosthesis components and AORI type 2A, 2B and 3 femur and/or tibia defects, the dual cementation method is recommended along with other methods of defect replacement.

In patients with high risk of intraoperative blood loss in patients with aseptic or septic instability of knee endoprosthesis components and AORI type 2A, 2B and 3 femur and/or tibia defects, the dual cementation method is recommended to reduce intraoperative blood loss.

In patients with high risks of postoperative periprosthetic infection and instability of knee endoprosthesis components and AORI type 2A, 2B and 3 femur and/or tibia defects, the dual cementation method is recommended, since this method allows the use of bone cement augments with local antibiotic therapy.

The developed method of double cementation is recommended for use in clinics performing revision knee arthroplasty as the most cost-effective method of replacing bone defects.

REFERENCES

1. Lopez C.D., Boddapati V., Neuwirth A.L., Shah R.P., Cooper H.J., Geller J.A. Hospital and Surgeon Medicare Reimbursement Trends for Total Joint Arthroplasty. Arthroplasty Today. 2020 Jun 23;6(3):437-444. https://doi.org/10.1016/j.artd.2020.04.013
2. Nham F.H., Patel I., Zalikha A.K., El-Othmani M.M. Epidemiology of primary and revision total knee arthroplasty: analysis of demographics, comorbidities and outcomes from the national inpatient sample. Arthroplasty. 2023 Apr 2;5(1):18. https://doi.org/10.1186/s42836-023-00175-6
3. Sloan M., Premkumar A., Sheth N.P. Projected Volume of Primary Total Joint Arthroplasty in the U.S., 2014 to 2030. J Bone Joint Surg Am. 2018 Sep 5;100(17):1455-1460. https://doi.org/10.2106/JBJS.17.01617.
4. Qiu Y.Y., Yan C.H., Chiu K.Y., Ng F.Y. Review article: Treatments for bone loss in revision total knee arthroplasty. J Orthop Surg (Hong Kong). 2012 Apr;20(1):78-86. https://doi.org/10.1177/230949901202000116
5. Ponzio D.Y., Austin M.S. Metaphyseal bone loss in revision knee arthroplasty. Curr Rev Musculoskelet Med. 2015 Dec;8(4):361-7. https://doi.org/10.1007/s12178-015-9291-x
6. Lei P.F., Hu R.Y., Hu Y.H. Bone Defects in Revision Total Knee Arthroplasty and Management. Orthop Surg. 2019 Feb;11(1):15-24. https://doi.org/10.1111/os.12425
7. Huten D. Femorotibial bone loss during revision total knee arthroplasty. Orthop Traumatol Surg Res. 2013 Feb;99(1 Suppl):S22-33. https://doi.org/10.1016/j.otsr.2012.11.009
8. Gergely R.C., Toohey K.S., Jones M.E., Small S.R., Berend M.E. Towards the optimization of the preparation procedures of PMMA bone cement. J Orthop Res. 2016 Jun;34(6):915-23. https://doi.org/10.1002/jor.23100
9. Gaudin G., Butcher C., Lustig S., Darwish N., Neyret P. Screw and cement augmentation of tibial defects in primary total knee arthroplasty: satisfactory midterm outcomes. Journal of ISAKOS. 2018;3(3), 134-139
10. Lachiewicz P.F., Wellman S.S., Peterson J.R. Antibiotic Cement Spacers for Infected Total Knee Arthroplasties. J Am Acad Orthop Surg. 2020 Mar 1;28(5):180-188. https://doi.org/10.5435/JAAOS-D-19-00332
11. Lee K.J., Bae K.C., Cho C.H., Son E.S., Jung J.W. Radiological Stability after Revision of Infected Total Knee Arthroplasty Using Modular Metal Augments. Knee Surg Relat Res. 2016 Mar;28(1):55-61. https://doi.org/10.5792/ksrr.2016.28.1.55
12. Innocenti B., Fekete G., Pianigiani S. Biomechanical Analysis of Augments in Revision Total Knee Arthroplasty. J Biomech Eng. 2018 Nov 1;140(11):111006. https://doi.org/10.1115/1.4040966
13. Jabbal M, Simpson AHR, Walmsley P. Mechanisms of bone loss in revision total knee arthroplasty and current treatment options. Orthopedic Reviews. 2023;15. https://doi.org/10.52965/001c.75359

14. Kirschbaum S., Perka C., Gwinner C. Facing metaphyseal bone stock defects: Mid- and longterm results of cones. J Orthop. 2020 Dec 23;23:31-36. https://doi.org/10.1016/j.jor.2020.12.015.
15. Bonanzinga T., Gehrke T., Zahar A., Zaffagnini S., Marcacci M., Haasper C. Are Trabecular Metal Cones a Valid Option to Treat Metaphyseal Bone Defects in Complex Primary and Revision Knee Arthroplasty? Joints. 2017 Dec 14;6(1):58-64. https://doi.org/10.1055/s-0037-1608950
16. Wirries N., Winnecken H.J., Lewinski G.V., Windhagen H., Skutek M. Osteointegrative Sleeves for Metaphyseal Defect Augmentation in Revision Total Knee Arthroplasty: Clinical and Radiological 5-Year Follow-Up. J Arthroplasty. 2019 Sep;34(9):2022-2029. https://doi.org/10.1016/j.arth.2019.04.024
17. Zanirato A., Cavagnaro L., Basso M., Divano S., Felli L., Formica M. Metaphyseal sleeves in total knee arthroplasty revision: complications, clinical and radiological results. A systematic review of the literature. Arch Orthop Trauma Surg. 2018 Jul;138(7):993-1001. https://doi.org/10.1007/s00402-018-2967-0
18. Anderson L.A., Christie M., Blackburn B.E., Mahan C., Earl C., Pelt C.E., Peters C.L., Gililland J. 3D-printed titanium metaphyseal cones in revision total knee arthroplasty with cemented and cementless stems. Bone Joint J. 2021 Jun;103-B(6 Supple A):150-157. https://doi.org/10.1302/0301-620X.103B6.BJJ-2020-2504.R1
19. Berger C., Larsson S., Bergh P., Brisby H., Wennergren D. The risk for complications and reoperations with the use of mega prostheses in bone reconstructions. J Orthop Surg Res. 2021 Oct 14;16(1):598. https://doi.org/10.1186/s13018-021-02749-z
20. Berger C., Parai C., Tillander J., Bergh P., Wennergren D., Brisby H. High Risk for Persistent Peri-Prosthetic Infection and Amputation in Mega-Prosthesis Reconstruction. J Clin Med. 2023 May 20;12(10):3575. https://doi.org/10.3390/jcm12103575
21. Salari P, Baldini A. Revision knee surgery: the practical approach. EFORT Open Rev. 2021 Jun 28;6(6):495-500. https://doi.org/10.1302/2058-5241.6.210018
22. Postler A., Lützner C., Beyer F., Tille E., Lützner J. Analysis of Total Knee Arthroplasty revision causes. BMC Musculoskelet Disord. 2018 Feb 14;19(1):55. https://doi.org/10.1186/s12891-018-1977-y
23. Engh G.A., Ammeen D.J. Classification and preoperative radiographic evaluation: knee. Orthop Clin North Am. 1998 Apr;29(2):205-17. https://doi.org/10.1016/s0030-5898(05)70319-9.