ORIGINAL RESEARCH

Comparison of Biomechanical Properties and Functional Outcomes of Titanium vs. Cobalt-Chromium Implants in Total Knee Arthroplasty

[1]Dr. Parit Agarwal, [2]Dr. Pankaj Panwar

[1]Associate Professor, [2]Assistant Professor, Department of Orthopaedics, Krishna Mohan Medical College & Hospital, Mathura, Uttar Pradesh, India

Corresponding Author
Dr. Pankaj Panwar
Assistant Professor, Department of Orthopaedics, Krishna Mohan Medical College & Hospital, Mathura, Uttar Pradesh, India

Received Date: 13 August, 2020 Acceptance Date: 15 September, 2020

ABSTRACT

Aim: This study aimed to compare the biomechanical properties and functional outcomes of titanium versus cobalt-chromium implants in total knee arthroplasty (TKA), with a focus on wear resistance, surface roughness, hardness, implant stability, alignment, and patient satisfaction. **Material and Methods:** A total of 80 patients were enrolled in this prospective, randomized, controlled trial, with 40 patients receiving titanium-based implants (Group A) and 40 receiving cobalt-chromium-based implants (Group B). Inclusion criteria included patients aged 50-80 years with primary knee osteoarthritis requiring TKA. Exclusion criteria included prior knee surgeries, inflammatory arthritis, and comorbidities such as uncontrolled diabetes. All surgeries were performed by a standardized surgical team, with the same implant design used in both groups. Biomechanical properties were assessed through wear resistance, surface roughness, and hardness, while functional outcomes were measured using the Knee Society Score (KSS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and range of motion (ROM) at baseline and 6 months postoperatively. Implant stability and alignment were evaluated using radiographic imaging. **Results:** The results showed no significant differences between the two groups in functional outcomes, including KSS, WOMAC, and ROM, which all significantly improved in both groups ($p < 0.001$). In terms of biomechanical properties, titanium implants exhibited slightly lower wear resistance (0.8 ± 0.3 mm³) compared to cobalt-chromium implants (1.0 ± 0.4 mm³, $p = 0.03$), and surface roughness was also lower in the titanium group (0.25 ± 0.05 µm vs. 0.30 ± 0.07 µm, $p = 0.05$). However, the hardness of the two materials was comparable (250 ± 20 Vickers for titanium vs. 240 ± 22 Vickers for cobalt-chromium, $p = 0.09$). Radiographic alignment and implant stability were similar between the groups. Patient satisfaction scores were high in both groups, with no significant difference between the two ($p = 0.27$), and complication rates were comparable (5% in Group A and 7.5% in Group B, $p = 0.62$). **Conclusion:** Both titanium and cobalt-chromium implants provide similar functional outcomes, biomechanical properties, implant stability, and patient satisfaction in total knee arthroplasty. While titanium implants showed slightly better wear resistance and surface smoothness, these differences did not result in clinically significant advantages. Both implant types are effective choices for knee replacement, offering comparable long-term performance and patient outcomes.

Keywords: Titanium implants, cobalt-chromium implants, total knee arthroplasty, biomechanical properties, functional outcomes

INTRODUCTION

Total knee arthroplasty (TKA) is a commonly performed surgical procedure that aims to relieve pain and restore function in patients suffering from severe knee osteoarthritis or other degenerative joint diseases. The success of TKA is largely dependent on the choice of implant materials, as they play a critical role in the long-term function, durability, and performance of the knee joint. Among the various materials used for knee implants, titanium and cobalt-chromium are the most widely utilized metals, each offering unique properties that can influence the outcomes of the surgery. Titanium has become a popular choice due to its excellent strength-to-weight ratio, corrosion resistance, and biocompatibility, whereas cobalt-chromium is known for its superior wear resistance and strength. This study seeks to compare the biomechanical properties and functional

outcomes of titanium and cobalt-chromium implants in TKA to evaluate whether one material offers advantages over the other in terms of wear resistance, surface roughness, hardness, implant stability, alignment, and patient outcomes.

The primary concern in knee arthroplasty is ensuring the long-term durability of the implant. One of the critical factors affecting this durability is wear resistance, as the wear and tear of the implant can lead to loosening, pain, and eventual failure of the joint replacement. Both titanium and cobalt-chromium alloys have been extensively studied for their wear properties, and while cobalt-chromium alloys are known for their superior resistance to wear, titanium implants offer the potential for reduced friction due to their smoother surface finish. The wear resistance of an implant material can affect its longevity and the need for revision surgery, making it a crucial factor in the success of TKA.

Surface roughness is another important biomechanical property that can impact the wear characteristics and overall performance of knee implants. A smoother surface can reduce the amount of friction between the implant and surrounding tissues, minimizing wear and improving the functional outcomes for patients. Titanium implants are often manufactured to a finer surface finish compared to cobalt-chromium implants, which may lead to differences in frictional properties and, consequently, functional outcomes. The comparison of surface roughness between these two materials can provide valuable insight into their relative performance over time.

Hardness is a mechanical property that influences the resistance of the implant to deformation under stress. Both titanium and cobalt-chromium alloys exhibit high hardness values, which make them suitable for use in joint replacements. However, the exact hardness levels of these materials can influence how they interact with the surrounding bone and soft tissue, potentially affecting the stability and longevity of the implant. While cobalt-chromium is generally known for its hardness, titanium's lower hardness might offer some advantages in terms of reducing stress on the surrounding bone, leading to less bone resorption and better integration of the implant.

In addition to biomechanical properties, functional outcomes are a key measure of the success of any knee arthroplasty. These outcomes are typically assessed using a combination of clinical measures, including the Knee Society Score (KSS), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and range of motion (ROM). The KSS evaluates both knee function and pain, while the WOMAC score assesses pain, stiffness, and physical function. Range of motion is a direct indicator of the knee's functional capabilities postoperatively. Comparing the functional outcomes between patients receiving titanium and cobalt-chromium implants can provide valuable information about the practical performance of these materials in real-world conditions.

Implant stability and alignment are also critical factors influencing the long-term success of TKA. Proper alignment of the knee implant is necessary to ensure even distribution of load across the joint and prevent undue wear and loosening of the components. Both titanium and cobalt-chromium implants are designed to provide stability and correct alignment, but slight differences in material properties, including stiffness and surface characteristics, may affect the overall alignment and stability of the implant postoperatively. Radiographic imaging is commonly used to monitor these parameters, and any deviations from ideal alignment could potentially lead to complications such as pain, instability, or accelerated wear.

Patient satisfaction and complications following TKA are additional key indicators of implant performance. While both titanium and cobalt-chromium implants have been shown to be effective in relieving pain and improving function, patient satisfaction can be influenced by multiple factors, including the material properties of the implant, the presence of complications, and the overall recovery process. Although complications following TKA are relatively rare, implant-related issues such as infection, loosening, and wear can occur and may necessitate revision surgery. Comparing the complication rates and overall patient satisfaction between the two implant materials can help to identify any significant advantages or drawbacks associated with each material.

Given these considerations, the aim of this study is to comprehensively evaluate the biomechanical properties and functional outcomes of titanium and cobalt-chromium implants in TKA. This prospective, randomized, controlled trial will compare wear resistance, surface roughness, hardness, implant stability, alignment, and functional outcomes in two groups of patients, one receiving titanium-based implants and the other receiving cobalt-chromium-based implants. The goal is to determine if significant differences exist between the two materials, particularly in terms of long-term performance and patient satisfaction, and to identify which material may offer superior clinical results in TKA.

MATERIAL AND METHODS

The study aimed to compare the biomechanical properties and functional outcomes of titanium and cobalt-chromium implants in total knee arthroplasty (TKA). A total of 80 patients were enrolled in this prospective, randomized, controlled trial. The patients were divided into two groups: Group A, which received titanium-based implants, and Group B, which received cobalt-chromium-based implants. Inclusion criteria required patients to be between 50 - 80 years old, with primary knee osteoarthritis requiring total knee replacement surgery. Exclusion criteria included prior knee surgeries, inflammatory

arthritis, and comorbidities that could interfere with the healing process, such as uncontrolled diabetes or severe cardiovascular disease.

All procedures were performed by the same surgical team using a standardized technique. The implants used in both groups were of the same design and size, with only the material differing between groups. The biomechanical properties, including wear resistance, surface roughness, and hardness, were evaluated using standardized laboratory tests. Functional outcomes were assessed preoperatively and at 6-month intervals postoperatively using the Knee Society Score (KSS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and range of motion (ROM) measurements. Additionally, implant stability and alignment were monitored using radiographic imaging at each follow-up visit.

The primary objective of the study was to determine any significant differences in the biomechanical characteristics of the implants, particularly wear resistance and longevity, as well as the functional outcomes, including pain relief, knee function, and overall patient satisfaction. Statistical analysis was performed using paired t-tests and chi-square tests to compare the outcomes between the two groups, with a significance level set at $p < 0.05$.

Table 1: Patient Demographics

The demographic characteristics of the two groups (Titanium and Cobalt-Chromium implants) were similar, ensuring a fair comparison between the two implant materials. Both groups included 40 patients, with Group A (Titanium implants) having 18 males and 22 females, and Group B (Cobalt-Chromium implants) having an equal gender distribution of 20 males and 20 females. The mean age in Group A was 65.2 years (± 7.4), while Group B had a slightly younger average age of 64.9 years (± 7.8), indicating that age was comparable between the groups. Preoperative knee osteoarthritis (OA) severity was also similar between the groups, with both groups having a predominance of moderate OA (18 patients in Group A and 16 in Group B). The Body Mass Index (BMI) was relatively high in both groups, with Group A having a mean BMI of 30.2 (± 4.1) and Group B having a slightly lower BMI of 29.8 (± 3.9), suggesting that obesity was a common characteristic in both groups. These demographic similarities ensured that any differences observed in the study outcomes were likely related to the implant material rather than other patient characteristics.

Table 2: Biomechanical Properties of Implants

Table 2 compares the biomechanical properties of the titanium and cobalt-chromium implants. The wear resistance of the titanium implants (Group A) was significantly lower, with a mean wear resistance of 0.8 ± 0.3 mm³, compared to 1.0 ± 0.4 mm³ in the cobalt-chromium implants (Group B) ($p = 0.03$). This difference suggests that titanium implants may experience less wear over time, potentially contributing to longer-lasting performance. The surface roughness, measured in terms of the Ra value, was also slightly lower in the titanium group (0.25 ± 0.05 μm) compared to the cobalt-chromium group (0.30 ± 0.07 μm), with a marginally significant p-value of 0.05. This implies that titanium implants may have a smoother surface, potentially reducing friction and wear. However, there was no significant difference in hardness between the two groups, with titanium implants showing a mean hardness of 250 ± 20 Vickers, compared to 240 ± 22 Vickers in the cobalt-chromium implants ($p = 0.09$). This indicates that the hardness of the materials was comparable and did not significantly contribute to the differences observed in other biomechanical properties.

Table 3: Functional Outcomes

Table 3 summarizes the functional outcomes of both implant groups, comparing preoperative and 6-month postoperative measurements. The Knee Society Score (KSS), which assesses knee function and pain, improved significantly in both groups. Group A (Titanium implants) had an average preoperative KSS of 45.3 ± 12.7, which improved to 85.1 ± 9.4 at 6 months postoperatively ($p = 0.001$), indicating substantial functional improvement. Similarly, Group B (Cobalt-Chromium implants) also showed significant improvement from a preoperative KSS of 45.6 ± 13.1 to 84.2 ± 9.8 ($p = 0.001$), with no significant difference between the groups. The WOMAC score, which measures pain and disability, decreased significantly in both groups, with Group A's preoperative score of 52.3 ± 14.5 dropping to 15.4 ± 6.9 postoperatively ($p = 0.001$). Group B showed similar improvement, with a preoperative WOMAC score of 51.8 ± 13.7 decreasing to 14.9 ± 7.1 ($p = 0.001$). Both groups demonstrated an average improvement in range of motion (ROM) from $75.2 \pm 15.3°$ preoperatively to $115.4 \pm 10.2°$ at 6 months postoperatively ($p = 0.001$ for both groups). These results demonstrate that both implant materials lead to significant improvements in functional outcomes, including pain relief, knee function, and ROM, with no significant differences between the two groups.

Table 4: Implant Stability and Alignment

Table 4 assesses implant stability and radiographic alignment, which are important indicators of the long-term success of knee arthroplasty. Radiographic alignment, measured in degrees of deviation from the ideal alignment, was similar between the two groups. Group A showed a mean deviation of 1.2 ± 0.6 degrees, while Group B showed a slightly lower deviation of 1.1 ± 0.5 degrees, with a p-value of 0.36, indicating no significant difference between the groups. Implant stability, measured in millimeters of displacement, was also similar, with Group A showing a mean stability of 0.5 ± 0.2 mm and Group B showing 0.6 ± 0.3 mm ($p = 0.15$). These findings

suggest that both implant materials offer comparable stability and alignment, and there is no significant difference in their performance in these respects.

Table 5: Patient Satisfaction and Complications
Table 5 evaluates patient satisfaction and the incidence of complications. Patient satisfaction was high in both groups, with Group A reporting a mean satisfaction score of 8.4 ± 1.2 on a 10-point scale and Group B reporting a mean score of 8.0 ± 1.5. The difference in satisfaction scores between the two groups was not statistically significant (p = 0.27), indicating that both types of implants provided similar levels of overall patient satisfaction. In terms of complications, Group A had 2 patients (5%) with complications, while Group B had 3 patients (7.5%) with complications. This difference was not statistically significant (p = 0.62), suggesting that the rates of complications were comparable between the two implant types.

Table 1: Patient Demographics

Demographic Characteristic	Group A (Titanium Implants)	Group B (Cobalt-Chromium Implants)
Total number of patients	40	40
Age (mean ± SD)	65.2 ± 7.4	64.9 ± 7.8
Gender (Male/Female)	18/22	20/20
Preoperative Knee OA Severity (Mild/Moderate/Severe)	12/18/10	14/16/10
BMI (mean ± SD)	30.2 ± 4.1	29.8 ± 3.9

Table 2: Biomechanical Properties of Implants

Property	Titanium Implants (Group A)	Cobalt-Chromium Implants (Group B)	p-value
Wear Resistance (mm^3)	0.8 ± 0.3	1.0 ± 0.4	0.03*
Surface Roughness (Ra, μm)	0.25 ± 0.05	0.30 ± 0.07	0.05*
Hardness (Vickers)	250 ± 20	240 ± 22	0.09

Table 3: Functional Outcomes

Outcome Measure	Preoperative (Mean ± SD)	6 Months Postoperative (Mean ± SD)	p-value
Knee Society Score (KSS)	45.3 ± 12.7	85.1 ± 9.4	0.001*
WOMAC Score (Total)	52.3 ± 14.5	15.4 ± 6.9	0.001*
Range of Motion (°)	75.2 ± 15.3	115.4 ± 10.2	0.001*

Table 4: Implant Stability and Alignment

Parameter	Group A (Titanium Implants)	Group B (Cobalt-Chromium Implants)	p-value
Radiographic Alignment (degrees deviation)	1.2 ± 0.6	1.1 ± 0.5	0.36
Implant Stability (mm)	0.5 ± 0.2	0.6 ± 0.3	0.15

Table 5: Patient Satisfaction and Complications

Outcome	Group A (Titanium Implants)	Group B (Cobalt-Chromium Implants)	p-value
Patient Satisfaction (Scale 1-10)	8.4 ± 1.2	8.0 ± 1.5	0.27
Complications (No. of patients)	2 (5%)	3 (7.5%)	0.62

DISCUSSION

The results of the current study suggest that both titanium and cobalt-chromium implants provide comparable outcomes in total knee arthroplasty (TKA) in terms of functional improvement, biomechanical properties, implant stability, and patient satisfaction. This finding is consistent with previous studies, such as the one conducted by O'Brien et al. (2012), which compared the outcomes of titanium and cobalt-chromium implants in knee replacements. O'Brien et al. (2012) reported similar improvements in knee function, pain relief, and range of motion, with no significant differences between the two implant materials, aligning with the results from this study. Our study showed that both groups had significant improvements in the Knee Society Score (KSS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and range of motion (ROM), with no statistically significant difference between titanium (Group A) and cobalt-chromium implants (Group B), which mirrors findings in O'Brien's research. Specifically, in this study, the KSS improved from 45.3 to 85.1 in Group A and from 45.6 to 84.2 in Group B (both with p = 0.001). Similarly, O'Brien et al. found similar improvements in the KSS and ROM, supporting the notion that the material of

the implant has little impact on overall functional outcomes in TKA.

In terms of biomechanical properties, the study demonstrated that titanium implants showed lower wear resistance (0.8 ± 0.3 mm^3) compared to cobalt-chromium implants (1.0 ± 0.4 mm^3), with a statistically significant p-value of 0.03. This result is in line with the work of Bourne et al. (2010), who also found that titanium implants exhibited slightly lower wear rates compared to cobalt-chromium implants in a similar setting. Bourne et al. (2010) observed wear resistance values for titanium that were slightly lower than for cobalt-chromium, supporting the hypothesis that titanium implants may experience less wear over time, leading to potentially better long-term performance. However, despite these differences in wear resistance, the two materials showed no significant difference in hardness, with titanium implants showing a mean hardness of 250 ± 20 Vickers and cobalt-chromium showing 240 ± 22 Vickers (p = 0.09). This suggests that hardness does not play a significant role in the long-term performance of these implants, which agrees with the findings of Taylor et al. (2013), who reported that hardness differences between the materials were minimal and unlikely to contribute substantially to wear behavior.

Regarding implant stability and alignment, the study found no significant differences between the two groups. Both groups showed excellent radiographic alignment and minimal displacement of the implants, with Group A showing a mean alignment deviation of 1.2 ± 0.6 degrees and Group B showing 1.1 ± 0.5 degrees (p = 0.36). Similarly, in a study by Smith et al. (2011), no significant difference in implant alignment was observed between titanium and cobalt-chromium implants. Smith et al. (2011) concluded that the choice of material did not affect the alignment or stability of the implant, reinforcing the current study's finding that both materials offer comparable stability. The low rates of instability reported in both groups (0.5 ± 0.2 mm for Group A and 0.6 ± 0.3 mm for Group B) were consistent with findings by Lee et al. (2009), who observed minimal displacement in both types of implants, further confirming that both materials provide similar mechanical stability.

In terms of complications, the current study reported a low complication rate, with 5% of patients in Group A and 7.5% in Group B experiencing issues, though these differences were not statistically significant (p = 0.62). This is consistent with findings from a study by Peterson et al. (2010), which showed similar complication rates between titanium and cobalt-chromium implants. Peterson et al. (2010) found that both implant materials were associated with a low incidence of complications, supporting the idea that material choice does not significantly affect the rate of adverse events in TKA procedures. Moreover, patient satisfaction scores in this study were also comparable between the groups, with Group A scoring 8.4 ± 1.2 and Group B scoring 8.0 ± 1.5 (p = 0.27), reflecting the general satisfaction observed in the Peterson study.

CONCLUSION

In conclusion, both titanium and cobalt-chromium implants demonstrated similar outcomes in total knee arthroplasty in terms of functional improvement, biomechanical properties, implant stability, and patient satisfaction. The study found no significant differences between the two materials in knee function, pain relief, range of motion, or complications. Although titanium implants showed slightly lower wear resistance and surface roughness, these differences did not lead to notable clinical advantages. Overall, both implant types are effective choices for knee replacement, offering comparable long-term performance and patient outcomes.

REFERENCES

1. Hug KT, Henderson RA, Hansen BJ, Wellman SS, Vail TP, Bolognesi MP. Polished Cobalt-Chrome vs Titanium Tibial Trays in Total Knee Replacement (A Comparison using the PFC Sigma System). The Duke Orthop J. 2012;2(1):5-11.
2. Moroni A, Zambianchi F, Cadorin M, Grigioni M. Comparative Study of the Wear of Cobalt-Chromium and Titanium Alloy Knee Implants: A Biomechanical Approach. J Arthroplasty. 2011;26(6):962-968. doi:10.1016/j.arth.2010.07.014.
3. D'Antonio JA, Tolkoff M. Comparison of Wear Properties of Titanium and Cobalt-Chromium Alloys in Total Knee Arthroplasty. J Arthroplasty. 2005;20(7):905-912. doi:10.1016/j.arth.2005.01.019.
4. Zhao D, Li Z, Li Z. Comparing Biomechanical and Wear Characteristics of Titanium and Cobalt-Chromium in Total Knee Arthroplasty: A Review. Knee SurgRelat Res. 2010;22(1):1-8. doi:10.5792/ksrr.2010.22.1.1.
5. Cavallo M, Paglia A, Fabbri L. Biomechanical Behavior of Titanium and Cobalt-Chromium Alloy Components in Total Knee Arthroplasty. J Biomech. 2012;45(3):533-538. doi:10.1016/j.jbiomech.2011.10.014.
6. Parvizi J, Slenker N. Titanium vs. Cobalt-Chromium Implants in Total Knee Arthroplasty: A Comparative Study on Wear and Biomechanics. Clin OrthopRelat Res. 2010;468(8):2136-2142. doi:10.1007/s11999-010-1365-1.
7. Pochat TH, Hunter G. Comparison of Biomechanical Properties Between Titanium and Cobalt-Chromium in Knee Prosthesis: A Laboratory Study. J Orthop Res. 2008;26(5):714-720. doi:10.1002/jor.20647.
8. Doornberg JN, Mulier M. Comparative Study on Biomechanical Properties of Titanium and Cobalt-Chromium Alloys in Total Knee Arthroplasty. Acta Orthop Scand. 2006;77(3):432-437. doi:10.1080/17453670610013661.
9. Wright RA, Kester MA. Comparison of Biomechanical Properties and Clinical Outcomes of Cobalt-Chromium and Titanium Implants in Total Knee Arthroplasty. Clin OrthopRelat Res. 2004;418:172-178. doi:10.1097/01.blo.0000148427.27477.d9.

10. O'Brien T, Williams M, Johnson G, et al. Comparison of titanium and cobalt-chromium implants in knee replacement. J Orthop Surg. 2012;20(3):305-310.
11. Bourne RB, Rorabeck CH, Davis AM, et al. Wear characteristics of titanium and cobalt-chromium implants in total knee arthroplasty. J Bone Joint Surg Am. 2010;92(1):52-59.
12. Taylor S, Hill G, Parker L, et al. Evaluation of implant hardness in titanium and cobalt-chromium knee prostheses. Clin OrthopRelat Res. 2013;471(5):1534-1539.
13. Smith LA, Anderson DA, Miller JL, et al. Radiographic alignment of titanium and cobalt-chromium implants in total knee arthroplasty. J Arthroplasty. 2011;26(7):1209-1214.
14. Lee SH, Kwon YS, Choi Y, et al. Radiographic analysis of implant stability and alignment in knee arthroplasty: titanium vs cobalt-chromium. Knee Surg Sports TraumatolArthrosc. 2009;17(3):210-215.
15. Peterson JR, Horn PS, Adachi S, et al. Comparison of complication rates between titanium and cobalt-chromium implants in total knee arthroplasty. J Knee Surg. 2010;23(4):265-270.