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Inflammatory markers in conventional vs. active robot-assisted total knee arthroplasty and other variables

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Abstract

Background Conventional Total Knee Arthroplasty (CTKA) has long been the standard for arthroplasty. Recent technological advancements have introduced Robot-Assisted Total Knee Arthroplasty (RATKA) and its more automated versions, such as active RATKA offering enhanced precision, accuracy, and potentially superior outcomes. Their role in inflammatory markers has been sparsely explored. Inflammatory response has a direct effect on functional recovery following joint replacement. Our study aimed to understand the natural progression of these inflammatory markers post-surgery. It compared the inflammatory response of CTKA and active RATKA to identify their differences. It also evaluated the role of comorbidities, gender, tourniquet usage, and unilateral or bilateral surgery on inflammatory markers.

Methods CRP, IL6, ESR, and TLC were measured preoperatively, on postoperative day 2 (POD2), POD14, and POD30 in 192 consecutive cases of TKA.

Results CRP increased from 6.59 mg/ml(SD 4.92) preop to 190.57 mg/ml(SD 77.62) on POD2, then decreased to 53.55 mg/ml(SD 42.3) on POD14 and 16.72 mg/ml(SD 14.04) by POD30(p-0.001). ESR rose from 18.81 mm/hr(SD 7.17) preop to 62.78 mm/hr(SD 34.41) on POD2, with a decrease to 57.05 mm/hr(SD 26.63) on POD14 and 27.18 mm/hr(SD 22.42) by POD30(p-0.001). IL6 was markedly elevated at 163.60pg/ml(SD 51.05) on POD2 compared to 6.55pg/ml(SD 2.58) preop(p-0.001). The RATKA group had lower CRP, ESR, and TLC levels than CTKA ($p < 0.05$). Diabetes Mellitus was associated with increased inflammation ($p < 0.05$).

Conclusion RATKA cases showed a lower inflammatory response in several markers and slightly better pain scores compared to the conventional approach. Factors such as tourniquet usage and patient gender did not significantly impact inflammatory markers. Among the comorbidities, Diabetes Mellitus increased inflammation. In the majority of the normal patients, the inflammatory markers did not return to the normal reference even 1 month post-surgery. This physiological variation should be considered when assessing for potential prosthetic joint infections.

Keywords Total knee arthroplasty, Robot-assisted total knee arthroplasty, Active RATKA, Full automated RATKA, Inflammatory markers, Interleukin-6, C-reactive protein, Tourniquet

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Introduction

Conventional Total knee arthroplasty (CTKA) has been the standard practice, traditionally. Advancements in technology have introduced robot-assisted total knee arthroplasty (RATKA) techniques which offer greater precision and potentially improved outcomes with fewer complications. The body responds to any surgery by initiating an inflammation process. Inflammation plays a critical role in the recovery process, influencing pain, function, and overall healing.

Inflammatory markers like C-reactive protein (CRP), Erythrocyte Sedimentation Rate (ESR), Total Leukocyte Count (TLC), and Interleukin-6 (IL6), help evaluate the body's response to surgery and track the healing process. Hall et al. stated that inflammatory response has a direct effect on functional recovery following joint replacement [1]. They also reported IL6 and CRP levels to have the most correlation with the ability to walk post-surgery. Ugras et al. emphasized the role of IL6 and CRP on functional recovery [2]. A similar association was also reported in the RCT by Feng et al. [3]. These markers also have diagnostic potential for periprosthetic joint infection, with IL6 and CRP being the most promising [4].

This study aimed to understand the natural progression of these inflammatory markers post-surgery. Its primary aim was to compare the inflammatory response of CTKA and active RATKA to identify their differences, and also to evaluate the role of comorbidities, gender, tourniquet usage, and unilateral or bilateral surgery on inflammatory markers. The impact of robotic assistance on the inflammatory response has been explored very little so far, as it is still a relatively new technique. The active RATKA system has the potential to influence this by minimizing soft tissue damage, reducing the need for ligament releases, and facilitating minimally invasive surgical approaches. The secondary aim of the study was to look for pain and functional outcomes between the groups.

Methods

This retrospective study comprised 192 cases of total knee arthroplasty. It was done with approval from the institutional ethics committee (NHH/AEC-CL-2024-1237). Cases who underwent either CTKA or RATKA in 2024 for severe knee osteoarthritis (Kellgren-Lawrence grade 4) were included in the study. The cases with known renal or hepatic disorders, inflammatory arthritis, or those on DMARDS were excluded from the study. The patients who had RATKA were grouped separately and matched with CTKA cases based on age, gender, and proportion of unilateral to bilateral surgeries. All cases were performed at a leading tertiary care centre by a team of two surgeons. The surgeons and operating room staff were experienced in both conventional and robotic arthroplasty, having surpassed the learning curve, with no difference in surgical duration between the two techniques.

Surgical technique Before RATKA surgery, the patient's computer tomography scan (CT) data was analyzed using the robotic system's computer software (J-Planner) to check the anatomy, segmentation, reference points, depth of bone cuts, sizing, and positioning of the implants All the cases were done using spinal anesthesia with the addition of epidural in cases of bilateral. Image-based Robotic System (CUVIS-MERIL) was used in all the cases. Cemented implants of the models Destknee and Oppulent (Max Meril, Meril Life Sciences Pvt. Ltd.) were used. Tourniquet usage was based on surgeon preference.

Medial parapatellar approach was used for exposure. After the joint exposure, pins were placed into the femur and tibia for the attachment of the Tracker-Array frame. The femur and tibial pre-set points were registered using the marker probe. Once the registration process was completed on the Optical Tracking System, osteophytes were removed. Ligament tension and gap were checked. Gap balancing was done using alterations in the femur and tibial bone cuts. All the bone cuts were done by the burr-based robotic arm. Following the bone cuts, tibial preparation, trial implantation, and confirmation of gap balance on the monitor using the markers, implantation, and closure were done in a standard fashion.

In the conventional arthroplasty surgery, the same approach was used for joint exposure. Gap balancing was achieved through soft tissue releases, and bone cuts were made using an intramedullary jig for the femur and an extramedullary jig for the tibia. Postoperatively, both surgeries followed a standard protocol for analgesics, antibiotics, and rehabilitation.

Inflammatory markers considered for the study were IL6, CRP, ESR, and TLC. They were measured preoperatively for baseline measurement, on postoperative day 2 (POD), and POD30. Additionally, CRP, ESR, and TLC were also measured on POD14.

IL6 (reference value: 0 to 7 pg/ml) was done on the Cobas 6000 system (Roche Diagnostic Products Ltd, a Hitachi Group company) by electrochemiluminescence immune assay technique as per manufacturer instructions using patient serum.

CRP (reference value: 0 to 6 mg/ml) was done on the Vitros system (Ortho Clinical Diagnostics Inc.) by chemiluminescence technique as per manufacturer instructions using patient serum.

ESR (reference value: 0 to 20 mm/hr) was done on Ves Matic Cube 80 system (DIESSE diagnostica S.p.a) by modified Westegren technique as per manufacturer instructions using patient blood with EDTA.

TLC (reference value: 4000 to 11000 cells/μL) was done on DxH900 machine systems (Beckmen Coulter, Inc.) by

Table 1 Demography of the study groups

Characteristic	RATKA Group (*n* = 122)	CTKA Group (*n* = 70)
Age Group		
< 50 years	12 (10%)	7 (10%)
50–60 years	49 (40%)	28 (40%)
> 60 years	61 (50%)	35 (50%)
Gender		
Men	43 (35.2%)	25 (35.7%)
Women	79 (64.8%)	45 (64.3%)
Unilateral/Bilateral		
Unilateral	62 (50.8%)	36 (51.4%)
Bilateral	60 (49.2%)	34 (48.6%)
Tourniquet Use		
Tourniquet used	71 (58.2%)	41 (58.6%)
No tourniquet used	51 (41.8%)	29 (41.4%)

Table 2 Inflammatory markers in postoperative period

	Preop	Pod2	Pod14	Pod30	*P*
CRP	6.59 (4.92)	190.57(77.62)	53.55 (42.3)	16.72 (14.04)	**0.001***
ESR	18.81 (7.17)	62.78 (34.41)	57.05 (26.63)	27.18 (22.42)	**0.001***
TLC	8.72 (2.53)	10.11 (2.55)	9.11 (2.44)	7.92 (2)	**0.004***
IL6	6.55 (2.58)	163.60 (51.05)		20.31 (14.43)	**0.001***

Statistical Test- One-Way ANOVA; *P*-Value < 0.05- Significant*

Table 3 Role of diabetic on inflammatory markers from POD2

	Diabetic	Non-Diabetic	*P* value
IL6	195.6 (SD 63)	146.84 (SD 86.9)	**0.029***
CRP	204 (SD 58.7)	180.8 (SD53.3)	**0.008***
ESR	63.12 (SD 34.19)	63.08 (34.43)	0.883
TLC	10.84 (2.50)	10.26 (2.54)	0.148

Statistical Test:: Independent T-Test; *P*-value < 0.05- Significant*

electric impedance method as per manufacturer instructions using patient blood with EDTA.

All the statistics were done using the SPSS software version 27. Student T-test was done between pre-operative and post-operative hemoglobin concentration. Annova test was done for the inflammatory markers. Univariate analyses were conducted to compare RATKA with CTKA and to assess differences between other individual variables. Multivariate linear regression analyses were done for the significant ones. The comparison between RATKA and CTKA was further evaluated by subgroup analyses using an Independent T-test for parametric data and a Mann- Whitney U-test for Non-Parametric data.

Results

A total of 192 cases were included in the study, of which 68 were men, and 124 were women. The average age of the study group was 64 years (S.D 8.1, range 47–81). Bilateral cases were 94 and unilateral were 98. RATKA were 122 and CTKA were 70. A tourniquet was used in 112 of the cases. Table 1 shows further demographic details of the study groups.

The overall trend of the inflammatory markers from preoperative to day 30 is depicted in Fig. 1 and their Annaova test results in Table 2. Of the total 192 cases, 68 had diabetes mellitus (DM), 21 had thyroid dysfunction and 25 had hypertension. Of all these comorbidities, DM showed a significant effect on inflammatory markers (Table 3).

The analysis between RATKA vs. CTKA is depicted in Table 4. In the univariate analysis of several variables, only the comparisons that showed statistically significant results are mentioned here. IL6 of POD 2 was more in the bilateral group (mean 202.73, S.D 86.43) compared to the unilateral (mean 129.29, SD 55.23; $p < 0.001$). A similar result was noticed with CRP from POD 2 (mean 222.58 S.D 75.02 for bilateral and mean 158.51, S.D 66.9 for unilateral *P* value 0.001). the results in the gender and

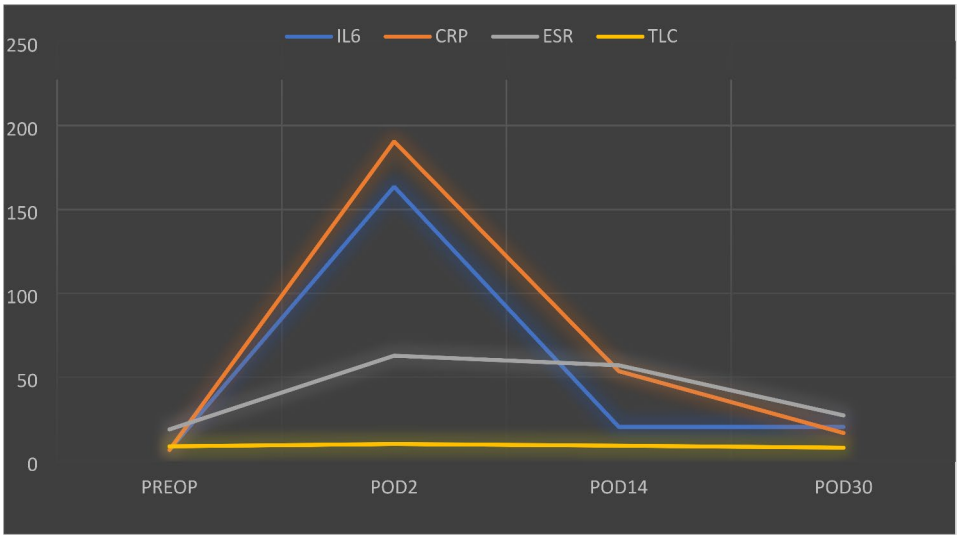

Fig. 1 Graph showing trend of various inflammatory markers in postoperative period

Table 4 Comparing the CTKA and RATKA

	CTKA	RATKA	*P*- Value
IL6-D2	184.39 (117.95)	160.86 (134.32)	0.365
IL6 -D30	17.17 (12.4)	21.52 (34.68)	0.602
TLC-D2	10.85 (3.19)	10 (2.4)	0.090
TLC- D14	10.07 (2.81)	8.85 (2.9)	**0.028***
TLC- D30	7.94 (1.62)	7.94 (2.11)	0.996
CRP-D2	246.29 (74.72)	178.59 (73.6)	**< 0.001***
CRP-D14	46.3 (31.278)	56.07 (45.22)	0.322
CRP-D30	19.4 (14.57)	16.29 (26.25)	0.612
ESR-D2	64.26 (33.95)	61.9 (34.3)	0.737
ESR-D14	65.20 (25.6)	54(26.61)	0.063
ESR-D30	36.6 (27.09)	24.64 (20.89)	**0.033***
OKS	37.32 (2.9)	39.68 (4.05)	0.103
Pain score at 2 wks	5.87 (1.27)	5.43 (1.61)	0.136
Pain score at 1 m	3.32 (1.431)	2.47 (1.073)	**0.018***

Statistical Test: Independent T-Test; *P*-Value < 0.05- Significant*

tourniquet use showed no statistically significant difference. Multivariate linear regression analysis showed that bilateral surgery significantly Raised IL6 POD 2 levels (B: 71.647). the multivariate analysis revealed that both robotic surgery and unilateral surgery were associated with significantly lower CRP levels on the second day after surgery than their counterparts. (B: -59.907 for robotic cases; B: -62.161, for unilateral cases).

The comparison between RATKA vs. CTKA cases was further evaluated using subgroup analysis for IL6 and CRP of POD 2, shown in Tables 5 and 6 respectively. Overall OKS improved from an average of 23.1 (S.D 6.8) to 38.35 (S.D 3.1). No cases of infection were observed in either group.

Discussion

Among the various inflammatory markers, CRP and IL-6 have demonstrated the most consistent results in post-arthroplasty patients according to several studies [5]. For this study, CRP, IL-6, ESR, and TLC were considered. Wasko et al. investigated the kinetics of different inflammatory markers in arthroplasty patients [5]. Their findings revealed that IL-6 and CRP were the most reliable serum markers when compared to interleukin-1β, IL-8, and N-terminal propeptide. They observed that IL-6 exhibited an earlier rise and fall than CRP and noted no significant correlation between IL-6 and body mass index (BMI), unlike CRP. Similar results were echoed by Motaghedi et al. making IL-6, a more reliable marker even in obese patients [6].

Si et al. explored the relationship between post-operative pain and inflammatory markers and muscle damage markers in 96 cases of TKA [7]. They observed a positive correlation between pain scores and inflammatory markers such as IL-6, prostaglandin E2 (PGE2), and CRP, as well as muscle damage markers like myoglobin, creatinine kinase, and LDH. All the cases in their study used a medial parapatellar approach, which may have contributed to increased muscle damage. Niki et al. reported that muscle-related enzyme levels rose with the extent of muscle damage associated with the approach and degree of medial release [8]. This suggests that a quadriceps-sparing or minimally invasive approach, which is more feasible in RATKA, may result in less inflammation.

Clementsen et al. investigated the impact of tourniquet application on inflammatory markers during TKA and found no significant difference [9]. Similarly, Laurence

Table 5 Subgroup analysis between CTKA and RATKA for **POD2 - IL6**

S. No	Parameter	Mean ± SD / Median (IQR)		*P* - value
		Conventional	Robotic	
1	Unilateral	139 (79.4–177)	101 (68.5–149.75)	0.385
2	Bilateral	177.5 (144.75–394)	159.5 (108.25–228.25)	0.172
3	Tourniquet-Yes	158 (78.05–188.5)	105 (75–171.5)	0.434
4	Tourniquet-No	157 (135.5–248)	155 (116.35–240.5)	0.607
5	Male	160 (116–182.5)	147.5 (98.25–244)	0.954
6	Female	156.5 (81.25–325)	117 (73.5–180)	0.091

Statistical Test: Mann- Whitney U test; *P*- value < 0.05- Significant*

Table 6 Subgroup analysis between CTKA and RATKA for **POD2 - CRP**

S. No	Parameter	Mean ± SD / Median (IQR)		*P* - value
		Conventional	Robotic	
1	Unilateral	211.73 ± 67.47	148.77 ± 62.54	**< 0.001***
2	Bilateral	278.69 ± 67.87	210.76 ± 71.38	**< 0.001***
3	Tourniquet-Yes	203.5 (174.75–260.5)	165 (104–224.5)	**0.029***
4	Tourniquet-No	273.76 ± 73.17	197.41 ± 73.04	**< 0.001***
5	Male	232 (185–286)	199 (114–253)	**0.085***
6	Female	264 (192.5–307.5)	162 (113.5–232.5)	**< 0.001***

Statistical Test: Parametric data: Independent T-Test; Non- Non-Parametric data: Mann- Whitney U test; *P*-value < 0.05- Significant*

et al. assessed tourniquet-induced ischemia during TKA and reported no notable differences when the duration of tourniquet application was limited [10]. The multivariate analysis in our study also showed that tourniquet use did not significantly affect the inflammatory markers.

Gandhi et al. explored the ability of inflammatory markers to predict long-term pain following TKA [11]. They found that patients with higher levels of synovial and serum inflammatory markers before surgery experienced poorer pain relief. Despite some limitations, their findings highlighted the potential of using perioperative inflammatory markers to predict outcomes and customize treatment. In our study, we observed a similar relationship between pain scores and inflammatory markers when comparing RATKA to CTKA. The RATKA group showed slightly better pain scores and a smaller rise in inflammatory markers compared to the CTKA group.

In our study, the levels of CRP, IL-6, and ESR on POD2 significantly increased from their preoperative values. This is consistent with findings from Wasko et al., who reported peak levels of IL-6 and CRP within the first 5 days after surgery [1]. By POD 14, CRP had decreased to 25% and ESR to 10% of their POD2 values. By POD30, CRP levels had reduced to 8%, IL-6 to 12%, and ESR to 43% of their POD2 values. Although the rise and fall in total leukocyte count (TLC) were statistically significant, the changes were minimal. Similar changes in the TLC were also reported by Hughes et al. and other studies [12, 13, 14].

It was observed that not all inflammatory markers had returned to normal reference values even one month after surgery, in our study. None of the cases exhibited clinical signs or symptoms that would indicate the need for a culture, nor did they meet the serum marker thresholds for periprosthetic joint infection (PJI) according to the MSIS criteria [15]. The observed levels of inflammatory markers are likely a result of the normal physiological response to surgery, rather than an indication of infection. Elevated inflammatory markers at the 4-week mark in otherwise normal patients could potentially raise suspicion or complicate the diagnosis of periprosthetic joint infections. Therefore, using POD2 levels as a baseline and comparing subsequent changes may help in reducing the risk of misdiagnosis.

Koppensteiner et al. [16] investigated the use of IL-6 and other inflammatory markers as criteria for discharging patients after arthroplasty. They found that incorporating IL-6 levels of POD2 and POD4 as discharge parameters resulted in a reduction in the length of hospital stay for patients.

The RATKA system has shown benefits in enhancing precision, alignment, implant positioning, and clinical outcomes, as documented in other studies [17, 18]. However, its effects on inflammatory markers have been sparsely explored. This study was done using an Active robot system equipped with an automated robotic arm and a high-speed burr for milling [19, 20]. The system is designed to avoid damaging the quadriceps, patella, and medial collateral ligament (MCL) by leaving bone intact in the anterolateral femur and postero-medial tibia. It also features boundary constraints to prevent the burr from extending beyond the planned surgical field. Improved implant sizing and positioning accuracy can prevent overhang and thus avoid soft tissue irritation. These factors, combined with a reduced need for ligament releases for gap balancing, may all contribute to lowering the inflammatory response.

Jia-Zheng Xu et al. conducted a retrospective study on 65 knee arthroplasty cases, comparing the inflammatory response between RATKA and CTKA [21]. They found that the serum levels of ESR, CRP, IL-6, and creatine kinase (CK) were lower in the immediate postoperative period for the RATKA group compared to the CTKA group. However, no significant differences were observed in pain and functional scores between the two groups. Similarly, in a randomized controlled trial involving 30 knee arthroplasty cases, Kayani et al. observed significantly reduced levels of ESR, CRP, IL-6, CK, and tumor necrosis factor-alpha (TNF-α) in the RATKA group during the first week post-surgery [22]. Our study, which included 192 cases, also shows a similar trend, with several markers being lower in the RATKA group.

In our study, among the inflammatory markers between the RATKA and CTKA groups, CRP of POD2 (p 0.001), TLC of POD14 (p 0.28), and ESR of POD30 (p 0.03) were lower than CTKA with statistical significance. The pain scores at 1 month were also better in the RATKA group (p 0.018). The subgroup analyses also suggest that the inflammatory markers levels are less in RATKA group for every individual sub-group with statistical significance for values of CRP from POD2. This difference can be attributed to fewer ligament releases and soft tissue dissection, and lack of need to open the femoral medullary canal in the RATKA group. Smaller incisions and more anatomical approaches can be accommodated with RATKA.

Upon evaluation of other variables in our study, it was found that gender did not influence inflammatory markers. Among comorbidities, DM appeared to increase the inflammatory response. This association of inflammatory markers and DM was also reported in other studies [23, 24]. This suggests that DM may not only elevate the risk of infection and wound complications but could also affect pain and outcomes. Further large-scale studies are needed to explore this potential relationship in greater depth.

The major limitation of the study is that it is a retrospective study and sampling was non-random. However,

confounding factors like age, gender, and comorbidities were identified. Many of them were addressed by matching (age, gender) and exclusion criteria. Although comorbidities weren't specifically matched, the incidence of diabetes (DM) was similar in both groups, as was the use of tourniquet. We performed a subgroup analysis between RATKA and CTKA to analyze the differences and further multivariate analysis to adjust for imbalances in baseline characteristics. Some results demonstrated strong statistical significance, indicating that a more extensive study could be highly beneficial for confirming these findings and strengthening the evidence. Notably, this study is among the few to compare RATKA and CTKA with regard to inflammatory markers, especially considering the numerous variables taken into account. This could presumably pave the way for more randomized controlled trials in this field.

A major strength of the study is the measurement of key inflammatory markers at multiple intervals throughout the postoperative period, extending up to a month, an approach not commonly used in many studies. Additionally, the study analyzed the impact of many variables, including robotic assistance, on these markers. Another strength of this study is its larger sample size of 192 cases, whereas most referenced studies on inflammatory markers in TKA involved fewer than 100 cases [1, 5, 7, 21, 22]. Exploring the inflammatory response over the postoperative course can offer valuable insights for optimizing patient outcomes, such as tailoring postoperative medication, customizing rehabilitation protocols, and refining discharge plans. Understanding the natural trends of inflammatory markers may also help reduce the risk of misdiagnosing prosthetic joint infections.

Conclusion

RATKA cases showed a lower inflammatory response in several markers and slightly better pain scores compared to the conventional approach. Factors such as tourniquet usage and patient gender did not significantly impact inflammatory markers. Among the comorbidities, Diabetes Mellitus increased inflammation. In the majority of the normal patients, the inflammatory markers did not return to the normal reference even 1 month post-surgery. This physiological variation should be considered when assessing for potential prosthetic joint infections.

Author contributions

A.S.P: Author Contributions: Study conceptualization, Guidance, Editing, and Proofreading. K.S: Author Contributions: Research, Writing, Statistics, Drafting, Editing, Proofreading. P.B.N: Author Contributions: Editing, Proofreading.I.I: Author Contributions: Data collection, Research.S.S: Author Contributions: Research.

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Data availability

The data supporting the findings of the study can be acquired from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the institutional Ethics Committee: NHAEC (NHH/AEC-CL-2024-1237). The NHAEC is registered under DCGI with the EC Registration No. ECR/772/Inst/KA/2016/RR-22 valid till date 27 February 2027 issued under Rules 122DD of the Indian Drugs and Cosmetics Rules 1945 and also under DHR with Registration number EC/NEW/INST/2022/KA/0123. All human participants provided informed consent to participate in this study.

Consent to Publication

All five authors give consent for submission and publication of the article to this journal.

Clinical trial no

N/A.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

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