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Restoration of CPAK type in total knee arthroplasty does not lead to superior clinical outcome: A study based on arthroplasty registry data

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Abstract

Purpose: To assess the pre- and post-operative distribution of patients undergoing total knee arthroplasty among the nine categories of the Coronal Plane Alignment of the Knee—CPAK classification (Aim 1). Another goal was to assess whether the clinical outcome (patient-reported outcome and implant survival) differed between those whose CPAK type changed vs. those who maintained their CPAK type (Aim 2). Most previous studies investigated only small cohorts and provided only pre-operative data. Moreover, no studies related the change in CPAK type to robust clinical information such as implant survival.

Methods: A retrospective, comparative design was applied and included patients who had undergone primary total knee arthroplasty. A digital analysis of whole-leg radiographs was performed to allocate the cases to the CPAK classes pre- and post-operatively. Likewise, the patient-reported outcomes were assessed pre- and 1 year post-operatively using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).

Results: 2056 patients (742 men, 1314 women; age 69.55 ± 8.61 years) were analysed. Pre-operatively, the most frequent CPAK types were V, II and I, constituting 18.6%, 18.3% and 17.6% of cases, respectively. The mean follow-up period for the whole study population regarding implant survival was 8.36 years. Following TKA, CPAK type V was dominant with 46.1% followed by types IV and VI with 15% and 14.2%, respectively. Of the study patients, 80.0% ($n = 1645$) underwent a change in CPAK type. One year post-operatively, WOMAC total was 12.29 (4.77–26.97) for CPAK changers and 11.76 (4.31–25.53) for CPAK maintainers ($p = 0.399$). Moreover, no differences were seen in the WOMAC subscores pain, stiffness or function ($0.128 < p < 0.678$). The 10-year implant survival was 91.2% among the CPAK changers and 92.9% among the maintainers ($p = 0.506$).

Conclusions: The pre-operative CPAK knee alignment was preserved in 20% of patients. However, this did not seem to have a negative impact on

Abbreviations: CPAK, coronal plane alignment of the knee; HKA, hip–knee(–ankle) angle; JLO, joint line obliquity; KOOS, Knee Injury and Osteoarthritis Outcome Score; SD, standard deviation; TKA, total knee arthroplasty; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

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clinical outcome, as CPAK type changers and CPAK type maintainers did not show significant differences in WOMAC scores or implant survival.

Level of Evidence: Level III.

KEYWORDS
alignment, arthroplasty, CPAK, knee, phenotype

INTRODUCTION

A variety of surgical philosophies on how to handle frontal plane leg alignment during total knee arthroplasty (TKA) have been published over the last decade [7, 13, 26, 27]. In addition, a variety of classification systems were also proposed over recent years, suggesting how to categorise knee alignment [5, 11, 14, 16, 20]. Overall, the issue of 'leg alignment and TKA' has dominated most arthroplasty symposia and journals worldwide in recent years.

Beyond other classification systems for leg alignment in the context of TKA [3, 10, 12] the coronal plane alignment of the knee (CPAK) classification was introduced by MacDessi et al. in 2021 [20]. That instrument uses the hip-knee angle (HKA) in the coronal plane and joint line obliquity (JLO) to categorise knee phenotypes in nine classes. According to the authors, the classification is meant as a pragmatic, but comprehensive tool for coronal plane knee alignment.

Some authors have already applied the CPAK classification in healthy [20] and arthritic populations [14, 20, 25]. Others have even applied the CPAK classification to patients after TKA to investigate for potential changes in knee alignment as part of the surgical procedure [4, 8, 22]. Most of those publications reported an emphasis on CPAK types I, II, III and V before TKA, whereas after TKA CPAK type V was by far dominant in most cohorts. However, so far, only a few researchers have tried to elucidate whether changing or keeping the pre-operative type of frontal plane leg alignment during TKA had an effect on clinical outcome [17, 24, 22]. Unfortunately, these studies partly suffered from various drawbacks like low case number and less robust clinical outcome parameters.

Hence, it was the goal of this study to assess the pre- and post-operative distribution of knees among the nine categories of the CPAK classification and, in doing so, also to determine the number of patients that keep or change their pre-operative CPAK type when undergoing TKA (Aim 1). Another goal was to assess whether the clinical outcome (patient-reported outcome and implant survival) differed between those who changed the CPAK type versus those who maintained their CPAK type (Aim 2).

METHODS

A retrospective, registry-based, multicenter cohort study design was conducted. After approval by the institutional ethics review board, data were extracted from the Tyrol prospective arthroplasty registry including all patients who underwent TKA between 2004 and 2019. That arthroplasty registry routinely documented revision-free survival as well as the three subscales of the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) [1] collected in German language the day before surgery and one year post-operatively. Inclusion criteria were: (a) primary TKA, (b) primary implants, (c) full dataset of pre- and post-operative WOMAC score d) pre- and post-operative standing whole-leg radiographs available. All diagnoses for primary TKA were accepted (osteoarthritis, inflammatory diseases, posttraumatic arthritis). Even patients with severe deformities and previous knee surgery (non-prosthetic) were also accepted. Only patients with revision implants used in primary TKA were not considered for inclusion.

After applying eligibility criteria 2056 available cases were included in the final analysis and measurements of the whole-leg radiographs were then performed to allocate the cases to the CPAK classes as previously described by MacDessi et al. [20]. CPAK uses the hip-knee angle (HKA) in the coronal plane and joint line obliquity (JLO) to categorise knee phenotypes in nine classes (Figure 1). This was done for the

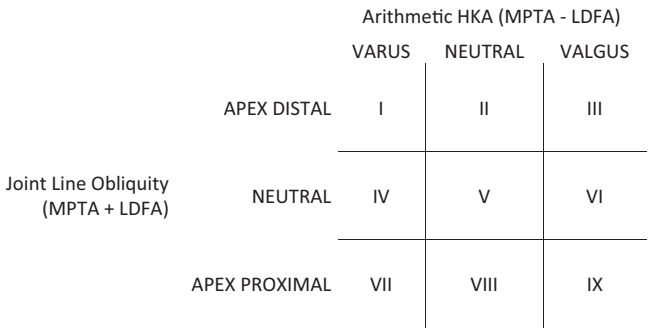

FIGURE 1 Coronal plane alignment of the knee (CPAK) classification according to MacDessi et al. [20]. HKA, hip–knee (–ankle) angle; LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.

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patients' pre-operative whole-leg radiographs and separately for their post-operative whole-leg radiographs. To assess measurement reliability, both interrater and intrarater agreement were evaluated using the intraclass correlation coefficient (ICC). Interrater reliability showed ICC values ranging from 0.858 to 0.994 (all $p < 0.001$). Intrarater reliability showed ICC values ranging from 0.794 to 0.995 (p-values between < 0.001 and 0.011).

The WOMAC questionnaire collects data on pain, stiffness, and physical function. Every item was completed on an 11-point Likert scale and normalised to a 0–100 scale, 0 denoting the best and 100 the poorest response. The score for each of the three main dimensions is defined as the sum of all item scores divided by the number of items. The total score was defined as the sum of pain, stiffness and function scores divided by three. The following TKA systems were used during the study period: The majority of implants were from Zimmer (NexGen design), accounting for 43.38% of cases and Stryker systems comprised 51.91% of cases, including Scorpio variants (34.49%) and Triathlon variants (17.42%). DePuy Attune implants accounted for 2.33% of cases. Additional implants included Zimmer Flex (2.04%) and Natural-Knee II (0.24%). Rarely used systems were DJO Foundation (0.05%) and Smith and Nephew Journey II (0.05%).

Statistical analysis was performed with IBM SPSS Statistics, version 29 (IBM Corp., Armonk, NY, USA) and with R software, version 4.3.3 (R Foundation for Statistical Computing, Vienna, Austria). For descriptive statistics the frequencies (absolute and relative) of cases in the nine CPAK classes were determined pre- and post-operatively. In addition, a Sankey diagram analysis was performed to illustrate the migration between the groups from pre- to post-operative [21]. For inferential statistics alpha was defined as 0.05. Testing was always two-sided. The cases with restored CPAK type (from pre- to post-operative) were compared to the cases whose CPAK type changed regarding the WOMAC scales, namely with the Mann–Whitney U test. To also compare these two groups regarding implant survival we estimated cumulative revision-free survival from date of surgery until date of revision, date of death or end of follow-up (2022-12-31), whichever occurred first, by applying the Kaplan–Meier method. Differences in survival curves were tested using the log-rank test.

RESULTS

The 2056 patients included 1314 women and 742 men. Pre-operative WOMAC total and subscores for the whole study population were as follows (median [IQR]): WOMAC total 50.49 [36.33–63.56], WOMAC pain 48.00 [32.00–62.00], WOMAC function 50.00 [35.29–65.22], WOMAC stiffness 55.00 [35.00–70.00]. Mean age of the study population was 69.6 ± 8.6 years (mean ± SD). Of the included knees, 1053 (51.2%) were right knees. Pre-operatively, the HKA angle was −0.05° ± 5.16° (mean ± SD). Post-operatively, the HKA angle was −0.01° ± 3.14° (mean ± SD). Negative values indicate varus alignment and positive values valgus alignment. The mean follow-up period for the whole study population regarding implant survival was 8.36 years. No significant difference in the mean follow-up time between the CPAK changers and maintainers was shown ($p = 0.461$).

Regarding our Aim 1, namely to assess the distribution of cases to the CPAK types, it was found that the CPAK types most frequently found pre-operatively were V, II and I, namely 18.6%, 18.3% and 17.6%, respectively. After TKA, CPAK type V was dominant with 46.1%, followed by types IV and VI with 15% and 14.2%, respectively (see Table 1 and Figure 2). The changes in CPAK type from pre- to post-operative are illustrated by the Sankey diagram in Figure 3. Of the study patients, 80.0% ($n = 1645$) underwent a change in CPAK type.

Regarding our Aim 2, namely to investigate whether restoring the individual CPAK type during TKA surgery led to a better outcome, we found that 1-year post-operative WOMAC total was 12.3 (4.77–26.97) for CPAK changers and 11.8 (4.31–25.53) for CPAK maintainers ($p = 0.399$). Moreover, no differences were seen in the WOMAC subscores pain, stiffness or function ($0.128 < p < 0.678$; Table 2). The 10-year implant survival was 91.2% among the CPAK changers and 92.9% among the maintainers ($p = 0.506$). Due to the inclusion period, not all patients had the potential to reach a 10-year follow-up. A total of 746 of 2056 cases (36.3%) had a minimum follow-up of ≥ 10 years. This included 592 of 1645 CPAK changers (36.0%) and 154 of 411 CPAK maintainers (37.5%). The distribution of cases with ≥ 10 years of follow-up was comparable between groups.

DISCUSSION

The most important findings with regard to the study's aims were that the dominant CPAK types were types I, II and V pre-operatively and type V post-operatively. In only 20% of the cases was the pre-operative CPAK type of leg alignment restored during TKA. In addition, it was found that the clinical outcome in terms of WOMAC score or implant survival did not significantly differ between CPAK-type changers and CPAK-type maintainers.

When attempting to compare our findings with those of previous studies it appears that a broad range of studies have already investigated the distribution of

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TABLE 1 Pre- and post-operative distribution of the cases to the CPAK types.

CPAK class	Pre-Op absolute frequency	Pre-Op relative frequency (%)	Post-Op absolute frequency	Post-Op relative frequency (%)
CPAK I	362	17.6	61	3.0
CPAK II	375	18.3	150	7.3
CPAK III	256	12.5	65	3.2
CPAK IV	274	13.3	309	15.0
CPAK V	383	18.6	947	46.1
CPAK VI	298	14.5	292	14.2
CPAK VII	27	1.3	50	2.4
CPAK VIII	31	1.5	143	7.0
CPAK IX	48	2.3	37	1.8

Abbreviation: CPAK, Coronal Plane Alignment of the Knee classification.

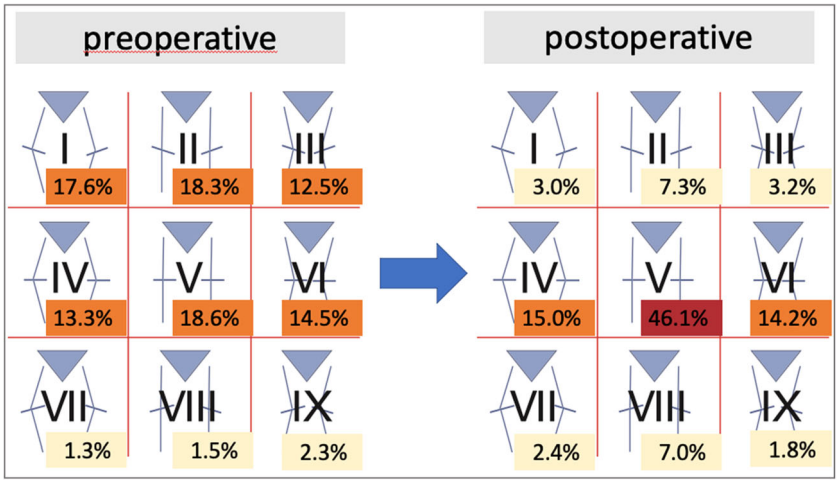

FIGURE 2 Distribution of the 2056 cases among the nine CPAK types before and after total knee arthroplasty surgery. CPAK, coronal plane alignment of the knee classification, according to MacDessi et al. [20].

CPAK types in patients with knee osteoarthritis [4, 8, 14, 17, 20, 25]. Not surprisingly, the majority of those studies reported CPAK types I, II, III or I, II, V as being predominant, which is in agreement with the study at hand.

The literature is more limited when it comes to the question of CPAK type distribution after TKA or even the change in CPAK distribution from pre- to post-operative (Table 3). Corban et al. examined both pre- and post-operative CPAK-type frequencies in 700 patients undergoing mechanically aligned TKA [4]. They reported that the pre-operatively dominant CPAK types II, I, III changed to V, VI, IV as the most frequent types post-operatively. Most frequent was CPAK type V, seen in approx. 60% of their cases. According to the authors, the pre-operative CPAK type was restored during TKA in only 5% of the cases. Konishi et al. also investigated CPAK types in 284 TKA pre- and post-operatively [17]. Pre-operatively, CPAK types I, IV and II were the most common, whereas post-operatively the dominant CPAK types were V, II and IV. Unfortunately, the authors did not mention the ratio of patients who changed versus those who maintained their CPAK type. The third study reporting both pre- and post-operative CPAK-type data included 178 cases of mechanically aligned TKA [22]. While types I and II were dominant pre-operatively, types V and IV were most frequent post-operatively. According to the authors, the pre-operative CPAK type was restored during TKA in 14% of the cases. Sappey-Marinier et al. also investigated CPAK types before and after TKA and found types I, II, III and V, IV, VI to be the most prevalent groups pre- and post-operatively, respectively [24]. Overall, the pre-operative CPAK type was restored in just 18% of the cases. The current study is in very good agreement with the above-mentioned studies regarding (a) post-operative distribution of CPAK

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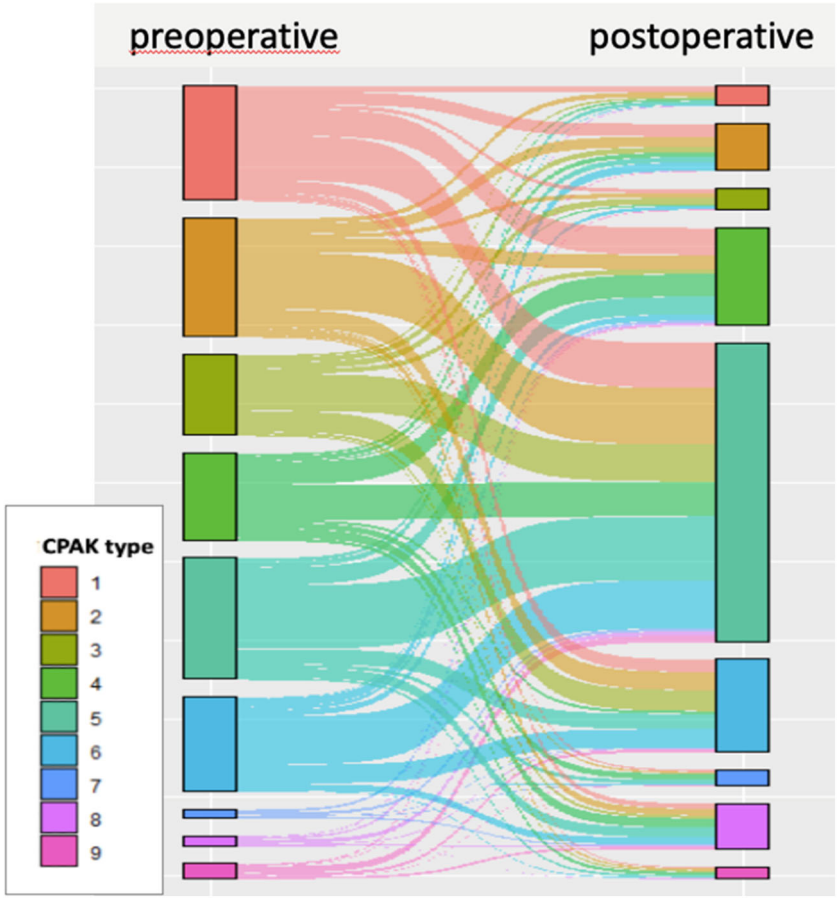

FIGURE 3 Pre-operative to post-operative changes in CPAK types of the 2056 knees during total knee arthroplasty surgery. Flow width represents the number of cases. CPAK, coronal plane alignment of the knee classification.

TABLE 2 WOMAC score data from both groups at one year post-operative.

	CPAK type changed: Md [IQR] ($n = 1645$)	CPAK type not changed: Md [IQR] ($n = 411$)	p-Value
WOMAC total 1 y postop	12.29 [4.77–26.97]	11.76 [4.31–25.53]	0.399
WOMAC pain 1 y postop	8.00 [2.00–20.00]	8.00 [0.00–18.00]	0.128
WOMAC stiffness 1 y postop	15.00 [5.00–30.00]	15.00 [5.00–30.00]	0.678
WOMAC function 1 y postop	12.35 [4.12–28.24]	11.25 [2.94–25.88]	0.255

Abbreviations: CPAK, coronal plane alignment of the knee classification; IQR, interquartile range; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

TABLE 3 Overview of studies that reported CPAK types of TKA patients before and after surgery.

Authors	Year	Number of TKA	Top 3 CPAK types pre-operative (descending)	Top 3 CPAK types post-operative (descending)	CPAK type restored
Sappey-Marinier et al. [24]	2022	1078	I, II, III	V, IV, VI	18%
Konishi et al. [17]	2024	284	I, IV, II	V, II, IV	?
Pangaud et al. [22]	2024	178	I, II, III	V, IV, II	14.6%
Corban et al. [4]	2024	700	II, I, III	V, VI, IV	5%
Present study	*2026*	*2056*	*V, II, I*	*V, IV, VI*	*20%*

Abbreviations: CPAK, coronal plane alignment of the knee classification; TKA, total knee arthroplasty.

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types and (b) rate of restoration of the pre-operative CPAK type during TKA (range 5%–20%) (Table 3).

Regarding the second aim of the present study, namely to compare clinical outcome between those who change vs. those who maintain their pre-operative CPAK type, it appears that only one other study has so far investigated this topic [22]. Pangaud et al. included 178 TKA patients, in whom they assessed the Knee Injury and Osteoarthritis Outcome Score (KOOS), the Forgotten Joint Score and overall patient satisfaction at a minimum follow-up of two years. When they compared patients who changed their CPAK type during TKA with those who maintained their CPAK type, they found that restoration of the CPAK type had a positive effect on overall patient satisfaction and on the activities of daily living and quality of life subscores on the KOOS. No effects were determined regarding the Forgotten Joint Score. Nor were any differences seen between CPAK-type changers and maintainers in terms of implant survival. This can most likely be ascribed to the fact that the range of the follow-up was 2–4 years. Two other studies did not specifically compare CPAK-type changers and CPAK-type maintainers, but still tested whether the pre-operative kind of frontal plane leg alignment was maintained [17, 24]. Konishi et al. applied the KOOS score, the Forgotten Joint Score and the Knee Society Score in 284 TKA patients [17]. According to the authors, changing from valgus to varus alignment or vice versa was associated with inferior outcome in terms of the KOOS score and the Forgotten Joint Score. Sappey-Marinier et al. reported on 1078 TKA patients, in whom they determined post-operative pain (as derived from part of the Knee Society Score) [24]. For the subgroup of patients having a joint line obliquity with the apex pointing toward distal pre-operatively (CPAK types I, II, III) the authors found that not restoring that kind of joint line obliquity during TKA was associated with more post-operative pain. Taken together, the findings from the studies by Pangaud et al., Konishi et al. and Sappey-Marinier [17, 24, 22] show that it is obvious that the findings from the current study are incongruent. While those three publications state that restoring the pre-operative kind of frontal plane leg alignment is associated with favourable outcome, the findings made in the current study suggest that keeping the pre-operative alignment during TKA does not necessarily lead to better clinical outcome. The reasons for that incongruence remain unclear at the moment.

The following potential limitations of the study are acknowledged. First, the data were derived from an arthroplasty registry and therefore from numerous centres with multiple surgeons with a variety of surgical philosophies. The respective surgical philosophy that was applied during a given procedure was not documented in the registry. However, from the fact that CPAK type V was dominant post-operatively, it might be assumed that most surgeons applied some kind of mechanical alignment philosophy during their TKA procedure. Second, we did not adjust for potential confounders like multiple centres, heterogeneous diagnoses, implant types, and differences in baseline alignment. Third, the categorisation in solely 'changers' and 'maintainers' as a binary variable may oversimplify alignment effects as it ignores magnitude and the direction of change. In addition, the CPAK classification itself as the current study's main discriminant parameter may be of limited validity. This is because there is still considerable heterogeneity within one CPAK category (within-class heterogeneity). Moreover, all CPAK groups except for II, V and VIII are unbounded, meaning that they can have a large variety of varus or valgus values. (unbounded categories). These shortcomings of the CPAK classification are well-documented meanwhile [2, 6, 15, 18, 19, 23].

This is in contrast to others who already adopted more up-to-date surgical alignment philosophies [9]. Further, it was a retrospective study with the typical weaknesses associated with such studies and although previously suggested [28], we did not succeed in collecting physical activity data or health-related quality of life data in conjunction with the knee-specific WOMAC data.

It is regarded as a strength of our study that it employed the by far largest number of patients and the longest follow-up period. Moreover, the applied outcome parameters were well-established parameters and were regarded as having high data quality as they were derived from an arthroplasty registry.

The study findings are deemed to have high clinical relevance as they contribute to the issue of 'leg alignment and TKA', which has dominated most arthroplasty symposia and journals worldwide in recent years.

It is concluded that in a setting involving multiple departments, surgical philosophies and implants it appears that in only 20% of cases is the pre-operative type of knee alignment (CPAK type) preserved. Nevertheless, there were no significant differences between CPAK changers and CPAK maintainers in WOMAC scores or implant survival.

AUTHOR CONTRIBUTIONS

Michael Liebensteiner and Paul Nardelli contributed to the study conception and design. Florian Pedross and Sabrina Neururer performed data extraction and statistical analyses. The Tyrol Arthroplasty Group, Paul Nardelli, Rohit Arora, Benedikt Koller and Martin Fischer contributed to data acquisition and/or registry data collection. Paul Nardelli, Michael Liebensteiner and Michael Tobias Hirschmann interpreted the data. Michael Liebensteiner and Paul Nardelli contributed to the writing of the manuscript. Michael Liebensteiner, Paul Nardelli, Michael Tobias Hirschmann and Florian Pedross critically revised the manuscript. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study can only be made available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Ethical approval was obtained from the Ethics Committee of the Medical University of Innsbruck. (Approval code: 1230/2020).

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