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Twenty-Four-Hour Movement Behaviors in Adults and Older Adults before Total Knee Arthroplasty: a Study Based on Compositional Data Analysis

24hodinové pohybové chování u dospělých a starších dospělých před totální náhradou kolenního kloubu: studie založená na analýze kompozičních dat

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ABSTRACT

PURPOSE OF THE STUDY

This study aims to describe and analyze the age differences in the 24-hour movement behavior patterns among a sample of adults and older adults with end-stage knee osteoarthritis referred for total knee arthroplasty (TKA).

MATERIAL AND METHODS

A total of 86 patients referred for TKA were included in this study. Sleep duration, sedentary behavior (SB), light physical activity (LPA), and moderate-to-vigorous physical activity (MVPA) were assessed using multi-day 24-hour raw data from wrist-worn accelerometers. Compositional data analysis was used to analyze the differences between the age categories.

RESULTS

On average (SD), the adults were 59.0 (± 4.9) years; 63% female. The older adults were 72.4 (± 5.5) years; 58% female. The adults reached 23.9 milli-gravitational units (m*g*) as a mean acceleration over the whole day; 34% (8.1 h/day) of the time was classified as sleep, 48.9% (11.7 h/day) as SB, 12.1% (2.9 h/day) as LPA, and 5.1% (72.9 min/day) as MVPA. The older adults reached 21.3 m*g*; 35.2% (8.4 h/day) of the time was classified as sleep, 50.4% (12.1 h/day) as SB, 11.3% (2.7 h/day) as LPA, and 3.1% (44.9 min/day) as MVPA. Compared with the older adults, the proportion of time spent in total MVPA ($P = 0.008$) and MVPA bouts of ≥1 min were greater ($P \leq 0.028$) in the adult group, while the proportion of time spent in total SB was lower ($P = 0.045$). No age difference was found for the proportion of time spent asleep.

DISCUSSION

Sleep, SB, and PA are exclusive and exhaustive parts of the overall 24-h day. Using accelerometer-based measures of 24-hour movement behavior to describe these behaviors more accurately is crucial for a better understanding of patients with end-stage KOA.

CONCLUSIONS

Our findings suggest that the adults and older adults referred for TKA are physically active despite suffering from severe knee osteoarthritis. Such a high level of physical activity may be difficult to increase by TKA postoperatively. If replicated by other studies, 24-hour movement behaviors should be implemented among the examinations required before TKA.

Key words: knee osteoarthritis, accelerometer, sedentary behaviour, physical activity, sleep, 24-hour lifestyle behaviour.

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INTRODUCTION

Knee osteoarthritis (KOA) is among the most frequent causes of pain and physical disability in the elderly with many health and quality of life implications (28). The end-stage of KOA can only be treated with total knee arthroplasty (TKA). An appropriate evaluation of a therapeutic intervention requires precise knowledge of the baseline characteristics before therapy.

Pain associated with KOA is considered an important factor affecting 24-hour movement behaviors in terms of time spent sleeping, sedentary behavior (SB), and physical activity (PA). A resulting pattern of daily movement behaviors can have a negative long-term impact on health and well-being. To date, the vast majority of research on movement behaviors in KOA patients examined the PA and SB and relatively little has focused on sleep (30). Patients with KOA reported sleep disturbances, lack of PA and spent the majority of their time awake in SB (22). These studies examined each 24-hour movement behavior separately or in a specific combination (29), but studies examining all 24-hour movement behaviors remain scarce (23).

Sleep, SB, and PA are exclusive and exhaustive parts of the overall 24-hour day (2). Increasing time in one behavior (e.g., PA) must be compensated by decreasing an equivalent amount of time in one or two remaining behaviors, making the proportions of time spent in each movement behavior perfectly collinear (17). It is now widely accepted that analysis of 24-h data has to be done using the appropriate analytic procedure such as compositional data analysis (CoDA), (6).

Patients can have high expectations for the benefits of TKA, but only those whose expectations are achievable had better post-intervention quality of life outcomes (7). One of the most predominant indicators of postoperative satisfaction is improvement in everyday PA. Thus, information on true preoperative PA might be of great interest before TKA because that knowledge could modify a patient's expectations before surgery, affecting the overall satisfaction with the TKA. Therefore, the aim of the present study was 1) to provide a detailed description of sleep, SB, and PA over an entire 24-hour period and 2) to use CoDA to examine the differences in 24-hour movement behavior compositions among a sample of adult and older adult patients referred for primary TKA.

MATERIAL AND METHODS

Patient cohort

A total of 94 patients with primary and secondary KOA were indicated for primary TKA between April 2019 and February 2020. Exclusion criteria included mental disabilities, dementia, and poor compliance. We used the 65-year retirement age as the cut-off point to classify our sample between the adults and older adults. Descriptive characteristics of the patients are shown in Table 1.

The clinical study has been approved by the Hospital Committee for Conduction of Clinical Research (registration number: FN OL 2018 87-12) in accordance with the 1964 Helsinki Declaration. All the enrolled patients agreed to the use of the anonymized data for the research purpose of this study. Prior to enrolment in the study, patients signed informed consent.

Study protocol

Patients were invited for a follow-up about three months before the scheduled TKA, where they received an accelerometer to be placed on their wrist. The accelerometer was worn for seven consecutive days, and patients were asked to keep daily logs of their sleep (i.e., the estimated time of sleep onset and wake-up time) in a pre-printed diary. The outpatient follow-up provided basic history, including the primary diagnosis, and a clinical examination was performed. The interpretation and categorization of the X-ray findings were performed by the first author (JL). We used multicomponent scores (Knee Society Score and Oxford Knee Score) to comprehensively evaluate the knee condition before TKA. The Charnley classification was applied to estimate the walking capacity of recruited patients (20). The first author repeatedly checked the correctness of imaging and clinical data.

Twenty-four-hour movement behaviors

Device-measured 24-hour movement behaviors, including sleep, SB, light physical activity (LPA), and moderate-to-vigorous physical activity (MVPA), were assessed using Axivity AX3 accelerometers (Axivity Ltd, Newcastle, UK). The Axivity AX3 is considered to be equivalent to GENEActiv (21) and was used for monitoring behavior among 96,600 adults in the UK Biobank study (5). Participants were instructed to continuously wear the device on their non-dominant wrist for seven days (24 h/day) and only remove it for water activities. The wrist placement site was chosen to reduce amounts of missing data and in accordance with the protocol of the National Health and Nutrition Examination Survey (1). Accelerometers were initialized at a sampling frequency of 100 Hz with a dynamic range of ± 8 g and downloaded using Open Movement software (Open Lab, Newcastle University, UK). Raw accelerometer data (.cwa) was processed using the GGIR package 1.11-0 (https://cran.r-project.org/web/packages/GGIR/) in the R software (http://cran.r-project.org). The process of using the GGIR package included:

1) autocalibration of raw data according to the local gravity,
2) detection of sustained abnormal values and non-wear time,
3) imputation of detected non-wear time and high abnormal accelerations by the average accelerations from the same valid time interval on the other days,
4) Euclidean Norm Minus One (ENMO) as $\sqrt{(x^2 + y^2 + z^2)} - 1G$ (where 1G = 9.8 m/s^2) with negative values rounded to zero, and
5) calculation of z-angle (arm angle relative to the horizontal plane), (14).

Sleep time (periods with no change in the z-angle of >5° for at least 5 minutes) was calculated using an algorithm proposed by van Hees et al. (27) and the identification of onset and wake-up time was guided by the participants sleep log. Average acceleration was used to describe the volume of movement behavior, and the intensity gradient was used to describe the intensity distribution of activities across a 24-hour cycle. To categorize time spent in waking movement behaviors, we used proposed ENMO thresholds for SB: <45 mg (8), LPA: ≥45 and <100 mg, and MVPA ≥100 mg (9). The average duration in activity and sedentary bout (minutes/day) was also determined. Given the recommendation for bouts of at least 10 minutes duration has been removed from the latest WHO guideline on PA (3), a one-minute bout length was selected. The weighted averages for sleep, SB, LPA, and MVPA were calculated as [(average value for weekdays × 5 + average value for weekend days × 2) / 7]. Only data from participants who had worn the accelerometer for at least 16 hours per day for at least 4 days (including 1 weekend day), with valid data available for all 15-min windows per 24-hour cycle, and with post-calibration error ≤ 0.01 g were included in the analyses (13).

Table 1. Descriptive characteristics of KOA patients by age group

	Adults *n* = 27		**Older adults** *n* = 59		***P – value***[b]
	n	**% of *n***	***n***	**% of *n***	
Sex					
Female	17	63.0	34	57.6	0.638
Side					
Left	10	37.0	32	54.2	0.141
Primary osteoarthritis	25	92.6	54	91.5	0.864
Body height (cm)[a]	171.6	10.8	169.8	11.3	0.486
Body weight (kg)[a]	99.4	20.4	90.0	17.7	**0.033**
BMI (kg/m^2)[a]	33.8	6.6	31.0	4.3	**0.022**
≥ 30 kg/m^2	20	74.1	36	61.0	0.240
Charnley type					
A	9	33.3	13	22.0	0.280
B1	9	33.3	33	55.9	0.051
B2	6	22.2	10	16.9	0.560
C	3	11.2	3	5.1	0.307
X-ray K-L classification					
K-L ≥ IIIC	24	88.9	44	74.6	0.132
X-rays IKDC classification					
IKDC C	8	29.6	27	45.8	0.158
IKDC D	19	70.4	32	54.2	0.158
Axis deviation (degrees)[a]	11.3	5.3	9.7	3.2	0.077
Type of deformation					
Varus	23	85.2	51	86.4	0.882
Valgus	4	14.8	8	13.6	0.882
KSS general[a]	55.3	19.7	60.0	14.5	0.224
< 55 points	11	40.7	24	40.7	0.999
KSS functional[a]	55.9	15.1	55.3	13.1	0.834
< 60 points	15	55.6	36	61.0	0.638
Oxford Knee Score[a]	31.3	8.4	29.2	5.4	0.175
≥ 30 points	18	66.7	31	52.5	0.220
ROM (flexion)[a]	101.7	11.8	108.5	12.6	**0.020**
≥ 100 degrees	16	59.3	45	76.3	0.109
UCLA activity scale					
> 5 points	13	48.1	26	44.1	0.731
Walking aids					
Yes	12	44.4	31	52.5	0.488
Self-reported walking distance					
≥ 1–2 km	15	55.6	28	47.5	0.488
Able to walk before the pain in knee becomes severe					
≥ 15 minutes	16	59.3	24	40.7	0.111
Pain in bed (VAS)					
None	10	37.0	33	55.9	0.106
Most nights	17	63.0	26	44.1	0.106
Low back pain (VAS)					
> 4 points	10	37.0	34	57.6	0.078
Other side knee pain (VAS)					
> 4 points	14	51.9	23	39.0	0.265
24-hour activity profile					
Average acceleration (m*g*)[a]	23.9	7.6	21.3	6.6	0.119
Intensity gradient[a]	–2.78	0.18	–2.88	0.19	**0.027**

[a] Values represented as a mean (SD). [b] Independent samples t-test or chi-squared test.
BMI: Body mass index; K-L: Kellgren–Lawrence classification; IKDC: International Knee Documentation Committee; KSS: Knee Society Score; VAS: visual analogue scale (range 1–10; 1 = minimal pain; 10 = severe pain); ROM: range of motion; UCLA, University of California, Los Angeles activity scale (range 1–10; 1 = regular participation in impact sports, 10 = no physical activity, dependent on other). Charnley classification (type) was described as the following: class A = patients with only unilateral knee osteoarthritis; class B1 = bilateral knee osteoarthritis; class B2 = knee osteoarthritis before TKA and other side with TKA; class C = multi-joint involvement, inflammatory arthritis, overall frailty, hemiplegia, severe cardiovascular or respiratory disability (20).

Statistical analysis

The analyses were conducted using the R software version 3.4.2 (R Foundation for Statistical Computing, Vienna, Austria) and the IBM Statistical Package for the Social Sciences (SPSS) software version 23 (SPSS Inc., an IBM Company, Chicago, IL, USA). The means and standard deviations were calculated for the continuous variables. For compositional variables, the robust compositional means were calculated (24). The robCompositions-package for R was used for the analysis of compositional data (i.e., 24-hour movement behaviors).

Two specific 24-hour compositions were used. The first one was a 4-part composition, including sleep, SB, LPA, and MVPA. The second was a 10-part composition that took into account sleep, SB, and PA, broken into bouts of different durations. The independent two-sample t-test for unequal sample size was used to analyze the differences between age groups. The first pivot coordinate represents the dominance of a given time-use component over the remaining ones. In the analysis, the first pivot coordinates were expressed as the isometric log-ratios (i.e., *ilr*1), (16). The analysis was carried out for adults and older adults separately to take into account the time-use change in the 24-hour movement behaviors that are associated with the transition to retirement (15). The level of significance was set at $P < 0.05$.

RESULTS

Of the 94 patients selected for the study, a total of 86 patients met the inclusion criteria. Participants were excluded because did not meet inclusion wear time criteria (n=4), their data showed a post-calibration error higher than 0.01 *g* (n=3) or because the accelerometer malfunctioned (n=1). The final analytical sample included 35 males and 51 females, with a mean (SD) age of 68.2 (± 8.2) years. Primary KOA was the most frequent indication of TKA (91.8%). Patients with a body mass index (BMI) higher than 30 kg/m^2 were predominant. Participants wore accelerometers on average 1,428.8 (± 23.4) min/day and had an average of 5.9 (± 0.3) valid days.

The detailed characteristics of the sample classified by age are presented in Table 1. The adults (n = 27) were an average age of 59.0 (± 4.9) years, and 63% were female. The older adults (n = 59) average age was 72.4 (± 5.5) years; 58% female. The adults were heavier by 9.4 kg ($P = 0.033$), had a higher BMI by 2.8 kg/m^2 ($P = 0.022$), and had and reached lower values in ROM flexion by 6.8 degrees ($P = 0.020$). The adults had a significantly greater intensity gradient by 0.1 units ($P = 0.027$) than the older adults.

Table 2 summarizes the age differences in the proportion of time spent in 24-hour movement behaviors

Table 2. Differences between age categories in 24-hour movement behaviors

	Adults (<65 years) n = 27		Older adults (≥65 years) n = 59		Adults vs. Older adults	
	Mean[a]	Var[b]	Mean[a]	Var[b]	Difference	***P* – value**[c]
Sleep (min/day)	488.9	38.4	506.4	42.7	–17.6	0.087
SB (min/day)	703.6	47.8	725.2	44.7	–21.6	**0.045**
LPA (min/day)	174.7	38.7	163.4	31.8	11.2	0.210
MVPA (min/day)	72.9	75.2	44.9	80.7	28.0	**0.008**
Bouts of SB (min/day)						
sporadic	139.1	13.4	123.0	11.6	16.1	0.325
1–9 min	107.3	12.7	87.8	11.6	19.4	**0.039**
10–29 min	126.6	14.0	100.7	13.7	25.9	0.226
30–59 min	102.4	18.3	110.7	13.6	–8.4	0.234
≥60 min	203.3	30.2	262.7	41.2	–59.3	**0.040**
Bouts of LPA (min/day)						
sporadic	154.1	11.2	145.2	10.6	8.9	0.480
≥1 min	26.5	33.4	32.7	16.6	–6.2	**0.012**
Bouts of MVPA (min/day)						
sporadic	58.2	13.4	44.6	14.5	13.5	**0.027**
≥1 min	13.2	40.8	6.6	54.0	6.6	**0.028**

SB: sedentary behavior; LPA: light-intensity physical activity; MVPA: moderate-to-vigorous physical activity.
[a] The robust compositional mean, arithmetic mean for non-compositional continuous variables.
[b] The part of total variance related to a given time-use component, standard deviation for other variables.
[c] t-test for independent samples, where the first pivot coordinate was used to represent each time-use variable.
All movement behaviors were adjusted to 24-hour wear time before analysis.

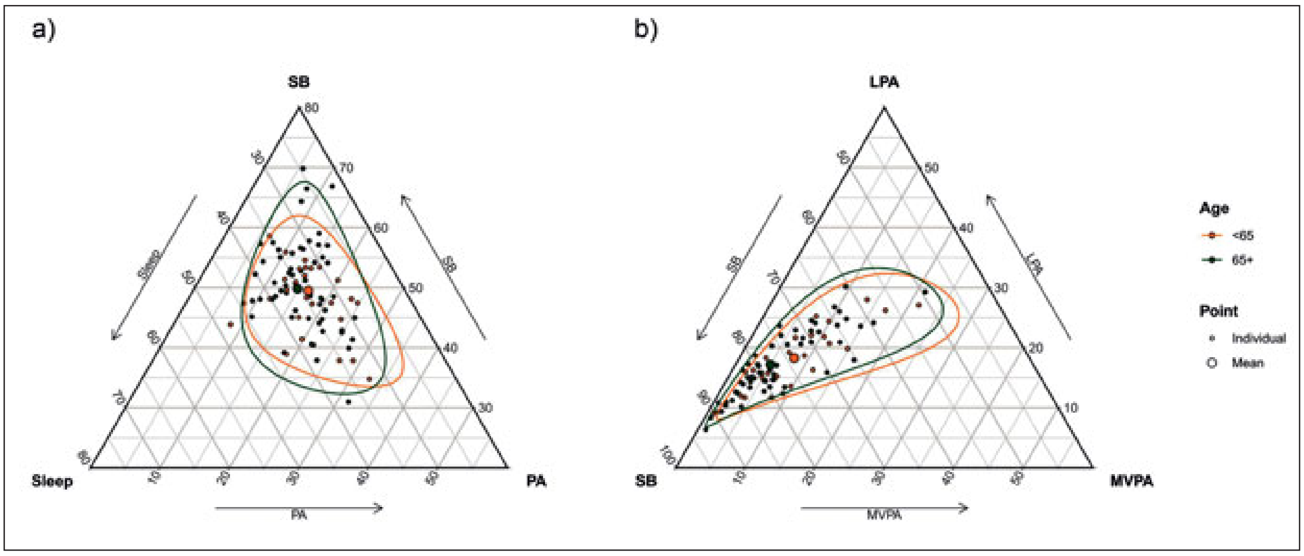

Fig 1. The 24-hour (a) and waking-time (b) composition of movement behaviors for age categories.
The ternary plot is the tool for analyzing time-use data. It depicts the ratios of three variables that the sum is equal to the constant. In the present study, the constant is represented as 100% (i.e., 24 hours or waking hours). LPA – light physical activity, MVPA – moderate-to-vigorous physical activity, PA – physical activity, SB – sedentary behavior.

and the 24-hour activity profile. In adults, the mean acceleration over 24 hours was 23.9 (± 7.6) mg; regarding a 4-part composition, 34% (8.1 h/day) of a 24-hour cycle was identified as sleep, while 48.9% (11.7 h/day), 12.1% (2.9 h/day), and 5.1% (72.9 min/day) were classified as SB, LPA, and MVPA, respectively. Older adults achieved 21.3 (6.6) mg; 35.2% (8.4 h/day) of their 24-hour cycle was identified as sleep, while 50.4% (12.1 h/day), 11.3% (2.9 h/day), and 3.1% (72.9 min/day) were classified as SB, LPA, and MVPA, respectively. The proportion of time spent in movement behaviors within the 24-hour and wake-time composition for age categories is illustrated in Figure 1. Relative to the remaining behaviors within the 24-hour composition, the adults spent less time sedentary by 21.6 min ($P = 0.045$), in SB bouts in ≥60 min durations by 59.3 min ($P = 0.039$), and in LPA bouts in ≥1 min durations by 6.2 min ($P = 0.012$) than the older adults. Moreover, the adults spent more time in MVPA by 28 min ($P = 0.008$), in SB bouts in 1–9 min durations by 19.4 min ($P = 0.039$), in sporadic MVPA by 13.5 min ($P = 0.027$), and MVPA bouts in ≥1 min durations by 6.6 min ($P = 0.028$) than the older adults.

DISCUSSION

We believe this study is the first to analyze device-measured sleep, SB, and PA in adults and older adults referred for TKA using CoDA. Both analyzed groups spent the majority of their time in SB. The adult patients exhibited significantly higher daily accumulation of MVPA and spent less time sedentary than the older adults. No differences were found in sleep duration and time spent in LPA.

We showed that both adults and older adults with end-stage KOA are physically active as they engaged in a sufficient level of MVPA (i.e., 150–300 min/week) recommended by the World Health Organization in its latest guideline on PA (3). In our study, adults and older adults achieved 510 min/week and 314 min/week of MVPA, respectively. A comparison of our results with those published in the literature is minimal. Previous studies examining the movement behavior of adults with KOA used a hip-worn uniaxial accelerometer only for the waking period (22), and the accelerometer data were usually recorded at 60-sec intervals, which might lead to underestimation of PA. We believe only one study used an accelerometer and 24-hour wear protocols in adults and older adult patients before TKA (23). Although Song et al. (23) presented a noticeably lower level of MVPA than was found in our study, caution is needed when comparing these findings because different placements, devices, and approaches to estimate MVPA were used (13). We estimated the proportion of time spent in each 24-hour behavior using the ENMO metric derived from raw acceleration. We collected on three axes of wrist-worn accelerometers. Song et al. estimated SB and PA from counts collected on the 1-axis of waist-worn accelerometers.

The high level of MVPA in our sample implies that the pain associated with KOA could not be a significant barrier for engagement in habitual PA. Previous studies could support this assumption using wrist-accelerometers among the general population, in which the weekly MVPA ranged from 397 to 525 min (4, 11, 19). Similarly, the mean acceleration over the 24-hour cycle (23.9 m*g* in adults and 21.3 m*g* in older adults) was comparable with that reported in the general population (4, 5, 11, 19). Thus, our results coincide with the existing literature (26) and suggest that individuals with KOA are not less active than the general adult or older adult population. If these data are replicated in other studies with patients before TKA using a similar methodology, then we should include a determination of 24-hour movement behavior into the preoperative examinations before TKA. The reason for that is simple. Preoperative expectations substantially affect the level of satisfaction with TKA at one year postoperatively (7). According to the same study, having TKA expectations met definitively was associated with significantly greater overall satisfaction. Expectations regarding walking capacity, independence from walking aids, using stairs, and sleep length (quality) have similar weight in assessing pain relief. Therefore, we need to know the true PA before TKA to modify unrealistic expectations preoperatively, leading to an appropriate talk with a patient before/after the surgery.

We confirmed previous findings from studies using wrist-worn accelerometry, which concluded that SB increases and MVPA declines with age (19). In contrast, we observed that the older adults spent more time in LPA bouts ≥1 min than the adults. One possible explanation could be the time-use change following retirement. Olds et al. (15) have found that time no longer spent working is associated with an increased amount of time spent in light-intensive activities, such as household chores, which are not affected by KOA-related pain. The second explanation could be age-related differences in walking speed, which is the most common type of PA in older adults. These individuals with limited function are characterized by brief bouts of slow walking (18) and these activities are based on acceleration, likely to be classified as LPA.

We found that both adults and older adults achieved the recommended amount of sleep per day (10) and that the sleep duration did not differ between age categories. However, it can be assumed that KOA-related pain does not affect sleep duration, but it can negatively influence sleep quality, particularly when pain is severe. Our unpublished data support this assumption by showing relatively high wake after sleep onset (WASO), resulting in low sleep efficiency in both age categories (80% for adults and 81% for older adults). This finding is in line with the meta-analysis by Mathias et al. (12) who revealed significantly worse WASO and sleep onset and awakenings in those with chronic pain in comparison with healthy controls. For this reason, sleep quality and patterns should be investigated in further research, as this was beyond the scope of the current study.

Our study has several limitations. First, potential inaccuracies in movement behavioral data may have occurred. The accelerometer cannot fully distinguish between long interrupted sitting and restless sleep, as found by Thewlis et al. (25). Thus, we could potentially misclassify daily sleeping time as SB or vice versa. Second, given that wrist-worn accelerometers produce higher output than waist-worn (9), we could have misclassified LPA and MVPA occasionally. A third limitation is that the relatively small sample size does not allow adjustment for variables (e.g., functional limitation pain, radiographic severity, psychosocial factors, and sex) that may potentially affect 24-hour movement behavior.

CONCLUSIONS

Using accelerometer-based measures of 24-hour movement behavior to describe these behaviors more accurately is crucial for a better understanding of patients with end-stage KOA. Our findings suggest that adults and older adults referred for TKA are physically active individuals with sufficient sleep duration. Our findings indicate higher MVPA and lower SB in adults compared with the group of older adults. The information is useful to consider more achievable expectations in the benefits of TKA in the different age groups of patients.

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