Original Article

Intraindividual Reproducibility of Blood Pressure Surge upon Rising after Nighttime Sleep and Siesta

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The surge in blood pressure (BP) upon rising after waking in the morning has been associated with increased risk of target organ damage and cardiovascular events. The reproducibility of this phenomenon within the same 24-h period was tested in subjects with a siesta during ambulatory BP monitoring by assessing the morning surge (MS) *vs.* the evening surge (ES) after siesta. Ambulatory BP recordings with reported siesta from hypertensive subjects were analyzed. MS and ES were assessed using four different definitions. The intraindividual reproducibility was assessed using the standard deviation of differences between MS and ES, the concordance correlation coefficient, the coefficient of variation and the agreement between MS and ES in detecting "surgers" among hypertensive subjects (top quartile of the BP surge distribution). A total of 562 ambulatory recordings were analyzed (476 subjects, mean age 54.9±13.2 [SD] years, treated 47%). Average MS (16.3/14.4 mmHg, systolic/diastolic) was higher than ES (13.3/12.1 mmHg, $p<0.001$) due to higher post-rising BP in the morning ($p<0.01$). The intraindividual reproducibility was rather poor, with no clear differences among different definitions. However, there was about 70% agreement between MS and ES in the detection of "surgers" (systolic and diastolic, κ statistic 0.18). These data suggest that, although the intraindividual reproducibility of the BP surge within the same 24-h period is rather poor, about 70% of the "morning surgers" were also "evening surgers." Thus, the BP surge might be an inherent pathophysiological characteristic of the BP behavior of an individual and deserves further investigation. (*Hypertens Res* 2008; 31: 1859–1864)

Key Words: **morning surge, evening surge, siesta, ambulatory blood pressure monitoring, reproducibility**

Introduction

An exaggerated morning surge (MS) in blood pressure (BP) upon rising from bed, independent from the average 24-h BP value, has been associated with increased risk of target organ damage (*1*–*5*) and of cerebrovascular (*6*–*8*) and cardiovascular events (*1*).

In subjects who had a daytime sleep (siesta), an evening surge (ES) in BP has also been observed upon rising from bed after waking (*9*, *10*). One study showed that, as is the case with the MS, the ES in BP parallels the evening rise in heart rate and physical activity and also the evening rise in the risk of stroke onset (*10*). Several methods have been used to quantify the MS (*1*, *6*, *8*, *9*, *11*, *12*), whereas for the ES only one study has proposed a method for its calculation (*9*). To date, no study has reported investigating the potential health risks associated with an exaggerated ES.

If the BP surge upon rising from bed after waking is a true intrinsic pathophysiological characteristic of the BP behavior of an individual, then it should be consistent in the morning after nighttime sleep and also in the evening after a siesta. To address this question, we assessed the intraindividual reproducibility of the BP surge within the same 24-h period in the morning (MS) and the evening (ES) in patients who had a siesta during ambulatory BP monitoring. We also attempted to define an optimal method for quantifying the magnitude of the ES.

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This study was presented at the 18th European Society of Hypertension Meeting in Berlin, Germany, June 2008.
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Received April 25, 2008; Accepted in revised form July 21, 2008.

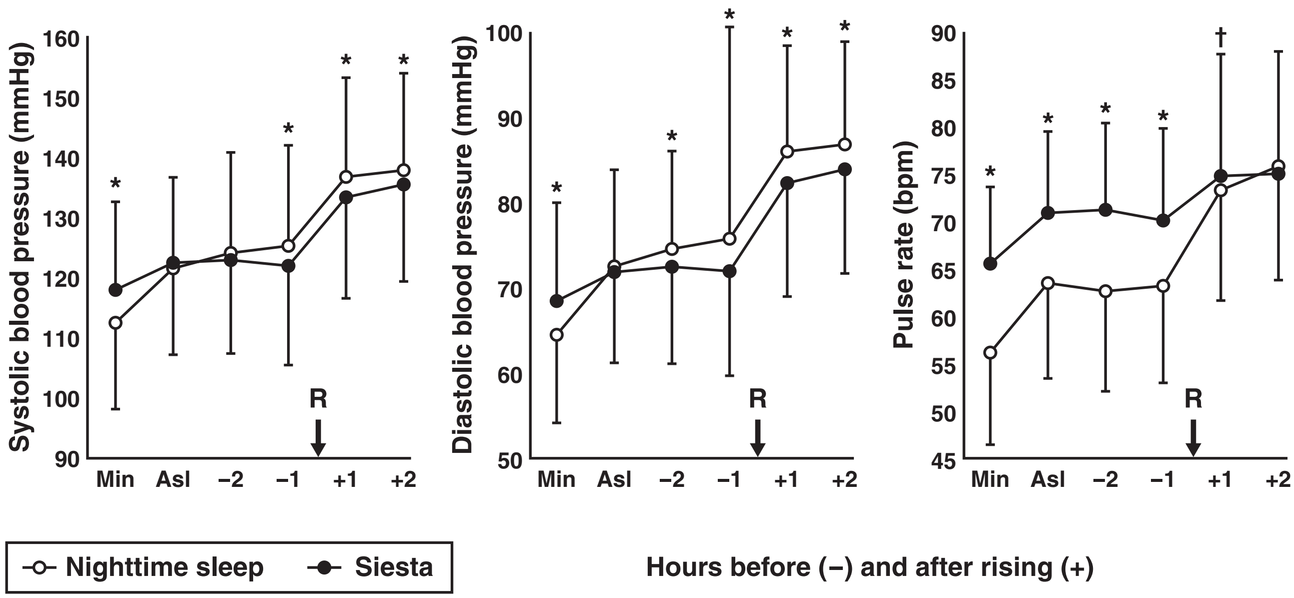

Fig. 1. *Ambulatory blood pressure and pulse rate before and after rising in the morning and the evening in subjects with nighttime sleep and siesta (mean values with SD bars). R, time of rising from bed after nighttime sleep or siesta; Min, average of 3 consecutive readings centered on the lowest reading during nighttime sleep or siesta; Asl, average asleep values during nighttime sleep or siesta. *$p<0.001$, †$p<0.002$ for comparison between measurements during nighttime and siesta.*

Methods

Inclusion Criteria

Twenty-four-hour ambulatory BP recordings from treated and untreated adults referred to an outpatient hypertension clinic from May 1993 to March 2005 were collected. Exclusion criteria were: lack of demographic data, age <18 years, lack of sleeping hours diary, no evening sleep (siesta), less than 20 valid BP readings during the awake period, less than 10 valid readings during the nocturnal sleep period, less than 4 valid BP readings during the siesta period according to the subject's diary (readings at 20 min intervals throughout the 24-h period). In the case where more than one ambulatory BP recording per subject was available, only the first recording (chronologically) for each treatment condition (treated or untreated) was included in the analysis.

Ambulatory BP Monitoring

Twenty-four-hour ambulatory BP monitoring was performed on routine workdays using SpaceLabs 90207 oscillometric devices (SpaceLabs Inc., Redmond, USA; bladder size 23×12 cm, or 30×14 cm where appropriate; measurements at 20 min intervals throughout the 24-h period) (*13*). Subjects were instructed to follow their usual daily activities but to remain still with the forearm extended during each reading. A brief diary was supplied to report the time when they went to bed and arose during ambulatory BP monitoring. Before each ambulatory BP monitoring session, the accuracy of the devices was tested against a standard mercury sphygmomanometer by manual activation (three succeeding readings; Y connector) in order to ensure that there was no consistent difference of >10 mmHg in measured BP.

MS Definitions

The calculation of the MS in BP was based on four different definitions used in previous studies: MS-1: average of BP readings of the 1st hour after rising minus the average of readings of the 1st hour before rising (*11*); MS-2: BP readings 2 h after minus 2 h before rising (*6*); MS-3: BP readings 2 h after rising minus the average of all the readings during sleep (*9*, *12*); MS-4: BP readings 2 h after rising minus the average of the 3 consecutive BP readings centered on the lowest reading during sleep (*6*).

ES Definitions

The calculation of the ES in BP was based on four different definitions based on the MS definitions used in the study: ES-1: average of BP readings of the 1st hour after rising minus the average of readings of the 1st hour before rising; ES-2: BP readings 2 h after minus 2 h before rising; ES-3: BP readings 2 h after rising minus the average of all the readings during siesta; ES-4: BP readings 2 h after rising minus the average of the 3 consecutive BP readings centered on the lowest

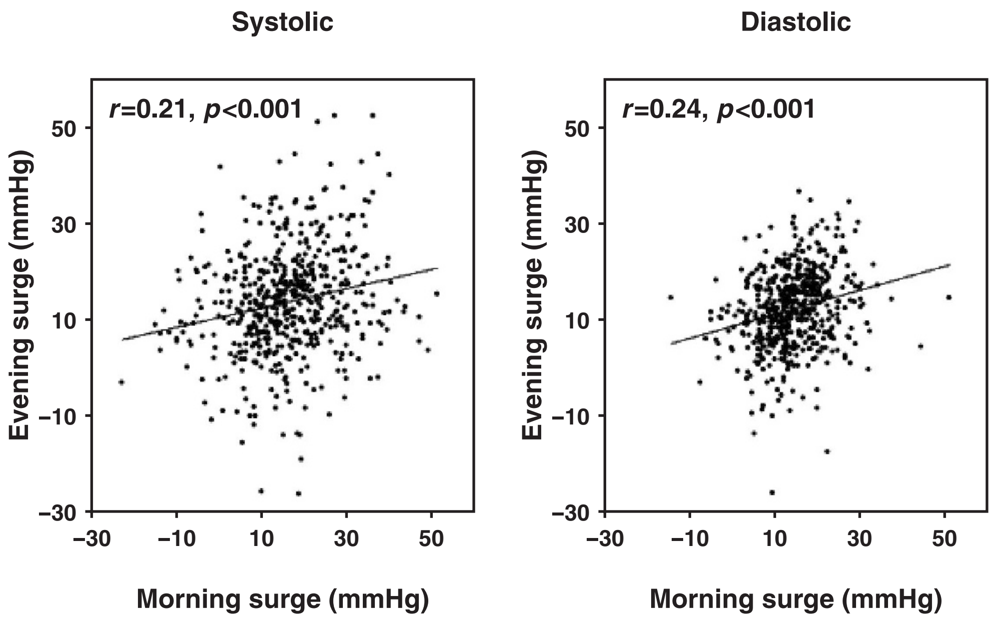

Fig. 2. *Relationship between the morning and the evening surge in systolic and diastolic blood pressure.*

reading during siesta.

Criteria of BP Surge Reliability

1) The stability of the average MS and ES values quantified using different definitions was assessed on the basis of their standard deviation (SD).

The intraindividual reproducibility of the surge phenomenon by each definition was assessed using the following criteria:

2) Reproducibility quantified by the concordance correlation coefficient (CCC), the SD of differences (SDD) and the coefficient of variation (CV) between MS and ES values of each subject.

3) Agreement between MS and ES values in detecting "surgers" (defined as subjects with MS or ES at the top quartile [Q4] of the MS or the ES distribution respectively) quantified by calculating the percentage of subjects with agreement in the diagnosis.

Data Analysis

Ambulatory BP data and additional recorded information from the report files generated by the ambulatory monitors were batch imported and organized in a relational database (Microsoft-Access 2000) using a Visual Basic program. This program designed by L.G.R. (author) for statistical analysis of ambulatory BP monitor–derived data reads the ASCII text files generated by the monitor and performs multiple data procedures and analyses including flagging erroneous readings, valid readings, and duplicate readings (repeats), and it calculates average awake and asleep BP according to the individual's in-bed and out-of-bed periods. Measurements flagged by the monitor software as being technically erroneous were excluded, as were measurements with systolic BP <50 or >260 mmHg and those with diastolic BP <30 or >150 mmHg. The different definitions for the calculation of MS and ES were incorporated in the program as reading selections and calculations. The data were transferred to the Minitab software for statistical analysis (Minitab, Inc., State College, USA; release 13.31). Student's paired *t*-tests were used for the comparison of BP measurements in the same subjects, with Bonferroni's correction for multiple comparisons applied where appropriate. CCC, SDD, and CV (SD/μ where SD is the average of the SD values of MS and ES for each individual and μ is the average of the mean values of MS and ES for each individual) were calculated for each MS and ES definition per subject. The κ statistic was used to assess the level of agreement in the diagnoses of morning *vs*. evening surgers. A probability value $p<0.05$ was considered statistically significant.

Results

A total of 1,934 consecutive ambulatory BP recordings were collected, and 1,372 were excluded according to the study exclusion criteria, leaving 562 recordings from 476 subjects for analysis. The mean age of the subjects was 54.9±13.2 (SD) years, 322 were men (57%), and 264 were treated for hypertension (47%). The average number of valid ambulatory BP readings obtained during siesta was 6.3±2.0 (range 4–15). Subjects who did not report a siesta ($n=337$) were younger (mean age 48.2±12.9 years, $p<0.001$), more likely to be men (61.7%, $p<0.02$), less likely to be treated for hypertension

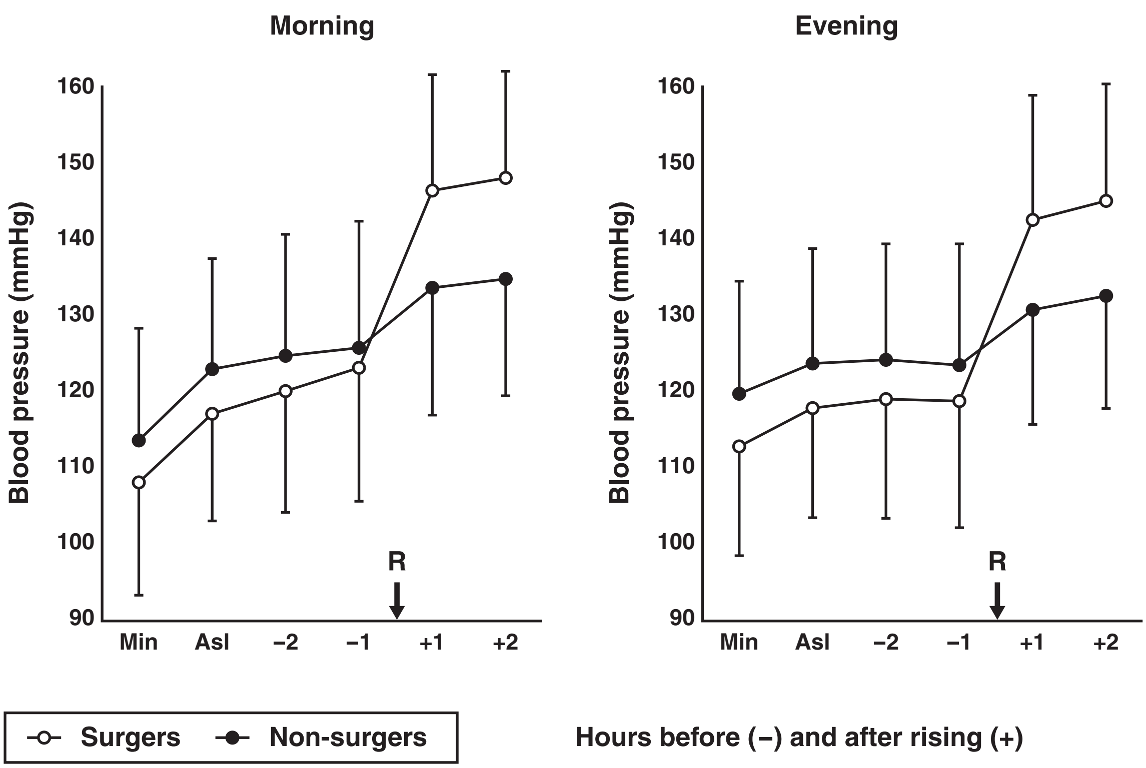

Fig. 3. *Ambulatory systolic blood pressure before and after rising in the morning and the evening in surgers and non-surgers (mean values with SD bars). R, time of rising from bed after nighttime sleep or siesta; Min, average of 3 consecutive readings centered on the lowest reading during nighttime sleep or siesta; Asl, average asleep values during nighttime sleep or siesta.*

(32.6%, $p<0.001$), and had higher average 24-h ambulatory BP (131.1/132.9/80.8/83.8 mmHg, systolic/diastolic, $p<0.05/p<0.001$) and higher morning surge (6.3/14.7 mmHg, $p<0.05/p<0.05$, MS-3 definition).

There was no difference in average ambulatory BP between sleep (121.6±14.8/72.3±10.7 mmHg, systolic/diastolic) and siesta (121.9±15.8/71.9±11.6 mmHg). Minimum BP was significantly lower during sleep than during the siesta ($p<0.001$, Fig. 1).

The average hourly BP and pulse rate in the 2 h before and after the morning and evening rise, as well as the average value during sleep and the minimum reading during nighttime sleep and siesta, are presented in Fig. 1. All pre- and post-rising BP values, except average BP during sleep and minimum BP, tended to be higher in the morning. The pre-rising pulse rates were higher during siesta compared to nighttime sleep, with clinically irrelevant differences in the post-rising period. There was a significant association between MS and ES (for systolic BP surge $r=0.21$, $p<0.001$ and diastolic $r=0.24$, $p<0.001$, Fig. 2).

The cut-off points of the top quartiles used for the classification of surgers were 19.2/16.0, 22.1/17.6, 23.0/19.2 and 33.0/28.1 mmHg, systolic/diastolic, for MS-1, MS-2, MS-3 and MS-4, respectively, and 19.0/16.6, 19.1/17.0, 19.8/17.5 and 24.8/21.3 mmHg for ES-1, ES-2, ES-3 and ES-4, respectively.

The average hourly systolic BP values 2 h before and after waking, as well as the average asleep BP and the minimum reading during sleep for surgers and non-surgers detected in the morning and the evening, are presented in Fig. 3.

The BP surge calculated using the four different definitions in the morning and the evening are presented in Table 1. There was a tendency for the BP surge magnitude assessed by all definitions to be consistently higher in the morning than in the evening, which is attributed mainly to the higher post-rising BP in the morning (Fig. 1). Definition 4 gave the highest MS and ES values for systolic and diastolic BP, and definition 1 gave the lowest (Table 1, $p<0.001$ for all differences among BP surge values calculated by different definitions).

The findings regarding the criteria used for the assessment of the reliability of the different MS and ES definitions are presented in Table 1.

Criterion 1: There was a consistent trend for lower SD using the S-3 definition in the morning and the evening, but none of these differences reached statistical significance.

Criterion 2: S-3 gave the highest CCC and the lowest SDD values between morning and evening BP surge for both systolic and diastolic values, whereas S-3 and S-4 gave the lowest CV values.

Criterion 3: All definitions reached the same agreement

Table 1. Mean Values and Intraindividual Reproducibility of Morning and Evening Blood Pressure Surge Assessed by Different Definitions

Definition	Morning	Evening	CCC	CV	SDD	Agreement* (%)	κ
Systolic BP							
S-1	11.6±12.7	11.9±12.0	0.17	0.75	15.9	67	0.13
S-2	14.3±12.0	12.8±11.1	0.17	0.61	15.1	66	0.10
S-3	16.3±11.3	13.3±11.0	0.20	0.51	14.0	69	0.18
S-4	25.6±12.3	16.7±12.0	0.19	0.44	15.3	68	0.15
Diastolic BP							
S-1	10.3±9.7	10.5±9.3	0.20	0.62	11.9	70	0.19
S-2	12.3±8.7	11.4±8.3	0.20	0.49	10.8	70	0.19
S-3	14.4±7.8	12.1±8.2	0.23	0.41	9.7	68	0.14
S-4	22.1±8.9	15.4±8.8	0.19	0.39	11.2	67	0.12

n=562. Mean±SD. BP, blood pressure; S-1 to S-4, surge in blood pressure assessed by 4 different definitions (see Methods); CCC, concordance correlation coefficient between morning and evening surge; CV, coefficient of variation; SDD, standard deviation of differences; κ, kappa statistic for agreement in the diagnosis. *Agreement between morning and evening surge in the detection of surgers.

between MS and ES in detecting surgers, with up to 70% of morning surgers also being evening surgers and κ statistic values suggesting slight agreement.

When the BP surge was quantified as a proportional (%) rather than absolute (mmHg) BP change, the findings regarding the above mentioned criteria were similar (data not shown).

The definitions MS-3 and ES-3 were used to investigate for determinants of MS and ES. Age was weakly correlated with both MS (r=0.01/r=−0.13, systolic/diastolic, n.s./$p<0.01$) and ES (r=0.11/r=−0.10, $p<0.01$/$p<0.05$). Mean MS tended to be lower in women than men ($p<0.05$), with no difference in ES. No differences in MS or ES were found between treated and untreated subjects. In a multiple regression analysis model using age, sex, and treatment status, only sex reached statistical significance as a predictor of systolic MS ($p<0.05$) and age of systolic ES ($p<0.01$).

Discussion

This study assessed the intraindividual reproducibility of the BP surge within the same 24-h period upon rising from bed after waking in the morning and the evening in hypertensive patients who had a siesta during ambulatory BP monitoring. The main finding is that, despite the rather poor reproducibility of the BP surge, a clinically important percentage (about 70%) classified as surgers in the morning were also surgers in the evening. These data support the view that the BP surge might be an intrinsic pathophysiological characteristic of the behavior of an individual's BP.

This study also provided a direct comparison of the intraindividual reproducibility of four different definitions of the BP surge in the morning *vs*. the evening. None of these definitions gave clearly superior BP surge values in terms of their stability and reproducibility. It might be argued that regular alcohol drinking, which has been shown to be a determinant of exaggerated morning hypertension (*14*), might affect the MS differently compared to the ES, thus affecting the intraindividual reproducibility of the BP surge investigated in this study. We have previously shown that the reproducibility of the MS tested in repeated ambulatory BP recordings 2 weeks apart is superior using the MS-3 as compared to the other definitions (*15*). Again, in that study, the MS was not particularly reproducible, yet up to 80% of morning surgers in the first ambulatory recording were also surgers in the second recording. In line with our previous report (*15*), we showed that, overall, S-3 appears to provide the most reliable assessment of the BP surge phenomenon in terms of intraindividual reproducibility within the same 24-h period. The lower CV value of S-4 is attributed to the higher surge values provided by this definition, which are used in the denominator of the formula used to calculate CV.

In agreement with other studies (*16*, *17*), our findings show that the BP decline during siesta is similar to that during nighttime sleep (Fig. 1). The higher post-rising BP in the morning might be attributed to higher levels of physical activity in the morning due to participants' preparations to leave home in order to bring the monitor back to the clinic, whereas in the evening, many of them remained at home during the two post-rising hours included in the present analysis. Unfortunately, no monitoring of activity was performed in this study to prove this hypothesis. It is important to note that the BP behavior of surgers appeared to be characterized not only by a greater increase in post-rising BP but also by a lower pre-rising BP, which was evident in both the morning and the evening (Fig. 3).

Interestingly, pulse rate was significantly lower during nighttime sleep than during siesta (Fig. 1). Because it has been shown that subjects who wake up but remain in bed show a much greater rise in pulse rate than in BP (*18*), we presume that, during several of the BP measurements during the siesta period, the participants were in bed but awake. This is because the present analysis of nighttime sleep and siesta was based on reported in-bed periods, whereas the actual time asleep is not known. We excluded subjects with fewer than 4 valid BP readings during siesta (minimum duration of siesta 60 min) to get clearer data, but this smaller number of measurements during the siesta period (*vs*. the nighttime sleep period) meant that the "in bed but awake" effects (resulting in icreased pulse rate) had a larger impact on the calculated average pulse rate of siesta comparing to nighttime sleep. Another limitation of this study is that the only participants were people with elevated BP; thus, the findings apply only to this population.

Almost two-thirds of the recordings of our initial database were recordings with reported siesta. As expected, subjects who reported a siesta tended to be older, mostly female, more often treated, with lower mean 24-h BP and MS and probably more often retired and less physically active. However, the present analysis was performed exclusively in patients with a siesta; that is, MS and ES were both assessed in the same subjects and in the same 24-h ambulatory BP recording.

In conclusion, these data suggest that the BP surge is a phenomenon with rather poor intraindividual reproducibility within the same 24-h period, which is affected by the formula used for its calculation. Nevertheless, hypertensive subjects with an exaggerated BP surge in the morning appear to also have an exaggerated BP surge in the evening after a siesta. Thus, the BP surge might be an inherent pathophysiological characteristic of the BP behavior of an individual and deserves further investigation. These findings, together with the recent data showing an association of an exaggerated MS with increased cardiovascular risk, suggest that the MS has interesting potential for clinical application as a risk marker and eventually as a treatment target (*19*).

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