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Dispensing and serving temperatures of coffee-based hot beverages

Exploratory survey as a basis for cancer risk assessment

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Abstract

The International Agency for Research on Cancer (IARC) has evaluated drinks that are consumed "very hot" (> 65 °C) as "probably carcinogenic to humans". Therefore, the purpose of this study is to obtain an initial insight into the dispensing and serving temperatures of coffee-based hot beverages in the home and in the food service industry. Overall, the study recorded the serving temperatures of 356 coffees in the food service industry and the dispensing temperatures of 110 coffees in private households. The measured temperatures were on average 10 °C above the IARC threshold temperature both in the household and in the food service industry (mean value of all measurements: 75 °C, standard deviation: 5 °C). Furthermore, the cooling period, both with and without the addition of milk, should be taken into account. As a rule, a minimum cooling time of > 10 min or the addition of > 20 mL of cold milk is sufficient to cool coffee to temperatures < 65 °C. Generally speaking, from this study, it can be concluded that the recommendation should be to cool hot beverages before drinking in most cases, either by observing a waiting period or by adding milk.

Keywords: coffee, temperature, esophageal cancer, risk assessment

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Introduction

In 1991, the lifestyle factor "coffee drinking" was evaluated by the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) for the first time and it was categorized as group 2B: "Possibly carcinogenic to humans". The rationale behind this was based on epidemiological studies available at the time indicating that coffee may increase the risk of bladder cancer. In addition, there were hypotheses regarding an association with breast cancer, colon cancer, and other types of cancer [1, 2]. 25 years later, based on findings obtained in the intervening period, the IARC recategorized coffee as group 3, which means that coffee is not classifiable as to its carcinogenicity to humans. The 1991 hypothesis regarding bladder cancer has been rejected in numerous studies and the evidence of an association between coffee and other types of cancer has been evaluated as insufficient [1, 2].
In addition to coffee, mate has also been evaluated by the IARC many times. Mate is a kind of tisane-like tea infusion that is primarily consumed in South America [3]. What is particular about this drink is that in many regions, it is consumed extremely hot. In 1992, the IARC categorized this drink as group 2A: "Probably carcinogenic to humans". This decision was based on epidemiological studies from South America that indicated that this hot drink led to an increased risk of esophageal cancer. On the other hand, there are several studies that show that when not drunk so hot, mate has no carcinogenicity and is therefore categorized as group 3 [1, 2].
Based on the hypothesis that the temperature of mate may have cancer-causing effects, but that the drink itself does not have any such effect, it follows that it is possible that all hot drinks are carcinogenic. This is also confirmed by studies on other hot drinks such as tea made of *Camellia sinensis*, which suggest that the carcinogenicity generally depends on the temperature of the

drink alone [1, 2, 4, 5]. Based on this epidemiological data, "very hot" drinks have been categorized as group 2A in the latest IARC evaluation of 2016, meaning that they are "probably carcinogenic to humans" [1, 2]. According to WHO data for 2012, in Germany, the incidence of esophageal cancer was 6,950 cases (1.4% of all cancer cases) and the mortality rate was 5,169 cases (2.4% of all cancer cases) [6]. It is estimated that 75% of cases are triggered by the consumption of alcohol and tobacco [7]. There are no absolute figures available for the effect of nutrition. Meta-analyses show that the risk of esophageal cancer is roughly doubled by consuming very hot drinks (odds ratio after correction for smoking/alcohol consumption: 2.39 [95% confidence interval: 1.71–3.33]) [5].

In order to be able to make a statement about a threshold temperature for hot beverages, based on data from studies in animals, an estimate was made regarding the temperature at which a beverage might be harmful [1, 8]. The IARC considers any hot beverage with a temperature above 65°C "very hot" [1]. This temperature is therefore currently assumed to be a threshold for a probable carcinogenicity of hot beverages at higher temperatures. The mechanism for carcinogenesis through the influence of temperature is largely unknown. The possibility of heat-induced inflammations of the esophageal mucosa, which has a very high thermal conductivity, has been discussed [9]. It has been found that drinking a beverage at 65 °C warms the esophagus to 43–49 °C [10]. Even this temperature range has been classified as potentially dangerous in analogy to fever temperatures [9].

Only limited findings are available regarding the temperatures of hot beverages at the point of drinking [1]. In Tanzania, the average drinking temperature of tea was 71 °C [11]. In the USA, on the other hand, the average drinking temperature was much lower at 60 °C (range: 37–88 °C) [1]. The serving temperatures in the food service industry are largely unknown. Only data from a lawsuit against a fast food chain in the USA shows that coffee was dispensed at between 75 and 88 °C, depending on the machine type [12]. Initial findings from sensory studies show that consumers' preferred drinking temperature for coffee is between 60 and 70 °C [13–16].

Study question

There is hardly any information available regarding the actual dispensing/serving temperature of coffee in Germany. Only a few normative documents provide information on temperature ranges: To determine the energy consumption of commercial hot beverage makers, a temperature of more than 75 °C is assumed for espresso, café crème and filter coffee measured directly at the outlet; for cappuccino, latte, and latte macchiato, a temperature of more than 65 °C is assumed [17]. To ensure proper food hygiene during the production and dispensing of hot beverages from hot beverage makers, the water must reach a minimum temperature of 65 °C during product preparation [18]. Foods that need to be kept hot ready for consumption (e.g. filter coffee) must be dispensed at a temperature of more than 65 °C for food hygiene reasons [19]. When preparing a coffee sample for sensory analysis, the beverage should be cooled to less than 55 °C and the first tasting should be done at between 50 and 55 °C [20, 21].

The aim of this study is to provide the broadest possible collection of data on the dispensing temperatures of hot beverages from household coffee machines and the serving temperatures of machines in the food service industry as part of a preliminary investigation and to use the results of this overview to determine initial practical recommendations.

Methodology

Theory

Coffee should only be brewed in coffee machines at temperatures of up to max. 92 °C because higher temperatures reduce the sensory quality (taste) of the coffee [22]. After the coffee is poured into a drinking vessel, it undergoes a complex transient cooling process, which is determined by the following superimposed sub-processes: heat transfer to the inner surface of the vessel, heat conduction and heating and subsequent cooling of the vessel material, heat transfer to the outer surface of the vessel by convection and radiation and heat transfer to the open surface of the coffee by convection, radiation and evaporation.

Initially, the heating of the vessel wall is dominant and takes place with a large temperature gradient over time (phase 1). After the temperature of the coffee and the container has equalized, a continuous drop in temperature takes place due to heat transfer to the surrounding environment, which happens much more slowly (◆ Figure 1). In practice, in many cases, cold milk is added to the coffee at the end of phase 1. The resulting temperature drop of the mixture initially takes place once again with a large temperature gradient over time (phase 2) and this is dominant until the temperatures of the components have equalized to a certain extent. The temperature of the mixture of hot and cold liquid can be calculated approximately using Richmann's mixing rule, which is based on the law of energy conservation [23]. Afterwards, a slow temperature reduction occurs due to the heat transfer to the surrounding environment. The later the milk is added, the lower the temperature of the mixture of coffee and milk will be because the hot drink has the chance to release more heat into the surrounding environment before being cooled down further by the cold milk.

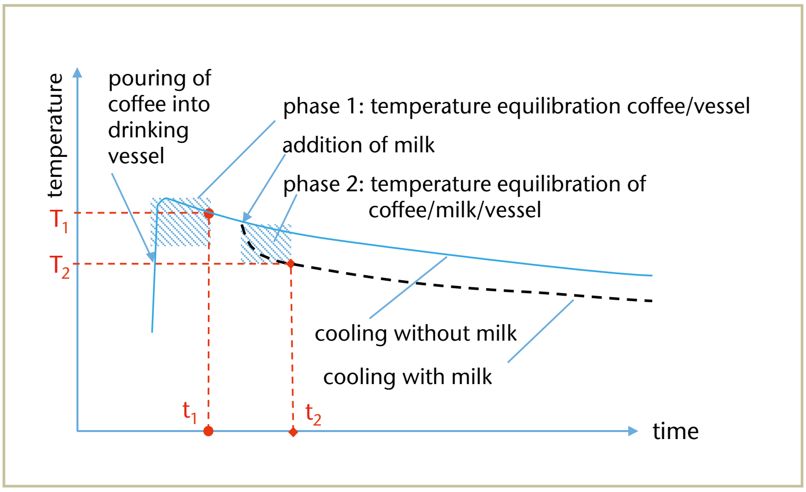

Fig. 1: **Theoretical cooling behavior of coffee in a drinking vessel**
Initially, the temperature equalization between coffee and vessel or between coffee, milk, and vessel dominates. After that, there is a relatively slow reduction in temperature.

Materials

The dispensing temperatures of household coffee machines and the serving temperatures in the food service industry were measured using the officially calibrated temperature measuring device Testo 112 with stainless steel food sensor, accuracy ± 0.2 °C (Testo, Lenzkirch/Germany). In some cases, in the food service industry, the measurements could only be carried out using a Bluetooth thermometer NC 3888-675 (Rosenstein und Söhne, Buggingen/Germany), which was checked in advance using the calibrated Testo thermometer. The data was collected from randomly selected restaurants in the German cities of Karlsruhe, Stuttgart and Constance in the months of March and April 2017. Three different types of machines were found in the food service industry: filter machines, espresso machines (with portafilter), and fully automated machines. In the case of coffee served from a counter (about 70% of the samples), the measurements were carried out within 2 minutes of when they were handed over the counter, and in the case of table service, they were done immediately after serving. The measurement results therefore represent the usual serving temperature or the possible immediate consumption temperature ("worst case scenario").

The measurements on household machines were carried out in 16 private households within the authors' private circles. Five different machine types were found and investigated in this setting (filter, capsule, pad, and portafilter machines, as well as fully automated machines). The results were obtained by repeating the coffee dispensing several times (no repeat measurements of individual samples).

Statistical data analysis

The descriptive data analysis was done using Microsoft Excel 2016. Histograms and graphical evaluations were created using OriginPro 7.5 G (OriginLab Corporation, Northampton, MA/USA). Testing for normal distribution (Anderson-Darling test), t-test on both sides, and variance analysis with Tukey's post-hoc test were done with Minitab 17.3.1 (Minitab GmbH, Munich/Germany). The significance level was set at 0.05 in each case.

Results

Dispensing temperature of coffee in private households

In total, 110 measurements were performed on 16 different household coffee machines in private households. In the case of two fully automated machines, repeated measurements were taken at different temperature settings. One of the capsule machines that we encountered actually had a "cold" setting, at which the coffee had a temperature of about 30 °C. The data from this setting has been eliminated from further evaluations. The average value of all measured dispensing temperatures in the household is 75 °C, and the range is 58–86 °C (◆ Table 1). All of the data exhibits a normal distribution ($p = 0.085$). The dispensing temperatures of different machine types differ significantly ($p \leq 0.05$). Capsule machines have the lowest average dispensing temperature: 66 °C. This is followed by the average dispensing temperatures of the portafilter machines with 70 °C, the filter machines with 72 °C, the pad machines with 75 °C, and the fully automated machines with 76 °C.

Serving temperature of coffee in the food service industry

A total of 356 measurements of individual coffee portions were carried out in 85 food service establishments (1 measurement per coffee). The mean value (± standard deviation) of the measured temperatures immediately after dispensing to the customer is 75 °C ± 5 °C. The values exhibit a normal distribution ($p = 0.44$). The dispensing temperature differs significantly depending on the various machine types (◆ Table 2) ($p \leq 0.001$), with coffee from filter machines exhibiting the lowest average serving temperature (72 °C). In comparison, the average serving temperature of fully automated machines is 75 °C, and for portafilter machines the average temperature is 77 °C.

Household	Minimum temperature [°C]	Maximum temperature [°C]	Arithmetic mean ± SD	Median [°C]	P25 [°C]	P75 [°C]	% of values > 65°C
total							
n = 110	27	86	72 ± 12	75	68	79	86
n = 104[a]	58	86	74 ± 6	75	69	79	90
filter machines (2 machine types)							
n = 15	68	76	72 ± 3	74	70	75	100
capsule machines (4 machine types)							
n = 29	27	81	66 ±19	81	63	78	77
n = 23[a]	58	81	75 ± 6	78	74	79	87
pad machines (2 machine types)							
n = 11	64	81	75 ± 5	76	72	80	91
portafilter machines (2 machine types)							
n = 13	62	77	70 ± 6	71	66	75	77
fully automated machines (6 machine types)							
n = 42	63	86	76 ± 7	75	68	83	93

Table 1: **Overview of actual dispensing temperatures of coffee machines in private households**
[a] evaluation excluding the "cold" machine setting
P25 = 25th percentile; P75 = 75th percentile; SD = standard deviation

Food service industry	Minimum temperature [°C]	Maximum temperature [°C]	Arithmetic mean ± SD	Median [°C]	P25 [°C]	P75 [°C]	% of values > 65°C
total							
n = 356	58	88	75 ± 5	75	71	78	98
filter machines							
n = 44	58	83	72 ± 6	72	70	77	91
portafilter machines							
n = 132	65	88	77 ± 5	77	74	80	100
fully automated machines							
n = 164	63	87	75 ± 5	74	71	77	99

Table 2: **Overview of actual serving temperature in the food service industry by machine type**
P25 = 25th percentile; P75 = 75th percentile; SD = standard deviation

Comparison of the dispensing temperature of household machines and the serving temperature in the food service industry

The dispensing and serving temperature ranges of household machines and food service industry machines are very similar and do not differ significantly (p = 0.33), so the overall distribution across all data can be stated: According to this, the average temperature of all measured coffees (n = 460) is 75 °C ± 5 °C (range: 58–88 °C). The median is 75 °C, P25 is 71 °C and P75 is 79 °C. 95% of the values are above 65 °C. The distribution is shown as a histogram in ◆ Figure 2.

Temperature of cappuccino in private households and in the food service industry

The measured values of the hot beverage "cappuccino" (household machine n = 5; food service industry n = 56 across 15 establishments) all fall within the temperature range of 51–77 °C, with an average value of 62 ± 6 °C. The median is 61 °C, P25 and P75 are 58 and 65 °C respectively. The data exhibits a normal distribution (p = 0.50).

When coffee and cappuccino were measured at the same place, no uniform picture was found either in food service establishments or in private households. The average serving temperatures of coffee and cappuccino were identical in one food service establishment, and a difference of only 4 °C was found when measuring a household machine. In contrast, two other system food service establishments exhibited major differences. Cappuccino was 8 °C and 12 °C colder than the coffee in each respective case.

Cooling of coffee to the IARC threshold temperature of 65 °C

Additional investigations into the cooling time confirm that there are clear differences depending on the vessel used and the initial temperature. In a porcelain cup, cooling from 79 °C to 65 °C takes about 7 minutes, and cooling from 72 °C to 65 °C takes about 3 minutes. In the case of insulated travel mugs, cooling to the threshold temperature strongly depends on the material and – at the ambient temperatures in which the coffee would usually be consumed and with various cups/mugs from different system food service establishments – cooling takes about 14 minutes from 77 °C, about 22 minutes from 79 °C, and about 17 minutes from 83 °C. The initial temperature of the beverage, the thickness of the vessel, its specific thermal capacity, and its thermal conductivity are the determining factors.

Cooling of coffee after the addition of milk

◆ Figure 3 shows the result of the approximate calculation for the temperature of the mixture as a function of the volume of milk added according to Richmann's mixing rule. The diagram shows two scenarios for milk: one for milk at 8 °C (refrigerator temperature) and one for milk at 20°C (room temperature) and two scenarios for coffee at initial temperatures of 80 °C and 75 °C. The volumes of milk that must be added to reach the threshold value are between 27 and 67 mL per cup of coffee (150 mL).

Discussion

This study is the first study on the "drinking" temperature of coffee in Germany. The results of the survey of the serving and dispensing temperatures of coffee in the food service industry and in the household context show that it is usually served very hot (i.e. above 65 °C), and that there is no great difference between the average dispensing temperatures in the household and the average serving temperatures in the food service industry. Both mean values are about 10 °C above the IARC threshold temperature and therefore have the potential to cause damage to the esophageal mucosa if consumed immediately, which the IARC considers to be associated with a probable increase in cancer risk [1].

It is assumed that consumers who consume hot food and beverages for years will gradually become less sensitive to the sensation of "hot" – i.e. temperatures that are initially perceived as hot (e.g. in childhood) will increasingly be perceived as pleasant or too cool, which may cause the drinking temperature to rise steadily during their lifetime [9].

Since customers expect a "very hot" coffee, the coffee machines used in the food service industry are obviously also set up to provide this. In the case of restaurant chains and coffee machines that are preset by external service providers, according to our observations, individual branches often have no option to determine the temperatures of the hot beverages themselves during sampling. A very high temperature may also be preferred as a way of dealing with perceived microbiological hazards, although temperatures above 55 °C are generally regarded as sufficient to control this problem [9].

Interestingly, the values of 87–90 °C [1] published in the trial documents of a lawsuit against branches of a large restaurant franchising company that was successfully sued in the USA due to scalding with very hot coffee were not reached in our measurements. At the 9 branches of this chain that were investigated, the average serving temperature was 74 °C (n = 36). There may be cultural differences in coffee preparation and machine types in Germany compared to the USA.

The highest temperatures in the food service industry can be found

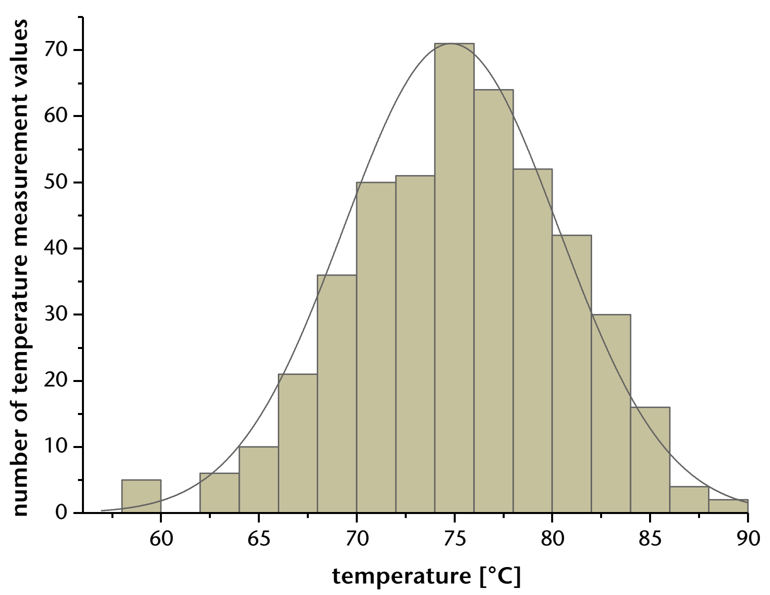

Fig. 2: **Histogram of the dispensing and serving temperatures of coffee in private households and in the food service industry (n = 460) in comparison to a normal distribution**

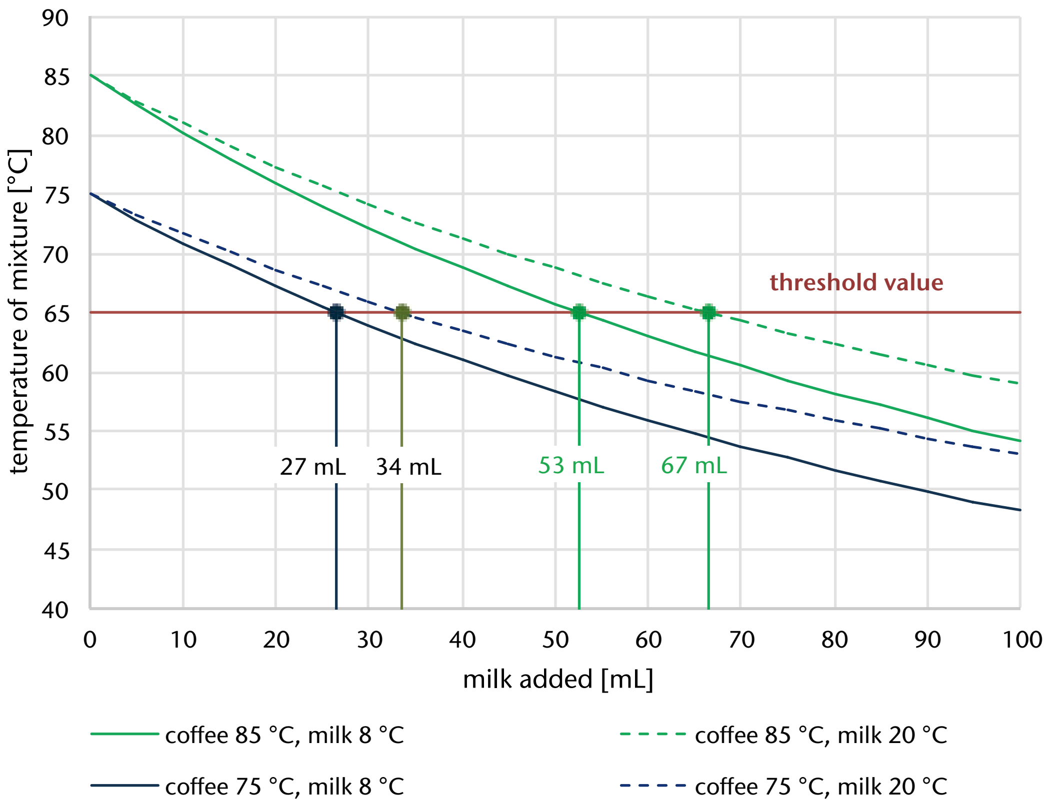

Fig. 3: **Approximate calculation of the temperature of coffee (150 mL) and milk as a function of the volume of milk added**

in portafilter espresso machines. During data collection, it was observed that some of the portafilter machines exhibit pressure tank settings of 120 °C, meaning that the initial temperature upon pressure release is approximately 100 °C. Therefore, in addition to the very high serving temperature, a negative effect on the sensory result (taste) is to be expected [21, 22].

The data on household machines shows that the temperatures are comparable to those in the food service industry. As consumers rarely have the option to change the temperature of the coffee on household machines, the coffee is therefore also dispensed at very high temperatures in the home context. During data collection, it was found that only some fully automated machines have a temperature setting function, and where this function was present, the threshold temperature of the IARC was still exceeded even at the lowest setting.

The findings on cooling time and milk addition show that a combination of both of these measures is ideal. Immediate cooling of a cup of coffee to 65 °C can only be achieved through the addition of a large volume of milk (approx. 30 mL). Therefore, a waiting period of 5 minutes could be combined with the addition of 20 mL of milk in order to reliably reach the threshold value.

Further investigations into optimal cooling are necessary given the number of uncontrollable parameters such as the temperature of the cup or fluctuations in the filling quantity and filling temperature of the coffee.

Further limitations of the study include the lower number of samples from household machines and the fact that sampling from within the food service industry was arbitrarily limited to establishments in southwest Germany. Since the large coffee chains are active throughout Germany and there are only a limited number of coffee machine manufacturers, the results may be regarded as largely typical for the German coffee market.

It would also be interesting to record cooling processes under real-life conditions instead of the single point measurements that we carried out. Further investigations are also needed with regard to the influence of the various cups and containers (e.g. insulated travel mugs) and the serving temperatures of other mixed coffee drinks such as latte macchiato and other hot drinks such as tea, mulled wine, etc. There are large gaps in our knowledge about both the development of cancer due to very high food temperatures and the population's exposure due to hot drinks. This study provides some initial information about exposure, which should be considered critical in the light of the IARC evaluation. Until further toxicological data is available to allow the determination of an evidence-based threshold value, it is possible to use the estimated threshold value of 65 °C provided by the IARC as a basis for evaluation in the context of precautionary consumer health protection. Overall, evaluations of the serving temperatures of coffee show that in most cases the temperatures are very high (> 65 °C), meaning that the potential for damage to the esophagus cannot be ruled out.

Conclusion

Accordingly, advice to consumers should be to allow the coffee to cool before consumption. This can be achieved either by adding milk or by observing a certain cooling period. In the case of the average temperature of 75 °C, at least 20 mL of milk is required for one cup of coffee (27 mL for immediate consumption). The cooling period depends on the vessel from which the coffee is being drunk. Pre-warmed cups/mugs are generally not recommended. A cooling time of about 5 minutes is recommended for a normal cup and about 12 minutes is recommended for an insulated travel mug. The recommendation to the coffee maker industry is to equip coffee machines with at least one temperature selection option, or to limit the maximum dispensing temperature to 80 °C (75th percentile), for example.

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Conflict of Interest
The authors declare no conflict of interest.

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