Application of Queuing Theory to Optimize the Triage Process in a Tertiary Emergency Care (“ER”) Department

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Abstract

Context: Time from triage to patient care is usually evaluated, but time elapsed between the arrival of patient to emergency room (ER) and triage (pretriage) is not usually measured. Aims: The present study evaluates how the application of the queuing (or “waiting line”) theory in the triage process can generate effective strategies to improve patient care in the ER. Settings and Design: A “before-and-after” study was conducted in the ER of the Hospital Universitario San Ignacio, a tertiary emergency care in Bogotá, Colombia. Subjects and Methods: The pretriage time was evaluated, and queuing theory was applied to the evaluation; according to the results, the number and distribution of the necessary nursing personnel were determined. Statistical Analysis Used: The change in waiting times was compared using a paired t-test. Results: In a first 7 months evaluation period, 89,898 patient visits were considered, with an average pretriage time of 22.15 min. According to the arrival distribution by hours and days of the week and considering the results of the calculations made using queuing theory, the number of nurses needed in the service per hour was determined for each day of the week, and schedule changes were implemented without increasing staff. In a second similar evaluation period, 94,497 patient visits were considered demonstrating a reduction of the pretriage time to 7.5 min (mean difference 14.64 min, 95% confidence interval 14.42–14.85, P < 0.001). Conclusions: The use of queuing theory in the planning of the daily personnel requirements in the triage area of ER can reduce the pretriage time by 65% without incurring additional cost.

Keywords: Emergency, queuing theory, triage

INTRODUCTION

Patients prefer to visit the emergency room (ER) to alleviate their health problems for several reasons, including the possibility of having access 24 h a day, relatively fast attention, as well as the easy availability of human and biotechnological resources.[1] This situation has generated an increased demand and saturation in institutions providing this service, which has stimulated to review and restructure the processes to optimize patient care.[2-8]

In the ER, the patient classification process is the first stage of care. The application of tools, such as triage, allows the evaluation, classification, and administration and prioritization of patients according to the severity of the symptoms and not according to the order of arrival.[9] However, this first stage of care is associated with a greater clinical risk, which could be prevented if patients were treated in a timely manner.[3,4,6,8-13]

In the last 3 years (2015–2017), our ER received an average of 168,000 patients/year. In the first semester of 2016, complying with the national regulations, a five-level triage system was implemented, attended by nursing professionals. Three months after this change, a software was introduced to recognize patient visits as soon as they arrive and to organize the attention. Specifically, the patients registered in electronically and the software assign a number to be evaluated in the triage area. This made it possible to measure the time elapsed between the arrival of the patient and the triage (pretriage). In general,
this time is not considered when measuring the emergency care process and its indicators.\textsuperscript{[6,8,13]}

Pretriage should be as short as possible, considering that the longer the prioritization time, the greater the clinical risk of the patient.\textsuperscript{[3,9]} In an institution that provides health services in Bogotá, Colombia, which serves an average of 3592 patients/month, the researchers found long pretriage times with an average time of 18 and 23 min for patients classified as Emergency Severity Index (ESI) Level 2 and 3, respectively.\textsuperscript{[10]} In another institution, an average pretriage time of 24 min was found for nocturnal visits and 48 min on weekends\textsuperscript{[11]} for 150 patients classified as ESI level 2. Both cases show long pretriage periods. Similar to what was reported in other institutions, our research found that in our emergency department the preclassification time frequently exceeded 30 min in 2016. The long waiting time motivated this investigation, with the intention of evaluating how to organize the staff’s schedules, using queuing theory to reduce pretriage time.

**Subjects and Methods**

We conducted a “before-and-after” study in the ER of the Hospital Universitario San Ignacio, a tertiary academic urban Hospital in Bogotá, Colombia. We included adult patients who requested emergency care and excluded gynecology and pediatric triages, considering that these patients have different facilities and access routes to our hospital. We did not collect sociodemographic data from patients since they are not related to pretriage times.

For the 7-month period from August 2016 to February 2017, we determined the time elapsed between the arrival of the patient to the ER and the triage process (pretriage). We consider the information registered in the automated software used to assign the order of attention.

In general, the implementation of queuing theory allows a better understanding of the dynamics of services such as ER\textsuperscript{[3,13]} and facilitates the development of strategies to improve its functioning.\textsuperscript{[6,14]} It is a mathematical model used in “waiting lines” that allows analyzing variables such as waiting times and dead times.\textsuperscript{[3,4,8,13-15]} When applying this theory to the triage process, it is assumed that there are three fundamental variables that affect the total attention times: (1) number of patients, (2) time used by the nurse to classify a patient, and (3) times of wait. The queue formed in the waiting room of the triage service was approximated using a $M|M|c$ model, where the first M represents the distribution of the times between arrivals, calculated every hour thanks to the accuracy of the data delivered by the software used to assign turns. The second M refers to the service process, and the letter c represents the number of people serving. M means Markovian, a reference to the memoryless property of the exponential distribution, which implies that both the times between arrivals and the time used in a single attention follow an exponential distribution in each hour. According to this, we can define that arrivals to the waiting room for triage will occur according to a Poisson distribution, which would guarantee the exponentially of the times between arrivals.\textsuperscript{[3,6,15,16]}

The followings were the assumptions that we considered for the calculations based on the queuing theory:\textsuperscript{[2]}

- Patient waiting time should not exceed 5 min (data obtained from the historical data of this procedure in the department)
- Patient care capacity per hour ($\mu$) varied according to the number of nursing professionals needed to avoid exceeding 5 min.

The formul\textsuperscript{[19]} and nomenclature used were the following:

- $\lambda = \text{arrival rate when there is } n, \text{in this case, the average number of patients who came per hour.}$
- $c = \text{number of nurses on duty (varies to meet the first guideline).}$
- $\mu = c * 12 = \text{patient care capacity per hour.}$
- $\rho = \lambda/\mu = \text{utilization rate.}$
- $L = \rho/(1-\rho) = \text{expected number of patients.}$
- $L_q = \rho*L = \text{expected number of patients in the queue.}$
- $W = L/\lambda = \text{customer waiting time in the system (refers to the time elapsed since he/she takes the turn until the end of the attention).}$
- $W_q = \text{waiting time in the queue (refers to the time elapsed since taking the turn until the call to be attended).}$

After we analyzed our pretriage state at baseline and determined the optimum distribution of nurses using queuing theory, we made changes in staff’s schedules based on this analysis. Specifically, our intention was to define the number of nurses needed to reduce the waiting time in the queue to a minimum (ideally <5 min) but looking for a neutral resource approach or minimal impact with respect to the number of nurses.

We evaluated a second 7-month period from August 2017 to February 2018. Finally, we compared baseline pretriage times, before and after staff’s schedules changes using a paired $t$-test. A STATA 15 statistical package (StataCorp., 2015. Stata Statistical Software, College Station, TX: StataCorp LP) was used.

**Results**

For the first evaluation period, 89,898 patient visits were considered (monthly average of 11,237 turns). Table 1 shows information on the average number of patients who came per hour and the average number of patients per day. Although the number of users from Monday to Sunday was different, the arrival behavior was the same, with maximum peaks from 10:00 am to 12:00 pm and from 2:00 pm to 4:00 pm.

Our model allowed us to design the ideal staff’s schedules to keep wait times less than 5 min. As we considered that the
average number of patients arriving each day was different, we obtained different results for each day. Table 2 shows the results of the analysis for Monday, including the expected time in queue and waiting time in queue. Table 3 shows the number of professionals (c) needed in the triage service per hour each day of the week, according to the model.

With this information, we organized the staff in a new schedule. The existing staff included eight professional nurses in triage area, and a supernumerary chief nurse who had different functions. The staff employed after the changes included the same number of professionals but with functions in triage for the supernumerary chief nurse in some hours. Table 4 shows the distribution of nursing staff in both periods.

When observing the staff distribution, it is evident that there is a surplus of staff in certain hours, comparing the suggested and the implemented schedule [Table 5]. It allowed us to cover the additional functions that the supernumerary chief nurse covered in the preintervention period, to support other areas of the emergency department. These changes were consulted and supported by the nurses of the area, which facilitated its implementation.

To evaluate the impact of the changes in the triage procedure, we compared the data of periods before and after the implementation of the staff distribution suggested by the model [Table 6]. For the second evaluation period, we took into account the information on 94,497 turns (monthly average of 11,812 turns). Table 6 shows that the average pretriage waiting time in the queue in the 2016–2017 period was 22.15 min, while the pretriage waiting time in the 2017–2018 period, after implementing the changes, was 7.5 min. This was a significant difference (mean difference 14.64 min, 95% confidence interval 14.42–14.85, \( P < 0.001 \)).

**Discussion**

The present work evaluates the impact of an intervention based on queuing theory in pretriage time in an ER. It showed a significant improvement in service times, without affecting costs or personnel employed, which shows that personnel planning with this strategy is effective to achieve a timely classification. Although a similar number of patients were received each month, the time before triage was reduced by an average of 14.6 min. This corresponds to a 65% reduction in the waiting time.

Table 6 shows that the average wait time in the queue (Wq) for the period 2017–2018 was 7.5 min. In the last 3 months of this period (December to February), the behavior was stable, with an average time of approximately 6.2 min, evidencing a progressive decrease in the average time in the queue (Wq), which began in August 2017 with 8.5 min and ended in February 2018 with 6.4 min.

| Average Number Day-Hour | Average Number Day-Hour |
|--------------------------|--------------------------|
| HOURS                    | Monday                   | Tuesday                  | Wednesday                | Thursday                  | Friday                    |
| 0 to 1                   | 3.81                     | 5.80                     | 3.69                     | 5.97                      | 4.77                      | 5.00                     | 4.66                     |
| 1 to 2                   | 3.18                     | 2.73                     | 2.78                     | 2.56                      | 3.41                      | 3.69                     | 3.24                     |
| 2 to 3                   | 2.22                     | 2.33                     | 2.44                     | 2.73                      | 3.18                      | 3.18                     | 2.84                     |
| 3 to 4                   | 1.42                     | 1.99                     | 1.65                     | 2.16                      | 2.16                      | 2.05                      | 2.27                     |
| 4 to 5                   | 2.33                     | 2.95                     | 2.27                     | 2.39                      | 2.56                      | 3.07                      | 2.50                     |
| 5 to 6                   | 4.94                     | 5.68                     | 4.60                     | 4.49                      | 4.60                      | 3.86                      | 2.73                     |
| 6 to 7                   | 9.60                     | 10.91                    | 10.85                    | 11.82                     | 10.11                     | 9.89                     | 5.80                     |
| 7 to 8                   | 26.93                    | 24.43                    | 22.10                    | 22.90                     | 23.01                     | 15.28                    | 11.31                    |
| 8 to 9                   | 32.22                    | 35.11                    | 28.30                    | 28.47                     | 28.52                     | 18.35                    | 12.90                    |
| 9 to 10                  | 40.40                    | 35.68                    | 37.27                    | 34.03                     | 31.59                     | 23.69                    | 15.45                    |
| 10 to 11                 | 48.30                    | 41.25                    | 41.59                    | 40.97                     | 34.38                     | 27.27                    | 19.55                    |
| 11 to 12                 | 45.57                    | 46.76                    | 39.60                    | 40.85                     | 34.30                     | 29.94                    | 22.73                    |
| 12 to 13                 | 39.72                    | 36.02                    | 37.61                    | 33.69                     | 29.60                     | 23.24                    | 18.18                    |
| 13 to 14                 | 31.65                    | 27.44                    | 26.19                    | 26.93                     | 27.73                     | 23.81                    | 17.67                    |
| 14 to 15                 | 36.08                    | 31.42                    | 30.45                    | 26.25                     | 28.35                     | 21.19                    | 17.90                    |
| 15 to 16                 | 33.13                    | 33.07                    | 31.08                    | 32.61                     | 30.85                     | 22.90                    | 17.73                    |
| 16 to 17                 | 32.33                    | 31.76                    | 27.95                    | 25.91                     | 26.65                     | 19.20                    | 15.40                    |
| 17 to 18                 | 26.48                    | 25.28                    | 23.92                    | 21.88                     | 23.58                     | 16.82                    | 13.64                    |
| 18 to 19                 | 21.36                    | 21.76                    | 20.11                    | 21.99                     | 23.86                     | 15.91                    | 13.81                    |
| 19 to 20                 | 14.89                    | 11.99                    | 12.61                    | 13.81                     | 12.50                     | 10.28                    | 9.89                     |
| 20 to 21                 | 12.84                    | 11.88                    | 11.65                    | 11.25                     | 11.65                     | 11.65                    | 9.72                     |
| 21 to 22                 | 13.35                    | 13.07                    | 11.14                    | 12.50                     | 12.16                     | 10.97                    | 11.88                    |
| 22 to 23                 | 10.23                    | 11.36                    | 10.80                    | 11.76                     | 10.45                     | 9.09                     | 8.69                     |
| 23 to 24                 | 8.81                     | 9.49                     | 8.52                     | 8.18                      | 8.75                      | 8.13                     | 6.02                     |
| Total                   | 501.76                   | 480.17                   | 449.20                   | 446.08                    | 428.47                    | 338.47                   | 266.48                   |
Table 2: Distribution of triage professionals proposed by the model using queuing theory for Mondays

| Hours          | Arrival of users (λ) | Number of triage professionals | Patient care capacity per hour (μ) | Utilization rate (ƿ) | Expected number of patients (l) | Expected number of patients in the queue | Waiting time in the queue (min) |
|----------------|----------------------|--------------------------------|-----------------------------------|----------------------|-------------------------------|----------------------------------------|-------------------------------|
| 0 to 1         | 4                    | 1                              | 12                                | 0.32                 | 0                             | 0                                      | 2.32                          |
| 1 to 2         | 3                    | 1                              | 12                                | 0.27                 | 0                             | 0                                      | 1.80                          |
| 2 to 3         | 2                    | 1                              | 12                                | 0.18                 | 0                             | 0                                      | 1.13                          |
| 3 to 4         | 1                    | 1                              | 12                                | 0.12                 | 0                             | 0                                      | 0.67                          |
| 4 to 5         | 2                    | 1                              | 12                                | 0.19                 | 0                             | 0                                      | 1.20                          |
| 5 to 6         | 5                    | 1                              | 12                                | 0.41                 | 1                             | 0                                      | 3.50                          |
| 6 to 7         | 10                   | 2                              | 24                                | 0.40                 | 1                             | 0                                      | 1.67                          |
| 7 to 8         | 27                   | 3                              | 36                                | 0.75                 | 3                             | 2                                      | 4.95                          |
| 8 to 9         | 32                   | 4                              | 48                                | 0.67                 | 2                             | 1                                      | 2.55                          |
| 9 to 10        | 40                   | 5                              | 60                                | 0.67                 | 2                             | 1                                      | 2.06                          |
| 10 to 11       | 48                   | 5                              | 60                                | 0.80                 | 4                             | 3                                      | 4.13                          |
| 11 to 12       | 46                   | 5                              | 60                                | 0.76                 | 3                             | 2                                      | 3.16                          |
| 12 to 13       | 40                   | 5                              | 60                                | 0.66                 | 2                             | 1                                      | 1.96                          |
| 13 to 14       | 32                   | 4                              | 48                                | 0.66                 | 2                             | 1                                      | 2.42                          |
| 14 to 15       | 36                   | 4                              | 48                                | 0.75                 | 3                             | 2                                      | 3.78                          |
| 15 to 16       | 33                   | 4                              | 48                                | 0.69                 | 2                             | 2                                      | 2.78                          |
| 16 to 17       | 32                   | 4                              | 48                                | 0.67                 | 2                             | 1                                      | 2.58                          |
| 17 to 18       | 26                   | 3                              | 36                                | 0.74                 | 3                             | 2                                      | 4.63                          |
| 18 to 19       | 21                   | 3                              | 36                                | 0.59                 | 1                             | 1                                      | 2.43                          |
| 19 to 20       | 15                   | 2                              | 24                                | 0.62                 | 2                             | 1                                      | 4.08                          |
| 20 to 21       | 13                   | 2                              | 24                                | 0.54                 | 1                             | 1                                      | 2.88                          |
| 21 to 22       | 13                   | 2                              | 24                                | 0.56                 | 1                             | 1                                      | 3.14                          |
| 22 to 23       | 10                   | 2                              | 24                                | 0.43                 | 1                             | 0                                      | 1.86                          |
| 23 to 24       | 9                    | 2                              | 24                                | 0.37                 | 1                             | 0                                      | 1.45                          |

Table 3: Description of the number of professionals needed in the triage service by hour and day of the week, suggested by the model

| Days/Hours | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|------------|--------|---------|-----------|----------|--------|----------|--------|
| 0 to 6     | 1      | 1       | 1         | 1        | 1      | 1        | 1      |
| 6 to 7     | 2      | 2       | 2         | 2        | 2      | 2        | 1      |
| 7 to 8     | 3      | 3       | 3         | 3        | 3      | 2        | 2      |
| 8 to 9     | 4      | 4       | 4         | 4        | 4      | 3        | 2      |
| 9 to 10    | 5      | 4       | 4         | 4        | 4      | 3        | 2      |
| 10 to 11   | 5      | 5       | 5         | 5        | 4      | 4        | 3      |
| 11 to 12   | 5      | 5       | 5         | 4        | 4      | 4        | 3      |
| 12 to 13   | 5      | 4       | 4         | 4        | 4      | 4        | 3      |
| 13 to 14   | 4      | 4       | 3         | 3        | 4      | 3        | 3      |
| 14 to 15   | 4      | 4       | 4         | 3        | 4      | 3        | 3      |
| 15 to 16   | 4      | 4       | 4         | 4        | 4      | 4        | 3      |
| 16 to 17   | 4      | 4       | 4         | 3        | 4      | 3        | 2      |
| 17 to 18   | 3      | 3       | 3         | 3        | 3      | 3        | 2      |
| 18 to 19   | 3      | 3       | 3         | 3        | 3      | 2        | 2      |
| 19 to 24   | 2      | 2       | 2         | 2        | 2      | 2        | 2      |

Even when a five-level triage system based on the ESI was implemented 3 months before the beginning of this study, our surveillance showed that time to complete the triage process was stable in both periods of evaluation, so the changes are associated only with the changes explained in the staff schedules.

In addition, we evaluated the time elapsed between the triage and the evaluation by the physician. For patients classified as triage 1, 2, and 3, the times were 2.2 ± 3.85, 34.9 ± 4.49, and 53.1 ± 5.6 min respectively, without significant changes between the two evaluation periods. Thus, the reduction in pretriage time resulted in a real reduction in the total time.
Table 4: Allocation of human resources in the triage service by hour and day of the week: Comparison of previously used schedule and the implemented schedule

| Hours/Day | Previous Schedule | Implemented Schedule | Differences between previous and implemented schedules |
|-----------|-------------------|----------------------|-------------------------------------------------------|
|           | Monday through Friday | Saturday through Sunday | Monday through Friday | Saturday | Sunday | Monday through Friday | Saturday | Sunday |
| 0 to 7    | 1                  | 1                    | 2                        | 2        | 2      | +1                       | +1       | +1     |
| 7 to 8    | 5                  | 4                    | 5                        | 4        | 3      | 0                        | 0        | -1     |
| 8 to 9    | 5                  | 4                    | 5                        | 4        | 3      | 0                        | 0        | -1     |
| 9 to 10   | 5                  | 4                    | 5                        | 4        | 3      | 0                        | 0        | -1     |
| 10 to 11  | 5                  | 4                    | 5                        | 4        | 3      | 0                        | 0        | -1     |
| 11 to 12  | 5                  | 4                    | 5                        | 4        | 3      | 0                        | 0        | -1     |
| 12 to 13  | 5                  | 4                    | 5                        | 4        | 3      | 0                        | 0        | -1     |
| 13 to 14  | 4                  | 4                    | 5                        | 4        | 3      | +1                       | 0        | -1     |
| 14 to 15  | 4                  | 4                    | 5                        | 4        | 3      | +1                       | 0        | -1     |
| 15 to 16  | 4                  | 4                    | 5                        | 4        | 3      | +1                       | 0        | -1     |
| 16 to 17  | 4                  | 4                    | 5                        | 4        | 3      | +1                       | 0        | -1     |
| 17 to 18  | 4                  | 4                    | 5                        | 4        | 3      | +1                       | 0        | -1     |
| 18 to 19  | 4                  | 4                    | 5                        | 4        | 3      | +1                       | 0        | -1     |
| 19 to 24  | 2                  | 2                    | 2                        | 2        | 2      | 0                        | 0        | 0      |

Table 5: Differences between the number of professionals finally implemented and the number suggested by the model

| Hours/Day | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|-----------|--------|---------|-----------|----------|--------|----------|--------|
| 0 to 6    | +1     | +1      | +1        | +1       | +1     | +1       | +1     |
| 6 to 7    | 0      | 0       | 0         | 0        | 0      | 0        | +1     |
| 7 to 8    | +2     | +2      | +2        | +2       | +2     | +2       | +1     |
| 8 to 9    | +1     | +1      | +1        | +1       | +1     | +1       | +1     |
| 9 to 10   | 0      | +1      | +1        | +1       | +1     | +1       | +1     |
| 10 to 11  | 0      | 0       | 0         | 0        | +1     | 0        | 0      |
| 11 to 12  | 0      | 0       | 0         | 0        | 0      | +1       | 0      |
| 12 to 13  | 0      | +1      | +1        | +1       | +1     | +1       | +1     |
| 13 to 14  | +1     | +1      | +2        | +2       | +1     | +1       | 0      |
| 14 to 15  | +1     | +1      | +1        | +2       | +1     | +1       | 0      |
| 15 to 16  | +1     | +1      | +1        | +1       | +1     | +1       | 0      |
| 16 to 17  | +1     | +1      | +1        | +2       | +1     | +1       | 0      |
| 17 to 18  | +1     | +1      | +1        | +1       | +1     | +1       | 0      |
| 18 to 19  | +1     | +1      | +1        | +1       | +2     | +1       | 0      |
| 19 to 24  | 0      | 0       | 0         | 0        | 0      | 0        | 0      |

Table 6: Comparison of pre-triage times (in minutes) between August 2016 - February 2017 and August 2017 - February 2018 periods

| Month    | 2016-2017 Average | 2017-2018 Average | Average Difference | Confidence Intervals | Percentage Difference | P |
|----------|------------------|------------------|--------------------|----------------------|-----------------------|---|
| August   | 19.9             | 8.5              | 11.4               | 10.75-12.04          | 57%                   | <0.001 |
| September| 30.95            | 9.9              | 21.05              | 20.32-21.77          | 68%                   | <0.001 |
| October  | 24.47            | 7.63             | 16.84              | 16.24-17.43          | 69%                   | <0.001 |
| November | 26.6             | 7.17             | 18.83              | 18.19-19.58          | 71%                   | <0.001 |
| December | 18.5             | 10.57            | 12.43              | 11.97-12.88          | 67%                   | <0.001 |
| January  | 14.8             | 10.57            | 8.48               | 8.10-8.85            | 57%                   | <0.001 |
| February | 19.8             | 11.42            | 13.38              | 12.95-13.80          | 68%                   | <0.001 |
| Total    | 22.15            | 94.497           | 14.64              | 14.42-14.85          | 65%                   | <0.001 |

between arrival at the ER and the evaluation of patients by physicians. The success of this implementation was mainly due to four factors: (1) the choice of the appropriate method to address
the problem (queue theory); (2) the accuracy of the data used to perform the work, as the data from the software used to assign turns allowed to make precise calculations for an adequate distribution of the staff shifts; (3) the willingness of the ER leadership to understand the technical concept and the need to implement it quickly, associated with; and (4) the willingness and active collaboration of the nursing staff to implement the strategy.

Some limitations must be addressed. As with any standardized analysis model, the analysis performed in the first observation period is an approximation of real life, allowing a detailed overview of the system. However, even when the assumptions of the model are relatively few, some interactions between the factors could not be considered initially. However, the observation of a significant reduction in pretriage time, with a similar time when comparing the calculated time, and the time finally observed (5 vs. 7.5 min) suggested a correct model.

We assume that all the differences found in the pretriage time between both periods of observations are associated with the implementation of the of the personnel distribution suggested by the queue theory study; however, our model cannot rule out other possible explanations. For example, behavior of the staff could be associated with the knowledge that they were being observed, reducing the waiting time (Hawthorne effect); however, this explanation is unlikely, since the time observed in both periods was long (7 months).

**Conclusions**

The application of the queueing theory in health services allows a better understanding of the dynamics of complex services as the emergency department, which facilitates the application of strategies to improve its functioning and efficiency.

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**Conflicts of interest**

There are no conflicts of interest.

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