Low-Cost Feedback Program for Reducing the Door-to-Computed Tomography Time

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Keywords
Door-to-computed tomography time · Low cost · Interventions · Feedback · Nudge · Quality program

Abstract

Introduction: Early restoration of blood flow in stroke patients can be achieved by reducing the door-to-computed tomography (DTC) time. Previous research has proposed several methods to reduce the DTC time, but the implementation costs limit its transferability. This study aimed to propose a novel, simple, and low-cost method for reducing the DTC time by providing feedback on each patient’s DTC time to a small group of medical workers and physicians. Methods: A field experiment was conducted for 233 days, and the DTC time of 249 patients with stroke symptoms who were transported via ambulance to a medium-sized university hospital in Japan within 24 h after stroke onset was obtained. The first and second feedback reports on the 59th day and 154th day, respectively, were provided at the beginning of the field experiment. Using the data collected during the first 58 days as baseline data, the baseline data were compared with the post-intervention data. As part of the intervention, feedback on the DTC time for each patient was provided to six medical workers and physicians during regular meetings. The primary outcome was a continuous measure of DTC time (in min). The feedback effect hypothesis was formulated prior to data collection. Results: In a sample of 68 patients at baseline, the mean DTC time was 18.16 min with a standard deviation of 7.38 min. As a result of the two feedback reports, in the sample with outliers, the mean and standard deviation decreased to 15.64 min and 5.97 min, respectively. The difference in means was 2.51 min ($p = 0.021$ in $t$ tests). Results of the test of the equality of the standard deviations suggested that the two standard deviations were not equal ($p = 0.065$). Conclusions: The low-cost interventions successfully reduced both the mean DTC time and variation, suggesting an improvement in the quality and consistency of medical services. The result of our fine-grained analysis with a field-experiment design supports the role of feedback in achieving early treatment as suggested in the Target: Stroke initiative.

Introduction

Stroke is a leading cause of death and long-term disabilities [1, 2]. Stroke causes substantial damage to the brain, thereby decreasing its function. When stroke patients with large-vessel occlusions do not receive proper treatment, approximately 1.9 million neurons are de-
stroyed [3]. Therefore, the early restoration of blood flow in stroke patients, which can be achieved through the administration of recombinant tissue plasminogen activator or thrombectomy, is crucial [4]. Indeed, the Target: Stroke initiative suggests that the door-to-needle time for 85% or more of patients with acute ischemic stroke treated with intravenous thrombolysis should be less than 60 min [5]. This goal can be achieved by reducing the time between the arrival of emergency medical service personnel and the initiation of a computed tomography (CT) scan, also known as the door-to-CT (DTC) time [6].

Several studies have proposed and evaluated various methods to reduce the DTC times [7–10]. The proposed methods were used to create quality improvement teams, review and change current protocols and routines, develop mobile apps, and organize off-site quality meetings. In one study [11], researchers formed a multidisciplinary team and conducted an 18-week structured quality improvement program that included ten 2-h class sessions. The team performed several interventions, including clarification of individual roles, enhancement of material availability for the stroke code team, and development of new protocols that visually summarized how physicians and nurses should collaboratively work during stroke codes. Since such methods often require the investment of substantial resources, such as time, financial resources, and human resources [6], they are only implemented in medical facilities that can incur their implementation costs [12, 13]. This study aimed to propose a novel, simple, and low-cost method to reduce the DTC time and to assess the validity of providing feedback regarding each patient’s DTC time to a small group of medical workers and physicians through field experiments.

**Materials and Methods**

**Facility**

In this study, field experiments were conducted at a medium-sized facility owned by a medical university in Tokyo, Japan (490 beds and 24 clinical departments). This facility is the only local center that can provide primary medical care to patients around the clock. All patients in the local area with symptoms of stroke identified by the paramedics within 24 h of onset were transported to this facility and evaluated to determine the appropriate acute stroke treatment option required, such as intravenous thrombolysis or endovascular treatment.

During the observation period, the staff of the emergency care unit included 5 neurologists, 5 neurosurgeons, and 13 physicians. The facility was founded in 2006, and the DTC protocols were formalized 2 years prior to the data collection for our study, suggesting that the facility had already achieved a significant reduction in DTC time via experiential learning.

All patients who were tentatively diagnosed with stroke by paramedics were required to undergo a CT examination upon arrival at the facility. The emergency physician assigns a nurse to each patient and alerts the neurologist or neurosurgeon. Additional nurses were assigned depending on their availability, while the neurologist or neurosurgeon joined the treatment team upon arrival at the facility. The emergency entrance, room, and CT scan room were located on the first floor. The physical distances between the emergency entrance and emergency room and between the emergency room and CT scan room were 10 m and 15 m, respectively.

**Data Collection**

The DTC time data were collected from the fall of 2018 to the spring of 2019, with a total duration of 233 days. During the observation period, 249 patients with symptoms of stroke were admitted to the facility. The medical facility implemented a new information technology system in the summer of 2019. To avoid the confounding effects of the new system, our data collection was terminated prior to the implementation of that system.

**Interventions**

Based on previous research on learning in organizations [14], the DTC time for each incoming patient was accurately measured, and feedback on the current DTC time was presented to the medical workers and physicians. The provision of timely feedback is recommended by the Target: Stroke initiative as a measure to reduce the DTC time [15].

**Feedback on the DTC Time**

Feedback on DTC time was provided on two occasions, namely, on days 59 and 154, during the study period. The data collected were grouped as follows: (1) the data collected from day 0 to day 58 were considered baseline data (n = 68), (2) the data collected from day 59 to day 153 were considered as post-first-feedback data (n = 96), and (3) the data collected from day 154 to day 233 were considered as post-second-feedback data (n = 85).

On day 59, one of the researchers, who worked as a neurosurgeon, provided feedback regarding the DTC times during the regular monthly meeting that was also attended by a neurologist, an emergency doctor, and a managing nurse. During the meeting, handouts consisting of two A4-sized sheets were printed and distributed to the participants. The researcher presented the patient-by-patient DTC times, means, and standard deviations classified according to the time period and day of the week and some preliminary results of the regression analyses that predicted the DTC times.

On day 154, the same researcher provided a second feedback. The second meeting differed in two respects. In the first meeting, in order to minimize the implementation costs, the participants were not encouraged to actively share feedback with their colleagues; however, this was carried out in the second meeting. In the second meeting, the nudge approach was adopted [16, 17], which is used in behavioral economics to increase the feedback effectiveness without incurring additional costs. The nudge approach contends that by simply changing their ways of communication and expression, individuals can influence others’ decisions and choices in order to achieve the desired collective ends [18]. The approach is based on the following behavioral principle: to avoid loss, human beings tend to react more sensitively to expressions that are framed...
as losses; these expressions are termed loss-framing expressions. During the meeting, the researcher emphasized the extent of the neuronal damage resulting from a 1-min delay in the DTC time rather than focusing on descriptive statistics.

**Statistical Analysis**

Stata 16.1 packages were used to perform all statistical analyses. To identify the outliers in the DTC time distributions, the third quartile plus the interquartile range × 1.5 and the first quartile minus the interquartile range × 1.5 were used as the upper and lower bounds, respectively. The $p$ values obtained in the kurtosis tests for normality of the DTC time distribution were less than 0.000 in the data with outliers and 0.1017 in the data without outliers, suggesting that the DTC time does not follow a normal distribution. Therefore, to compare the baseline DTC time with the DTC time after the first and second feedbacks, $t$ tests and nonparametric Mann-Whitney U (MW) tests were used. The $p$ values were reported to assess the statistical significance.

In addition to comparing the baseline and post-intervention DTC times, an ordinary least squares regression analysis was performed to evaluate the feedback effects after controlling for other factors that can also influence the DTC time (e.g., patient’s age). Because the skewness of the dependent variable can cause heteroskedasticity, the robust standard errors for regression coefficients were calculated, and the $p$ values were reported to assess for statistical significance.

**Results**

**Baseline**

During the first 58 days of the observation period, the facility accepted 68 patients who had been diagnosed with stroke symptoms by the paramedics. During the baseline period, in the sample with outliers, the mean and standard deviation of the DTC time were 18.16 min and 7.38 min, respectively. In the sample without outliers, the mean and standard deviation were 15.71 min and 3.51 min, respectively.

**Effects of First Feedback**

Table 1 shows the feedback effect, in which the data of patient-by-patient DTC times from days 59 to 153 were used. In the period following the first feedback, the DTC time dropped by 1.57 min and 0.86 min in the sample with and without outliers, respectively. For the data with outliers, the $p$ values obtained in $t$ tests and MW tests for testing the differences were 0.237 and 0.012, respectively. For the data without outliers, the $p$ values in the $t$ tests and MW tests were 0.133 and 0.079, respectively. In the tests conducted to assess the equality of the standard devia-

| Table 1. Intervention effects |
|-------------------------------|----------------|----------------|
|                               | Baseline  | Post-first FB | Post-second FB |
| With outliers                 |          |               |               |
| Patients, n                   | 68       | 96            | 85            |
| Mean                          | 18.16    | 16.59         | 15.64         |
| SD                            | 7.38     | 8.94          | 5.97          |
| Diff. w/baseline              | –        | –1.57         | –2.51         |
| $t$ test                      | –        | 1.18 ($p = 0.237$) | 2.32 ($p = 0.021$) |
| MW tests                      | –        | 2.49 ($p = 0.012$) | 2.95 ($p = 0.003$) |
| Diff. w/post-first FB         | –        | –             | 0.95          |
| $t$ test                      | –        | –             | 0.82 ($p = 0.409$) |
| MW tests                      | –        | –             | 0.65 ($p = 0.514$) |
| SD test w/baseline            | –        | 0.68 ($p = 0.098$) | 1.52 ($p = 0.065$) |
| SD test w/post-first FB       | –        | –             | 2.24 ($p < 0.000$) |
| Without outliers              |          |               |               |
| Patients, n                   | 57       | 90            | 80            |
| Mean                          | 15.71    | 14.85         | 14.68         |
| SD                            | 3.51     | 3.29          | 3.36          |
| Diff. w/baseline              | –        | –0.86         | –1.03         |
| $t$-test                      | –        | 1.50 ($p = 0.133$) | 1.73 ($p = 0.085$) |
| MW tests                      | –        | 1.75 ($p = 0.079$) | 2.15 ($p = 0.031$) |
| Diff. w/post-first FB         | –        | –             | –0.17         |
| $t$ test                      | –        | –             | 0.32 ($p = 0.742$) |
| MW tests                      | –        | –             | 0.64 ($p = 0.521$) |
| SD test w/baseline            | –        | 1.14 ($p = 0.569$) | 1.09 ($p = 0.715$) |
| SD test w/post-first FB       | –        | –             | 0.95 ($p = 0.829$) |

The $p$ values are provided in the parentheses. FB, feedback; SD, standard deviation; MW tests, Mann-Whitney U tests.
tions, the $p$ values were 0.098 and 0.569 in the samples with and without outliers, respectively, suggesting that there is no strong evidence to reject the null hypothesis that the differences between the standard deviations were equal.

Effects of Second Feedback

Figure 1 depicts the histograms of the DTC time for the baseline, post-first feedback, and post-second feedback periods. A left shift was observed in the mean DTC time (i.e., a shorter DTC time), and the distributions were more centered around the mean (i.e., smaller variations in the DTC time) in the post-second feedback period. Similar results were observed in the post-first feedback period; however, the changes were more visible in the post-second feedback period (Fig. 1; Table 1). Figure 1 suggests that the mean and standard deviation of the DTC time decreased from baseline as a result of the two feedback reports. As shown in Table 1, in the sample with outliers, the mean decreased from 18.16 min to 15.64 min ($p$ values = 0.021 in $t$ tests and 0.003 in MW tests). The decrease from the baseline to the post-second feedback period was greater and more significant than that from the baseline to the post-first feedback period. Comparable results were obtained using a sample without outliers.

In the sample with outliers, the standard deviations decreased from 7.38 min to 5.97 min ($p = 0.065$). In the sample without outliers, the standard deviations dropped from 3.51 min to 3.36 min ($p = 0.715$).

Regression Analysis

To control for the effects of other variables, linear regression models were employed (Table 2). The samples with outliers were used in Models 1 and 2, while those without outliers were used in Models 3 and 4. The overall effects of the feedback were evaluated in Models 1 and 3, while the effects of each of the feedbacks were evaluated in Models 2 and 4. In the models, the dependent variable was DTC time. After controlling for the effects of other variables, the DTC times in the post-second feedback period were reduced by 4.62 min ($p < 0.000$) in the sample with outliers (model 1) and by 1.97 min ($p = 0.002$) in the sample without outliers (model 3). The former and latter values corresponded to 62% and 56% of the sample standard deviations, respectively. In Model 2, the coefficient of the post-second feedback ($b = -4.720$) was greater than that of the post-first feedback ($b = -4.236$); in Model 4, the post-first feedback effect was greater ($b = -2.090$ vs. $b = -1.952$).

In both meetings, the DTC time was presented as the time of day and the day of the week (Fig. 2). In the case of effective feedback, the medical workers were expected to be more attentive to the time periods and days with longer DTC time. This expectation was consistent with our find-
Table 2. Results of the ordinary least squares regression analyses

|                      | All samples |                      | Without outliers |                      |
|----------------------|-------------|----------------------|------------------|----------------------|
|                      | 1           | 2                    |                  | 3                    | 4                    |
| Patients’ age        | 0.016       | 0.015                | 0.025            | 0.026                |
|                      | (0.754)     | (0.760)              | (0.159)          | (0.157)              |
| Medical workers, n   | −0.491      | −0.501               | −0.388           | −0.387               |
|                      | (0.407)     | (0.391)              | (0.175)          | (0.178)              |
| Off-hours            | 0.033       | 0.032                | 0.285            | 0.287                |
|                      | (0.976)     | (0.976)              | (0.528)          | (0.527)              |
| Weekend              | −0.191      | −0.136               | 0.118            | 0.104                |
|                      | (0.872)     | (0.904)              | (0.819)          | (0.847)              |
| Neurosurgeon         | −3.670      | −3.686               | −0.824           | −0.819               |
|                      | (0.001)     | (0.002)              | (0.189)          | (0.193)              |
| Neurologist          | −2.291      | −2.337               | −0.402           | −0.389               |
|                      | (0.039)     | (0.046)              | (0.462)          | (0.485)              |
| Within 4.5 h         | −0.738      | −0.735               | 0.025            | 0.025                |
|                      | (0.525)     | (0.528)              | (0.958)          | (0.958)              |
| Temperature          | −0.232      | −0.211               | −0.078           | −0.084               |
|                      | (0.007)     | (0.016)              | (0.090)          | (0.115)              |
| Postintervention     | −4.623      | –                    | −1.978           | –                    |
|                      | (0.000)     | (0.002)              | (0.002)          | (0.002)              |
| Post-first feedback  | –           | −4.236               | –                | −2.090               |
|                      |             | (0.010)              | (0.009)          | (0.009)              |
| Post-second feedback | –           | −4.720               | –                | −1.952               |
|                      |             | (0.000)              | (0.004)          | (0.004)              |
| Constant             | 23.572      | 23.348               | 16.122           | 16.190               |
|                      | (0.000)     | (0.000)              | (0.000)          | (0.000)              |
| R-squared            | 0.069       | 0.0701               | 0.059            | 0.059                |
| Adjusted R-squared   | 0.032       | 0.0292               | 0.018            | 0.013                |
| Log likelihood       | −816.595    | −816.532             | −561.049         | −561.023             |
| F values             | 3.011       | 2.710                | 1.435            | 1.310                |
| Cases, n             | 238         | 238                  | 216              | 216                  |

DTC time was used as the dependent variable. “Postintervention” was a binary variable that was coded as 1 if a given patient was transported during the post-first or post-second feedback periods. “Post-first feedback” and “post-second feedback” were binary variables that were coded as 1 if a given patient was transported in the post-first and post-second feedback periods, respectively. We also included the following control variables in the regression models: the patient’s age and the number of nurses and doctors who participated in the treatment, which was denoted by the term “Medical workers, n.” “Off-hours” and “weekend” were coded as 1 if the patient was admitted during off-hours (7:00 p.m. to 7:00 a.m.) and weekends, respectively. “Neurosurgeon” and “neurologist” were binary variables that were coded as 1 if any neurosurgeon and neurologist participated in the treatment, respectively. The binary variable “within 4.5 h” was coded as 1 if a given patient was transported to the facility within 4.5 h from the onset of symptoms. The minimum temperature measured in degree Celsius on the day that a given patient was transported was denoted by the term “temperature.” The p values are provided in the parentheses. We used robust standard errors to compute the p values for the regression coefficients.
ings. In the right panels of Figure 2, the dots are lined up in a straight line after the two interventions, suggesting that the feedback was effective in reducing the DTC time, particularly for the time periods and days with longer DTC times. For example, the diagrams demonstrate that our interventions substantially reduced the DTC time in patients transported between 8:00 p.m. and 10:00 p.m., between 2:00 a.m. and 4:00 a.m., and on Sundays.

**Discussion**

This study aimed to propose and evaluate a low-cost intervention to reduce the DTC time in patients with suspected stroke. A field experiment was conducted to assess the effect of feedback on DTC time. As a result of the two feedbacks, a reduction in the mean and standard deviation of the DTC times was achieved. The post-second feedback effect was greater in the sample with outliers compared with that in the sample without outliers.

In this study, two reasons were postulated to justify the effectiveness of feedback. First, during semi-structured informal interviews that we conducted with four nurses and two physicians in the emergency care unit before developing the interventions, their estimate of the average DTC times was requested. Their estimates ranged from 5 to 10 min, while the actual DTC time was 18.16 min prior to the implementation of our interventions. Their underestimation could be due to the temporal illusion phenomenon, where individuals tend to perceive the duration of a specific task as shorter as their motivation to work longer is greater [19]. Hence, awareness of the DTC time corrects this illusion, thereby decreasing the DTC time. Therefore, the feedback provided

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Fig. 2. The feedback effects. The two plots on the left side indicate the means of the baseline and post-first feedback periods; these mean values were used by during the second feedback. The plots on the right side indicate the means of the baseline and post-second feedback periods. The two upper figures demonstrate the effects on patients’ arrival according to the time of day, whereas the two lower figures illustrate the effects according to the day of the week.
Reducing Door-to-CT Time

Second, as the feedback effects were stronger for time periods and days with longer DTC times, our feedback might have unveiled the weaknesses of the practices at this facility. The medical staff at the facility voluntarily changed the protocol after the second feedback report was provided. This was unexpected because of the implementation costs involved. The change included the removal of the patient’s clothes upon arrival at the facility and was made to ensure that no metal present on the patient’s body went undetected. Quantitative feedback is useful for identifying and solving the problems.

This study’s findings have several implications. First, the findings suggest the role of feedback in improving professional practice in managing patients with acute stroke. By focusing on the effects of feedback on DTC time, the applicability of the arguments of Ivers et al. [20], who found the effects of audit and feedback in various medical contexts, was strengthened. This study also substantiated the Target: Stroke initiative [7], which emphasizes the importance of applying evidence-based interventions for increasing the quality of thrombectomy services.

Second, the findings proposed a cost-efficient method of managing in-hospital stroke care pathways as an alternative to methods proposed in previous research, such as the reorganization of established in-hospital workflows [21] and the conduct of off-site structured quality improvement programs [11]. Unlike these approaches, our approach is more cost-efficient as the healthcare providers can simply present feedback by analyzing data that have already been archived in their facilities. A low-cost approach should be implemented in medical facilities with limited financial and human resources. This argument is in line with other studies that point out the advantage of using secondary data on emergency care for improving the quality of medical services, which facilities collect for routine documentation purposes [22–24].

Third, the findings also confirmed the argument by Ivers et al. [20] regarding the value of feedback intensity. The reduction in the means and standard deviations of DTC times was greater in the post-second feedback period compared with that in the post-first feedback period. The conduct of multiple feedback sessions might be more effective in improving professional practices than the conduct of single feedback sessions. Notably, reductions were observed in the standard deviations of the DTC times, suggesting that the feedback not only shortened the average, but also increased the consistency of the quality (i.e., each patient could receive an equally higher quality of medical services).

Fourth, the stronger effect of second feedback could also be attributed to the provision of feedback in the form of loss-framing expressions. If this is the case, our findings are in line with the nudge approach, which has become more commonly used in the medical setting [16]. However, as the nudge approach was only adopted in the second feedback, it remains unclear whether the stronger effect of the second feedback could have resulted from either repeated feedback or loss-framing expressions.

As the ultimate goal of the medical community is to shorten the door-to-puncture time rather than the DTC time [25, 26], the value of these study’s findings might be questionable. However, our study is highly relevant for the following reasons. First, a reduction in the DTC time will have a proportional effect on the door-to-puncture time [27]. Second, in our setting, all patients tentatively diagnosed with stroke must undergo CT examination; therefore, the relevance of our findings is significant because of the large number of patients who can benefit from these findings. Lastly, despite having focused solely on DTC time, our findings on the role of feedback are generic and should thus be pertinent to other interventions that may target door-to-puncture time. Our findings indicate that the door-to-puncture time will decrease if the medical workers and physicians continuously receive accurate feedback.

Limitations
Although we believe in the value, relevance, and transferability of our study, it has three critical limitations. First, the generalizability of the study may be limited because the data were collected from a single facility. To understand how unobserved local factors contribute to the reduction in DTC time, the collection of data from other facilities is imperative. Second, future studies should target the door-to-puncture time and assess the role of feedback. Third, although our field experiment demonstrates how the DTC time changes as a result of feedback, other factors should be considered, such as the function of the team at the site and the level of expertise of the medical staff working in the facility.

Conclusion
This study demonstrated that DTC time decreased when physicians and medical workers received feedback on the current DTC time and that the feedback led to a
reduction in the variation of the DTC time. This low-cost method is applicable and transferable to a wide range of medical facilities. In addition, it has the potential to improve the quality and consistency of medical services.

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Statement of Ethics

This study protocol was reviewed and approved by the Ethical Review Board at Keio University (18-011) and Juntendo University (30–43).

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Takashi Mitsuhashi and Hitoshi Mitsuhashi had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Concept and design: Takashi Mitsuhashi, Joji Tokugawa, and Hitoshi Mitsuhashi. Acquisition of data: Takashi Mitsuhashi. Drafting of the manuscript: Takashi Mitsuhashi, and Hitoshi Mitsuhashi. Critical revision of the manuscript for important intellectual content: Joji Tokugawa. Obtained funding: Hitoshi Mitsuhashi, Takashi Mitsuhashi, and Joji Tokugawa.

Data Availability Statement

The data that support the findings of this study are not publicly available due to their containing information that could compromise the privacy of research participants but are available from the corresponding author upon reasonable request.
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