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Abstract

The study aims to evaluate the efficacy of each category in physical therapy for improving motor function of patients with stroke, focusing on physical therapy alone. 106 patients who received the stroke physical therapy program in seven hospitals from April 2020 to March 2021 participated in the study. The contents of the program were classified into the following five categories; having no physical therapy (PT0), preparatory exercise in a static position (PT1), exercises to improve basic activities (PT2), gait exercises without special tools (PT3), and therapy with special tools (PT4). The endpoint of the study was the relative shortening ratio (RSR) that compared hours of supine-to-sitting before and after the program. The hours of supine-to-sitting before the program was identified as a confounder. Adjusting for the confounder, the relationship of PT1, PT2, PT3, and PT4 with RSR was evaluated by the method of multiple linear regression. Only PT2 was significantly related to the RSR; PT1, PT3, and PT4 were not. An equation was developed to predict the RSR based on PT2 adjusting for the confounder. The study indicates that the program putting higher percentage of hours for PT2 in stroke physical therapy could be more effective for improving the motor function of patients with stroke.

Key Words and Phrases: physical therapy, stroke, hours, category, evaluation.

1. Introduction

In the convalescent rehabilitation ward, the Japan Ministry of Health, Labour, and Welfare has decided the upper limit of the hours spent on rehabilitation consisting of physical therapy, occupational therapy, and speech therapy for patients with stroke up to three hours a day (Nagai et al., 2011). On the other hand, the allocation of the hours for physical therapy, occupational therapy, and speech therapy is left to each hospital; in particular, left the determination of details of the contents of each therapy and the hours spent for them up to each hospital; they have been empirically determined based on the context of the actual situation of patients (Van et al., 2004). It has been a big concern of each hospital to design efficient hours spent for stroke rehabilitation in limited hours (Kamo et al., 2019; Bennett et al., 2016).

Physical, occupational, and speech therapies in stroke rehabilitation are conducted under different purposes (Leach et al., 2010) to improve various problems of each patient,

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and not easy to deal with the optimal allocation of hours to those therapies. As the first step toward the complicated goal, we focus in the present paper only on physical therapy (stroke PT) to improve the motor function of patients with stroke; more precisely, by classifying the contents of stroke PT into five categories, we discuss the optimum allocation of hours to those categories by employing shortening hours of supine-to-sitting (Sunnerhagen et al., 2003) as the primary endpoint.

The allocation in stroke PT is considered important to improve movement disorders of patients efficiently (Kaur et al., 2012; English et al., 2014), but, so far as we know, no studies have challenged the problem in Japan. However, there are a few pioneering papers in the world. Bode et al. (2004) stratified the patients into four groups according to the length of hospital stay (2, 3, 4, and 5 weeks), divided the contents of the stroke PT into two categories, and estimated hours spent for categories in each group. Jette et al. (2005) classified the contents of the stroke PT into 13 categories and estimated the percentage of hours spent in each category.

2. Methods

2.1. Study design and patients

This was a multicenter observational study from April 2020 to March 2021, consisting of hospitals in Kyushu and Yamaguchi regions in Japan. The study subjects were patients diagnosed with post-stroke hemiplegia who were admitted to a convalescent rehabilitation ward and received stroke PT in those hospitals. Excluded from the study were patients with the risk associated with transfer on a bed and patients who had a history of traumatic brain injury or orthopedic disease such as fracture, postoperative hip or knee arthroplasty, spinal stenosis, and cervical herniation.

This study was approved by the Kyushu University of Nursing and Social Welfare ethics committee (Approval number: 31-009) and conducted by the principles of the Declaration of Helsinki. The written and verbal informed consent were obtained from all subjects and formally recorded.

2.2. Patient characteristics

Patient clinical characteristics including age, sex, type of stroke (hemorrhagic or ischemic), days after the onset, dominant hand paralysis, body mass index (BMI), and locomotion capability before the onset, were collected from medical records. Additionally, Brunnstrom Recovery Stage (BRS) and Functional Independence Measure (FIM) were measured before conducting the program.

2.3. Stroke PT program

The stroke PT program was conducted for 13 weeks. The program was classified into five categories referring to previous studies (Kuys et al., 2006; Bernhardt et al., 2004; Bernhardt et al., 2007) and termed PT0, PT1, PT2, PT3, and PT4, where PT0 represents having no stroke PT (assessment and interview that do not require therapy), PT1 consists of preparatory exercise in a static posture (relaxation, joint exercise, stretching exercise, muscle strengthening, etc.), PT2 consists of exercises to improve basic activities of daily living (roll-over, supine-to-sitting, sitting balance, etc.), PT3 consists of gait exercises without special tools (standing up, standing balance, applied gait, climbing stairs, etc.) and PT4 is therapy with special tools (robot, treadmill, cycle ergometer, biofeedback device, Functional Electrical Stimulation, hyperthermia, ultrasound, and low-frequency). Physical therapists recorded hours conducted for stroke PT daily and percentages of hours spent for PT0, PT1, PT2, PT3, and PT4 for each patient (Wittwer et al., 2000; Tyson and Selley, 2004).

2.4. Endpoint

The supine-to-sitting was defined as the movement from supine on the examination table to sitting at the table's edge without assistance and handrails. The size of the table was 200 cm length and 120 cm width, and the height was 45 or 50 cm according to each patient's height. The patient was maintained in a relaxed supine position on the table and moved at a comfortable speed following the direction of a physical therapist. The end of the movement is defined as the time when the patient was able to maintain a stable sitting position without trunk sway.

The hours of supine-to-sitting for each patient were measured three times with a stopwatch (Sunnerhagen et al., 2003), and its average was defined as the hours of supine-to-sitting (HSS). HSS are obtained twice from each patient; before conducting the program, which we call the pre-HSS, and after conducting the program, which we call the post-HSS. The measurements before and after the program were conducted by the same physical therapist for each patient in the same environment.

The endpoint of this study was the relative shortening ratio (RSR) which was defined as follows:

$$RSR = \frac{(pre\text{-}HSS) - (post\text{-}HSS)}{(pre\text{-}HSS)}$$

pre-HSS, the hours of supine-to-sitting before the program.
post-HSS, the hours of supine-to-sitting after the program.

3. Statistical analysis

Because the frequency distributions of the hours of PT1, PT2, and PT3 were heavy right tails, they were log-transformed in the statistical analysis. In addition, PT4 was converted to a binary variable (1; Yes, 0; No). Since the number of patients in one hospital dominated those of other hospitals, participating hospitals are also dichotomized (1: the hospital with the largest number of patients (n=49); 0: otherwise (n=57)). Other variables dichotomized were as follows; locomotion capability before the onset (1; independent walking, 0; otherwise), and BRS upper extremity, hand, and lower extremity (1; stage VI, 0; otherwise).

In observational studies, confounders could easily distort study findings and it is crucial to identify the confounders. Confounders should be identified basically based on scientific knowledge about the research subjects, but there are few of such in the present subject and we identified it statistically in this paper as follows. First, the variables associated with the RSR were selected when P-value<0.20. Then, among those selected variables, those associated with PT1, PT2, PT3, and PT4 were selected if P-value<0.20 as potential confounders; where 0.20 is selected for the purpose of screening the confounders among many variables. Six potential confounders were screened in the two-step process and we judged 0.20 was reasonable. Those six variables were found strongly correlated each other and we finally selected pre-HSS as the representative confounder. Note that a mathematical definition of confounders and a proposition is given in Appendix, where it is shown that third variables related both to cause and to effect in cause-effect relationship are confounders of the relationship.

A prediction equation was constructed in the framework of multiple linear regression; namely, starting from the model with RSR as the objective variable and 5 variables (PT1, PT2, PT3, PT4, and pre-HSS) as the explanatory variable, a step-down selection method was applied to establish a clinically meaningful predictive model. All statistical inferences were based on a significance level at 5%. R software (ver. 4.2.1; https://www.r-project.org/) was used for all statistical analyses.

4. Results

117 patients with stroke were enrolled from 7 hospitals. Applying the exclusion criteria, 106 patients were selected for statistical analysis. The number of subjects at each hospital is as follows; St. Mary's Healthcare Center (n=49), Sato Daiichi Hospital (n=22), Kumamoto Rehabilitation Hospital (n=19), Yoshimizu Hospital (n=5), Yasuoka Hospital (n=5), Takehisa Hospital (n=4), Sadamatsu Hospital (n=2). The number of patients in each hospital is small except for St. Mary's Healthcare Center, we dichotomized the hospital variable, thus the variability of PT program among hospitals could not be studied. The clinical characteristics of the patients are shown in Table 1.

Table 1: Patient characteristics (n=106)

Age, years, mean±SD	70.5±12.6
Sex, male/female, n	70/36
Hemorrhage/infarction, n	35/71
Days after onset, mean±SD	32.8±19.5
Dominant hand paralysis, n (%)	65 (61.3%)
BMI, mean±SD	22.9±3.7
Independent walking before onset, n (%)	91 (85.8%)
BRS, stage6, n (%)	
Upper extremity	62 (58.5%)
Hand	62 (58.5%)
Lower extremity	61 (57.5%)
FIM, mean±SD	
Motor subscale	61.4±18.4
Cognition subscale	27.3±7.2
Total	88.8±23.0

Table 2: Period and hours of the stroke PT program

Period of the stroke PT program (weeks)	8.0±3.9
Hours of the stroke PT program (hours)	63.0±35.6
Hours of each category in stroke PT	
PT0	7.0±5.7
PT1	15.4±11.5
PT2	13.2±12.2
PT3	24.9±16.0
Number of PT4, n (%)	35 (33.0%)

Data are presented as mean ± SD.

Table 3: Hours of supine-to-sitting and RSR

pre-HSS (seconds)	5.74±4.17
post-HSS (seconds)	4.03±2.44
RSR	0.22±0.22

The period and hours of the stroke PT program are shown in Table 2. The average period was 8.0 ± 3.9 weeks because some patients did not complete the 13-week stroke PT program due to transfer or discharge from each hospital. The hours of PT3 was the longest, followed by PT1 and PT2.

The hours of supine-to-sitting before the program and after the program and RSR are shown in Table 3. If the program ended less than 13 weeks, the RSR was calculated at the last point.

Table 4 gives p-values between background factors and RSR, and also between background factors and each of the hours of PT1, PT2, PT3, and PT4. The table shows that the p-values of six background factors, shown by the asterisk, are less than 0.2 with RSR and any of PT1, PT2, PT3, and PT4. We selected these six factors as potential confounders.

As shown in Fig.1 four confounders related to motor function among six confounders were strongly related to each other, and we selected the "BRS-lower extremity" as the representative confounder among the four. Furthermore, as shown in Fig.2, the "BRS-lower extremity" and the other two confounders, the "pre-HSS" and the "period of stroke PT", were also strongly related to each other. Thus we finally selected the pre-HSS as a confounder that represents six confounders.

The result of the multivariate linear regression analysis is listed in Table 5. The table shows that PT2 is a significant category to predict RSR; in other words, PT1, PT3, and PT4 are not selected as significant categories of the stroke PT program to predict the RSR, but the pre-HSS was selected as an important confounding variable to adjust for the prediction.

From Table 5 we get the following equation for predicting the RSR;

$$RSR = 0.040 + 0.024 ln PT2 + 0.024 pre\text{-}HSS$$

Table 4: P-values for the relationship of background factors with RSR and PT

Background factors	RSR	lnPT1	lnPT2	lnPT3	PT4	
Age	0.87	0.25	0.64	0.98	0.19	
Sex	0.60	0.90	0.31	0.43	0.83	
Type of stroke	0.45	0.57	0.56	0.60	0.38	
Number of days after onset	0.57	0.15	0.28	0.43	0.09	
Dominant hand paralysis	0.30	0.19	0.92	0.09	1.00	
BMI	0.39	0.16	0.05	0.72	0.50	
Locomotion capability before onset	0.00	0.33	0.49	0.23	0.56	
BRS						
Upper extremity	0.02	0.10	0.04	0.05	1.00	*
Hand	0.01	0.09	0.01	0.03	0.54	*
Lower extremity	0.01	0.04	0.01	0.07	1.00	*
FIM						
Motor subscale	0.03	0.00	0.00	0.02	0.37	*
Cognition subscale	0.70	0.10	0.01	0.02	0.18	
pre-HSS	0.00	0.01	0.01	0.11	0.11	*
Hospital	0.47	0.01	0.00	0.18	0.68	
Period of the stroke PT program	0.00	0.00	0.00	0.00	0.46	*

lnPTi, logarithm of hours of PTi (i=1,2,3); pre-HSS, hours of supine-to-sitting before the stroke PT program

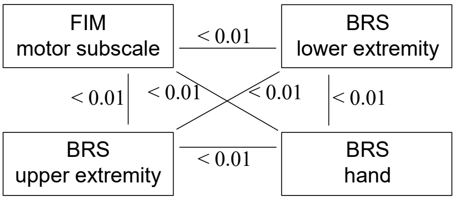

Figure 1: Relationship among four confounders related to motor function.

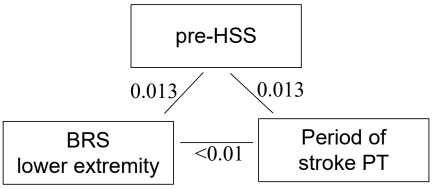

Figure 2: Relationship among confounders. pre-HSS, hours of supine-to-sitting before the program.

Table 5: The results of multivariate linear regression analysis

	β-Coefficient	Standard error	P-value
Intercept	0.040	0.035	0.252
lnPT2	0.024	0.012	0.044
pre-HSS	0.024	0.005	<0.001

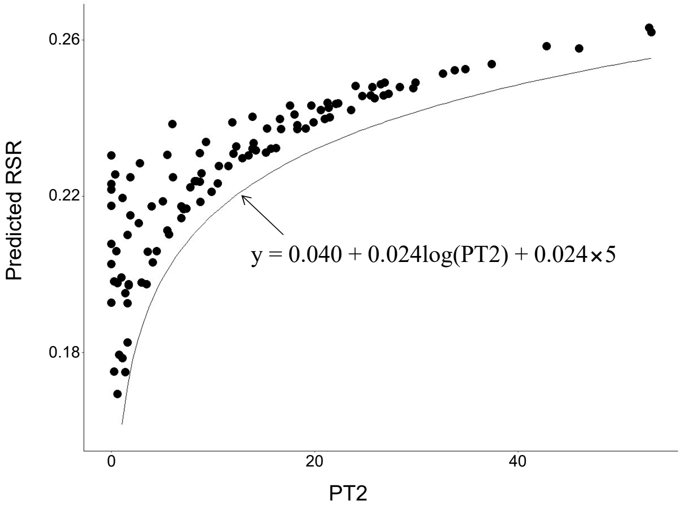

Figure 3: Relationship between PT2 and RSR. The dots show the predicted RSR for each patient if 20% of their PT1 and PT3 were divided into PT2.

5. Discussion

This study focused on the motor function of patients with stroke by using RSR as the endpoint and evaluated the efficacy of four categories of stroke PT, PT1, PT2, PT3, and PT4 for improving the RSR. The results made it clear that only PT2 was significantly associated with RSR but not PT1, PT3, and PT4. The finding indicates that since PT2 consists of basic activities of daily living if more hours were divided to the exercises such as roll-over and supine-to-sitting from the exercises of PT1, PT3, and PT4, the motor function could be improved. Furthermore, we identified the pre-HSS as the confounder that affects the relationship between RSR and PT2 and proposed the RSR prediction equation by PT2 adjusted for the pre-HSS.

The prediction equation could be used to determine effective hours of PT2 in the stroke PT for improving the motor function by dividing some percentages of PT1, PT3, and PT4 to PT2. We ignored PT4 because it was treated as a binary variable in this study. The dots in Fig. 3 show the predicted RSR of each patient if 20% of their PT1 and PT3 were divided to PT2. On the other hand, the smooth curve in the figure shows the relationship between RSR and PT2 in the prediction equation. The pre-HSS was fixed at 5 seconds. The figure demonstrates all dots are plotted in the upper part of the curve and distances between dots and the curve show a tendency of getting larger as hours of PT2 get shorter; showing the division of hours of PT1 and PT3 to PT2 could improve the motor function of patients with stroke; in particular, it would be more effective for patients whose hours of PT2 are shorter than those patients whose hours of PT2 are longer.

This study focused on the efficacy of categories in the stroke PT program. There remain important issues to be solved such as (i) Evaluate the efficacy of stroke PT by targeting other endpoints such as standing up, standing balance, and gait, (ii) To take into account occupational therapy, voluntary training, and training by nurses or caregivers in addition to the physical therapy. (iii) Evaluate efficacies of rapidly introduced therapies recently such as Transcranial Magnetic Stimulation, robotics, and virtual reality. We believe the method developed in this paper could be useful to solve these issues.

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Appendix

Consider causal relationship between Z and Y, where Z is the cause and Y is the effect. Let X be the third variable.

Definition. X is not a confounder in the relationship of $Z \to Y$ if and only if
(i) the relationship of $Z \to Y$ does not depend on $X = x$, and
(ii) X and Y are conditionally independent conditioned on Z, or X and Z are conditionally independent conditioned on Y.

Proposition 1. Suppose that (X, Y, Z) follows three-dimensional normal distribution. Then $\rho_{zx} = 0$, or $\rho_{xy} = 0$ if X is not a confounder in the $Z \to Y$ relationships, where ρ_{zx} and ρ_{xy} are Pearson correlation coefficients between X and Z, and X and Y, respectively.

Proof. Suppose that X is not a confounder in the $Z \to Y$ relationship, then by the definition the conditional Pearson correlation coefficient between Y and Z conditioned on $X = x$, denoted by $\rho(y, z|x)$, does not depend on $X = x$ and X and Y are conditionally independent conditioned on Z, or $\rho(y,z|x)$, does not depend on $X = x$ and X and Z are conditionally independent conditioned on Y. Since X and Y are conditionally independent conditioned on Z if and only if $\rho_{xy} = \rho_{yz}\rho_{zx}$, it follows that

$$\rho(y,z|x) = \frac{\rho_{yz} - \rho_{xy}\rho_{zx}}{\sqrt{(1-\rho_{xy}^2)(1-\rho_{zx}^2)}} = \rho_{yz}\sqrt{\frac{1-\rho_{zx}^2}{1-\rho_{yz}^2\rho_{zx}^2}}$$

Thus, $\rho(y,z|x)$ does not depend on $X = x$ if and only if $\rho_{zx} = 0$. Next, suppose that $\rho(y,z|x)$, does not depend on $X = x$ and X and Z are conditionally independent conditioned on Y. Then, similarly as above we may show $\rho_{xy} = 0$. (QED)

The proposition shows that if $\rho_{zx} \neq 0$ and $\rho_{xy} \neq 0$, then X is the confounder in the relationship of $Z \to Y$. Furthermore, we have the following proposition in the context of regression of Y on Z and X.

Proposition 2. Suppose that (X,Y,Z) follows three-dimensional normal distribution. Then, X and Y are conditionally independent conditioned on Z if and only if $E(Y|z,x) = E(Y|z)$, where $E(Y|z,x)$ is the conditional expectation of Y given $Z = z$ and $X = x$, and $E(Y|z)$ is the conditional expectation of Y given $Z = z$.

Proof. Let μ_x, μ_y and μ_z be expectations of X, Y and Z, respectively, and σ_x, σ_y and σ_z be standard deviations of X, Y and Z, Then

$$\begin{aligned} E(Y|z,x) &= \mu_y + (\frac{\sigma_y}{\sigma_x})\frac{(\rho_{xy} - \rho_{yz}\rho_{zx})}{(1-\rho_{zx}^2)}(x-\mu_x) + (\frac{\sigma_y}{\sigma_z})\frac{(\rho_{yz} - \rho_{xy}\rho_{zx})}{(1-\rho_{zx}^2)}(z-\mu_z), \\ E(Y|z) &= \frac{\sigma_y}{\sigma_z}\rho_{yz}(z-\mu_z) \end{aligned}$$

Thus, if X and Y are conditionally independent conditioned on Z, that is $\rho(x,y|z) = \rho_{xy} - \rho_{zx}\rho_{yz} = 0$, then $E(Y|z,x) = E(Y|z)$. The reverse is trivial. (QED).

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