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ARTYKUŁ ORYGINALNY / *ORIGINAL ARTICLE*

Effect of tandem lesions on haemodynamic parameters: an experimental study

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Abstract

Background: The morphology and extensity of the stenotic lesion is crucial as well as the obstruction ratio. It is well known that the complexity of lesions has a direct impact on endovascular treatment (PTCA/stent); however, the arrangement of the lesions is underestimated and not well studied.

Aim: We sought to evaluate the haemodynamic effects of different stenotic lesion models and arrangements in vitro.

Methods: Vascular circulation was simulated in vitro. Oxygenator, tubing set, polytetrahidroflouroethylene synthetic graft, pressure and flow rate, sensors were used to build the simulation model. Measurements of isolated short, isolated long, identical stenotic tandem short, identical stenotic tandem long, sub-critical long, and critical short lesion combinations were performed and haemodynamic parameters were recorded.

Results: Tandem lesions were more likely to result in critical stenosis comparing single lesions with the same obstruction ratio. This difference became more significant as the obstruction ratio was raised. Tandem long lesions also resulted in more critical stenosis than tandem short lesions. It can be claimed that tandem lesions can result in more flow restriction with reference to single lesions with the same stenotic ratio. Contrary to expectations, tandem short lesions were found to be more stenotic compared with the same degree long individual lesions.

Conclusions: It is effortless to give the decision for simple, discrete and individual lesions, while the ideal decision for long and complicated lesions may remain unclear. Even if these "grey zone" lesions are considered non-critical while investigating them one by one, it must be kept in mind that the overall stenotic effect of these lesions may lead to more haemodynamic impairment.

Key words: tandem vascular lesion, fractional flow reserve, circulation physiology

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INTRODUCTION

Assessment of severity of vascular stenosis in cardiology practice is often based on the angiographic images and other measurements taken during the procedure. Due to the possibility that these visual assessments could be interpreted subjectively, haemodynamic or physiological studies may be performed to obtain quantitative results. Haemodynamic impairment by the stenosis was shown to depend on blood flow, viscosity, vessel area, lesion length, and vessel diameter [1]. However, most of the available data were only acquired in the presence of a single lesion, which was less able to satisfy the needs when deciding therapeutic strategy for patients with tandem lesions, not an uncommon clinical entity.

In 1963 Vonruden et al. [2] were the first to report haemodynamic alterations in a case of tandem stenosis, which was defined as two significant stenoses less than three vessel reference diameters apart. Lesions that are further apart from each other should be considered as two separate lesions instead of tandem stenosis. There is limited data about the incidence of tandem lesions on coronary arteries. It is known that approximately 40% of patients with ST elevation myocardial infarction have multivessel disease, and an important

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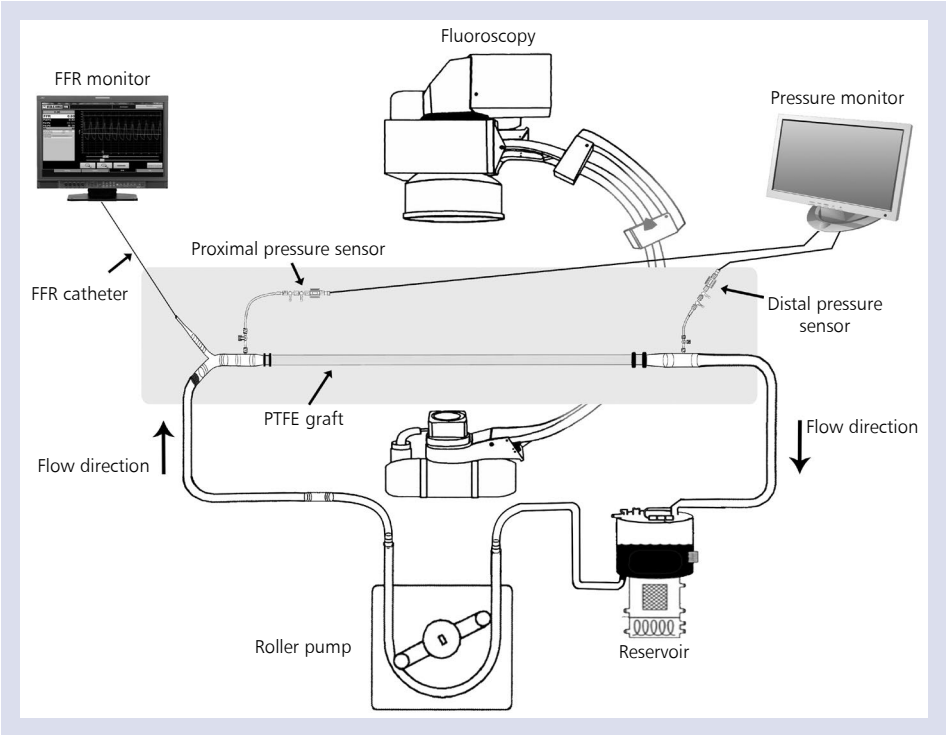

Figure 1. Schematic view of experimental setup

proportion of this subgroup have diffuse or tandem lesions [3]. Appelman et al. [4] report the incidence of tandem lesions as 20% in their cohort of patients that included those with complex coronary lesions.

In experimental studies performed on canine carotid arteries, it was shown that flow rate depended on the diameter of the stenosis, rather than its length. Furthermore, they stated that the main factor influencing the flow in the presence of tandem stenosis was the lesion that was more critical [2]. Conversely, some authors suggested that the total haemodynamic effect of the sequential lesions might be greater than that of the critical lesion [5].

This study aimed to investigate the haemodynamic effects caused by a variety of lesion types under experimental conditions to demonstrate the still clearly unidentified effects of tandem lesions

METHODS

This study was performed with the support of Hitit University Scientific Research Projects Coordinatorship in 2016 (Project No: TIP19002.14.002).

Vascular circulation was simulated in vitro in our study (Fig. 1). To achieve this simulation, 7 F no-ring ePTFE graft (PM Flow, Perosure Labs), paediatric oxygenator (Dideco Paediatric, Sorin Group), tubing set (Bicakcilar), FFR catheter (Volcano Precision Guided Therapy), transducer (W/1, Bicakcilar), and connecting components were used. As priming fluid, 1000 cc ringer lactate solution and erythrocyte suspension near expiry date were selected to simulate rheological properties of in vivo condition.

The prepared experimental system was connected to the roller pump of the heart-lung machine (C5, Sorin Group), followed by the initiation of the simulation at 1000 cc/min output.

Stenosis models

Varying numbers and combinations of stenosis degrees were generated on the grafts in vitro. While silk suture was used to create a short stenosis, three adjoining plastic clamps were placed with no space between to create a long stenosis. Degrees of stenosis were assessed by angiography. This was performed by scope images after administration of contrast material (Iomeron 350), where the degree of stenosis was measured in terms of diameter with the help of the software of the angiography device (Fig. 2). All lesions were calibrated in this manner to create the following types of lesions and degrees of stenosis:

1. Short single lesion: 10–30–50–60–70–80%;
2. Long single lesion: 10–30–50–60–70–80%;
3. Short tandem lesion of equal degree of stenosis (Short+Short): 10%–10%, 30%–30%, 50%–50%, 60%–60%, 70%–70%, 80%–80%;
4. Long tandem lesion of equal degree of stenosis (Long+Long): 10%–10%, 30%–30%, 50%–50%, 60%–60%, 70%–70%, 80%–80%;

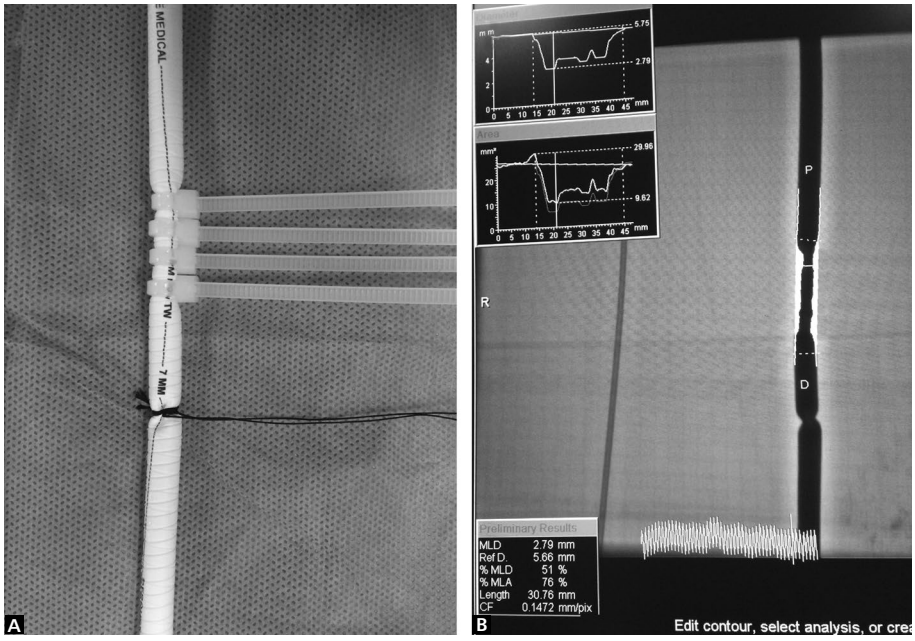

Figure 2. Sample lesion combinations for the created types of lesions (**A**) and calibration performed on the scope image of the obtained lesion (**B**)

5. Combination of long and short tandem lesion of equal degree of stenosis (Long+Short): 10%–10%, 30%–30%, 50%–50%, 60%–60%, 70%–70%, 80%–80%;
6. Non-critical long lesion + short critical lesion: L10S60, L20S60, L30S60, L40S60, L10S70, L20S70, L30S70, L40S70, L10S80, L20S80, L30S80, L40S80.

Haemodynamic parameters

Baseline values were recorded before creating any stenosis via the two pressure transducers at the origin and at the end of the graft. After creating the lesions, five measurements for each sampling were performed, and the mean values were recorded.

A fractional flow reserve (FFR) catheter was introduced from the service port at the graft origin to approximate the lesion. After recording of the pressure at this point, the pressure at a point 3 cm distal to the lesion was also recorded, as measured by FFR device. These measurements were repeated five times for each lesion type. There was no concern of maximal hyperaemia, and consequently no medication was used due to the nature of the in vitro setting. In tandem lesion models, the measurement that was taken from the most distal point of the overall lesion was taken into account. No measurement was performed between two lesions.

Statistical analysis

Statistical analysis was performed with SPSS (SPSS Inc., Chicago, IL, USA) 22.0 version software pack. Descriptive statistics were presented as mean ± standard deviation and median (min–max) for continuous variables according to distribution assumptions. Homogeneity of variances were examined with Levene's test. Group comparisons for more than two continuous variables were performed with variance analysis (ANOVA). Further pairwise comparisons to determine the origin of the difference after variance analysis was performed with post-hoc tests. Tukey test was used for pairwise comparisons regarding FFR values. Since assumption of homogeneity of variances was not met for the pressure values, post-hoc Tamhane T2 test was used for these results. Statistical significance was accepted for results with a p value below 0.05.

RESULTS

Initially, basal pressure and FFR measurements were performed on the prepared setup. Based on the graft length and connecting components, basal proximal pressure and the pressure distal to the graft at a 1000 cc/min output was 78 mm Hg and 39 mm Hg, respectively. First, pressure and FFR values for the short single lesion were recorded, followed by creation of a long lesion to measure and record pressure and FFR values for a variety of stenotic lesions (Table 1).

Measurements were continued with tandem short and tandem long lesions created with 1 cm intervals (Table 2). It was observed that tandem long lesions caused more critical FFR values than did tandem short lesions in stenosis degrees of ≥ 70% ($p = 0.009$).

Readings of tandem long and short lesion combinations of equal degree of stenosis are presented in Table 3. No difference was detected between the measurements of tandem long and short lesion combinations of equal degree of stenosis ($p > 0.05$ for all degrees of stenosis).

Finally, the effect of critical short lesions accompanying non-critical long lesions was assessed. No effect of non-critical long

Table 1. Pressure and fractional flow reserve (FFR) values in short and long lesions

	Proximal pressure		Distal pressure		FFR	
	Mean ± SD	Median (min–max)	Mean ± SD	Median (min–max)	Mean ± SD	Median (min–max)
S10	78.1 ± 1.02	79 (78–80)	39.1 ± 0.31	40 (39–40)	0.90 ± 0.02	0.90 (0.88–0.91)
S30	78.2 ± 0.91	79 (78–80)	38.3 ± 0.21	39 (38–40)	0.84 ± 0.01	0.85 (0.84–0.86)
S50	85.0 ± 1.10	86 (85–87)	38.2 ± 0.44	39 (38–41)	0.81 ± 0.03	0.81 (0.79–0.82)
S60	90.3 ± 1.12	90 (90–91)	37.1 ± 0.23	38 (37–41)	0.79 ± 0.02	0.79 (0.77–0.79)
S70	114.3 ± 1.37	116 (110–118)	38.4 ± 0.61	40 (39–41)	0.74 ± 0.01	0.73 (0.71–0.75)
> S80	277.2 ± 1.10	276 (273–281)	38.1 ± 0.21	38 (37–41)	0.57 ± 0.02	0.53 (0.51–0.55)
L10	82.1 ± 1.11	82 (81–83)	40.0 ± 0.31	40 (39–41)	0.96 ± 0.01	0.96 (0.96–0.97)
L30	86.2 ± 0.97	86 (85–87)	39.2 ± 0.23	39 (38–40)	0.95 ± 0.02	0.95 (0.94–0.97)
L50	97.1 ± 0.19	97 (96–98)	39.1 ± 0.21	39 (38–40)	0.85 ± 0.03	0.85 (0.85–0.87)
L60	100.3 ± 1.45	100 (99–102)	39.3 ± 0.45	39 (38–41)	0.80 ± 0.04	0.80 (0.79–0.83)
L70	124.1 ± 1.21	124 (123–125)	40.1 ± 0.36	40 (39–41)	0.73 ± 0.02	0.73 (0.72–0.74)
> L80	290.4 ± 1.44	290 (288–291)	39.2 ± 0.53	40 (38–42)	0.57 ± 0.01	0.58 (0.57–0.60)

S — short lesion; L — long lesion; SD — standard deviation

Table 2. Pressure and fractional flow reserve (FFR) values in tandem short and tandem long lesions

	Proximal pressure		Distal pressure		FFR	
	Mean ± SD	Median (min–max)	Mean ± SD	Median (min–max)	Mean ± SD	Median (min–max)
S10+S10	81.1 ± 1.10	81 (80–82)	40.1 ± 0.21	40 (38–41)	0.90 ± 0.03	0.90 (0.88–0.91)
S30+S30	94.2 ± 1.04	94 (94–96)	40.2 ± 0.12	40 (34–42)	0.83 ± 0.04	0.83 (0.81–0.84)
S50+S50	99.0 ± 2.12	99 (97–102)	41.1 ± 0.32	40 (39–41)	0.81 ± 0.01	0.81 (0.80–0.82)
S60+S60	110.0 ± 0.71	110 (109–111)	41.3 ± 0.21	40 (39–42)	0.75 ± 0.02	0.76 (0.75–0.77)
S70+S70	130.2 ± 1.30	131 (130–133)	40.1 ± 0.24	39 (37–42)	0.69 ± 0.01	0.70 (0.68–0.71)
S80+S80	290.1 ± 1.43	291 (290–293)	40.3 ± 0.12	40 (39–42)	0.57 ± 0.01	0.56 (0.54–0.57)
L10+L10	85.2 ± 0.92	85 (84–86)	42.1 ± 0.52	41 (40–42)	0.90 ± 0.01	0.89 (0.88–0.90)
L30+L30	88.1 ± 1.02	89 (88–90)	42.4 ± 0.19	42 (39–44)	0.87 ± 0.02	0.86 (0.85–0.87)
L50+L50	100.6 ± 1.14	101 (99–102)	45.1 ± 0.21	44 (41–46)	0.80 ± 0.01	0.89 (0.88–0.90)
L60+L60	113.8 ± 0.84	114 (113–115)	44.2 ± 0.32	43 (42–46)	0.74 ± 0.01	0.74 (0.72–0.75)
L70+L70	139.6 ± 1.52	139 (138–142)	44.2 ± 0.41	44 (40–47)	0.66 ± 0.01	0.65 (0.63–0.66)
L80+L80	293.3 ± 1.42	293 (292–297)	44.1 ± 0.22	44 (42–44)	0.56 ± 0.03	0.54 (0.53–0.56)

S — short lesion; L — long lesion; SD — standard deviation

lesions located proximal to the critical short lesions was found on the pressure or FFR values ($p > 0.05$ for all degrees of stenosis).

When the haemodynamic effect formed by the two short or long lesions of equal degree of stenosis was compared with that of a single lesion with the same degree of stenosis, the former lesions were seen to create more elevated pressure and more critical FFR values (Table 4). When tandem short lesions of 50% stenosis were compared with single short lesions of 50% stenosis, FFR values did not differ whereas tandem lesion had greater pressure values at the proximal readings ($p = 0.002$). When tandem long lesions of 50% stenosis were compared with single long lesions of 50% stenosis, FFR was found to be higher for the single lesion ($p = 0.001$). As the degree of stenosis increased, both pressure and FFR values were significantly higher in tandem lesions compared to the single lesion of the same degree. However, tandem short lesions were observed to create hemodynamically more significant stenosis compared to that of long lesions of the same degree of stenosis (Tables 4 and 5). Proximal pressure and FFR values of lesion models are presented in Figures 3 and 4.

Table 3. Pressure and fractional flow reserve (FFR) values in combined tandem long and short lesions of equal degree of stenosis

	Proximal pressure		Distal pressure		FFR	
	Mean ± SD	Median (min–max)	Mean ± SD	Median (min–max)	Mean ± SD	Median (min–max)
L10+S10	81.2 ± 1.04	82 (81–83)	41.3 ± 0.21	41 (40–42)	0.94 ± 0.01	0.95 (0.94–0.96)
L30+S30	88.3 ± 1.02	89 (88–90)	42.1 ± 0.24	42 (40–43)	0.89 ± 0.02	0.89 (0.88–0.90)
L50+S50	100.2 ± 1.22	101 (99–102)	40.2 ± 0.13	43 (41–43)	0.83 ± 0.02	0.83 (0.82–0.84)
L60+S60	111.1 ± 1.03	112 (111–114)	41.2 ± 0.42	43 (42–44)	0.77 ± 0.03	0.76 (0.75–0.78)
L70+S70	136.1 ± 0.92	136 (133–138)	43.4 ± 0.29	42 (41–44)	0.70 ± 0.01	0.70 (0.68–0.72)
L80+S80	290.2 ± 1.01	291 (292–295)	44.1 ± 0.22	42 (40–43)	0.55 ± 0.02	0.54 (0.53–0.56)

S — short lesion; L — long lesion; SD — standard deviation

Table 4. Comparative fractional flow reserve values of tandem lesions and single lesions of equal degree of stenosis (ANOVA-Tukey)

	S50	L50	S60	L60	S70	L70
S50	1.000	< 0.001**	0.046*	1.000	< 0.001**	< 0.001**
S50						
S60	< 0.001**	< 0.001**	0.021*	< 0.001**	0.009*	0.004*
S60						
S70	< 0.001**	< 0.001**	< 0.001**	< 0.001**	0.001*	0.002*
S70						
L50	0.001*	0.001*	< 0.001**	< 0.001**	< 0.001**	< 0.001**
L50						
L60	< 0.001**	< 0.001**	< 0.001**	< 0.001**	0.999	0.990
L60						
L70	< 0.001**	< 0.001**	< 0.001**	< 0.001**	< 0.001**	< 0.001**
L70						

S — short lesion; L — long lesion; *statistically significant — $p < 0.01$; **statistically significant — $p < 0.001$

Table 5. Comparative pressure values of tandem lesions and single lesions of equal degree of stenosis (ANOVA-Tamhane T2)

	S50	L50	S60	L60	S70	L70
S50	0.002*	1.000	0.034*	1.000	0.008*	< 0.001**
S50						
S60	< 0.001**	< 0.001**	< 0.001**	< 0.001**	0.972	< 0.001**
S60						
S70	< 0.001**	< 0.001**	< 0.001**	< 0.001**	0.013*	0.001*
S70						
L50	< 0.001**	0.057	< 0.001**	1.000	0.038*	< 0.001**
L50						
L60	< 0.001**	< 0.001**	< 0.001**	< 0.001**	1.000	< 0.001**
L60						
L70	< 0.001**	< 0.001**	< 0.001**	< 0.001**	0.001*	< 0.001**
L70						

S — short lesion; L — long lesion; *statistically significant — $p < 0.01$; **statistically significant — $p < 0.001$

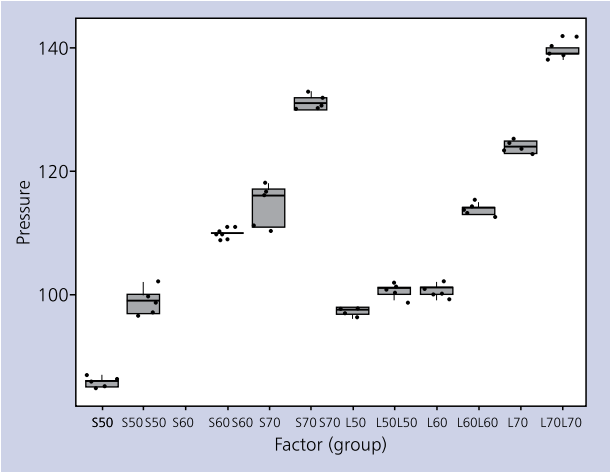

Figure 3. Box-plot graph of proximal pressure values for the lesion models

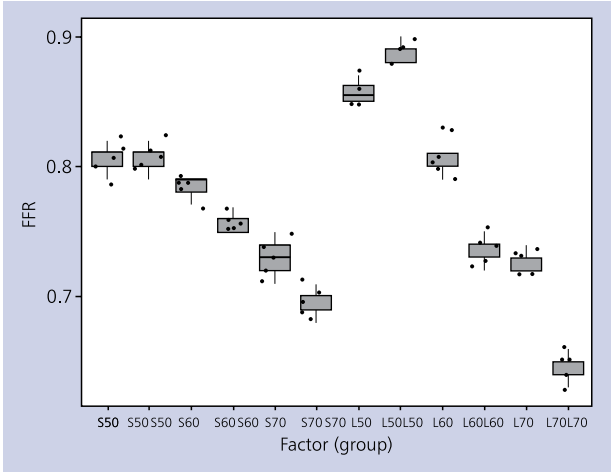

Figure 4. Box-plot graph of fractional flow reserve (FFR) values for the lesion models

DISCUSSION

In this simulation setting, the haemodynamic effect of tandem lesions of equal degree of stenosis was detected to cause a haemodynamically more critical stenosis as compared with the single lesion of equal degree of stenosis. However, this increment was not the same as the subsequent percentile in any degree of stenosis. In addition, tandem long lesions of equal degree of stenosis led to the formation of more critical stenosis than caused by tandem long lesions of equal degree of stenosis. Another finding of the study was that the tandem short lesion model gave rise to a greater haemodynamic impairment compared to the long lesion of the same degree of stenosis.

Determination of the best revascularisation strategy in patients with multi-vessel disease or complex lesion types remains contradictory among interventional cardiologists and cardiovascular surgeons. The criteria to prefer one revascularisation strategy over another include morphology of lesions, degree of stenosis, and clinical factors [6]. Clinical assessment of the severity of culprit lesion for ischaemia could be performed with several methods, including FFR. Routine performing of FFR before percutaneous interventions was reported to be useful for better clinical outcomes [7]. However, such studies often focused on a single lesion, creating an evidence gap for patients with tandem lesions. Niijer et al. [8] reported benefits of vascular haemodynamic mapping by FFR data obtained by pullback via an automated system in diffuse diseased coronary arteries where tandem lesions were located. In fact, the general tendency today is towards documenting the haemodynamic effect of the lesion rather than its visual assessment.

Another field where tandem lesions were examined was pathologies regarding carotid arteries. Numerous preclinical or clinical studies investigated the effects of tandem lesions, which were reported to cause more serious haemodynamic impairment and worse clinical outcomes compared to the isolated lesions [9–12].

In order to calculate the haemodynamic effect caused by a given stenotic lesion within the vessel lumen, these parameters must be known: blood flow, pressure gradient between the two ends, radius and length of the vessel, and viscosity. Poiseuille's Law states this equation for the calculation of flow rate (where η — viscosity, L — length, r — radius):

$$\text{Volume flow rate: } \frac{\text{Pressure gradient between two ends } (P1\text{-}P2)}{\text{Resistance } (R)}$$

$$\text{Resistance } (R): \frac{8 \cdot \eta \cdot L}{\pi \cdot r^4}$$

Our finding showing greater degree of stenosis by tandem long lesions compared to the tandem short lesions with the same degree of stenosis could be explained by Poiseuille's Law. The effect of de facto increase in length and narrowing in diameter in tandem lesions caused more critical stenosis than did the single lesions with the same degree of stenosis. Nevertheless, the important point is that whether this "more critical effect" is able to produce a haemodynamic impairment that is the same as that produced by the single lesion with the next upper degree (percentile) of stenosis. Our findings suggested that this impairment was usually not as high as that produced by the single lesion with the next upper degree of stenosis. This finding is in conflict with the opinion dominating some clinical practices that a subcritical tandem lesion behaves as a single critical lesion. On the other hand, a tandem short lesion was shown to create a more critical haemodynamic impairment even compared to the single long lesion with the same de-

gree of stenosis, which could not be explained by Poiseuille's Law. A turbulent flow that may be produced in the segment between the two sequential lesions may be attributed to this finding. Indeed, this needs to be addressed by further studies designated for this purpose.

The number of experimental studies that examine direct haemodynamic effects of tandem lesions is very limited [5, 13]. In one of the noteworthy studies, Guppy et al. [5] created a mathematical model based on Poiseuille's Law to simulate tandem carotid lesions and reported that a tandem lesion with 70% stenosis proximally and 80% distally had similar effect to that of an 82% stenotic single lesion. Consistent with our results, these findings support the notion that tandem lesions should not necessarily be assessed according to the more critical lesion.

The SYNTAX score, which is commonly used in clinical practice, is a computer-assisted scoring system that predicts percutaneous coronary intervention success based on the location of the lesion, involvement (ostial, mid, etc.), presence of total occlusion, and vessel diameter [14]. TASC classification is a morphological categorisation that assesses the extent of the disease in peripheral arterial disease [15]. Although the SYNTAX score is elevated along with the increase in the number of lesions on the affected vessel, these scoring systems do not use tandem lesions as a parameter. Our findings suggest that this may constitute a handicap for these systems, whose future versions may be updated to consider the presence of tandem lesions to offer more benefits for clinical practice.

Examined parameters in the study are very hard to detect in vivo. In fact, many factors such as irregularities in vascular endothelium, active neurohumoral responses, individual side-branch anatomy, presence of collaterals, variable cardiac output, and minute alterations of oxygen demand of the target organ (viable myocardium) hamper documentation of the net effect of tandem lesions. All of these alterations have a substantial effect on FFR values in vivo. While this is advantageous for our experimental setup, it is unclear which findings would be valid, more substantial, or non-significant for the in vivo setting. The stenosis model was created by external constriction method in this setup; although it did not resemble physiological conditions, it was a necessity. During designation of the project, intraluminal lesions were created as a stenosis model (by silicone/cyanoacrylate and intraluminal inflated balloon); however, none of those could preserve its integrity and disrupted the current flow. In addition, these methods are relatively hard to be accurately calibrated by angiography. Another limitation was the synthetic nature of the graft used in the study. Despite intending to use biological materials, we failed due to ethical reasons and restrictions. We attempted to keep connectors, access ports, and other connecting components at a minimum because of their probable resistance effects. In brief, all factors that have the possibility to affect system dynamics were used minimally to reveal a net effect of the stenosis.

A recent idea for the assessment of coronary physiology has been proposed, called instantaneous wave-free ratio (iFR). iFR is calculated as the ratio of distal coronary pressure to proximal aortic pressure over a specific period in diastole, known as the wave-free period, when resistance is naturally constant and minimised in the cardiac cycle. During this wave-free period of the cardiac cycle, flow resistance is very low and stable, and administration of a vasodilator drug is not necessary [8]. As this in vitro model is constituted on a roller pump and has minimum pulsatility, the predominant flow character in this system is almost wave-free, which is similar to the wave-free period of the cardiac cycle. So, it can be predicted that the FFR values might be similar to iFR values, if calculated. Optical coherence tomography and intravascular ultrasound are anatomical imaging techniques used to obtain data about the structure of the stenotic lesions. Tandem lesions may also be evaluated via these methods to learn the complexity of the stenotic plaque; however, functional evaluation techniques (FFR, iFR) are more successful for determining the haemodynamic effect of the lesion.

CONCLUSIONS

While the clinical decision tree for simple, discrete, or isolated lesions is usually more definite, long or complicated lesions, which represent grey areas of the clinical decision process, may be managed with different modalities and protocols. Besides these, when a tandem lesion is present, even if both components are regarded as non-critical visually, it should be considered that their collective haemodynamic impairment might be more critical. As an important finding of the study, this may direct the clinical decision in favour of intervention. Similarly, the fact that a tandem short lesion may lead to haemodynamic impairment that is comparable to that caused by a long lesion of the same degree of stenosis should be taken into consideration. This should also be kept in mind when determining prognostic significance in clinical practice.

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Wpływ zmian tandemowych na parametry hemodynamiczne: badanie eksperymentalne

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Streszczenie

Wstęp: Morfologia i długość zwężeń tętnic mają równie istotne znaczenie, jak stopień zwężenia. Powszechnie wiadomo, że złożoność zmian w tętnicach ma bezpośredni wpływ na leczenie wewnątrznaczyniowe (przezskórna wewnątrznaczyniowa angioplastyka wieńcowa/stent), jednak znaczenie konfiguracji zmian nie jest doceniane ani nie zostało wystarczająco zbadane.

Cel: Celem niniejszej pracy była ocena efektu hemodynamicznego różnych rodzajów zwężeń tętnic i ich konfiguracji w warunkach *in vitro*.

Metody: Wykonano model do symulacji układu naczyniowego w warunkach *in vitro*. Wykorzystano do tego oksygenator, zestaw drenów, syntetyczną protezę naczyniową z politetrahydroflouroetylenu oraz czujniki ciśnienia i przepływu. Przeprowadzono pomiary przy różnych konfiguracjach zmian (izolowane krótkie zwężenie, izolowane długie zwężenie, dwa identyczne krótkie zwężenia w układzie tandemowym, dwa identyczne długie zwężenia w układzie tandemowym, kombinacja długiego zwężenia podkrytycznego i krótkiego zwężenia krytycznego) i zarejestrowano parametry hemodynamiczne.

Wyniki: Zmiany tandemowe wiązały się z większym ryzykiem krytycznego zwężenia niż pojedyncze zmiany o takim samym stopniu zwężenia światła naczynia. Różnica była tym większa, im większy był stopień zwężenia. Długie zwężenia tandemowe również powodowały więcej krytycznych zwężeń niż krótkie zwężenia w układzie tandemowym. Można stwierdzić, że zmiany tandemowe powodują większe ograniczenie przepływu niż pojedyncze zwężenia o takim samym stopniu zwężenia światła naczynia. Przeciwnie niż oczekiwano, okazało się, że krótkie zwężenia tandemowe powodują większe zaburzenia niż pojedyncze długie zwężenia o tej samej średnicy.

Wnioski: Decyzje dotyczące leczenia nieskomplikowanych, ograniczonych i izolowanych zmian naczyniowych nie są trudne, natomiast w przypadku długoodcinkowych i złożonych zmian optymalna decyzja może być nieoczywista. Nawet jeśli te zmiany „szarej strefy" są uważane za niekrytyczne, w przypadku gdy ocenia się je niezależnie od siebie (każdą osobno), należy pamiętać, że sumaryczny efekt zwężenia łożyska naczyniowego może spowodować poważniejsze zaburzenia hemodynamiczne.

Słowa kluczowe: tandemowe zmiany naczyniowe, cząstkowa rezerwa przepływu wieńcowego, fizjologia układu sercowo-naczyniowego

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