

Abstract

In this study, an easy to use measurement method was developed to quantify the balloon dilatation catheters visibility, thus making them comparable. The visibility of the distal and proximal markers and the balloon (average values of the markers) was determined for fourteen balloons of the same type and material, but different lengths and diameters. Repeatability of these values was tested by one volunteer and reproducibility by two volunteers three times each for all the balloons used for the study. It was found that the average visibility for balloons was $12 \pm 2\%$, $13 \pm 2\%$ for distal markers, and $13 \pm 2\%$ for proximal markers. Values of distal and proximal markers did not represent significant difference ($p=0.20$). There was no significant difference determined for repeatability and reproducibility either (p values were between 0.71-0.93). Hence, the developed measurement method was repeatable and reproducible making it suitable for comparison of the balloon dilatation catheters based on visibility.

Keywords

balloon dilatation catheter, radiodetectability, visibility

1 Introduction

Cardiovascular diseases are the number one cause of death worldwide. 41% of death is caused by ischaemic heart disease and 35% by stroke [1]. These emergencies are caused by stenosis or occlusion of the vessels in the heart or brain [2]. One of the potential medical devices used for the dilatation of the vascular system is the balloon dilatation catheter [3].

The balloon dilatation catheter (so called balloon catheter [4-5]) is an intravascular catheter (single or multilumen tube), on which a balloon is located near the distal end (this end is introduced into the body). The hydraulic dilatation of this balloon dilates the narrowed, occluded vessel [3,6,7]. The balloon is monitored in the body using X-ray fluoroscopy [9-10].

The current standard for balloon dilatation catheters (ISO 10555-1:2013, ISO 10555-4:2013) and the guide of the U.S. Food and Drug Administration (FDA) specify that the balloon shall be radio-detectable when it is inserted into the body [3,6,11]. The placement of the balloon to the target place in the patient's vasculature is facilitated with radiopaque material. This radiopaque material is typically a metal marker band. It may be placed on the centre of the balloon (single metal marker) or on the ends of the balloon (double metal marker) [12,13].

In the standard for general requirements of the intravascular catheters (ISO 10555-1:2013), Part 4 relates to the balloon dilatation catheters, and requests the test method of visibility according to the standard ASTM F640-12 [3,6,14]. It contains standard test methods for determining radiopacity however; it does not specify the type of the medical devices. The guide of the FDA indicates that the radiopaque markers on the balloon should be investigated [11,14,15], but unified measure method is not recommended in the standards and literature. The manufacturer can measure this visibility by different methods, therefore they are not comparable. The methods of the manufacturer are not available. According to the standard (ASTM F640-12) pixel density or optical density are determined by some method.

The measured visibility values are not quantified; instead of terms were used for visibility's characterisation, such as: excellent [16], optimal radiopacity [17], optimal visibility [18], and increased radiopacity [19], extremely visible [20].

¹ Department of Materials Science and Engineering,
Faculty of Mechanical Engineering,
Budapest University of Technology and Economics,
H-1111 Budapest, Bertalan Lajos u. 7, Hungary

² MTA-BME Research Group for Composite Science and Technology,
H-1111 Budapest, Műegyetem rkp. 3, Hungary

* Corresponding author, e-mail: liza@eik.bme.hu

The aim of this study was to develop an easy to use measurement method for the objective determination of the balloon catheters' visibility based on the standard ASTM F640-12, the FDA and our earlier studies [11,14,21]. This method is suitable for quantifying, classifying, and comparing the balloon catheters based on this property. By this method established which marker material, which balloon is better visible than the others.

2 Materials and methods

The measurement method developed by us was tested on fourteen balloon catheters with same material (polymer balloon with two platinum iridium markers), but different length and diameter (Table 1) to determine the dependence of the visibility on the balloon length and diameter in case of our method.

Table 1 Diameter and length of the investigated balloons

Sample number	Balloon diameter (mm)	Balloon length (mm)
1.	2.25	8
2.	2.50	8
3.	3.00	20
4.	3.25	20
5.	3.50	12
6.	4.00	8
7-8.	4.50	8
9-10.	4.50	12
11.	4.50	20
12.	5.00	8
13-14.	5.00	12

The visibility of the radiopaque markers on the balloon was determined according to the current standard for balloon dilatation catheters (ISO 10555-4:2013) and the recommendation of the FDA [3,9].

X-ray images of the balloons were taken by Dage XiDAT XD6600 X-ray Inspection System. The parameters were adjusted to the ones used during clinical practice (beam voltage of 90-110 kV; cathode power set at 1.19-1.20 W and an average frame rate of 32 frames/sec) (Fig. 1a).

The greyscale images of the two markers (Fig. 1b-1c) and some parts of the background (Fig. 1d), which did not contain the balloon catheter but located close to the balloon or marker, were taken using an image-editing program (Gimp 2). During X-ray imaging base detector- errors may occur. If the comparable images are close to each other, these errors can manifest similarly.

The background of the balloon was the background of the sample holder of the X-ray Inspection System, which was the same for all balloons. Hence the measured visibility values were comparable.

Using software developed the research group to which I belong to, the visibility curve of the cut-out greyscale images

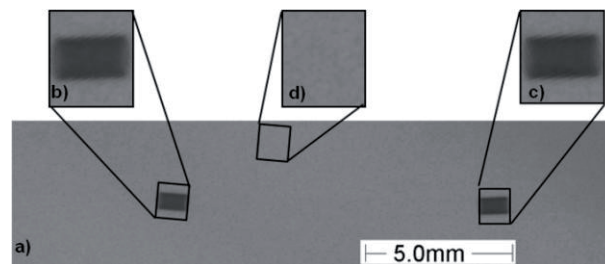


Fig. 1 a) X-ray microscopic image from the balloon marked parts of the sample: the cut-out segment from b) the distal marker (it is closer to the tip), c) the proximal marker (it is further from the tip), d) and the background

from each marker and from the background was determined (Table 2). Then the ratio of double integral curves of the background and the marker was calculated by the software. The value resulted by the image analysis software was the visibility of the marker against the background. The average of the two markers' value is the balloon's visibility; it characterizes the visibility of the balloon catheter. The operating principle of the image analysis software and the determination of the parameters to compare images are described in Ring's work [21].

Table 2 Calculated visibilities in case of a balloon

Compared images			Visibility		
Distal marker	+	Background	→	Distal marker	⇒ Balloon (average of the markers)
Proximal marker	+		→	Proximal marker	

The visibility was placed on a scale from 0 to 100%. If the value was '0', the marker was invisible. As the value increased, the visibility increased.

Statistical analysis

A region from the background was selected by a volunteer and its visibility was determined and compared to those of the distal markers (closer to the tip), the proximal markers (further from the tip) and the balloon catheter. The average and standard deviation of visibility was calculated separately for each of the fourteen balloons and distal and proximal markers (the average of the two marker values characterizes the visibility of the balloon catheter). From these values calculated, the relative standard deviation (so called coefficient of variation, which is the ratio of the standard deviation to average value) was obtained. If the obtained value was between 0 and 0.1, it indicated homogeneity, between 0.1 and 0.2 indicated low heterogeneity, between 0.2 and 0.3 meant higher heterogeneity and those from 0.3 to 1.0 meant highly volatile. The smaller the value, the more homogeneous the sample was, thus the measurement method was more reliable. The average values were compared using statistical tests. For two sample groups Mann-Whitney-Wilcoxon test and for three sample groups Kruskal-Wallis test was applied. Both these tests were non-parametrical

tests, meaning it was not used for normal distribution of the samples. If the p value of the probe is less than 0.05, so the significance level is below 5%, the compared groups are significantly different. Above this value, the samples did not differ significantly from each other.

Repeatability and Reproducibility

To determine the repeatability of the measurement method (the variation of the measured data caused by the replace with the background), one person measured three different random background segments for all the fourteen balloon catheters. To determine the reproducibility (the variation of the measured data caused by the volunteer who conducted the measurement), two volunteers performed the measurement with three different background segments each for all the fourteen balloon catheters. The average values of both the distal and proximal markers and the average of the balloon (which characterised the balloon catheter's visibility), and their coefficients of variation were calculated. These values were compared using the same statistical tests mentioned in the previous section (*Statistical analysis*).

3 Results

The average visibility measurements conducted by the first volunteer were $12 \pm 2\%$ ($CV=0.16$) for all the fourteen distal markers, $13 \pm 2\%$ ($CV=0.18$) for all the fourteen proximal markers and $13 \pm 2\%$ ($CV=0.17$) for the balloon catheters. The values of the coefficient of variation showed low heterogeneity ($0.1 < CV < 0.2$), therefore, the measurement method was acceptable. The average visibility of the distal and the proximal marker did not differ significantly neither from each other ($p=0.2$), nor from the average values of the balloon ($p=0.94$).

Repeatability

Three series of measurements were performed by the first volunteer (the markers' visibility was compared to three different background segments). The average visibility of the distal markers compared with the first background segment was $12 \pm 2\%$ ($CV=0.16$); $12 \pm 2\%$ ($CV=0.15$) with the second background segment; $12 \pm 1\%$ ($CV=0.13$) with the third background segment.

The average visibility of the proximal markers compared with the first background segment was $13 \pm 2\%$ ($CV=0.18$); $13 \pm 2\%$ ($CV=0.18$) with the second background segment; $13 \pm 2\%$ ($CV=0.13$) with the third background segment.

The average visibility of the balloons was $13 \pm 2\%$ ($CV=0.17$) in case of first measurement; $12 \pm 2\%$ ($CV=0.16$) in case of second measurement; $12 \pm 2\%$ ($CV=0.12$) in case of third measurement.

The three series of measurements did not show significant difference for the values obtained for the distal marker ($p=0.88$), the proximal marker ($p=0.93$), and the balloon ($p=0.87$).

The values of the coefficient of variation were between 0.1 and 0.2 (which meant low heterogeneity) for all series of measurements. Therefore, the three visibilities could be averaged in all cases (distal marker, proximal marker and balloon). Significant difference was detect neither between the average

visibility of the distal and proximal markers ($p=0.06$), nor between the markers and balloons ($p=0.91$).

Due to coefficient of variation insignificant differences, the new developed measurement method was repeatable.

Reproducibility

The average visibility with other three different background segments for all the fourteen balloon catheters was determined by a second volunteer. The obtained values were averaged (due to the low heterogeneity: $0.1 < CV < 0.2$) and were compared to the relative visibility measured by the first volunteer. There was no significant difference between the values measured by different volunteers ($p_{\text{distalmarker}}=0.71$, $p_{\text{proximalmarker}}=0.90$, $p_{\text{balloon}}=0.82$). Therefore, the measurement method was reproducible as well.

4 Discussion

The current standard for balloon catheters (ISO 10555-1:2013, ISO 10555-4:2013) does not include a measuring method for determining, quantifying the visibility. The current standard for determining radiopacity (ASTM F640-12) for medical use does not contain device specific measuring method. We do not know, which part or parts of the device must be tested.

In this study an easy to use measuring method was described which is suitable to uniformly determine the visibility of the balloon catheters, so they become comparable with each other.

The measuring method consists of five steps:

- Making an X-ray microscopic only from the balloon. (We can use medical images or laboratory X-ray image too.)
- Cutting of the markers and the section (with same parameters) of the background from the X-ray image.
- Converting it into greyscale images.
- Comparison of the background and the marker with each other by the software.
- Averaging of the markers' visibility.

This measurement without the picture's making is maximum five minutes. This measurement method is easy to learn, or easy to follow an instruction guide.

I have determined by statistical analysis that

- the investigation of the distal marker is repeatable;
- the investigation of the proximal marker is repeatable;
- the visibility of the distal marker and proximal marker is not significant difference;
- the visibility of the distal marker and proximal marker is averaged;
- the mean of the distal and proximal marker can characterise the visibility of the balloon;
- this characterisation is available independently from the balloon diameter and length;
- the investigation of the mean of the distal and proximal markers are repeatable;

- our method for visibility determination is reproducible. I have defined that
- the balloon markers shall be investigated in case of balloon catheters;
- the average visibility of the markers is the visibility of the balloon catheters.

Visibility was obtained by my measuring method compared to the background on a percent scale from 0% to 100%. If the background and the settings of the imaging is the same then the visibility is comparable. In my case, the equal background and the settings were solved.

In this study the visibility of polymer balloons with two platinum iridium markers were determined; they visibilities were 13%. In the literature there is not basis for comparison, therefore we do not know that it is good or not. Further studies are needed on different materials to determine the minimum values, and the 'best' marker material.

5 Conclusion

We made an easy to use, repeatable and reproducible measurement method, which is suitable to determine the visibility of balloon catheters in five steps. We have determined, that the average visibility is the balloon markers can characterise the visibility of the balloon catheter, no need to examine the total balloon catheter.

In the near future the visibility of the available balloon dilatation catheters will determine by the described measurement method. A database will be making from these values and by the help of physicians determine the minimum visibility which is usable during to angioplasty procedure.

Acknowledgement

This work is connected to the scientific program of the 'Development of quality-oriented and harmonized R+D+I strategy and functional model at BME' project. This project is supported by the New Hungary Development Plan (Project ID: TÁMOP-4.2.1/B-09/1/KMR-2010-0002).

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