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SOURCES OF ERRORS IN BIOMEDICAL OBJECT MEASUREMENTS

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Abstract − The article presents measuring errors whose source is medical measuring device of one side and biomedical object of the other side. Medical standard is an important thing. It is called predicted value, where a big error is contained.

Many of these errors are disclosed whereas the other ones are not. Some of them can be avoided or diminished. It is possible when the observer is attentive and experienced.

Keywords: biomedical engineering, measuring errors.

1. INTRODUCTION

Measurements with using electronic measuring instruments have become an integral part of clinical assessment of all diseases. But the results obtained are still of many controversies.

When we assume that from the metrological point of view a measuring instrument is of a good quality, measuring results change (Fig. 1) [1].

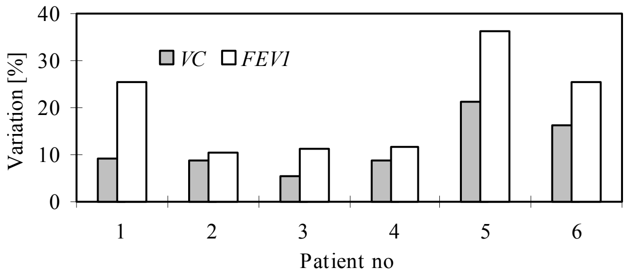

Fig. 1. Dispersion of some spirometric parameters measured in series (respectively: 10, 21, 10, 18, 8, 12 expirations). Remarks: *VC* (vital capacity) - the maximal gas volume expired after maximal, deep inspiration; FEV_1 (forced expiratory volume in one second) - gas volume obtained during forced expiration in the first second, counted from the starting point of expiration; variation δ is defined as: $\delta = (V_{max} - V_{min})/V_{max}$, where V_{max}, V_{min} - respectively: maximal and minimal value of volume, taken from a collection of samples. The differences are almost 30 %, what means that it is 0,2 dm^3 – 1 dm^3

One should answer the question what the source of such variations is. For a non-experienced investigator this is obvious: an instrument.

In biomedical engineering there are two types of uncertainties, that originate both from the instrument, as it was said above, and from the object measured.

In order to answer the question concerning errors, one must pay attention to the scheme of measuring process [2], characteristic only for biomedical investigations (Fig. 2).

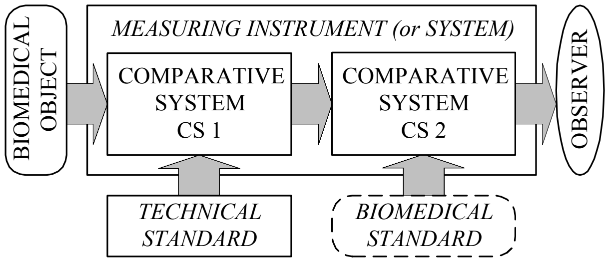

Fig. 2. Measuring structure for a biomedical object

For correct measuring experiment with a biomedical object two sources of standards must be used.

The first is *technical standard* needed for proper (right) instruments operation. This standard, chosen independently, made with a very high precision (e.g. 1 voltage standard) is used in many different instruments, constructed both for technical and for non-technical objects and phenomena tests.

The second is *biomedical standard*, "built" on the basis population tests of a huge group of people. It is characteristic only of such kind of measuring objects. It exists as a predicted value.

The obvious is that a biomedical object appears here twice: firstly, as an *unknown* object, secondly – as a *well-known* standard.

The quality of technical standard is usually known with high precision. The definition of biomedical standard causes many problems.

2. TYPES OF BIOMEDICAL DIAGNOSTIC SIGNALS

Many biomedical diagnostic signals are obtained independently of the patient's will, like during biochemical tests. Others can be modified by the patient or by the observer or both of them, respectively. Most of them change in time and are registered in a form of signals, important for medical diagnosis. These signals are of four types (Fig. 3):

1. spontaneous, existing independently of the patient's will (e.g. ECG signal),
2. specially modified by the patient (e.g. forced expiration),
3. modified by an observer (ed. evoked brain potentials),
4. caused by an artificial factor (e.g. rentgenographic signal

in densitometry).

The signal, which is the answer of the object' properties, changes and for this reason the measuring results interpretation is sometimes very difficult. The standardisation of this signal is possible only in some cases (see point ***3*** and ***4***, above).

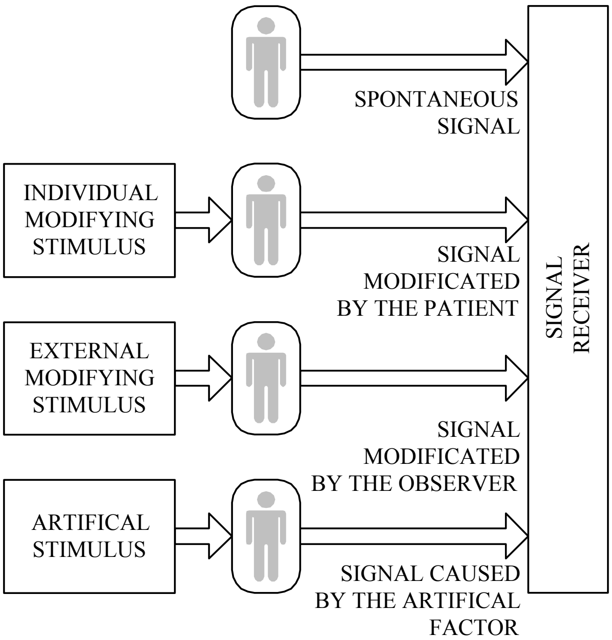

Fig. 3. The fundamental way of diagnostic signals generation in human body

Testing the respiratory system during forced expiration (see above, point ***2***) is a good example. The purpose of it is to disclose the mechanical properties of the lungs (flow resistance, lung tissue compliance) which is possible only when special testing signal is used (Fig. 4). At that moment the assumption is made that the exciting signal $S(t)$ has a well-known and unchangeable form.

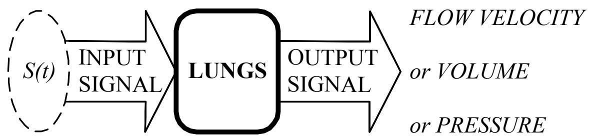

Fig. 4. Block diagram of lung testing. The patient generates testing signal $S(t)$ by himself. This signal depends on the patient's will. The assumption is made that $S(t)$ is a form of pressure jump $1(t)$

Theoretically $S(t)$ this is the pressure jump $P(t) = P_0\ 1(t)$. According to this excitation signal, the circuit answers in the way presented on Fig. 5.

This measuring situation is similar to this one, met in technical object testing, when transmittance $H(s)$ is being found [3], according to equation:

$$H(s) = \frac{S_{out}(s)}{S_{in}(s)} \qquad (1)$$

where $S(s)$ - input and output signal, respectively.

This is well known in practice that both beginning and final part of $V(t)$ curve are uncertain (see Fig. 5).

To avoid this problem ATS organisation [4] (American Thoracic Society) has presented the conditions, which must be fulfilled for the test acceptance from the point of view of signal testing:

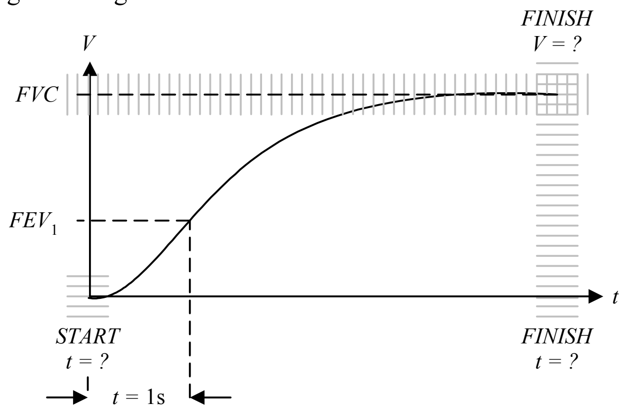

Fig. 5. The answer of the respiratory system in forced expiration. $V(t)$ curve has exponential form. This is the basis for two important spirometric parameters definition: FVC and FEV_1

A. acceptability, that means:
   1. satisfactory start of test (when $V(t)$ function is smooth at the very beginning),
   2. minimum exhalation time 6 seconds,
   3. early termination of expiration,
B. reproducibility:
   1. the set goal during a test result performance is to choose largest FVC value and second largest FVC, measured from acceptable curves $V(t)$, which should not vary by more than 5 % of reading or 0.100 dm^3, whichever is greater,
   2. identical criteria is in force FEV_1 parameter.

In this way the assumption concerning input testing signal $S_{in}(t)$ (on Fig. 4 - signal $S(t)$) has been made.

3. TECHNICAL SOURCES OF DIFFERENCES

The basic measuring uncertainty, which can't be avoided, flows from technical factors. This is mainly a measuring method and the instrument that carries out such a method.

They are:

– non-electric value transducer's linearity and precision,
– AD converter' resolution and precision (both sampling and quantisation),
– precision of other electronic blocks,
– generally: influence of different disturbances.

Many other measuring problems appear too (Tab. 1). Although at the first moment some of the above mentioned uncertainties seem to be "non-technical" they are, in fact, the result of using the instrument. Connecting the device to the patient can create an extremely different situation then during normal, spontaneous and nonextorted breathing and change his features substantially, giving unreal measuring results (this is pointed in Tab. 1, the letters in italics).

4. BIOMEDICAL SOURCES OF DIFFERENCES

A measured biomedical object has a specific feature that discriminates it from all the others, so-called “technical” objects. This is *biological changeability* that manifests during both a patient’s observation and a population test as well [5]. There are different causes of this changeability (Tab. 2).

TABLE 1. The sources of errors in biomedical errors conditioned by technical factors. The letters in italics show only the influence on a patient, resulting from his presence

No.	The source	Uncertainty characteristic
1.	Measuring instrument only	1. realised method - direct or indirect way of determination of biomedical object’ feature, 2. sensor sensitivity, accuracy, linearity, repeat-ability, ageing effect etc., 3. accuracy of data processing (sampling, quanti-sation, calculations), 4. additional (surrounding) influences like tem-perature, pressure, electromagnetic disturban-ces, etc.,
2.	Interactions	5. *patient - instrument*, e.g. adaptational stress, 6. *patient - observer*, e.g. psychical stress, 7. observer - instrument, e.g. observer fatigue, reading mistakes,
3.	*Patient effects*	8. *understanding of need of co-operation with the instrument*, 9. *the weariness caused by the test prolongation*,
4.	Observer effects	10. the medical test leading,
5.	The proce-dure of definition the final measuring values	11. results valuation, 12. number of tests, 13. choice of the most substantial results, 14. choice of the final result measure, 15. choice of predicted values (standards) such as the reference value.

TABLE 2. The sources of biological variation in biomedical object’ measurements

No.	Kind of variation	The source
1.	Intra-subject	1. measurement errors, 2. diurnal and seasonal effects, 3. endocrinologic effects,
2.	Inter-subject	4. all the above, 5. personal e.g. size, sex, age, race, past and present health, physical activity, race, genetic characteristics, 6. environmental,
3.	Inter-population	7. all the above, 8. selection factors determining inclusion or exclusion from the population tested

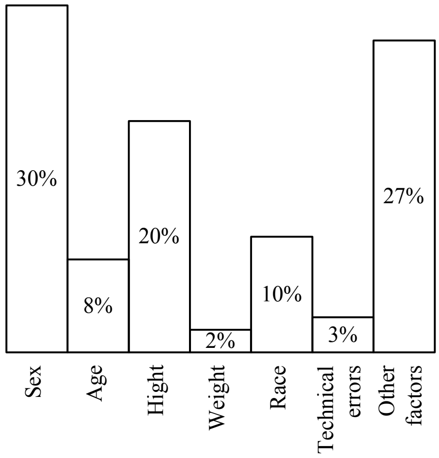

Fig. 6. Inter-subject variation in spirometric parameter *FVC*

The important thing is predicted value of every medical parameter that is used during finding pathological symptoms.

Individual patients’ features decide about inter-subject biological variation (Fig. 6). This is the next reason why medical standards are known with high uncertainty.

The last and very important reason is that predicted values are defined in different “statistical” conditions: number of patients, different age, etc. The result is different value of linear correlation coefficient, which precises final equation in order to calculate the value of predicted parameter, individually for the patient (compare: Fig. 7).

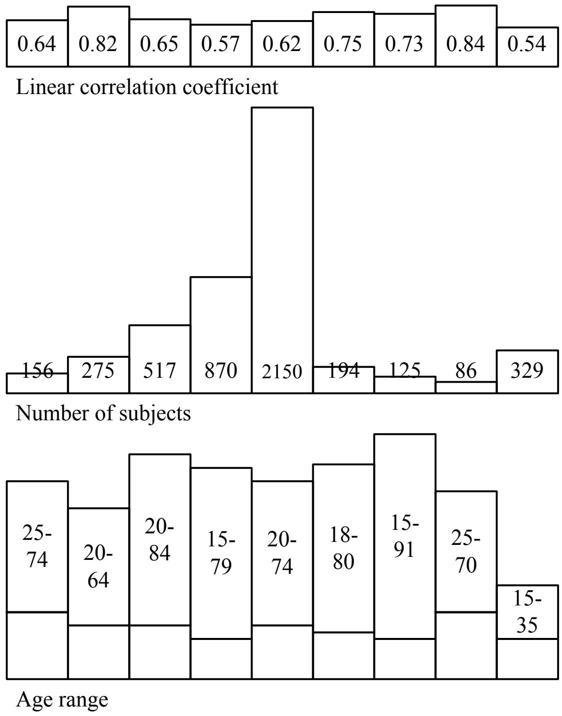

Fig. 7. Different conditions of defining the predicted values as an example of ventilation parameter *FVC*

A crucial thing observed during testing a biomedical object is that there exist sources of unexplained variation, that can sometimes play a very important role and, which is worst, impossible to notice and impossible to eliminate. The relation in such specified variation sources is presented in numbers on Fig. 8. They concern all investigations whose results are presented on Fig. 6 and 7. In this way all of the obtained numerical results of predicted value seem to be doubtful.

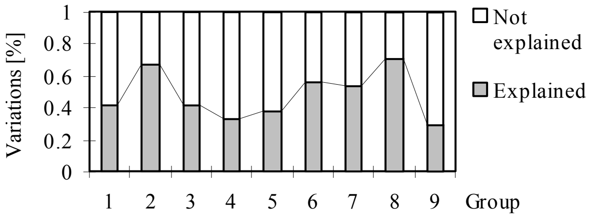

Fig. 8. Explained and unexplained sources of variation in lung tests that appeared during tests of different groups of patients

5. CONCLUSIONS

There exist similarities in the results interpretation of two categories of objects: technical and biomedical. It is more difficult to conduct measuring experiment with a biomedical object (naturally changing) than it is with a technical object. Many problems appear when the tested patient intentionally changes his state and wants to taint his medical parameters.

There exist two categories of the sources of uncertainties. The first is well known and comprises the measuring method, measuring instrument features and influence of surrounding environmental conditions.

The second category: it is not easy to notice how the measuring instrument can influence a patient and his medical features (so called adaptational stress).

The big problem is contained in medical predicted value identification because it is almost impossible to “construct” it for a very large group of patients in the same condition from a statistical point of view.

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