Penetration Ability of Microfocus X-Ray Radiography

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I. INTRODUCTION

The concept of "Microfocus X-ray radiography" includes a combination of techniques of X-ray imaging using radiation sources with focal spot size of less than 100 microns [1]. Research carried out over 20 years at the St. Petersburg State Electrotechnical University. VI Ulyanov (Lenin) "LETI", showed that the use of microfocus sources for the purposes of medical diagnosis shows a number of features of getting X-ray images of the inspected organ. Now fully studied and evaluated, so-called, the effects of increasing the contrast, reduction the exposure dose, a pseudo-3D image, phase contrast and other [2]. Thanks to these effects, principally increased informativeness of received X-ray images combined with a decreased dose to patients and medical staff. And the power consumed by the X-ray apparatus designed for microfocus X-ray radiography in one or two orders of magnitude smaller than the apparatus used in the standard X-ray radiography, when shooting the same objects.

In 1997, Harvard economist Clayton M. Christensen [3] first used the term "disruptive technology" to describe a new technology, in fact, "close" any existing. For example, digital cameras and camcorders by CCDs have replaced traditional film cameras and camcorders, and plasma panels - picture tubes in TVs. From this point of view, Microfocus X-ray radiography- Russian disruptive technology in medical diagnosis.

II. MATERIALS AND METHODS

Traditionally, X-ray radiography of objects is performed by contact shooting method standard radiography [4]. When shooting a contact method (Fig. 1), a source of radiation (1) with an extended focal spot *d* (d_1≈1 mm). Object 2 is located at a great distance *f* from the radiation source 1 and very close - "in contact" with the receiver of radiation 3 (Fig. 1a). Shows clearly that, first, the size of the focal spot *d*, and the distance between the source and the object *f* significantly influence on quality (blurriness Hr) images. The value of the distance *f* is chosen on the basis of the requirements for the blurriness of the images, in the particular size of focal spot of X-ray tube d_1 and the object thickness. Second, even a small increase in the distance between the radiation detector and the object to a distance $\Delta f = f - f_1$ leads to a significant deterioration of image quality due to increased blurriness Hr (Fig. 1b). Clear that for reduce blurriness of image necessary increase the distance between the object and the radiation detector.

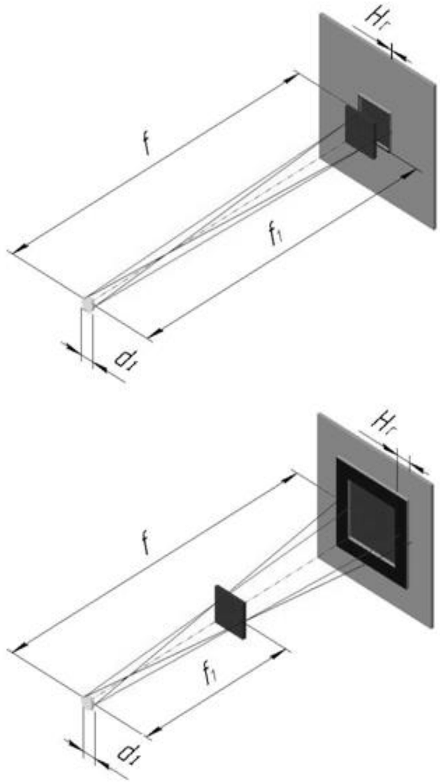


Fig.1 Optical scheme shooting in standard radiography: a – contact method; b – method with the increase.

When shooting with the increase the image used, the so-called point source of radiation 1 with micron focal spot *d* (d_2 <0,1 mm). Object 2 (Fig. 2) is located at a certain distance from the source as well as from the radiation detector 3. No matter in what position is the object in the space between the focal spot of the radiation source and the plane of the detector, the sharpness of the image is preserved (Fig. 2b).

Ratio of the distances *f* and f_1 determines coefficient of increase image of the object m compared to its true geometric dimensions

$$m = \frac{f}{f_1} .$$

To demonstrate the benefits of Microfocus X-ray radiography compared to the standard used the test object (skull of cat), which contains details of the structure size from a few tens of micrometers (Fig. 3).

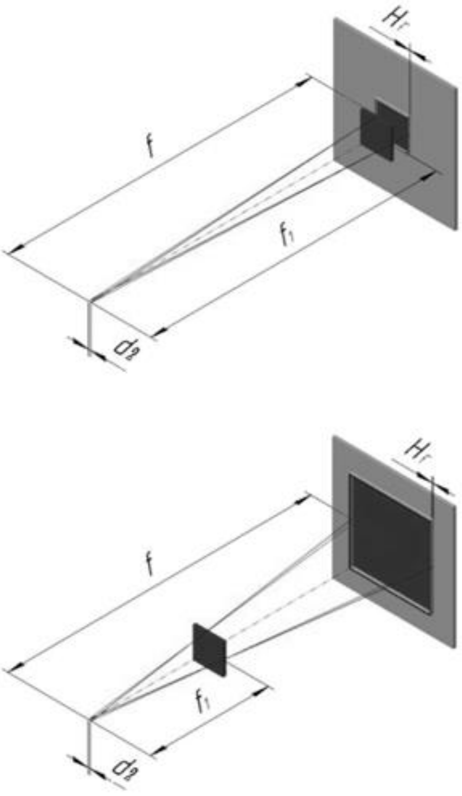


Fig. 2. Optical scheme shooting in Microfocus X-ray radiography:
a – contact method; b – method with the increase.

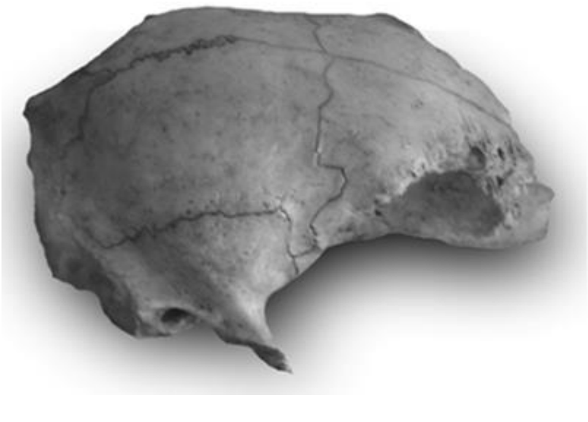


Fig. 3. Skull of cat.

In Fig. 4 shows the X-ray images of the test object, obtained by the method of standard radiography using apparatus with extended focal spot (d ≈ 1 mm) image without increase - contact (Fig. 4a) and with increase 2, 4, 8 times (Fig. 4b-d). Clearly seen that with increasing magnification of the image, informativeness of the images is reduced compared with the contact images due to appear blurriness of image.

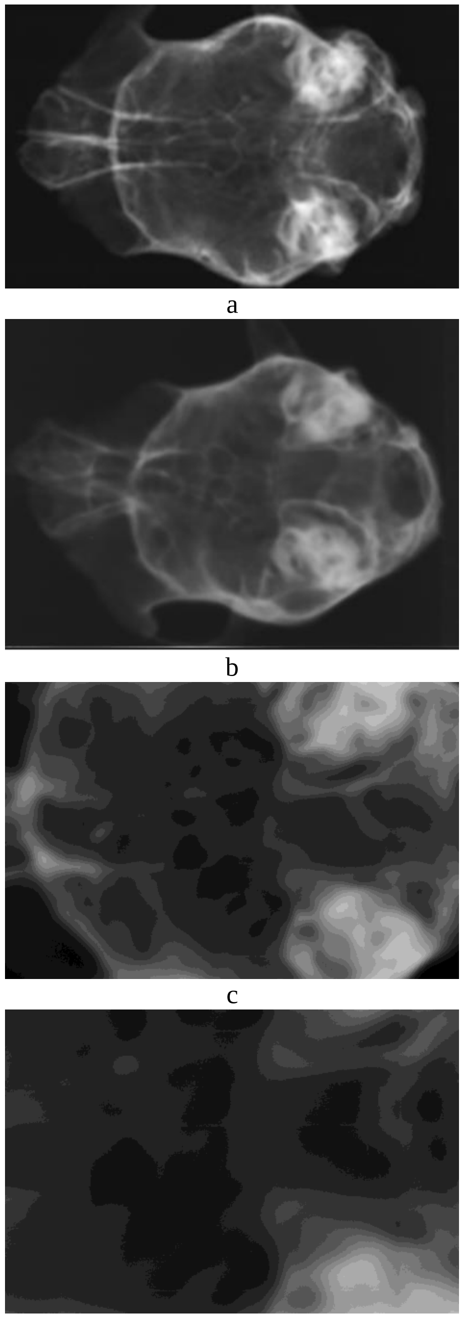
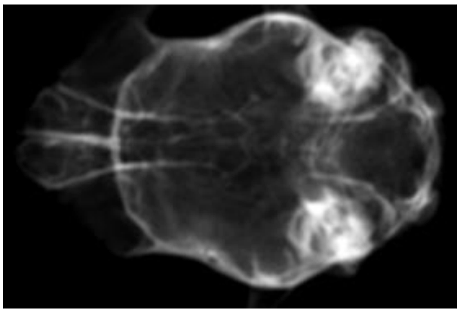
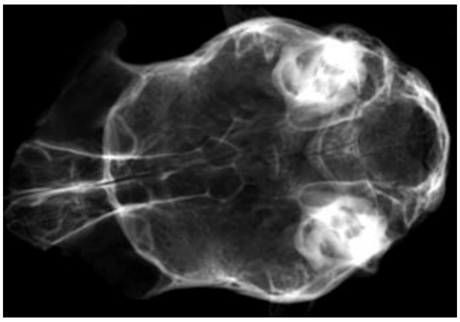


Fig.4 X-ray images of the test object obtained on the apparatus with an extended focal spot.

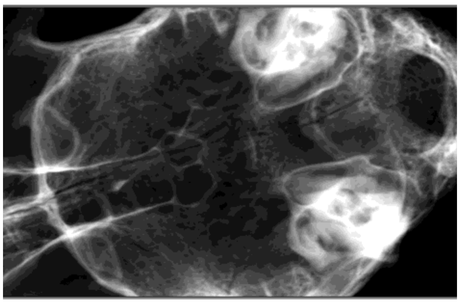
In Fig. 5 shows the X-ray images of the same test object, obtained by the method of Microfocus X-ray radiography on the apparatus with a point focal spot (d <0,1 mm) image without increase (Fig. 5 a) and with increase 2, 4, 8 times (Fig. 5 b-d). On the microfocus snapshoot with image increase not only retains its sharpness, but appear the new details of the structure of the object, not previously visible on the contact microfocus picture.



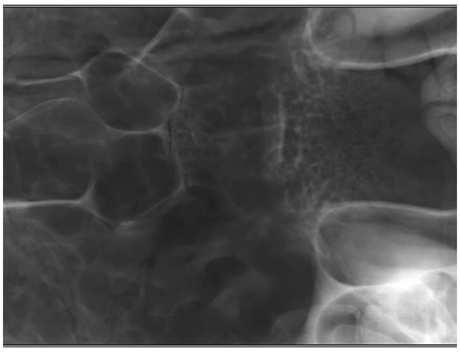
a



b



c



d

Fig.5. X-ray images of the test object obtained on the apparatus with point focal spot.

To estimate the diagnostic capabilities of X-ray radiography methodic created the notion of "penetration ability" which is characterized by power of X-ray source used to implement this methodic in a particular field of medicine [5]. Compare the penetration ability of Microfocus X-ray radiography and standard radiography methodics allows the ratio η of power P_1 and P_2 which are on the target of X-ray tube while shooting the same object on these methods in the respective devices, subject to obtaining the required quality of image

$$\eta = \frac{P_1}{P_2} \ .$$

III. RESULTS AND DISCUSSION

1. In evaluation the penetraion ability microfocus and standard techniques in dentistry studied Russian microfocus apparatus "Pardus-R" and Korean apparatus with extended focal spot "PORT-XII", both - in a portable version (Fig. 6).

The evaluation was conducted by analyzing the physical and technical conditions of dental shooting in non-specialized conditions, to define this conditions were used the table expositions for the Microfocus and standard X-ray radiography on portable devices. [6].

a

b

Fig. 6. Modern portable dental X-ray apparatus: a – Microfocus X-ray apparatus, b – apparatus with an extended focal spot.

TABLE 1. **PHYSICAL AND TECHNICAL CONDITIONS OF DENTAL SHOOTING WITH PORTABLE APPARATUS**

Shooting conditions	PARDUS-R	PORT-XII
Voltage, kV	55-65	60
Current, mA	0,15	2
Power on the target during shot, W	10	120
Maximum exposition time, sec	0,3	0,5
Maximum exposition of shoot, mAs	0,045	1
Skin-focus distance, mm	50	200

Comparison of conditions of dental shooting by the methodics of microfocus and standard X-ray radiography (Table 1) shows that:

- maximum exposition of one shoot on microfocus apparatus was 0.045 mAs. This is a record low value compared to any conventional dental apparatus;

- penetration ability of Microfocus X-ray radiography in dentistry, characterized by the ratio of power on the target X-ray tube in dental shooting, power on the apparatus with the extended focal spot at the contact shooting (Pc = 120 W) and on the apparatus with a point focal spot at the Microfocus shooting (Pm = 10 W)

$$\eta = \frac{P_{ê}}{Ð_{ì}} = 12 ,$$

penetration ability on the order above, than with a standard X-ray radiography.

Analytical evaluation of penetration ability of Microfocus X-ray radiography in dentistry is calculated by the following formula [7].

$$\eta = \frac{P_{ê}}{Ð_{ì}} = \left(\frac{m_{ì}}{m_{ê}}\right)^2 \cdot \left(\frac{f_{ê}}{f_{ì}}\right)^2 \cdot \frac{(1+\delta_{ê})}{(1+\delta_{ì})} \frac{t_{ì}}{t_{ê}} \qquad (1)$$

m – coefficient of increase, *f* – focal distance, δ – ratio of intensity of the scattered radiation to the primary intensity, *t* – exposition time (letter "m" marked conditions of Microfocus shooting, "c" - contact shooting) under the following conditions:

$$m_{ì} / m_{ê} \approx 1{,}3 ;\; f_{ì} / f_{ê} = 3 ;\; (1+\delta_{ê})/(1+\delta_{ì}) \approx 1 ;$$

$$t_{ì} / t_{ê} \approx 1$$

gives a value of $\eta = 16$.

2. In evaluation of penetration ability of Microfocus X-ray methodics in traumatology were made snapshots of the distal extremities with using Microfocus and standard (contact) methods of shooting [8]. Were examined, more than 70 patients with various injuries and diseases of bones and joints. Performed mostly snapshots of the lower extremities - foot, leg, knee.

The radiation source in Microfocus method of shooting used X-ray apparatus family "Pardus", in contact method in standard X-ray radiography - X-ray apparatus "Diagnost-56". The detector of X-ray image - visualisation system AGFA CR-85.

Figure 7 shows snapshots of metatarsus obtained by the methods of Microfocus and standard X-ray radiography.

b

Fig. 7. X-ray snapshots of metatarsus: a – Microfocus X-ray radiography, b – standard X-ray radiography.

During the research were compared physical and technical conditions of shooting of ankle Microfocus method with contact method of standard X-ray radiography (Table 2).

TABLE 2 **PHYSICAL AND TECHNICAL CONDITIONS OF EXTREMITIES SHOOTING**

Shooting conditions	Diagnost-56	PARDUS-Trauma
Voltage, kV	44	80-125
Current, mA	40	0,15
Power on the target during shot, W	1760	20
Maximum exposition time, sec	0,625	1-1,5
Maximum exposition of shoot, mAs	25	0,225
Skin-focus distance, mm	1000	200 - 250

Comparison of conditions of shooting in X-ray diagnosis of extremities in the experiment shows that in clinical traumatology Microfocus X-ray apparatus, power 20 W, has the same penetration ability as the apparatus, power 1760 W, in a standard X-ray radiography in contact method of shooting.

Power ratio at comparable image quality

$$\eta = \frac{P_{ê}}{Ð_{ì}} = 88 .$$

Analytical evaluation of penetration ability of Microfocus X-ray radiography in traumatology to the expression (1) with the following averages for this type of research conditions. $m_{ì} / m_{ê} = 2,5$, $f_{ì} / f_{ê} = 3$, $(1+\delta_{ê})/(1+\delta_{ì}) = 2$, $t_{ì} / t_{ê} = 1,6$ gives a value of $\eta = 180$.

Almost double difference in the experimental and analytical evaluations of penetration ability of Microfocus X-ray radiography in traumatology can be caused by a wide range of changes in the coefficient of increase and focal distance for specific areas of larger and three-dimensional objects of shooting than in dentistry.

III. CONCLUSION

Results of clinical tests of Microfocus X-ray diagnostic systems for dentistry and traumatology confirm the validity of selection of Microfocus X-ray radiography for create a truly low-doze technology of X-ray radiography examination, including, nonstationary conditions and the safety in X-ray examination with using X-ray apparatus.

The development of more powerful microfocus X-ray sources, for example, on the basis of small X-ray tube with a rotating anode, will allow to approach the diagnostic capabilities of microfocus X-ray apparatus to the characteristics of modern X-ray apparatus for the standard X-ray radiography.

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