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Grid-controlled fluoroscopy in paediatric radiology

Grid-controlled fluoroscopy has been adapted to meet the specialized requirements of paediatrics.

Diagnostic radiology places ever-increasing emphasis on the demand for reducing the radiation dose, combined with the smallest possible loss of diagnostic information in the radiographic images. To meet this demand, Philips developed a system for grid-controlled fluoroscopy, which was introduced about one year ago. Clinical results indicate that this system can reduce the patient dose by as much as 80 %. As paediatric radiology pays particular attention to radiation protection, the demand soon arose for adaptation of the grid-controlled fluoroscopy system to the specialized needs of paediatrics.

This article defines the requirements for a development of this type, and presents the results of our laboratory measurements together with the first clinical experience with the new system.

Requirements of paediatric radiology

The rapidly growing tissue of the child is up to eight times more sensitive to ionizing radiation than adult tissue. In addition, the life expectancy of a child is naturally greater than that of an adult, so that radiation-induced tumours occur more frequently. Genetic damage is also more likely to be passed on to subsequent generations. Thus, unlike the situation with adults, the 80 % reduction in patient dose cannot be regarded as sufficient for children.

In paediatric radiology, we have to aim for a significantly higher reduction in patient dose. The technology developed for the paediatric grid-controlled fluoroscopy system allows a dose reduction by a factor 8 to a factor 25 to be achieved, without restricting the range of diagnostic applications.

In order to be able to develop a fluoroscopy system suitable for paediatric applications, with such a high potential for dose saving, the developers must be fully aware of all the requirements for paediatric radiology. These requirements were therefore first defined in a study conducted together with several users, in order to provide a basis for the subsequent development work.

For the sake of clarity, the underlying technical concepts of the grid-controlled fluoroscopy system are described below, together with their principles of operation and their medical relevance.

1. The user must be able to select a special kV/mA curve for paediatric applications.

2. The user must be able to select an additional setting for 50 % less dose at the input of the image intensifier.

3. The pulse length (5–20 ms for adults) must be reduced to (typically) 2–10 ms for paediatric applications.

4. Special dynamic dose correction is needed to virtually eliminate undesirable dose increases during fluoroscopy.

5. Parallel control must be provided for selecting the pulse frequency from both the image intensifier holder and the generator control desk.

Table 1. Requirements for adapting grid-controlled fluoroscopy for paediatric applications.

Technical refinements and their medical relevance

Table 1 shows the special demands made by paediatrics on a system for pulsed fluoroscopy. The various technical refinements achieved in the course of the product development are presented below, and compared with the standard version of the system.

1. Special kV/mA curve

In paediatrics, exposures and fluoroscopy are often used only for assessing the shape, position

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and size of organs (e.g. digestive tract) or bones (e.g. spine, pelvis, hip joints, femur). This does not always place the same demands on detail recognition as the X-ray diagnosis of lesions or pathological processes in adult patients.

Appropriate use of a special kV/mA curve for paediatrics allows the user to dispense with redundant image quality, depending on the clinical application, in favour of a drastic reduction in the patient entrance dose rate.

The paediatric curve (Fig. 1) can be selected by the user, and is particularly important for premature and full-term newborn infants, as well as for children up to about 6 or 10 years of age. In these small patients, the examination is carried out without an antiscatter grid, in the range from 65 to 85 kV. As the objects are relatively 'thin', with a correspondingly weak absorption, the high kV required can only be obtained by using a specially developed kV/mA characteristic curve.

2. Additional doserate setting
Where there is a reduced requirement for detail rendition in favour of a lower patient dose, the image intensifier input dose (ID) can be reduced by an additional 50 %. However, at this low doserate, the fluoroscopy voltage would fall below the recommended minimum of 65 kV if it were not increased by the special paediatric kV/mA curve.

In other words, a further reduction in dose can only be achieved by the combination of the additional doserate setting with the special paediatric kV/mA curve.

The kV remains in the required high range, even when the object has low absorption.

3. Reduced pulse length
Due to the higher respiration frequency in children and the probable lack of response to such commands as 'hold your breath' or 'keep still', pulsed fluoroscopy requires very short pulses, i.e. shorter pulses than those used with adults. Instead of pulses of 5–20 ms, only pulses of 2–10 ms can be used in paediatrics (Fig. 2).

4. Dynamic dose correction
Children are not small adults. In very young children, in particular, the inability or unwillingness to co-operate presents a problem. For this reason, a successful X-ray examination requires adequate immobilization of the child. In this case, it is not always possible to prevent

The dynamic dose correction can be set to work in a one-way mode, so that the dose can only be reduced.

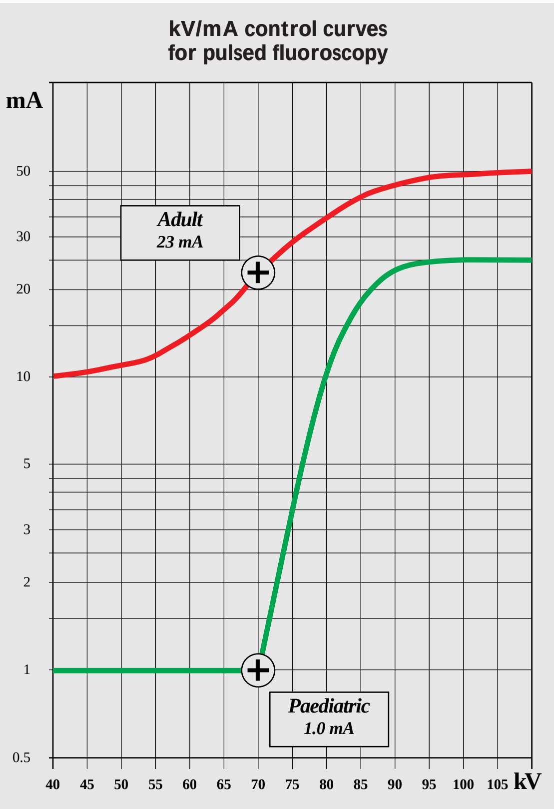

Fig. 1. kV/mA curves for 'paediatric' and 'adult'. In the 'paediatric' mode, the tube current is reduced (e.g. by a factor of 23 at 70 kV) in order to remain in the 65–85 kV range.

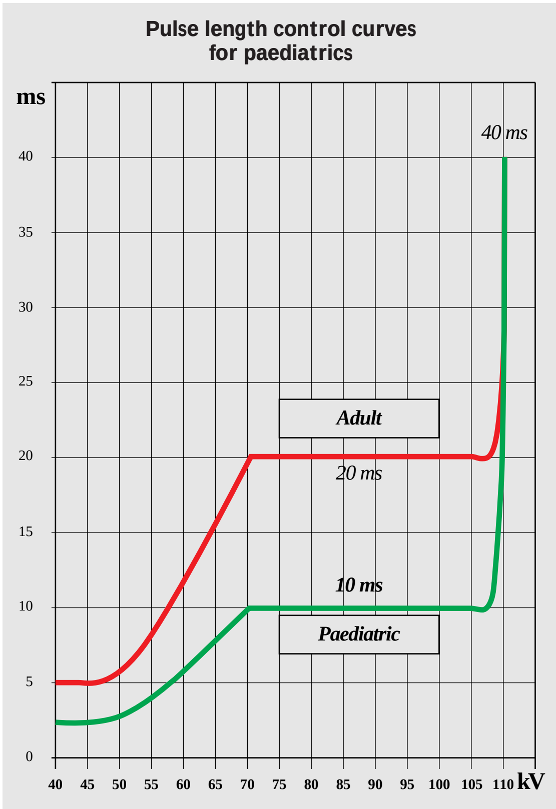

Fig. 2. Reduced pulse lengths for paediatrics. In the 'paediatric' mode, the pulse length is reduced by a factor of 2 to ensure sharp images, even during movements.

In paediatrics, the pulse length can be extremely short.

The examiner dispenses with redundant image quality in favour of a drastic reduction in radiation dose.

the hand of the person holding the child, or part of the immobilization device, coming into the X-ray beam, causing the automatic doserate control to increase the dose.

Dynamic dose correction must virtually eliminate this effect. In our design, the doserate control is blocked by a 'one-way object control', so that it can only work in the direction of reducing the dose.

Two examples of the medical relevance of dynamic doserate correction are given below.

Example 1. The examiner has to hold or guide the child with both hands during the X-ray examination. As a result, his lead gloves come into the measuring field. The normal automatic doserate control would see the lead glove as part of the object, and increase the dose accordingly.

Example 2. In the interests of radiation safety, the examiner does not wish to use the automatic doserate control in fluoroscopy of small objects during the administration of contrast medium. If he presses the 'one-way object control' button before the administration of contrast medium,

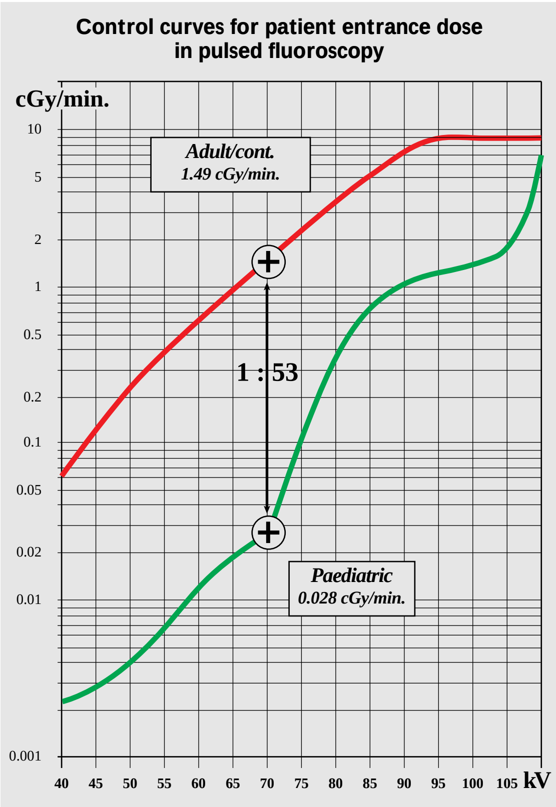

Fig. 3. Patient entrance doserate (PED) in paediatric pulsed operation and continuous fluoroscopy in adults. For the same image intensifier input dose (ID), the PED is reduced by a factor of 53.

the contrast medium will have no effect on the radiation dose. However, if there is a reduction in the thickness of the object and, consequently, in the absorbtion in the radiation beam, the automatic doserate control will work, as usual, in the required way.

Thus, the dynamic dose correction ensures that there is no undesirable increase in the dose to the patient, and effectively prevents the 'radiation but no information' effect.

Fig. 4. Control room showing the generator control desk. The GCF controls are on the left.

5. Parallel control
It must be possible to select the pulse frequency both from the image intensifier holder and from the generator control desk. When the examiner is holding or guiding the child himself, he will not have a hand free to change the pulse frequency during fluoroscopy. In such cases an assistant can use the parallel control to change the pulse frequency on command, via the generator control desk.

Application and operation

In the development of the system, every effort was made to ensure that operation requires the minimum of attention from the user. The examiner can operate all control functions himself while the radiation is on, without losing time.

Two ways to reduce the dose
The examiner can control both the image intensifier input dose (ID) and the patient entrance doserate (PED). In this way the ID can be increased to reduce the visibility of quantum noise in the image, which occurs at a low PED, to the extent required for the clinical application.

The PED can be changed by selecting the appropriate control curve: 'paediatric on' mode for the paediatric curve, or 'paediatric off' mode for the adult curve (Fig. 1).

The image intensifier entrance dose is reduced by using the 'dose' button. In the 'paediatric on' mode it can be reduced to 50 % or 25 % at choice. In the 'paediatric off' mode, the button switches between 100 % and 50 %.

Three levels for image quality and dose
The user's subjective experience of the quality of the fluoroscopy images depends on the physiological laws governing visual information processing, with its extremely nonlinear response. For this reason, image quality cannot be formulated and understood in absolute terms, but only in relation to a specific medical task.

On the basis of this understanding of image quality, the paediatric option allows the patient entrance doserate to be varied over a wide range. This enables the dose, and hence the image quality, to be adapted to each clinical application. The examiner can choose between three quality levels and the corresponding reductions in dose.

Level 1: ca. 4x dose reduction. This level provides optimum image quality. Typical applications are examinations of the digestive tract, and skeletal diagnostics.
Select adult curve and 100 % image intensifier input dose.

Level 2: ca. 10x dose reduction. This level provides reduced image quality with a somewhat lower signal-to-noise ratio. Typical applications are display of the digestive tract as a coarse contrast study.
Select paediatric curve and 50 % image intensifier input dose.

Level 3: ca. 25x dose reduction. This level provides greatly reduced image quality, which is nevertheless generally acceptable for many applications. Typical applications include gastro-intestinal function studies.
Select paediatric curve and 25 % image intensifier input dose.

Switching from adult to paediatric
When 'paediatric on' is selected in the pulsed fluoroscopy mode, the following technical parameters are changed in the background.

1. The patient entrance doserate (PED) is significantly reduced and a suitable kV value for paediatrics is selected in accordance with the recommendations of the relevant European standards.

2. The image intensifier input dose (ID) is reduced to 50 %.

3. The pulse length is reduced to an appropriate value for paediatrics and the object to be examined, typically from 2 to 10 ms.

4. The 'lock-in' button takes over the 'one-way object control' function. Automatic doserate control in response to changes in object density can only take place in the direction of lower dose.

5. The total pulse current sector will be switched to appropriate value pairs for paediatrics:
40 kV/1 mA – 70 kV/1 mA – 110 kV/25 mA.

The functions of the standard version of the grid-controlled fluoroscopy system, such as last image hold, image grabbing and fluoro filming are, of course, still available in the paediatric version. Because image grabbing and fluoro filming select images during fluoroscopy, they are of particular significance in paediatric applications.

The required image record is obtained in parallel with normal fluoroscopy, without additional radiation exposure. Fluoro filming also allows dynamic studies to be made with expenditure of time or the need for additional equipment such as a video recorder.

Three image-quality steps can be selected to meet different clinical requirements.

The required image record is obtained in parallel with normal fluoroscopy, without additional radiation exposure.

Examples of clinical images

The applicational possibilities of grid-controlled pulsed fluoroscopy can, of course, only be realistically presented in the live fluoroscopic images. The images shown overleaf can give no more than an inadequate impression. In Figure 4, a dynamic test phantom is used to show the effect of grid-controlled pulsed fluoroscopy on the image quality. It clearly demonstrates the superiority of pulsed fluoroscopy in showing moving objects. In fact, the results were far better

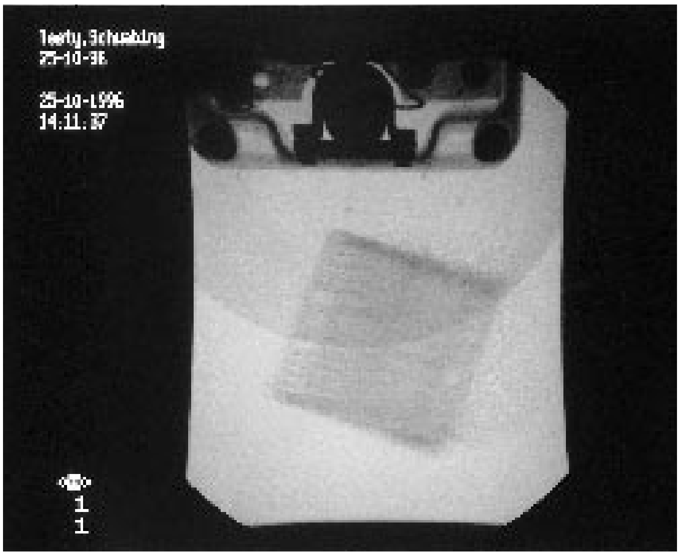

Fig. 5 a. Pulsed fluoroscopy with test card placed on dynamic test phantom. Speed at the periphery is 20 cm/s. Continuous fluoroscopy. Relative dose at object = 100 %. **100 %**

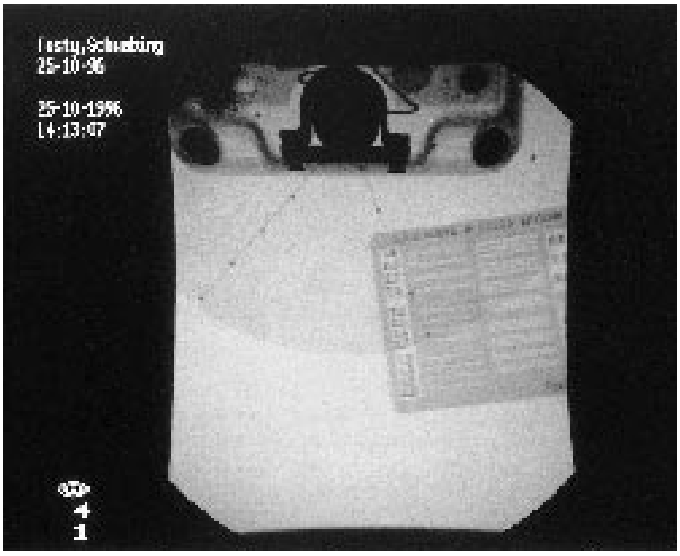

Fig. 5 b. Pulsed fluoroscopy with 'paediatric on' and reduced image intensifier input dose (ID minus). Pulse frequency 1.6 fr/s. Relative dose = 4 %. **4 %**

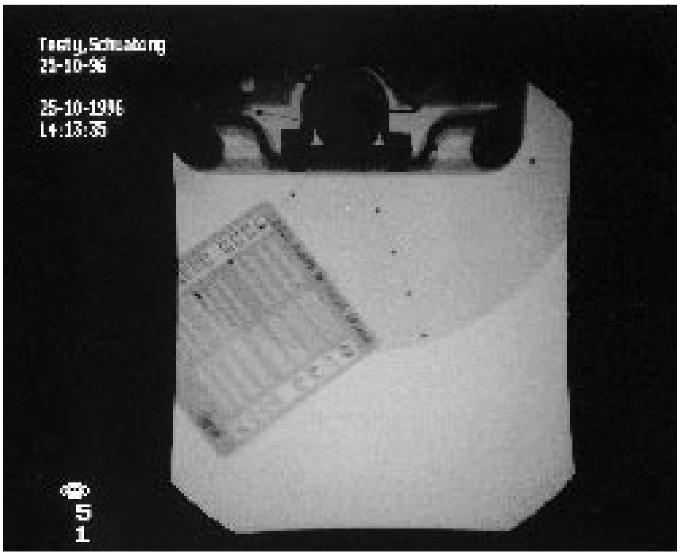

Fig. 5 c. Pulsed fluoroscopy with 'paediatric off', i.e. with characteristics for adults. Pulse frequency 3.12 fr/s. Relative dose = 18 %. **18 %**

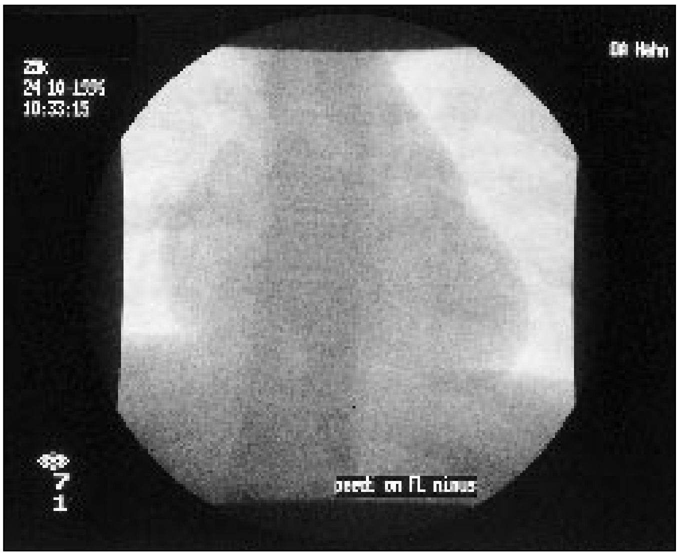

Fig. 6. Paediatric heart. Pulsed fluoroscopy with 'paediatric on' and reduced image intensifier input dose (ID minus). Pulse frequency 1.6 fr/s. Relative dose (PED) = 4 %. **4 %**

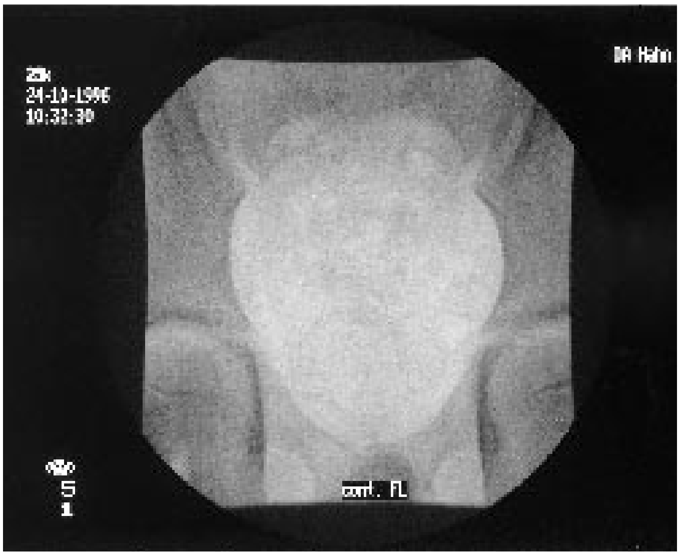

Fig. 7 a. Image of the bladder in a 7 year old child. Conventional continuous fluoroscopy. Relative dose (PED) = 100 %. **100 %**

Fig. 7 b. Pulsed fluoroscopy with 'paediatric on' and reduced image intensifier input dose (ID minus). Pulse frequency 1.6 fr/s. Relative dose (PED) = 4 %. **4 %**

than many of us expected. The loss of image quality is also much less than expected, even at extremely low doses.

Figures 6 and 7 show corresponding clinical examples. For those who are not directly involved in paediatric radiography, even the image made with continuous fluoroscopy (Fig. 7 a) may appear unusually noisy. However, it was made using the parameters that are now usual in paediatric radiology. The pulsed images are fully adequate for diagnosis of the clinical problem. The resolution is evident from the fact that an empty catheter can be seen. All images were acquired from a fluoroscopy run using the image grabbing function.

Realization and prospects

The paediatric grid-controlled fluoroscopy project was carried out in close co-operation between the clinical users and the Systems Development Group of Philips Medizin Systeme in Hamburg.

Since March 1996, the system has been undergoing tests in clinical application. In brief, the application tested has been completed to such an extent that those interested can visit the application site, on application to the authors, to form an impression of the possibilities of this new technology for themselves.

The authors are certain that the grid-controlled fluoroscopy technology will set new standards, not only paediatrics, but in radiology as a whole.

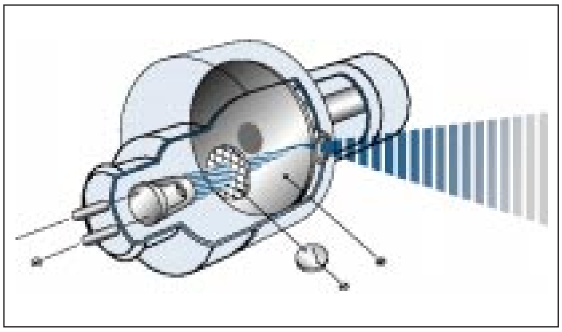

Fig. 8. Principle of the grid-controlled X-ray tube. The grid between the cathode and the anode can switch very short X-ray pulses with extremely steep flanks.

Pulsed fluoroscopy with a grid-controlled tube allows the dose in paediatric radiography to be reduced by a factor of 25x.

Conclusion

Pulsed fluoroscopy with the new paediatric system makes it possible, depending on the pulse frequency used, to achieve a dose reduction by as much as a factor 25 in comparison with conventional non-pulsed fluoroscopy.

This has only been made possible by the use of a grid-controlled tube (Fig. 8) connected to the 'Trinity' control system.

In the future, this technology could also be applied to classical radiography. In spite of the high costs likely to be involved in the development of grid-controlled radiographic techniques, the improved radiation safety and the improved image quality should lead the industry and governments to encourage this new technology.

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