Studying of Selective Common Factors Affecting Radiographic Quality and Related Exposure Doses

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Abstract: In recent decades, there were spectacular developments in imaging technology that lead to substantial enhance in using the radiography in diagnosis of diseases. This study aims to investigate the effect of some potential factors that may influence the radiographic quality and the relative exposure dose. These factors are the exposure dose, the focal size, the filters thickness and grid. Data analysis was done using EXCELL and JAVA SE (JRE) V. 6 software to convert the analogue image into digital. The data showed that the object dose in mGy and dose area product (DAP) in $mGy.cm^2$ were significantly increased ($R^2 = 0.9$) by factors of 0.09 and 0.04 per mA respectively. The broad focus gave high dose and DAP as (0.28 mGy and 2.18 $mGy.cm^2$) compared to fine focus as (0.14 mGy and 1.11 $mGy.cm^2$) respectively. The system output (O/P) in mGy and DAP were significantly increased ($R^2 = 0.9$) by factors of 1.02 and 1.05 respectively when the kVp increased up to 80. The presence of a filter significantly ($R^2 = 0.9$) reduced O/P and DAP to the object by a factor of 5.5 $mGy.cm^2$ and enhanced the image contrast but it reduced the image sharpness when a thick filter was used. The grid showed more homogeneous image contrast and eliminated the scatter, but it reduced the image sharpness. Finally, the data suggest that using image enhancing devices may increase the object dose and it should be done under "As Low As Reasonably Achievable" (ALARA) principles.

Keywords: Exposure-Factors, Image-Characteristics, Dose, Quality, Enhancement

Introduction
During the last decades, there were great developments in imaging technology including enhancement of detectors and resolution capability. In addition, there were magnificent developments in software used for reconstruction and displaying the anatomical and pathological results. So, radiological imaging was used for a wide range of clinical situations [1].

The basic task of medical diagnostic radiology is to provide high quality diagnostic image information about any disease or anatomical detail. Although, the best possible diagnostic information is required, the dose that the patient received should be kept to a minimum according to ALARA principle. This is the basic aim of quality assurance (QA) program optimization of radiological practice [2].

The radiographic exposure factors are under the control of the operator except for those fixed by the design of the x-ray machine. Within certain limits, increasing the image quality requires an increasing in patient exposure. The three basic image quality factors; contrast sensitivity, details and noise are related to patient exposure [3,4,5].

Several factors can influence the radiographic image quality. The most common of which are the exposure factors, the distance, the grid, the filter, the detectors, the contrast media and the compression band.

The exposure factors that can be controlled by the operator are the kilovoltage peak (kVp), Milliampair (mA), and Milliampair per second (mAs). The kVp is the unit used to measure the kinetic energy of an individual electron in the high-speed beam within the x-ray tube. It is equivalent to 1,000 electron volts. So, it is used to measure the energy of x-rays. The mA is an electrical factor controlling the rate of x-ray emission from the x-ray tube. While mAs is the product of x-ray electron tube current and the time in seconds that, the x-ray tube is on [6].

The grid is a common device used to eliminate the scattered radiation that blurred the radiograph image. Grid can be used in most radiographic cases but not in fluoroscopic pediatric and routine examination that is ascribed to dose limitation and practical issues [7]. The efficiency of grid to eliminate the scattered radiation is considered as a function of a set of factors or grid specifications including grid ration, grid frequency, the focus range, the cover and the inter-space materials [8]. As the usage of grid in radiographic examination has consequences of

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exposure dose increment, the technologists have to compromise between the image quality and the patient exposure dose. So, in most beneficial cases the usage of grid is replaced by air gap technique to overcome the dose increment. In such context Bushberg et al, [9] stated that the scattered radiation received by the detector could be defined as scatter-to-primary-ratio (SPR); the amount of energy deposited in specific location in the detector by scattered photons divided by the amount of energy deposited by the primary.

In view of grid application, Genya et al, [10] studied the impact of grid usage in chest radiography of Calves. They found that the grid 3:1 significantly enhanced overall image quality regardless to body size consideration. So, the grid 3:1 has been recommended for chest radiography of Calves using portable systems. However, the grid 8:1 improved the image quality for Calves smaller than 30 cm in thickness only. The filter (low atomic number materials) is used for hardening the beam of x-ray that leads to increase the effective energy and decrease the exposure dose to the patient by absorbing the weak energetic radiation [11]. As well an efficient reduction of patient entrance surface dose (ESD) up to 90% and dose area product (DAP), with no significant change in effective dose (E) or clinical image quality (*1.0 mm Aluminum filter*) has been confirmed by Davies et al, [12] and Papp, [13]. Relative to these results, researchers could enquire how far further filtration effects in the final radiograph quality which would be highlighted in the current study.

The aim of this work is to reveal the effect of using selective imaging factors including kV and mA, tube focal size, usage of the filter and grid on image quality and patient dose.

Methodology:
The experiment done with x-ray system (GE, healthcare, model Al01C II, July/2011- S. N: 3758, German), that equipped with Grids parallel (1/12) and external copper filters (Cu: 0 – 0.4 mm) that used with x-ray tube house.

The x-ray system output parameters were adjusted to 0.5 second, 60 kVp and 100 cm source to film distance (SFD) with variable mA (10 – 35) as tube current and accordingly the relative doses were recorded for the testing of mA effect on the dose. In addition, the different selection of fine focus size (0.25) and broad focus size (0.5) has been tested with predetermined fixed exposure factors as kVp=55, mAs = 0.5, SFD = 100 cm, and the field size (FS) was 10×10 cm; to assess the effect on the system output (O/P) (dose without back scatter) in mGy and the DAP in mG.cm^2.

The effect of filter thickness from 0 to 0.4 mm on O/P (mGy) and DAP (mG.cm^2) was assessed relative to applied kVp ranges between (40 – 100) with predetermined fixed exposure factors (mAs = 4, SFD = 100 cm and the FS = 10×10 cm). The effect of grid was assessed directly on the skull phantom by obtaining digital images with and without grid. The images were assessed using digitizing gray value across the images (yellow lines) using the software program JAVA SE RUNTIME ENVIRONMENT (JRE) VERSION 6 to convert the image into Digital Imaging and Communications in Medicine (DICOM) mode. These DICOM images could be used for further analysis where the gray values obtained and plotted versus distance (images width) then interpreted and a comparison between gridded and non-gridded image was done.

Results:
In this study, we report, the influence of selective factors in radiographic image quality and relative exposure dose. Figure (1); shows the correlation between applied tube current in (mA) and the relative doses O/P and DAP at 0.5 second, 60 kVp and 100 cm distance. It deduced that the radiation intensity has been increased significantly ($R^2 = 0.9$) for both O/P and the DAP which representing a correlation fitted to equations: $y = 0.0922x + 12.259$ and $y = 0.0431x + 8.7113$, respectively, where y refers to relative O/P in mGy and DAP (mGy.cm^2) and x refers to the applied current in mA. The increment of radiation intensity ascribed to more electrons cloud created from different orbits in the filament by thermionic emission at the cathode which are furtherly set-in kinetic energy when the desired kVp applied between the cathode and anode.
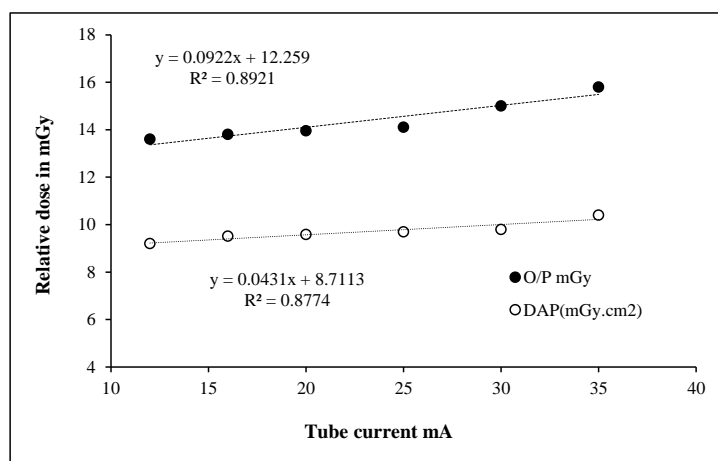

Figure 1: Shows the correlation between the applied tube current in (mA) ranges between (10 -35) and the relative doses for O/P in mGy & DAP in mGy.cm^2.

Other factor affecting the image quality as well as the O/P (mGy) and DAP (mGy.cm^2) was the selected focal size (*broad focus and fine focus*). As shown in

Figure (2) at selected exposure factors (kVp=55, mAs = 0.5, SFD = 100 cm, and FS = 10×10 cm) the broad focus gave 0.28 mGy and 2.18 mGy.cm^2 respectively, while the fine focus gave 0.14 mGy and 1.11 mGy.cm^2 for O/P and DAP respectively.
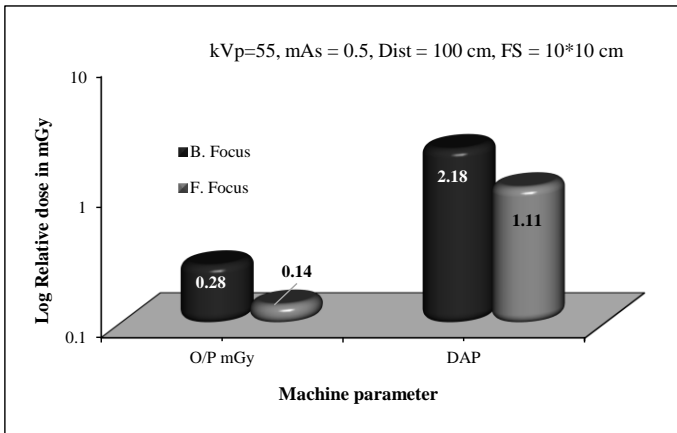

Figure 2: shows O/P (dose without backscatter) and DAP for different focal size (broad focus and fine focus) at kVp=55, mAs = 0.5, SFD = 100 cm, FS = 10*10 cm.

In Figure (3) the correlation between applied kVp and the relative dose output in (mGy) at mAs = 4, SFD = 100 cm and FS 10×10 cm (without filter) was measured. Both the O/P (mGy) and the DAP (mGy.cm$^{2)}$ showed significant (R^2 = 1) proportional exponential increment relationship of the form: $y = 1.7194e^{0.0164x}$ and $y = 0.1601e^{0.0457x}$ where 'y' refers to relative dose in mGy and 'x' refers to applied kV. Such increment in O/P as a function of kVp ascribed to more acceleration of electrons formed by thermal emission from different orbits of cathode material to bombard the anode in the x-ray machine.
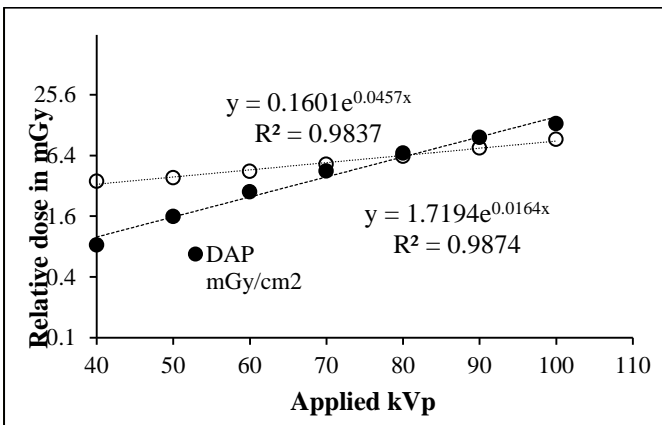

Figure 3: shows the correlation between applied kVp and the relative O/P (dose without backscatter) and the DAP without filter at mAs = 4, SFD = 100 cm and FS were 10×10 cm.

Figure (4); shows the correlation between applied kVp and the relative dose in mGy with Cu filters

(F1=0.1 and F2= 0.2 mm), mAs = 4, SFD = 100 cm and FS were 10×10 cm. The relative doses as O/P and DAP have been increased as the applied kVp increased which were fitted to the equations of the form: $y = 0.0752x - 2.6554$ and $y = 0.4479x - 8.2468$ respectively; where y refers to relative dose in mGy and x refers to applied kVp. The impact of filter significantly (R^2 = 0.9) splitting the curve of DAP in average to higher level (23.1 mGy.cm^2) exceeding the O/P for entire applied kVp which is ascribed to back scattered radiation that contribute in the surface area product by Compton process due to hardening radiation beam by filter.
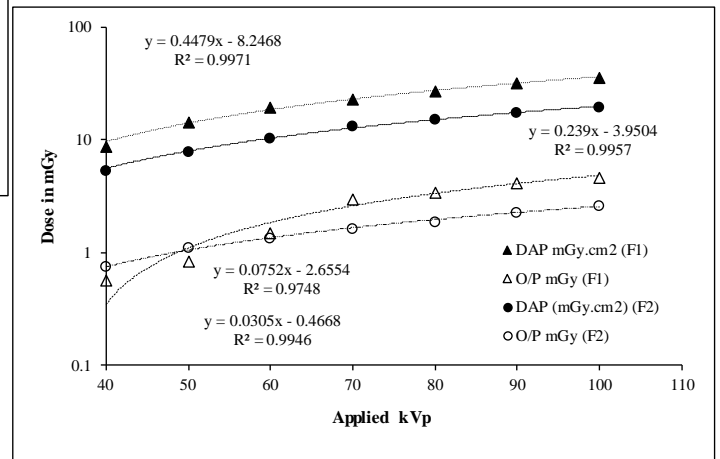

Figure 4: shows the correlation between applied kVp and the relative (log$_{10}$) O/P (dose without backscatter) in mGy and DAP in mGy.cm^2,

Figure (5); shows the correlation between applied different filter thickness and the O/P (mGy), and DAP (mGy.cm^2) with fixed exposure factors and distance (mA = 320, mAs = 1.6, kVp = 77, SFD = 100 cm and FS was 10×10 cm). The curves show both the O/P and DAP decreased as a function of filter thickness increment which were so significant (R^2 = 1) and the correlation were fitted to equations: $y = 0.7745e^{-3.711x}$ and $y = 4.5645e^{-3.524x}$ respectively.
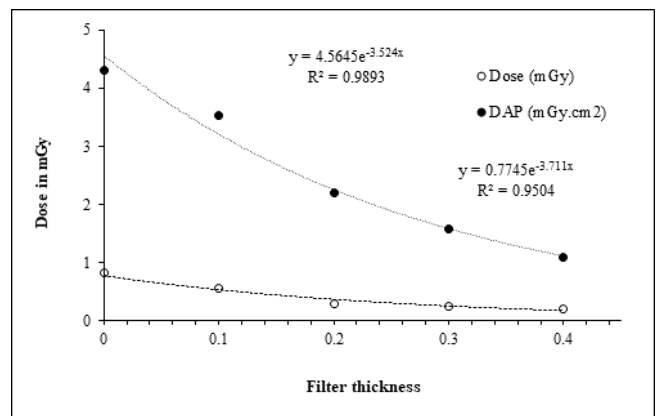

Figure 5: shows the correlation between applied different filter thickness and the relative O/P (dose

without backscatter) in mGy, and DAP in mGy.cm^2

Figure (6) shows the relative skull images with different Filters thickness (0.1, and 0.3 mm) with fixed exposure factors: mA = 320, mAs = 1.6, kVp = 77, SFD = 100 cm and FS 10×10 cm which highlighting undifferentiable contrast by necked eye. As the necked eye could not resolve such changes in image characteristics, a digitization of analogue image by JAVA SE RUNTIME ENVIRONMENT (JRE) VERSION 6 software has been carried out across the skull image for different filters (0.1, and 0.3 mm) to obtain digital curves for the images with different filters as shown in figure 7. The graph in Figure (7) shows the relative digitized gray values in pixels across the skull image distance at the level of front-occipital bone for different filters thickness (0.1, and 0.3 mm). The gradient reduction in the gray value corresponding to applied filters indicating a reduction in the dose received by the imaged object.

Figure 6: shows the relative skull images with different Filters (0, 0.1 and 0.3 mm thick) and exposure factors: mA = 320, mAs = 1.6, kVp = 77, SFD = 100 cm and FS was10×10 cm, highlighting undifferentiated contrast by necked eye. (No stretching applied to any phantom image)
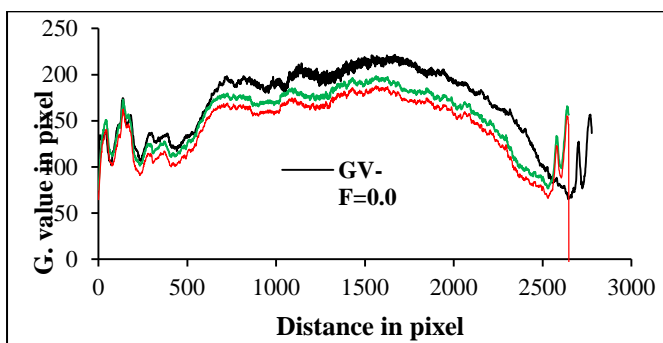

Figure 7: shows the relative digitized gray values in pixels across the skull image distance at the level of front-occipital bone for different Filters (0.1 and 0.3 mm thick) derived from Fig. 6.

Figure (8); shows the skull phantom images (a) without grid and (b) with grid, from which a digitized image curves obtained. The curves showed an obvious variation in digital gray value that convey with (DICOM) format; as high intense gray value in arbitrary unit (a u) with more tortuous boarder without grid compared with gridded image
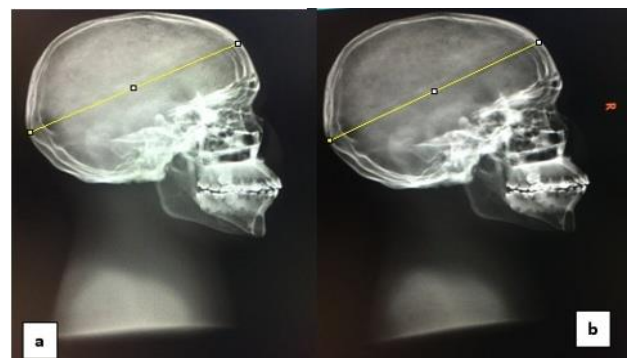

Figure 8: shows the skull phantom images (a) without grid and (b) with grid. The yellow line represents the level at which a digitization of analogue image has been obtained using JAVA SE (JRE) V. 6 software to convert the analogue image into digital. (No stretching applied to any phantom image)
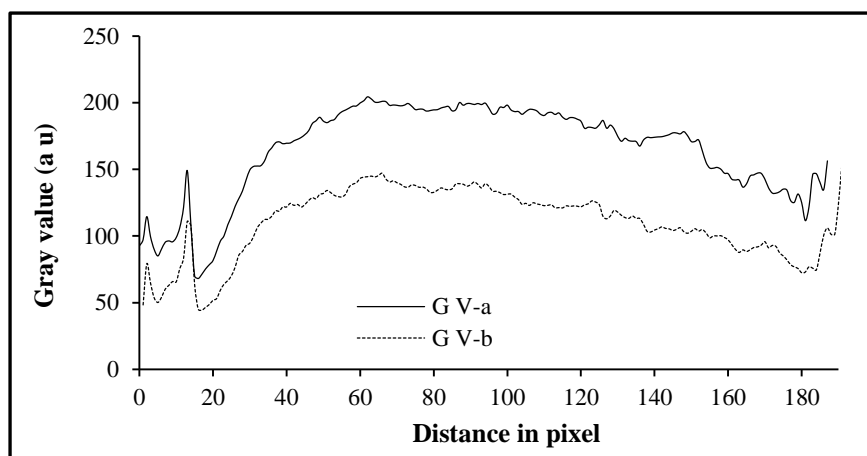
Figure 9: shows the conversion of skull phantom analogue images (a) without grid and (b) with grid into digitized image that convey with DICOM format across the yellow color line (derived from Fig. 8).

Discussion

As has been demonstrated in the figures above some selective imaging factors has an impact in radiographic image quality and relative exposure dose. Figure (1) shows that, increasing tube current in (mA) deduced that the radiation intensity has been increased significantly ($R^2 = 0.9$) for both O/P and the DAP. As a result, the increment of radiation intensity will increase the image dots intensity i.e. the contrast will be improved.

Other factor affecting the image quality as well as the O/P (mGy) and DAP (mGy.cm^2) was the selected focal size (*broad focus and fine focus*). As shown in Figure (2), The broad focus gave 0.28 mGy and 2.18 mGy.cm^2 respectively, while the fine focus gave 0.14 mGy and 1.11 mGy.cm^2 for O/P and DAP respectively. Hence, accordingly, the broad focus showed high density image with delineated small features compared with fine focus; however, such selection will increase the dose to patient. Therefore, the broad focus should be selected when the geometrical and fine details are more favorable to be justifiable; which is in accordance with the radiation exposure principle stated by ICRP.

Figure (3); shows Both the O/P (mGy) and the DAP (mGy.cm^2) with significant ($R^2 = 1$) proportional exponential relationship to the applied kV. The noticeable result is that; the DAP although is start less than O/P; however, at 80 kV and above it rises with considerable increment and exceeding the O/P. Such phenomena could be ascribed to more scattering of radiation that contribute in the DAP. Accordingly, the signal noise and the relative image blurring will be significant above the applied 80 kV. While the increment of O/P as a function of applied kVp ascribed to more acceleration of electrons formed by thermal emission from cathode to anode and furtherly

converted to x-radiation after bombarding the target.

Figure (4); shows the correlation between applied kVp and the relative dose in mGy with Cu filter (0.1 and 0.2 mm). The relative doses as O/P and DAP have been increased as the applied kVp increased. The impact of filter significantly ($R^2 = 0.9$) splitting the curve of DAP in average to higher level (23.1 mGy.cm^2) exceeding the O/P for entire applied kVp which is ascribed to back scattered radiation that contribute in the surface area product by Compton process due to hardening radiation beam by filter. Such effect of filter application would directly be affecting the image characteristics in view of sharpness, resolution, and contrast with considerable reduction in patient exposure dose. As the filter thickness increases from 0.1 to 0.2 mm, the DAP dropped to 12.8 mGy.cm^2 and still greater than O/P product and with same characteristics i.e. both O/P and DAP increased significantly ($R^2 = 0.9$) and exponentially as the applied kVp increased. The dropped in the DAP (10.3 mGy.cm^2) could be ascribed to attenuation of the primary radiation by the thicker filter (weaker energies). Figure (5); shows the correlation between applied different filter thickness and the O/P (mGy), and DAP (mGy.cm^2). The curves show both the O/P and DAP decreased as a function of filter thickness increment which were so significant ($R^2 = 1$) and the correlation were fitted to equations: $y = 0.7745e^{-3.711x}$ and $y = 4.5645e^{-3.524x}$ respectively. Such fact ascertaining the benefits of filter utilization in radiography i.e. reducing patient dose and improve the characteristics of the image (contrast, resolution and sharpness).

Figure (6) shows the relative skull images with different Filters thickness (0, 0.1, and 0.3 mm) with fixed exposure factors which highlighting undifferentiable contrast by necked eye. As the necked eye could not resolve such changes in image characteristics, a digitization of analogue image by JAVA SE RUNTIME ENVIRONMENT (JRE) VERSION 6 software has been carried out across the skull image for different filters (0, 0.1, and 0.3 mm) to obtain digital curves for the images with different filters as shown in figure 7. The graph in Figure (7) shows the relative digitized gray values in pixels across the skull image distance at the level of front-occipital bone for different filters thickness (0, 0.1, and 0.3 mm). The gradient reduction in the gray value corresponding to applied filters indicating a reduction in the dose received by the imaged object (more homogeneous energetic radiation) and

penetrative/energetic dose received by the detector. Such effects of more filtration reduce image sharpness as obviously indicated by the less tortuousness of the curve at filter 0.3 mm.

Figure (8); shows the skull phantom images (a) without grid and (b) with grid, from which a digitized image curves obtained. The curves showed an obvious variation in digital gray value that convey with (DICOM) format; as high intense gray value in arbitrary unit (a u) with more tortuous boarder without grid compared with gridded image. The resultant images showed more contrast (smooth curve) due to elimination of scattered radiation [14, 15]. Furthermore, the contrast reflected the homogeneity of radiation and penetrative beam quality received by the film or the detector but increasing object dose as shown in figure 9. Such result is agreed with the study curried out by Mohammed et al, [16] in which he showed same results in view of contrast enhancement, image resolution and increment of object dose.

Conclusion:
Good radiology practice involves effective communication about radiation risks and benefits of radiological procedures. Several factors have been identified as affecting Radiographic Quality and Related Exposure Doses. These factors can influence the awareness of radiation risks in medical imaging among the various participants. Our study data suggest that using image enhancing devices may increase the object dose and it should be done under "As Low As Reasonably Achievable" (ALARA) principles.

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