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Polymethyl methacrylate (Perspex) line pattern phantom:
A new gamma camera test pattern for assessment of extrinsic resolution and linearity

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شبح (دمية) البوليميثايل ميثاكراليت (الزجاج العضوي) على هيئة خطوط:
نمط فحص جديد لآلة التصوير غاما لغرض التقويم الخارجي لحدة الصورة وخطيتها

فاضل مهدي صالح و افكار ناظم الفارسي

الملخص: الهدف: تصميم وعمل شبح (دمية تشبيه) من البوليميثايل ميثاكراليت (الزجاج العضوي) بهيئة خطوط لاختبار حدة الصورة وخطيتها لآلة التصوير غاما . **الطريقة:** تم صنع الدمية من لوح من الزجاج العضوي سمكه ١٠ ملم ثبت فيه أنبوب بلاستيكي قطره الخارجي ١ ملم (قطره الداخلي ٠,٥ ملم) وذلك بحشره في أخاديد مستقيمة عمقها ١ ملم حفرت في سطح اللوح بنمط معين ، كان الترتيب النهائي للخطوط يقسم الدمية إلى أربعة أرباع متشابهة مما جعله يغطي جميع سطح راس آلة التصوير البالغ قطره ٤٢٠ ملم ، وقد ملأ الأنبوب بمادة التكنيشيوم ٩٩m المشع . سمح هذا الترتيب كشف وتشخيص أي تغير يطرأ على حدة الصورة وخطية الة التصوير على مجمل سطح راس الة التصوير . أجريت الاختبارات على آلتي تصوير أحاديتي الرأس المتوفرتين. **النتيجة:** أمكن بوضوح تام تمييز اقرب خطين تفصل بينهما مسافة ٦ ملم . وباستخدام آلية الانتشار الخطي أمكن حساب كامل العرض وبنصف الارتفاع الكلي الذي بلغ ٤,١ ملم . كما أمكن أيضا رصد أي اختلال في شكل الخطوط ، الذي أعتمد بدوره كمقياس للخطية، على كامل راس الكامرة . **الخلاصة:** أظهرت النتائج الحالية إن هناك تطابقا بين النتائج المستقاة من استعمال الدمية التقليدية المسماة شبح الأرباع الأربعة ذو الحواجز الخطية المستخدمة في الوقت الحاضر لاختبار حدة الصورة في جزء معين من سطح راس آلة التصوير فقط والشبح الحالي، غير أن العلاقة العامة المقبولة عموما لا تنطبق على الدمية الحالية التي تعطينا قياسا للخطية بعدة اتجاهات في كل ربع ، إضافة إلى انه لا يحتاج إلى مصدر إشعاع فيضاني مما يقلل من تكاليف الاختبار .

ABSTRACT. ***Objective:*** To evaluate the newly designed polymethyl methacrylate (Perspex) line pattern phantom (PLPP) for testing extrinsic resolution and linearity of gamma camera. ***Method:*** The phantom was made of 10 mm thick Perspex in which tubes of 1 mm external diameter and 0.5 mm internal diameter were inserted in 1 mm deep grooves, which had been machined in a particular pattern. The final arrangement of lines divided the phantom into four similar quadrants, which encompassed the whole surface of the gamma camera head. Such an arrangement permitted full detection of any change in the linearity and resolution. The tube was filled with technetium-99m (^{99m}Tc). Tests were performed on the only two single-headed gamma cameras available in Oman. ***Results:*** It was possible to resolve two lines as close as 6 mm. Using the line spread function (LSF) facility, the estimated full width half maximum height (FWHM) value was 4.1 mm. In addition, any distortion in the shape of the lines, used to measure linearity, could be easily detected over the entire surface of the camera head. ***Conclusion:*** Data obtained from the PLPP are in agreement with those obtained using the conventional four-quadrant bar pattern phantom (FQBP). The generally accepted relationship that the line profile FWHM is equal to approximately twice the minimal resolvable bar spacing does not apply to the PLPP. However, PLPP gives multi-direction linearity in any one quadrant. In addition, it does not need a flood source for imaging, thus minimising the test cost.

Keywords: gamma camera, phantom, resolution, linearity

GAMMA CAMERAS' extrinsic resolution, linearity, and energy resolution are some of the parameters that should be tested every six months. At the time of writing this, there are only two gamma cameras in Oman, one located in Sultan Qaboos University Hospital and the other in Royal Hospital, both in the Muscat capital area. The cameras are identical and together cater for a population of 2 million. Their heavy usage makes testing procedures difficult, which is further complicated by the tediousness and other problems associated with the existing test phantoms.

At present, there are a number of commercially available test phantoms for measuring resolution, and in some cases, linearity of the gamma camera.[1] Among those are phantoms that can provide a quick and qualitative assessment of resolution but giving only crude measures of FWHM of the associated line spread function.[2] In any case, test phantoms are often considered difficult, tedious, or requiring special software,[3] in addition to cost-effectiveness problems. Furthermore, quality control procedures are usually rescheduled to accommodate clinical imaging requirements, resulting in deviation from the intended

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phantom activity due to radionuclide decay. These reasons have been behind the efforts to develop a practical, handy and cheap phantom.

Recently, Dynamic Line Phantom (DLP)[4] offered a solution for the increasing need for quick, simple-to-perform quality control tests with a single, readily available piece of equipment. This is a line source consisting of a stainless steel catheter 500 mm long, with an internal diameter of 1 mm and wall thickness of 0.3 mm, filled with a radioactive liquid. The total volume of the catheter is 0.4 ml and both ends are documented to have a zero dead volume union. The catheter is fixed in a rigid Perspex strip, which is seated in a holder on the main body of the equipment. Unfortunately, the reproducibility of result of the DLP is poor, making the techniques insensitive to small changes in camera performance. Another method was also described for rapid objective measurement of resolution using statistical moments.[5] This method was applied to images of an FQBP acquired with various collimators. For this method to provide high accuracy, the formulae originally described for intrinsic measurements needs to be modified. Consequently, we were prompted to design a new test phantom that would combine simplicity with quality, and one that would overcome some of the problems encountered in quality control tests such as the possible distortion on the bar phantom image by the collimator,[6] caused by a relative positioning of the collimator septa and phantom bars, or the interplay of the bar or hole pattern and the lead septa of the collimator.[1] This has always been a problem with medium or high energy collimators and possibly with low energy collimators.

The intrinsic resolution represents the reproducibility of the calculated coordinates for the gamma rays incident on the same site in the crystal.[2] Therefore, the resolution should be measured along both the x and the y co-ordinates of the camera to evaluate any orientational variation in the spread function.[7] In addition, the resolution of the camera is related to the sharpness of the image produced, which in turn is dependent upon the spatial linearity of the camera.

The purpose of this work was to design and make a new phantom for testing extrinsic resolution and linearity, and to compare its performance with the conventional FQBP used in the routine assessment of gamma camera extrinsic resolution. The tests were performed on the aforesaid two identical single-headed Siemens Orbiter gamma cameras. These cameras contain 75 photo-multiplier tubes (PMTs), and have thallium-activated sodium iodide [NaI(Tl)] scintillation crystal with a useful field of view of 38.7 cm. The new method assesses the linearity and resolution of the gamma camera in both the x and the y co-ordinates simultaneously.

METHOD

The PLPP, which was designed and built locally in Sultan Qaboos University (SQU), was basically a Perspex disk, 420 mm in diameter and 10 mm in height, weighing 1,725 g [Figure 1]. The phantom had a quadra-symmetrical geometry, consisting of orthogonal engraved lines separated by set distances of 30, 20, 10, 5, 5, 30, 50, and 6 mm. The engravings were 1 mm wide in both x and y directions, while their depths were 1 mm in one direction and 2 mm in the orthogonal direction to allow for easy cross-over of the capillaries (made of fine-bore polythene tubing with outer diameter of 1.00 mm and inner diameter of 0.50 mm) that filled the grooves.

About 7.5 m long capillary was used to fill the x direction, while another capillary of the same length filled the y direction. Both capillary ends were securely fitted with syringe needles, which had been cut short to 2 cm, and blunted to avoid capillary puncture. The syringe needles were then fitted with ventilating stoppers. Precaution was taken to ensure no air bubble remained in the syringe prior to the administration of ^{99m}Tc into the capillaries. Both ventilating stoppers were removed when the ^{99m}Tc was injected, one end to allow for the administration and the opposite end to allow for the flow. The syringe containing the ^{99m}Tc was then securely attached to the syringe needle to avoid leakage. It was the desire of the investigator to fill one of the

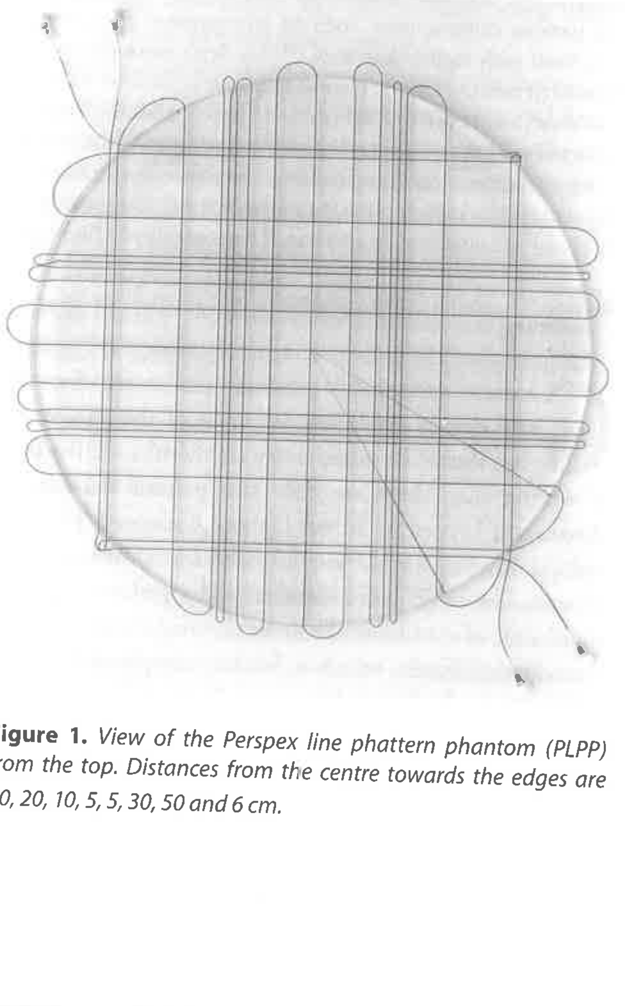

Figure 1. *View of the Perspex line phattern phantom (PLPP) from the top. Distances from the centre towards the edges are 30, 20, 10, 5, 5, 30, 50 and 6 cm.*

capillaries or both. Using only one capillary would require double the number of tests to collect same amount of information comparable to when using two capillaries.

A 3 ml stock of the 500 MBq activity ^{99m}Tc was prepared and dyed with black ink to facilitate for better visual follow-up of the solution flow and solution front as the stock was injected into the capillary. The dye had two advantages: it allowed for visual detection of the undesirable bubbles, and acted as a visual indicator against overflow and possible bench contamination.

All acquisitions were made by collecting 10^6 counts in presence of a high-resolution parallel hole 140 keV collimator. The tests were performed by placing the phantom directly on the gamma camera collimator. The phantom was placed so that the face containing the capillary tubes was always up. The patterns were initially positioned to superimpose the x and the y coordinates. The phantom was then rotated 3 times, clockwise, 30° at a time, to ensure complete coverage of the whole field. It may be worthwhile noting that a test was performed with capillary tubes *facing down* but no detectable difference was observed. Therefore, for the ease of aligning phantom with the coordinates, we carried on testing with the capillary tubes facing up.

In order to simulate the possible radiation scatter in the body of the patient, a number of sheets of tissue-equivalent Perspex (half value thickness = 4.02 cm) of varying thickness (5, 10 and 15 cm) were placed between the phantom and the camera head. This arrangement presented an additional factor: the increased distance between the phantom and the camera. Therefore, a number of additional tests were carried out to elucidate the changes in the image quality as the distance between the phantom and the camera varied. Accordingly, the phantom was imaged at distances of 5, 10 and 15 cm away from the head without Perspex sheets.

The availability of the line spread function analysis in the SQU Hospital camera allowed a direct measurement of the FWHM. In the Royal Hospital Camera, where this facility was not available, the FWHM value was estimated with a pixel size of 0.82 mm. It was also possible to use the LSF to reflect the extent of radiation scattering that occurs in the patient's body during imaging when the Perspex was used to simulate the body.

Simultaneously, a number of tests were also carried out using a FQBP with Cobalt-57 (^{57}Co) flood source. It was hoped that these tests would permit direct comparison between the efficiency of the PLPP and the FQBP.

RESULTS

Figure 2 shows a scintigraph of the phantom for the SQU hospital gamma camera. It was possible to resolve two lines separated by a distance of 6 mm. However, lines separated by 5 mm distance were difficult to resolve in the present arrangement. These data are taken as an indication that the resolution of the camera is fairly good. Support for this comes from the LSF analysis [Figure 3] which gave a value of FWHM of 4.1 mm. Visual inspection of the shape and the alignment of each line of the PLPP were adopted as a means for judging the goodness of linearity. Lines were fairly straight and well aligned. Accordingly the linearity was considered satisfactory.

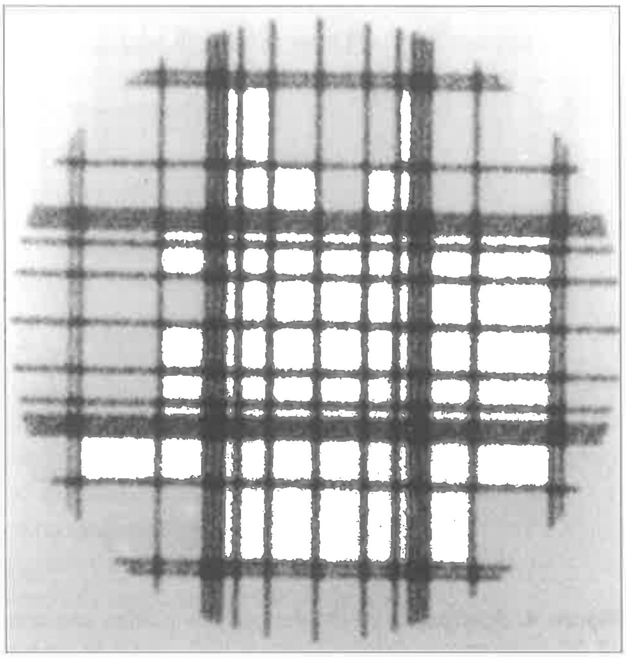

Figure 2. *Scintigraph of the Perspex line pattern phantom (PLPP) showing the outermost resolvable 6 mm apart lines*

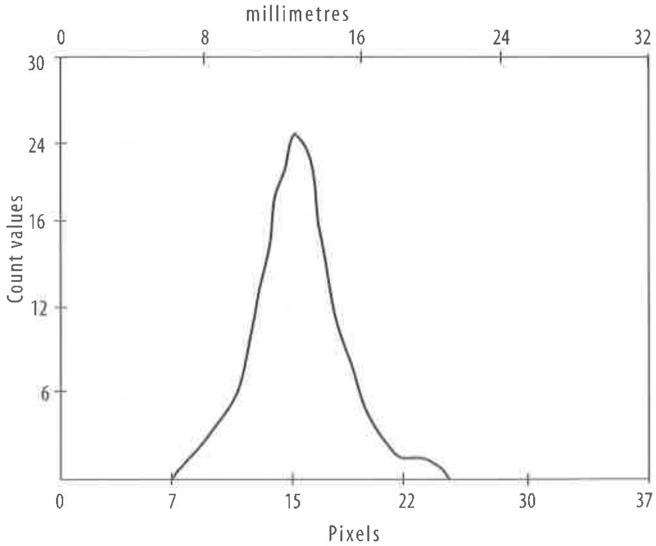

Figure 3. *Count profile of the line spread function (LSF) across one of the lines of the Perspex line pattern phantom (PLPP)*

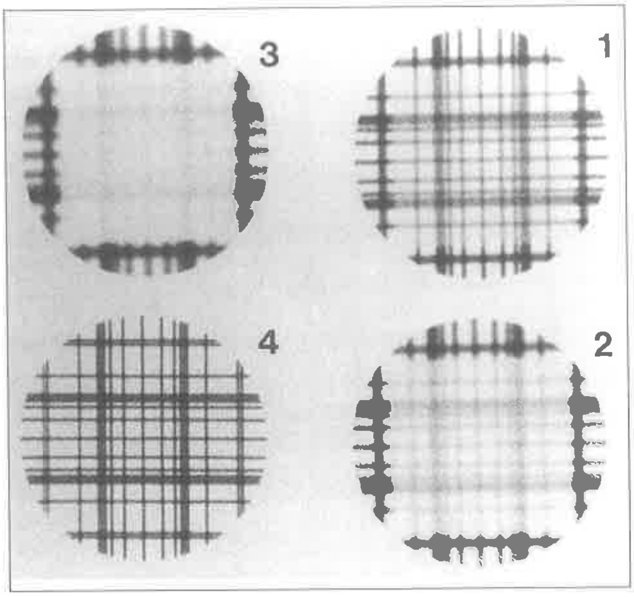

Figure 4. *Scintigraphs of the Perspex line pattern phantom (PLPP) in presence of Perspex sheets of (1) 5 cm, (2) 10 cm and (3) 15 cm (Scintigraph number 4 is without added Perspex).*

When Perspex sheets were placed between the phantom and the camera the resolution worsened and the scintigraph clarity deteriorated as the thickness of the Perspex sheets increased from 5, 10, to 15 cm [Figure 4]. This was possibly due to (1) radiation attenuation by the Perspex, (2) radiation scatter and (3) increasing distance separating the phantom from the head. Naturally increasing the distance would affect resolution. Nevertheless, the effect of increasing distance was tested and the findings supported the suggested effect [Figure 5]. Radiation scattering, on the other hand, is well supported by data in Figure 6 where the LSF analysis indicates radiation scatter in Perspex, which appears as increased count values with two higher peaks at the margins of the Perspex image.

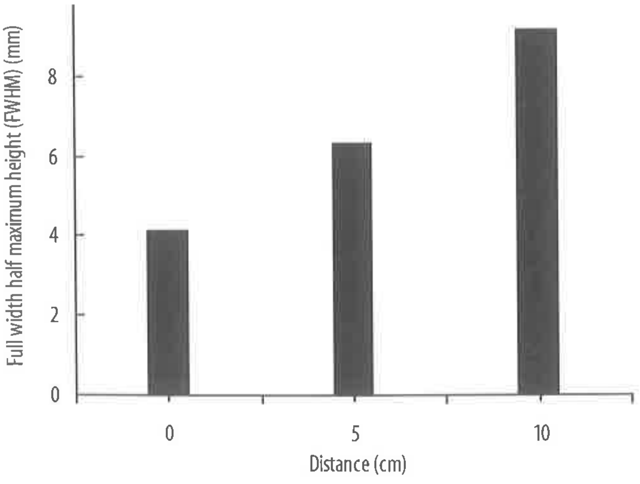

Figure 5. *Values for Full Width Half Maximum Height (FWHM) for Perspex line pattern phantom at distances 0, 5 and 10 cm from the camera head*

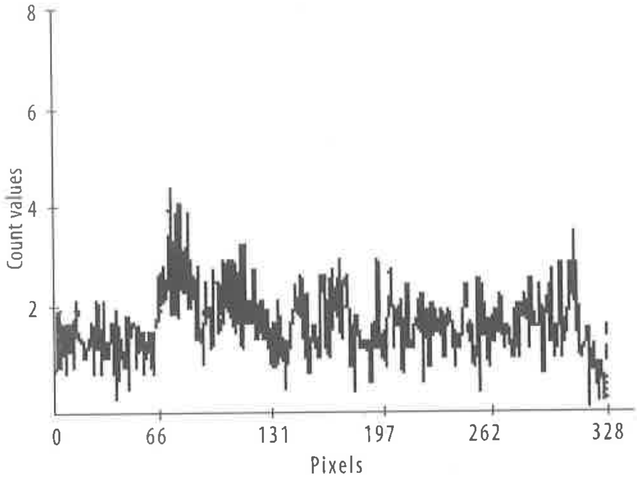

Figure 6. *Count profile of the line spread function (LSF) along one of the lines of the Perspex line pattern phantom (PLPP) which was superimposed by a 5 cm Perspex sheet*

DISCUSSION

The frequent need for testing the resolution and linearity of the gamma camera necessitates practical, simple and inexpensive tools that can perform the quality control tests easily and as accurately as possible. A number of phantoms have been designed but none has met the ideal specifications.[1–6] However, manufacturers are now making bar phantoms specifically designed to suit a given gamma camera. Nevertheless, we committed our design hoping to meet as many practical criteria as possible. The new PLPP phantom we developed has an advantage over many other phantoms, particularly the FQBP, in linearity and resolution assessments. It is much less expensive than the FQBP. Most resolution test phantoms measure the resolution over a small field of view. Our new phantom, however, measures resolution over a large portion of the field of view, thereby providing a good indication of the overall system linearity [Figure 2]. This phantom can also be used in a department with multiple gamma cameras. In addition, the FQBP provides a qualitative index of spatial resolution.

It is generally agreed that the line profile FWHM is equal to approximately twice the minimal resolvable bar spacing.[7] Moreover, Wasserman[5] suggested a range of FWHM of 4.5–7.2 mm if well-resolved images of bars wider than 3.0 mm were used. Whereas, the PLPP gave a value of 4.1 mm with a minimum resolvable distance of 6 mm separating two lines [Figure 3]. It is clear that our data do not fully agree with the previously reported results.[5,7] This discrepancy cannot be explained at present except that the line sources of the PLPP are too thin (0.5 mm), which permitted a better resolution when measured by the LSF. Accordingly, the generally accepted relationship between FWHM and the minimal resolvable bar spacing[7] does not apply to the PLPP, which should, otherwise, have allowed us to resolve a line spacing of at least 2 mm for our measured FWHM value of 4.1 mm. Another reason for this discrepancy may be the fundamental differences in the designs and materials of the two phantoms. Perspex in the PLPP does not collimate the radiation coming from line sources, whereas the lead bars in the FQBP partially collimate the radiation, giving a subjective minimum resolvable spacing of 4.8 mm.

Any changes in linearity can be visually detected over the entire surface of the camera head. The linearity of the two cameras, however, was satisfactory as indicated by the straight and smooth lines [Figure 2].

The new phantom pattern's dimensions and geometry possibly allow for the detection of a PMT failure. Unfortunately this capacity was not practically tested due to technical difficulties. But this particular arrangement of the phantom lines would lead to have the biggest plane area in the phantom to be smaller than the area of one PMT. Thus, malfunction of a PMT may create a distortion in the lines surrounding that particular area. In addition, the recommended rotation of the phantom will allow line repositioning which will further reduce the uncovered area, thereby enhancing the possibility of a PMT failure detection.

To understand the factors affecting the quality of a patient's scintigraphic image, sheets of Perspex were placed between the phantom and the camera head as a way to simulate the patient's body influence. Results were as expected [Figure 4]. Perspex affected resolution tremendously and the lines were not clear enough, making it difficult to accurately determine the linearity and to clearly resolve lines separated by 6 mm. This, of course, was due to (1) radiation absorption by Perspex, clearly indicated by the blurring of phantom lines in the image, (2) changing the distance between phantom and head (0, 5, and 10 cm) altered the FWHM values, as shown in Figure 5, (3) scattered radiation, which can be justified simply by examining the scintigraph, particularly the boundaries of the Perspex image [Figure 4]. A dark black line was generated along the borders, which was an indication of the scattered radiation resulting from the interaction of radiation with the Perspex. Support for this is shown in Figure 6. When the LSF analysis was performed on any of the lines crossing the Perspex sheet, the count value generally increased as the Perspex covered the line. Two additional higher peaks appeared at the beginning and the end of the Perspex-covered part of the line. These two peaks were possibly responsible for the dark lines at the boundaries of the Perspex image.

CONCLUSION

We are not assuming that our design is outstanding and exhibits no weaknesses. But it has proved very practical, particularly when ^{57}Co flood source is not available. However, when comparing the quality of tests done using the PLPP with other types of test phantoms it would be clear that the PLPP permits better quality of test and definite decisions. However, the validity of the new phantom may not be well-supported by comprehensive practical tests due to the availability of only two gamma cameras, one of them without the LSF facility. This, of course, does not deny the significance and usefulness of the present findings, which are fairly supported by the above proofs.

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