Measurement Consistency and Single Pixel Noise of Two Epson Flatbed Film Scanners and a Vidar VXR-16

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Abstract

This white paper reports the evaluation of scanner measurement consistency and single pixel measurement noise for the Epson 1680 and 4990 flatbed color scanners in transmission and reflection modes and compares their performance with the Vidar VXR-16. The principal means of evaluation for transmission measurements was standard reference material SRM 1008 available from the U.S. National Institute of Standards and Technology. All scanners have a performance suited to use for film dosimetry. The Epson scanners show better measurement consistency than the Vidar VXR-16, while the latter scanner has slightly lower single pixel noise. The work uses FilmQA™ validation software to investigate the improvement in single pixel noise provided by application of a 3x3 Weiner filter to the scan data. The results imply that when using FilmQA™ software[1] (www.3Cognition.com) for image analysis and evaluation, all three scanners would exhibit similar low single pixel noise over the dynamic range of GAFCHROMIC® EBT dosimetry film. As confirmation, an analysis of single pixel noise for the film-scanner system was made using a GAFCHROMIC® EBT dosimetry film step tablet and the Vidar VXR-16 and Epson 1680 scanners.

1.0 Introduction

The purpose of this study was to analyze and evaluate the performance of film scanners with respect to their suitability for film dosimetry. In particular a goal was to compare the performance of high quality professional flatbed color film scanners and the Vidar VXR-16 scanner using black/white negative film and colored, radiochromic film. The combination of radiographic film such as Kodak EDR2 with the VXR-16 scanner typifies the film/film measurement system used for IMRT patient treatment plan verification in many radiotherapy clinics. In this white paper we deal with the measurement consistency and single pixel noise characteristic of these scanners. In a second paper we will address the effects of light scattering by radiographic films when using these scanners and the correction of this artifact that is uniquely addressed by employing tools in FilmQA™ validation software, a powerful and cost effective new tool for IMRT treatment plan verification that has been optimized for use with GAFCHROMIC® EBT dosimetry film.

1. FilmQA™ Validation Software, 3Cognition, Port Jefferson, NY is a low-cost software designed for film dosimetry related to IMRT treatment plan validation. It contains functions, not available in other film dosimetry software, to correct for the scanner field flatness. Such corrections are important in optimizing the performance of Epson scanners with GAFCHROMIC® EBT film, but it is essential when using the Vidar VXR-16.

With the emergence of various electronic imaging techniques and the employment of electronic portal imaging, digital reconstructed radiography (DRR) and virtual simulation there is a strong trend in the medical field away from the use of silver-based films. As a result, the infrastructure supporting the handling and processing of these conventional films has diminished. This, in turn, focuses the burden of the operational effort and costs for film processing on the remaining users. Since the overall costs for film processing are spread over a small number of films, the cost of film processing can be several multiples of the film cost and becomes the dominant cost factor in using conventional silver film.

Self-developing radiochromic film is an alternative to silver film for dose assessment in radiotherapy applications. The recent introduction of GAFCHROMIC EBT has reduced radiochromic film price by an order of magnitude and increased film sensitivity also by an order of magnitude. Not only does GAFCHROMIC EBT film offer an overall cost advantage for dosimetry film use, but it also provides several important technical advantages. In particular the response of EBT radiochromic film is essentially energy independent over the range from 30keV into the MeV range. Furthermore, EBT film has a response that is independent of dose rate and dose fractionation. In external beam therapy applications, and particularly in IMRT, the energy spectrum at a point in the treatment volume is significantly dependent on the treatment depth and the field size. beam use in external beam therapy applications. Since it is well established that the response of conventional silver film (e.g. EDR2, XV) can change by an order of magnitude between the keV and MeV ranges, the use of energy-independent EBT radiochromic film is less controversial in calibrating and measuring dose for IMRT plan verification.

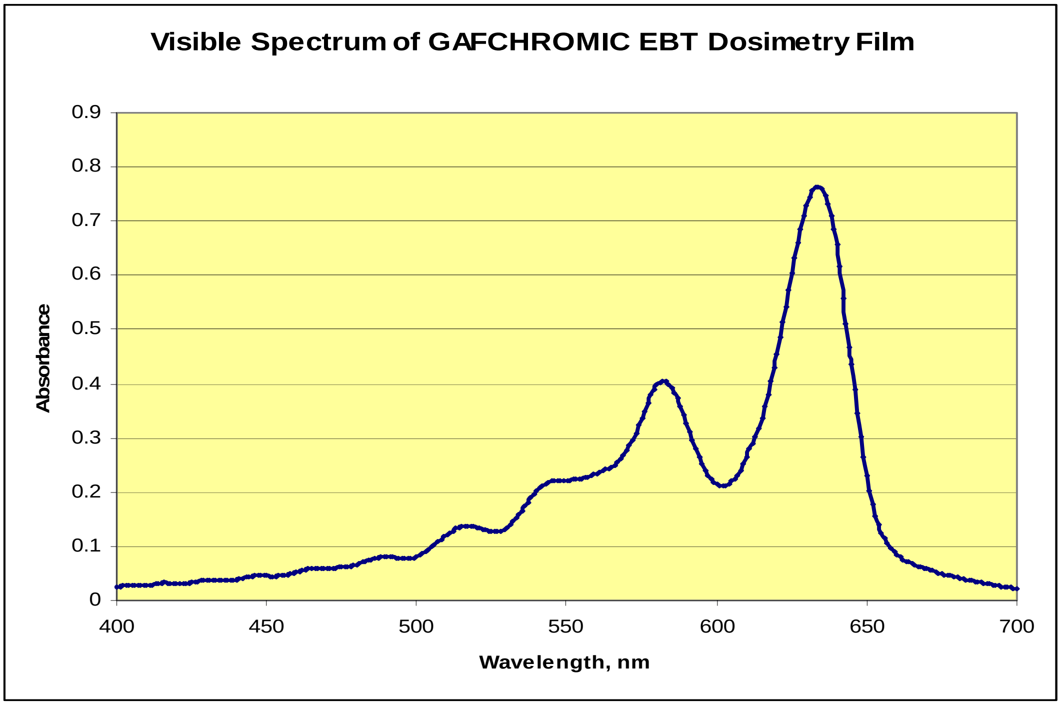

Figure 1: Visible Spectrum of GAFCHROMIC EBT

Radiochromic films produce colored images when exposed to radiation. In contrast to the grey/black image of a conventional film that has practically uniform light absorption at all visible wavelengths, the color of radiochromic film signifies that the film absorbs light more strongly in one part of the spectrum than another. GAFCHROMIC films all have a blue colored image and absorb most strongly in the red portion of the spectrum (approximately 600-700nm). The absorption spectrum of exposed EBT film, Figure 1, shows the absorption maximum at about 635nm. Since EBT film has stronger red light absorption, there is a potential advantage to scanning this radiochromic film with a scanner designed for color film scanning, measurement and analysis rather than with a scanner designed for black-and-white films. Numerous flatbed color film scanners are designed for digitizing transparent and reflective color film and produce rgb data output with simultaneous measurement in red, green and blue color channels. In considering such scanners we have restricted our attention to high-quality, professional film scanners with the capability of digitizing both transparent and reflective media.

Among the flatbed scanners we have found that several models made by Epson consistently produce results that are comparable to those from the Vidar VXR-16 model scanner that is widely used in film dosimetry applications. As a result, there is an advantage for prospective customers who have a choice of Epson flatbed scanners ranging from <\$500 to about \$2600 in price against much more expensive scanners with prices of \$20,000, or more. The prices of the Epson scanners depend on the maximum scan area. They are 8"x10" for the Epson Expression 4990 (<\$500); 8.5"x11" for the Epson Expression 1680 (~\$1000 with transparency adapter); and 12.8"x17" for the Epson 10000XL (~\$2600 with transparency adapter).

A film dosimetry system is minimally comprised of a film, a scanner and analysis software. GAFCHROMIC EBT film in combination with FilmQA verification can work at least as well with the Epson scanners as with the Vidar VXR-16. A system composed of EBT film, flatbed scanner and FilmQA software can provide an accurate, convenient and economical approach to film dosimetry.

1.1 Scan Mode – Potential Advantages of Transmission and Reflection

Film dosimetry has been almost exclusively conducted using densitometers or scanners to measure the optical density or transmittance of a transparent film medium. However, there are no fundamental reasons why dosimetry could not be done by measuring the reflection density of the film. Devices for reflection measurement such as reflection scanners and densitometers are well developed and routinely used by the printing industry, for example.

The film substrate for reflective media, including photosensitive films as well as printed media, is usually a uniform white base that is an integral part of the film. However, even a transparent film can be read in reflection by placing it upon a diffuse white surface and this accommodation is available in most flatbed scanners. Light incident on the film is transmitted through the image layer where it is attenuated according to the absorbance of the layer. Light is scattered back toward the observer is further attenuated as it transmits the image a second time. Since the reflected light transmits the image twice, the contrast is doubled. This increase in contrast might be valuable because it might increase the precision of measuring films having relatively low absorbance, i.e. it might increase the precision of low-dose measurements.

Limitations of reflection measurement are that spatial resolution is limited to around 10 lp/mm and at higher absorbance, i.e. higher dose, the contrast of the image rolls off because the signal (reflected light) is increasingly dominated by front surface reflection. Since film dosimetry for IMRT requires only mm resolution, reflection densitometry will provide more than enough spatial resolution.

The advantage of reflection measurement is that it can increase low-dose precision and be useful in checking treatment plans around critical organs having a high-sensitivity to radiation. In this regard, reflection measurements should not be viewed as a replacement for transmission measurements, but rather as an addition to transmission measurement. In this way, the physicist can benefit from the advantages of each. One way to do this is to use a scanner capable of making both transmission and reflection measurements. The Epson 1680 and 4990 scanners are preferred because they can scan in both modes. The Vidar VXR-16 cannot be used to scan in reflection.

2.0 Measurement Objectives and Test Protocol

The scanners studied in this work were the Epson Expression 4990, the Epson Expression 1680 (with transparency adapter), the Epson 10000XL (with transparency adapter) and the Vidar VXR-16. Work with the Epson scanners was conducted for both transmission and reflection scanning. The VXR-16 is a transmission scanner only.

3.0 Scan-to-Scan Consistency for Transmission Measurements

3.0.1 Method

A first objective was to establish the scan-to-scan consistency of the scanners over a range of film densities. To do this, data was gathered by scanning a U.S. National Institute of Standards and Technology SRM 1008 standard reference photo step tablet. For each scanner and scan type, transmission or reflection, data was obtained by consecutively scanning the step tablet 20 times over a period of about 30 minutes. The Epson scanners are professional rgb color scanners and data collection was restricted to the red color channel since this color channel is the one used when scanning radiochromic film. The VXR-16 scanner is white-light scanner with only a single channel. In all cases measurements were made at 16-bit resolution.

The Epson scanners have spatial resolution exceeding 2000dpi and the VXR-16 has a spatial resolution of about 300dpi. The spatial resolution of all the scanners greatly exceeds the requirements for most external beam dosimetry. One of the principal uses of film dosimetry is in the verification of IMRT treatment plans. Since the planning systems typically produce treatment plans with dose points >1mm apart, it is unnecessary to scan film at high resolution. A spatial resolution of about 3 points per mm is a good compromise for film scan data. It provides sufficient margin for the scan data to be filtered to remove the effect of isolated pixels that deviate substantially from the values of their neighbors with minimum effect on resolution. This may be done using, for instance, a low-order Weiner or median filter, both types that have a negligible effect on spatial resolution. Employing such filtration over 3x3 pixel areas in the images easily preserves 1mm spatial resolution. In this study the step tablets were digitized at 75dpi on the Epson scanners and at 71dpi on the Vidar VXR-16.

The scanned images were measured using MIRA AP (Axiom Research Inc., www.axres.com) and FilmQA™ (3Cognition LLC, www.3cognition.com) software. Each step on each scanned image was measured over an area-of-interest approximately 6mm x 6mm in size, comprising about 300 pixels. The results for each step, scanner and type of scan were tabulated and the mean and standard deviation of the measurements was obtained.

3.0.2 Results and Discussion

The consistency of measurements for each scanner was evaluated by calculating the standard deviation/mean, expressed as a %, and plotting that value vs. the calibrated optical density of the step on the NIST tablet. For transmission scan data the results are presented in Figure 2.

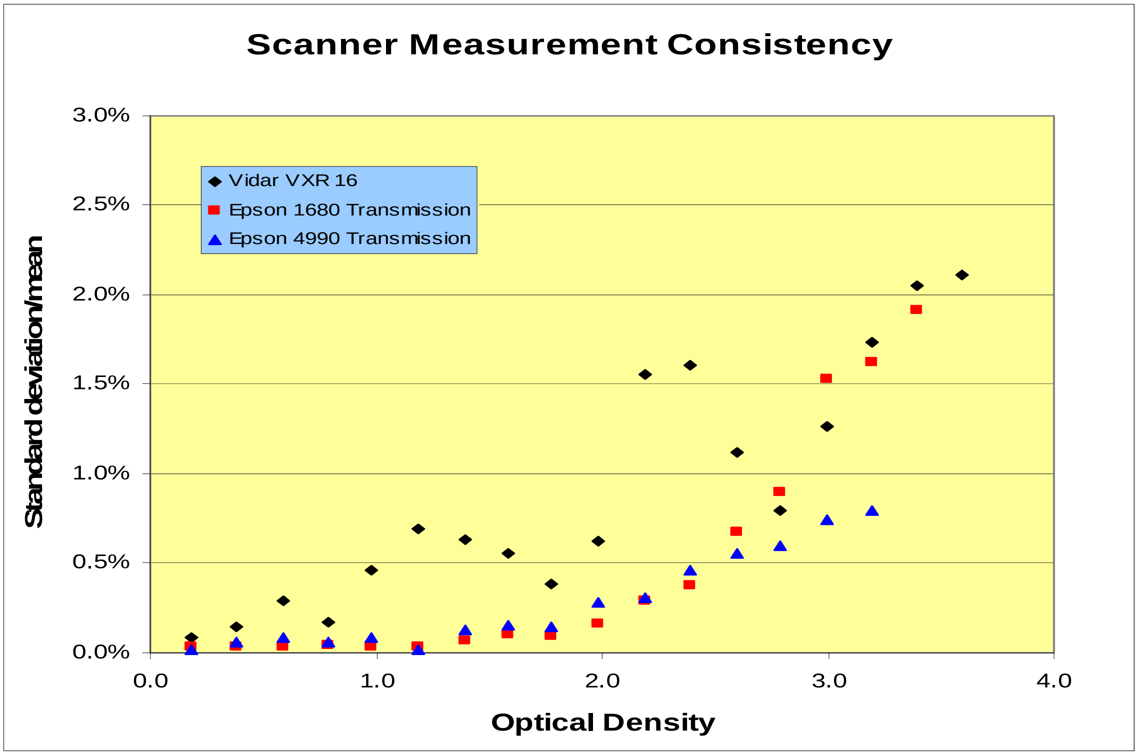

Figure 2: Scanner Measurement Consistency in Transmission Mode

While all the scanners show measurement variability less than 1% at densities less than about 2, the two Epson scanners provide a much more consistent response than the Vidar scanner. For the Epson 1680 and Vidar scanners the measurement error rises markedly for film densities greater than about 3 and indicates that best results would be provided below density 2.5. Overall, the results support the use of the flatbed scanners to make high quality transmission measurements for film dosimetry.

Figure 3 depicts a typical dose-density response for EBT film measured on the red channel of an Epson 1680 scanner. At 800cGy dose the density of EBT film on an Epson 1680 is less than 2. This implies that measurement variability of an area of interest attributable to the Epson 1680 scanner would be <0.2% over the 0-800cGy dynamic range of EBT film. Kodak's published data indicates that EDR2 reaches a density of 3 between 600-700cGy and this implies that measurement variability of an area of interest attributable to the VXR-16 would be less than about 1% over the dose range. Since the vast majority of external beam dosimetry is performed at doses less than about 400cGy, film densities for EBT/Epson would be less than 1.2 and less than 2.0 for EDR-2/Vidar. Both combinations of film/scanner would provide consistent density measurement over the 0-400cGy dose range.

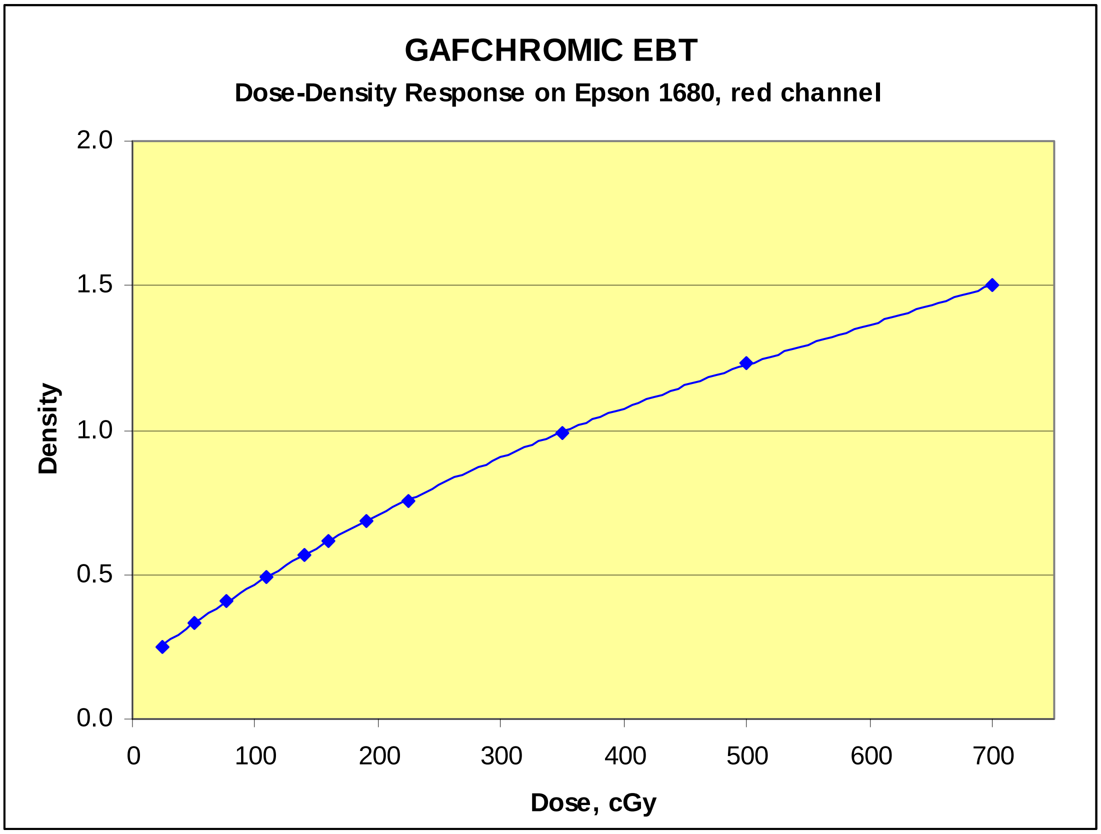

Figure 3: Dose-Density Response of GAFCHROMIC EBT on Epson 1680 Scanner

Using the dose-density response of EBT film on the Epson 1680 and Vidar VXR-16 the densities of the steps on the calibration tablet measured by the scanners were related to equivalent dose values for each step. By plotting the scanner response vs. the equivalent dose values and calculating the slope of the resulting response curve it is possible to predict the effect of scanner measurement consistency upon dose determination. The results are shown in Figure 4 and indicate that the better measurement consistency of the Epson 1680 in transmission mode should also produce lower dose error than the VXR-16. Except at the lowest dose (approximately 6cGy) the dose errors for the Epson 1680 and VXR-16 are respectively about 0.1% and 0.3% of the measured dose.

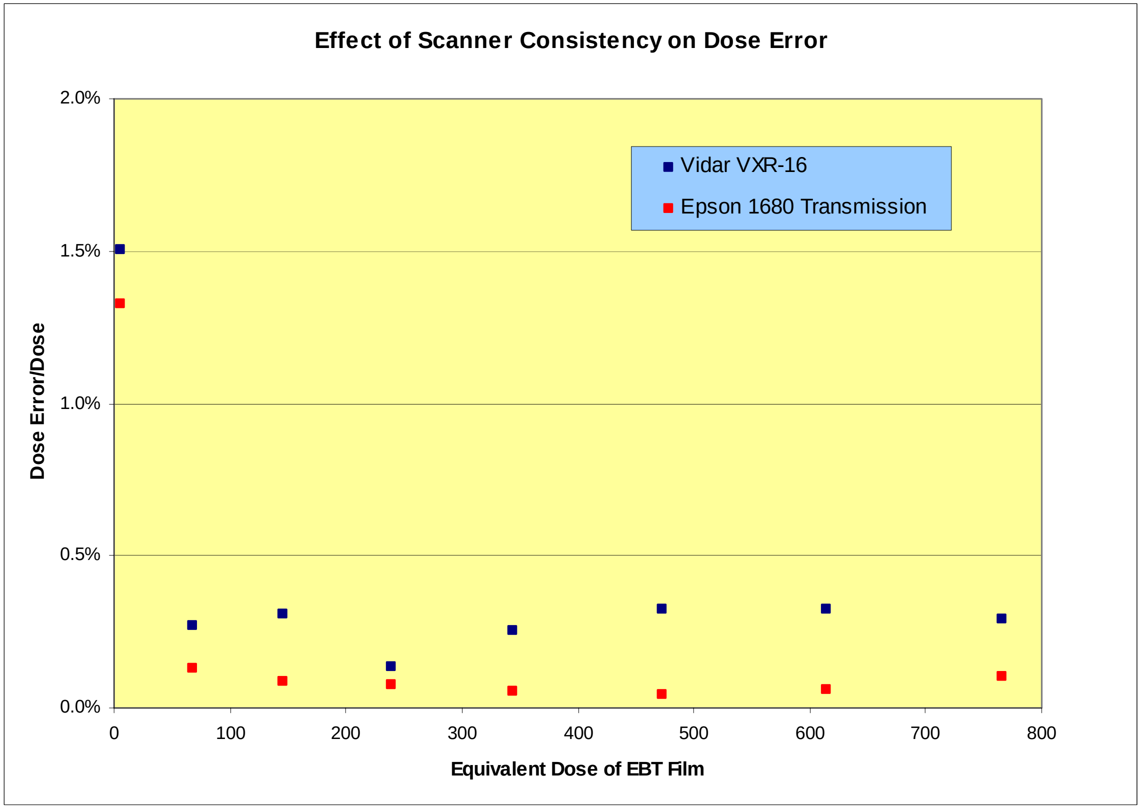

Figure 4: Effect of Scanner Measurement Consistency on Dose Error

4.0 Scan-to-Scan Consistency for Reflection Measurements

Reflection densitometry is a widely used means for measuring printed photographic or image media. The reflection density of a sample is related to its reflectivity in a similar way that the transmission density of a film is related to its transmission. Although the term reflectivity is used, it is really a misnomer since most of the light seen by the observer is scattered back from the media rather than reflected. While transmission density values >3 (transmission <0.1%) are readily measured, reflection density is, in practice, limited to values <2 (reflectivity >1%) and in some cases to values substantially less than this. The practical limitation arises because almost all surfaces will reflect or backscatter 1-3% of the incident light. As a result the characteristic curve of a sample measured in reflection will not be linear. The density values roll off because all steps have a reflectivity of 1-3% characteristic of the media.

The Epson scanners will scan transparent films in reflection mode. To do this, the manufacturer provides a uniform reflective white substrate that is placed behind the film medium during scanning. Alternatively the user could replace the manufacturer's reflective substrate with one of their own choosing. In any event, there remains the practical limitation of that the reflection measurements will be restricted to densities less than about 2.0.

4.0.1 Method

An investigation was made of the consistency of the Epson scanners in reflection mode. The procedure was analogous to that described for the transmission measurements in Section 3.0.1 except that a 20-step printed step tablet (Kodak Gray Scale) was used. Scan data were obtained in the red color channel at a spatial resolution of 75dpi (approximately 3 dots/mm). For each scanner 20 consecutive scans were collected over a period of about 15 minutes and measurement of the scan images was obtained over an area approximately 5mm x 7mm in size at the center of each step. The area of interest contained about 300 pixels. Data for each scanner were tabulated and the mean and standard deviation of the 20 measurements for each step was determined.

4.0.2 Results and Discussion

The consistency of the reflection measurements for each scanner was evaluated by calculating the standard deviation/mean, expressed as a %, and plotting that value against the reflection densities of the steps on the tablet. Figure 5 shows the results for the Epson scanners in reflection mode. Values for the Vidar scanner are presented for reference, bearing in mind that the VXR-16 provides only transmission measurements.

The results show that reflection scanning provides a reproducible means of measuring reflective film media. Inspection of the results in Figure 5 demonstrates that the Epson scanners yield similar consistent performance in reflection mode to their performance in transmission mode. The measurements have a variability of less than 0.2% and again the Epson scanners provide a markedly more consistent response than the Vidar scanner. Based on these results the flatbed scanners, in addition to their excellent performance in transmission measurements, can also provide high quality reflection measurements suitable for film dosimetry in addition to their .

Since the upper limit of reflection measurements is at a density about 2.0, this will lower the dynamic range of the film. In the case of EBT film the upper dose limit for reflection scanning is about 400cGy as opposed to 800cGy for transmission scanning. However, since the vast majority of film dosimetry for IMRT is performed at doses less than about

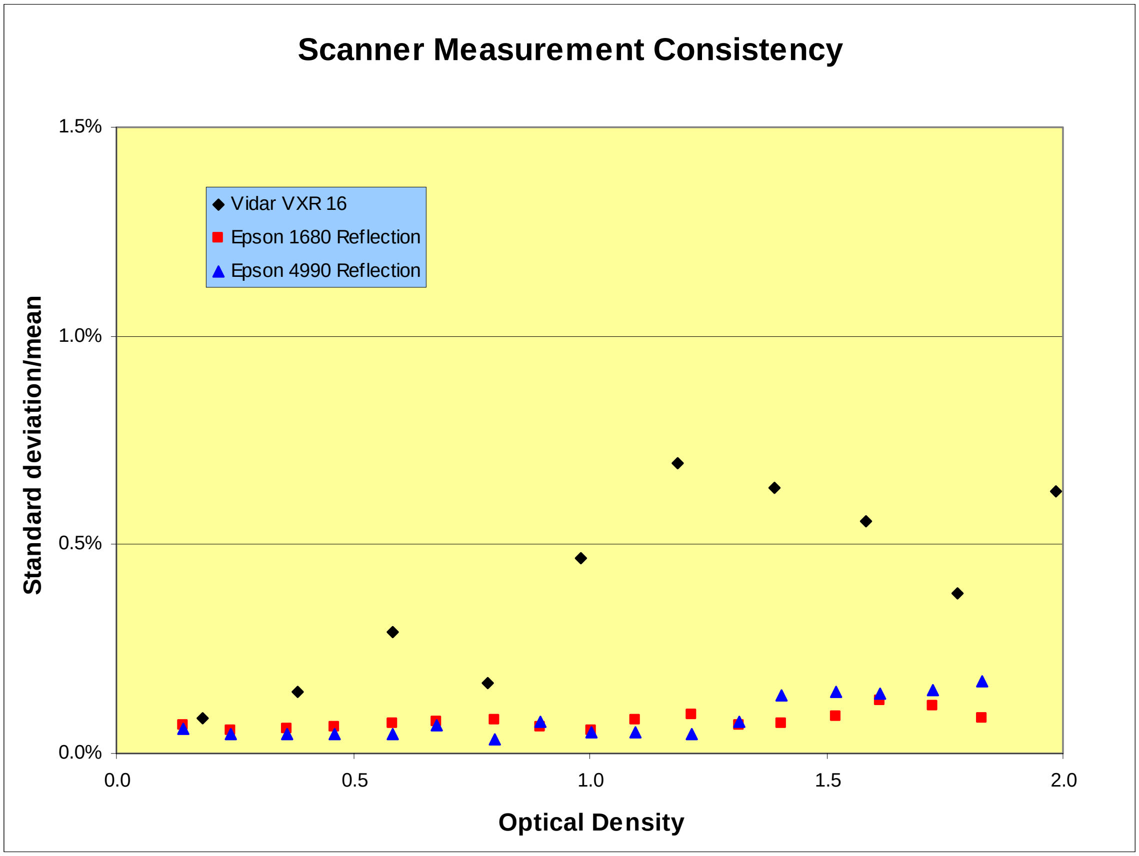

Figure 5: Epson Scanner Measurement Consistency in Reflection Mode

300cGy the reduced dynamic range of EBT film will not present a practical limitation to the use of reflection scanning. Indeed as shown in an accompanying white paper, the practical results of the analysis of EBT patient treatment films measured in reflection are virtually indistinguishable from the results measured in transmission.

Based on the dose-density responses of EBT film measured in reflection and transmission modes on the Epson 1680 the densities of the steps on the calibration tablet measured in both instances were related to equivalent dose values for each step. By plotting the scanner response vs. the equivalent dose values and calculating the slope of the resulting response curve it is possible to predict the effect of scanner measurement consistency upon dose determination in both measurement modes. The results are shown in Figure 6 and predict lower dose error for measurements in transmission mode. The dose errors in reflection mode are similar to those for the Vidar VXR-14 (see Figure 4)

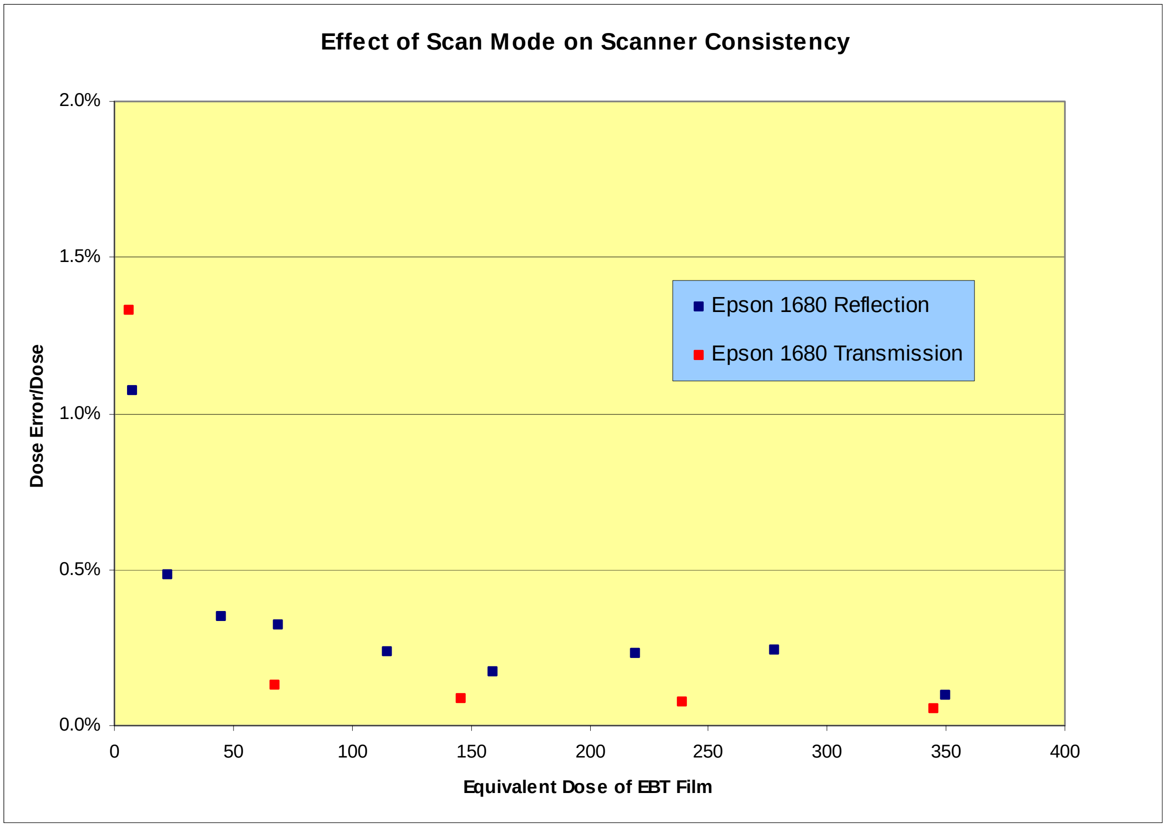

Figure 6: Effect of Scan Mode on Dose Error

5.0 Single Pixel Noise

The first analysis was made with the U.S. National Institute of Standards and Technology SRM 1008 standard reference material. This was chosen for its exceptionally high uniformity. The very high uniformity of the standard reference material is desirable because it will not mask the measurements of single pixel noise while contrasting the performance of the scanners.

A second analysis was performed using a step tablet made from GAFCHROMIC EBT film. This is of more practical significance for film dosimetry since it provides an assessment of the overall effect of a dosimetry film and the scanner on single pixel measurement noise.

5.1 Transmission Measurements with Standard Reference Material

Consideration of single-pixel noise was made in two ways. Firstly an analysis of the raw pixel-by-pixel data was done. However, film scans data can be affected by defects on the film and in the optical path (fingerprints, scratches, dust, etc.) as well as noisy detector elements. Most film analysis software, including FilmQA™ software, has the capability to perform appropriate filtration of the raw data to attenuate the effects of a few wild pixel values greatly different from the mean. Therefore, as a practical demonstration of the effect of single-pixel noise, a second analysis was done with filtered data. This analysis was done using FilmQA™ software which routinely applies a 3x3 Weiner filter to the pixel values. A Weiner filter subtly attenuates the contribution of isolated wild pixels and has minimal effect on spatial resolution.

5.1.1 Analysis - Without Use of Data Filtration

The scan data used for the analysis of the single pixel noise of the scanners in transmission mode was the same as that employed in the comparison of scan-to-scan consistency (Section 3.0.1). For the purpose of comparing the performance of the scanners, measurements of the standard deviation of a single pixel were made over areas of interest containing about 300 pixels centered in the middle of each of the steps of the NIST calibration tablet. The average standard deviation for the pixel in each step was then determined. The response data (scanner response vs. optical density (OD)) was plotted for each scanner. After fitting the data for each scanner with a 4th order polynomial, the slope of the response curve was calculated for each of the steps on the tablet. Using the calculated slope at each step and each scanner and the corresponding standard deviation for the single pixel response value, the effect of noise in the single pixel measurements was determined by calculating the absolute value of the OD error divided by OD:

$$\mathrm{ABS}(\sigma_n/S_n)*100/D_n$$

where:
σ = average standard deviation for a single pixel measurement of at the nth step
S = slope of pixel value-density response at the nth step
D = optical density of the nth step
ABS = absolute value

The data are presented in Figure 7. The results indicate that all scanners have single pixel measurement noise less than about 1% over a substantial range of densities and that the VXR-16 has a little lower single pixel noise, particularly at densities above 2.0. However, it can be seen from Figure 3 that EBT film on the Epson 1680 has a density much less than 2 and this implies that the single pixel noise attributable to the Epson 1680 would be in the range from about 0.5% - 1% at doses up to 800cGy.

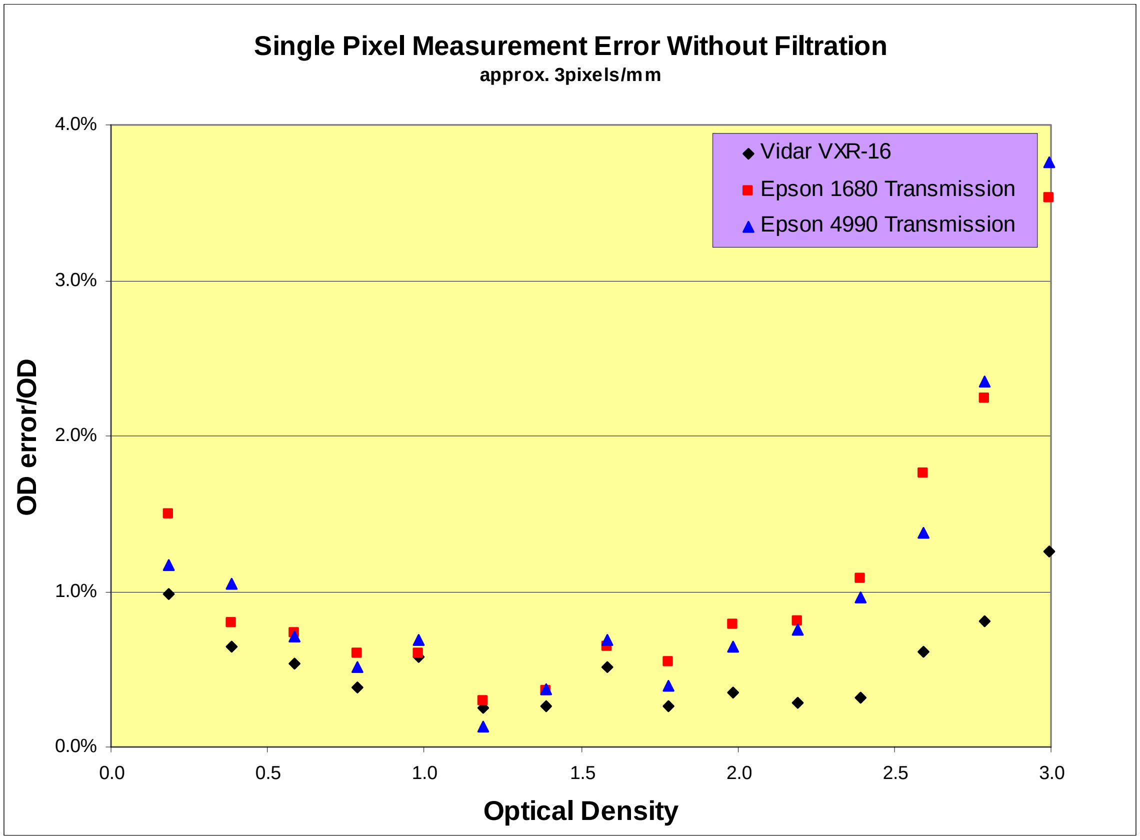

Figure 7: Single Pixel Measurement Error in Transmission– without data filtration

5.1.2 Analysis - With Data Filtration

In practice the small effect of single pixel measurement noise can be diminished even more by applying a low order of data filtration, for example with a 3x3 median or Weiner filter. These types of filters subtly smooth the image and remove the contribution of isolated wild pixels. They have negligible effect on the spatial resolution of features within the image.

To demonstrate the effect of filtration a 3x3 Weiner filter was applied to the raw data from the Epson and Vidar scans to reduce the effects of pixels that deviate substantially from the values of its neighbors. The data filtration and subsequent measurements were effected by using of FilmQA™ dosimetry verification software. This software, which has features optimized for use with GAFCHROMIC EBT film such as pixel-by-pixel correction. The measurement and data analysis procedure was the same as described in Section 2.0.2.1.

The results are shown in Figure 8 and they indicate that the filtration is effective in reducing single pixel noise at densities less than 2. Since the single pixel noise of the flatbeds is greater than the VXR-16 it is not surprising that the data filtration is more effective on the Epson scanners. Noise reduction was about 30% and 15% for the Epson and Vidar scanners respectively. The result is that the single pixel noise for all scanners is very similar at densities less than 2. As pointed out previously EBT film has a density much less than 2 at 800cGy, the top end of its dynamic range.

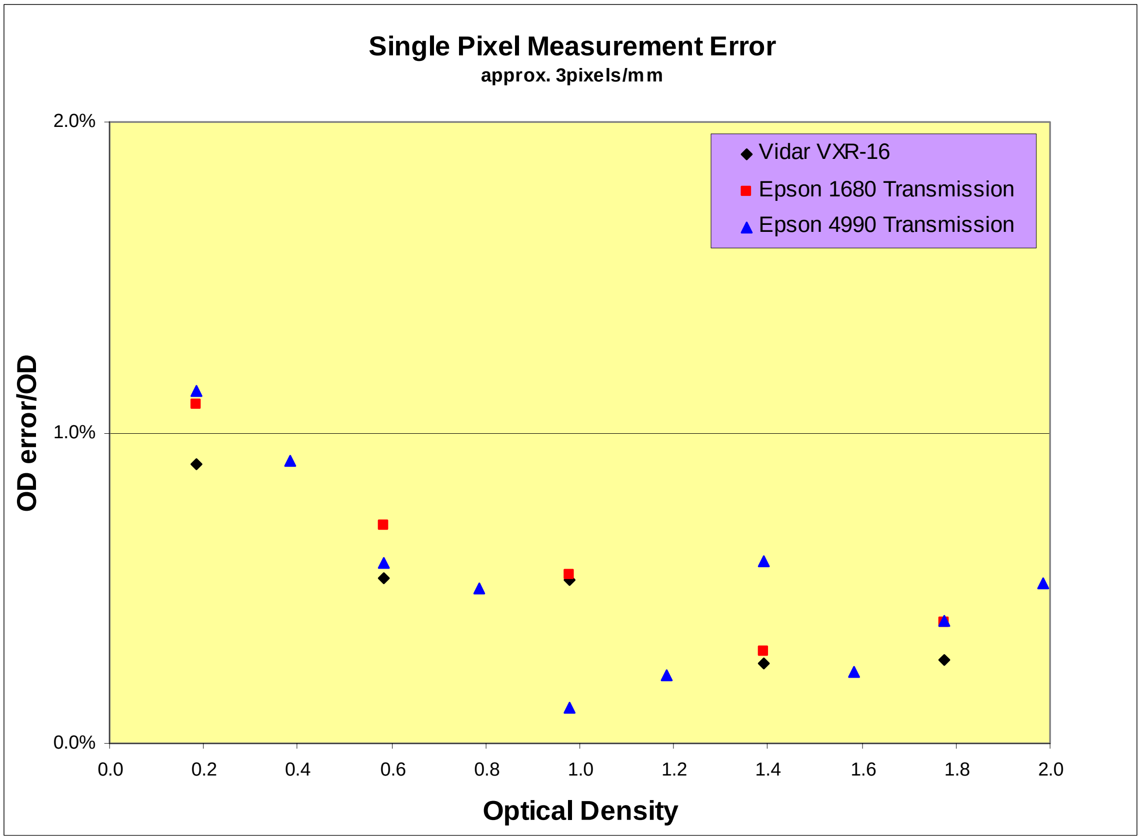

Figure 8: Single Pixel Measurement Error in Transmission – with data filtration

The density error is essentially a measure of measurement noise at the single pixel level. For both scanners the minimum noise is about 0.4% and occurs at a density of about 1.5. The Vidar shows marginally lower noise than the Epson 1680 scanner at densities less than about 2.5 and is markedly better at higher densities. The results indicate that the very low single pixel noise from the Epson flatbed scanners makes them suitable for application in film dosimetry.

5.2 Reflection Measurements

Analysis of the single pixel noise for the Epson scanners in reflection mode was done first without and then with the application of a 3x3 Wiener filter using the approach described for transmission measurements in Sections 5.0.1 and 5.0.2.
The results of the analyses without and with data filtration are shown in Figures 9 and 10 respectively. The VXR-16 functions only in transmission mode and the results for this scanner are shown for reference. Qualitatively the single pixel noise measured in

reflection shows a similar characteristic to the results for transmission measurements, i.e. the noise is highest at high and low densities, falling to a minimum at intermediate densities. However, at the lowest density (0.14) and at densities >1.4 the single pixel noise for Epson scanners in reflection mode is significantly greater than for the VXR-16. At intermediate densities, between approximately 0.3 and 1.2 the single pixel noise is similar for all scanners.

With application of the Weiner filter to remove the effects of isolated wild pixels the single pixel noise of the flatbed scanners is significantly reduced. For the lowest and highest densities (0.14 and >1.5 respectively) the noise reduction approaches 50% for the flatbed scanners. At intermediate densities noise reduction is somewhat less – about 30% for the flatbed scanners and 15% for the VXR-16. For densities less than about 1.4 , the noise values for the Epson scanners in reflection mode after application of the Weiner data filter are quite similar to the noise for the Vidar measurements (also with application of the Weiner filter.

As with the results for transmission measurements, the very low single pixel noise from the Epson flatbed scanners makes them suitable for application in film dosimetry when measuring in reflection, subject to an upper density limitation of about 1.5. GAFCHROMIC EBT film measured in reflection mode on the Epson scanners has a density of approximately 1.3 at a dose of 400cGy. This implies that the flatbed scanners can make reflection measurements of EBT film and maintain single pixel noise at about 1%, or better, at doses between about 25cGy and 400cGy. And over most of the dose range the noise would be less than 0.5%.

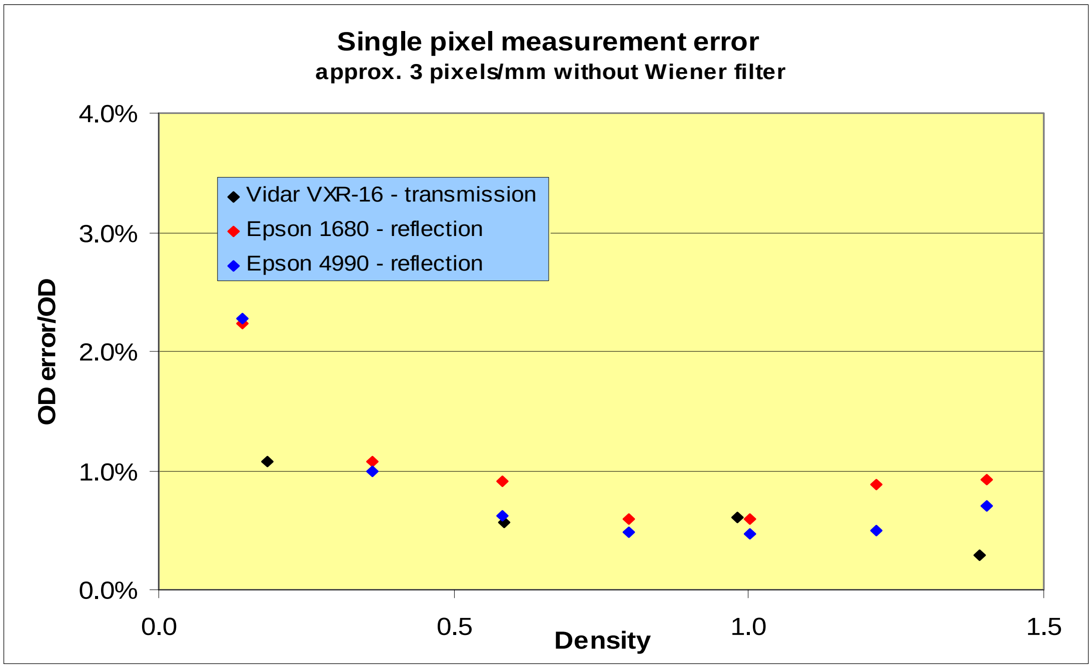

Figure 9: Single Pixel Measurement Error in Reflection– without data filtration

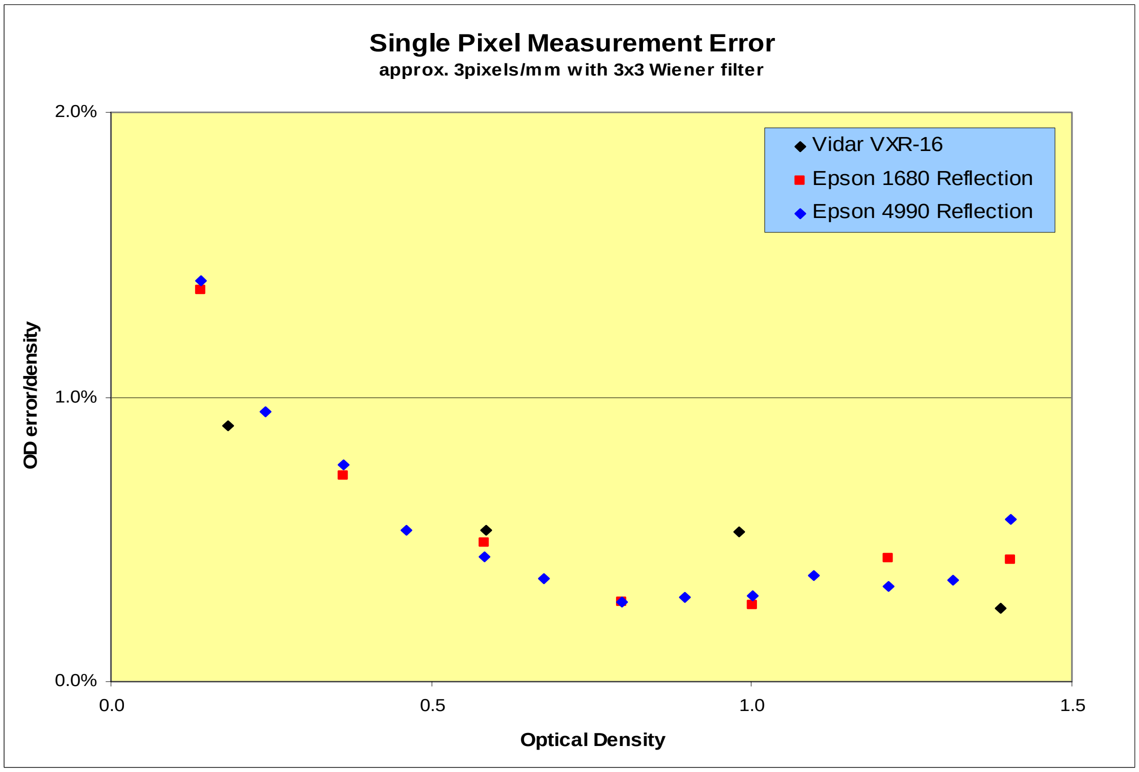

Figure 10: Single Pixel Measurement Error in Reflection – with data filtration

5.3 Measurements with GAFCHROMIC® EBT Calibration Films

The final part of the investigation was to scan a step tablet made from GAFCHROMIC® EBT film with the Epson 1680 and Vidar VXR-16. The scan data was used to evaluate the effect of the single pixel noise on dose error. An 8-step calibration tablet with doses ranging from about 25cGy to 225cGy was exposed onto EBT film. The calibration film and an unexposed film (i.e. zero dose) were measured by scanning on an Epson 1680 using the red color channel in transmission and reflection modes and on a Vidar VXR-16 scanner. The scan resolution was 75 dpi for the Epson scanner and 71 dpi for the Vidar VXR-16.

Measurement of the scan images were done using FilmQA™ software and a 3x3 Weiner filter was applied to the raw data. The mean pixel value and standard deviation in area of interest approximately 10 pixels x 10 pixels was measured on each step. For each scanner or scan mode five sets of measurements were made and averaged. The pixel value and dose data were plotted. After fitting to a fourth order polynomial, the slope of the response curve (change in pixel value per unit dose) was calculated at each dose point. Single pixel noise results in an uncertainty in dose measurement and this can be represented by calculating dose error as a percentage of the dose.

Thus:

$$\text{Dose error} = \sigma/S_{ABS}$$

where σ is the mean standard deviation of the pixel values in the area of interest and S_{ABS} is the absolute value of the slope of the response curve for that step.

For measurements made in transmission, Table 1, dose error values for the VXR-16 are marginally lower than for the Epson 1680. However, the differences are not significant. Except for the lowest dose (24.5cGy) the values of dose error/dose are all between about 0.5% and 0.9%. At the lowest dose, the dose errors for a single pixel were <0.4 cGy in absolute value. Considering the very high spatial frequency of scan data (approximately 900 dose points per cm^2), as well as the contribution of all other error sources to dose measurement, the effect of 1% noise at the single pixel level would be insignificant for practical film dosimetry. From this point of view, the performance of the Epson 1680 and Vidar VXR-16 with GAFCHROMIC EBT film are equally good and very satisfactory fro practical film dosimetry.

Table 2 shows the dose errors for the measurements made with the Epson 1680 in reflection. The performance at the lowest dose (24.5cGy) is slightly better for the transmission measurements. The higher slope of the response curve at this point reflects the higher contrast provided by reflection measurements. As explained previously, this is the result of the film having an active layer that is effectively twice as thick because light passes through the active layer two times when measurements are made in reflection. However, at higher exposures, the slope of the response curve diminishes rapidly and the standard deviation of the pixel values in the measurement area is higher than the values for transmission measurement. This reflects the influence of three factors. Firstly, the contribution to uncertainty due to noise within the active layer of the film will be higher because of the layer is effectively twice as thick. Secondly, when scanning in reflective mode, light has to be scattered back through the film by a diffuse white reflector behind the film and imperfections in this diffuse reflector also contribute to the measurement noise. Thirdly, the signal at the detector has a component due to front and back surface reflection from the film (i.e. at the film-air interfaces). Again, microscopic imperfections in the surface of the film will contribute to noise in the signal at the detector. Finally, since the front surface reflection is independent of film exposure, the signal at the detector is increasingly influenced by light reflected from the front surface as the active layer in the film darkens and absorbs more light. As a result the slope of the response curve diminishes. The overall consequence is that the single pixel noise is higher for reflection scanning resulting in dose error of about 1%-1.5% of dose as compared to values generally 0.5%-1.0% for transmission scanning.

	GAFCHROMIC EBT with Epson 1680 transmission				GAFCHROMIC EBT with VIDAR VXR-16			
Dose, cGy	Mean Pixel Value	Standard Deviation	Slope, pixel value/cGy	Dose error/Dose	Mean Pixel Value	Standard Deviation	Slope, pixel value/cGy	Dose error/Dose
0	50982	86	-223	-	40101	58	-226	-
24.5	46218	75	-176	1.7%	37200	68	-168	1.6%
50.2	42248	62	-136	0.9%	31175	47	-123	0.8%
76.4	38797	75	-105	0.9%	28633	55	-91	0.8%
108.9	36097	69	-78	0.8%	27243	58	-66	0.8%
139.6	34032	43	-61	0.5%	25961	38	-54	0.5%
160.2	32587	56	-53	0.7%	23314	51	-49	0.7%
189.6	31365	70	-47	0.8%	22122	42	-43	0.5%
225.3	29483	86	-43	0.9%	21623	67	-33	0.9%

Table 1: Single Pixel Noise for EBT film using Transmission Scanning

	GAFCHROMIC EBT with Epson 1680 reflection			
Dose, cGy	Mean Pixel Value	Standard Deviation	Slope, pixel value/cGy	Dose error/Dose
0	44611	104	-335	-
24.5	37136	76	-234	1.3%
50.2	32763	94	-157	1.2%
76.4	29348	97	-103	1.2%
108.9	26502	82	-64	1.2%
139.6	24975	89	-48	1.3%
160.2	23607	95	-43	1.4%
189.6	22637	81	-40	1.1%
225.3	21457	104	-34	1.4%

Table 2: Single Pixel Noise for EBT film using Reflection Scanning

7.0 Conclusion

When measuring calibrated step tablets composed of the standard reference material the Epson 1680 and 4990 flatbed scanners provide markedly more consistent measurements of small areas of interest in both transmission and reflection mode than the Vidar VXR-16. At densities <2 all scanners have consistency better than 1%.

When the single pixel measurement noise is evaluated, the Vidar scanner produces slightly better performance than the Epson scanners. However, all scanners have a single pixel noise <1% over a large part of the measurement range. Furthermore, by using FilmQA™ verification software to apply a 3x3 Weiner filter to the scan data, as would typically be done in an IMRT film dosimetry analysis, the single pixel noise is similar for all scanners and is <0.5% over much of the density range.

The results with the standard reference material also predict that for EBT film exposed at doses up to about 800cGy, the Epson 1680 and Epson 4990 scanners will provide highly repeatable measurements with low single pixel noise. Good performance is also predicted for the Epson scanners measuring EBT film in reflection mode at doses up to about 400cGy.

The suitability of GAFCHROMIC EBT film and the scanners for film dosimetry was confirmed by measurements using a step tablet composed of that film and the results demonstrated that the system delivers single pixel noise less than 1% for the Vidar VXR-16 and Epson 1680 in transmission. Results for reflection scanning were slightly inferior and at this time it is recommended to use transmission scanning when it is available.

Overall the results demonstrate that the Epson flatbed scanners provide performance comparable to the Vidar VXR-16. Considering the dynamic range of GAFCHROMIC® EBT film, the results indicate that the flatbed scanners are very suitable for use in high quality film dosimetry when used in transmission mode and only slightly inferior in reflection mode. As a system with EBT film and FilmQA™ verification software, the flatbed scanners can provide a high-quality, cost-efficient film dosimetry means that, because EBT film is self-developing, is compatible with the filmless radiotherapy department.