Repeatability and calibration results of GAFchromic EBT film with flatbed and medical scanners

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Abstract:
The newly introduced GAFChromic EBT film presents some challenges for film dosimetry. Its manufacturer suggests that this self-developing film may have the best response from "consumer grade" graphic arts flatbed scanners if the "red" channel is used. We have performed extensive testing on "consumer grade" graphic arts scanners and present some of the results in this paper. Additionally, data comparing film digitizing results of EBT film using a medical grade scanner are compared to the results from digitizing with the manufacturer's recommended "consumer grade" graphic arts scanner.

The results indicate that the "consumer grade" scanners performed significantly worse in the areas of repeatability, maximum OD, and clinical film scanning than the medical grade scanner.

The results also show an unexpected response curve from EBT film when relating scanner values to dose. These results indicate medical physicists should fully understand EBT's characteristics before using it in clinical situations.

Introduction:
Film dosimetry software has been very successfully used to scan and convert to dose many types of transparent media. In addition to Kodak XOMAT-V, TL, and EDR2 films, GAFChromic MD series film, and even copier films have been used for dosimetry purposes.

The new ISP EBT film presents some unique challenges for dosimetry applications. It has the advantages of being less expensive, larger, and more sensitive to dose than the MD series of radiochromic films. Both of these films are self developing, which has significant appeal for medical facilities which may be removing conventional film processors. ISP suggests that a "consumer grade" graphics art scanner can be used for converting these films to dose. Additionally, ISP recommends using only the red channel (from these three channel color scanners) to improve the dose correlation [2][3].

The primary purpose of this paper was to test these "consumer grade" scanners and compare their performance to a "medical grade" (FDA 510(k) cleared) scanner in order to determine if a low cost scanner could be used for dosimetry. It is well understood that cost may be a significant issue for some radiation treatment facilities. If a low cost scanner could perform as well as a medical grade scanner, perhaps the regulatory issues could be addressed in order to comply with the FDA GMP requirements for a Film Dosimetry System or Film Scanning System as a Class II medical device under 21 CFR 892.5050. Three scanners were tested which were representative of three price ranges: the Vidar Dosimetry Pro (>$10,000), the Epson 1680 (>$1000), and the Epson 1670 (>$100). The Vidar Dosimetry Pro and the Epson 1680 are transmissive scanners. The Epson 1670 is a reflective scanner. The Epson 1680 can be used in either reflective or transmissive modes, but only transmissive mode was used for this testing.

The secondary purpose of this paper is to directly compare ISP sample films as scanned by the manufacturer's recommended [6] scanner (an Epson Expression 1680 Professional document scanner)[1] in the recommended configuration and the same films scanned with a Vidar VXR16 Dosimetry Pro medical grade scanner. Note that Epson makes no claim of this product's suitability for dosimetry or medical applications. Identical tests were conducted with numerous other "commercial grade" graphics arts scanners. The results of these tests were similar for each price range of scanner. Therefore, only the results of these three scanners will be presented.

Test configuration for generalized scanner testing:
Complete digitizer qualification tests involve several hundred measurements made from scanning a specific set of test films. These tests typically take two to three weeks. The details of these tests and their analysis will be the subject of a future paper. For this scanner comparison, the analysis will focus on a small subset of the qualification tests.

One of the key tests for a scanner to be used for dosimetry is the performance that is measured when scanning an optical density (OD) step wedge. A step wedge made by Stouffer Industries (South Bend, Indiana) is used for these tests (Stouffer part number L-402). The step wedge is made using an optical process to enhance the uniformity. This step wedge is calibrated by Stouffer to a NIST standard. A calibration report is included with each step wedge. The step wedge contains 32 distinct and uniform optical density steps from approximately 0.05 to approximately 3.8 OD. The step wedge is 8 inches by 10 inches and the useable area for analysis trims off about one inch on the right and left side to eliminate film edge effects. Areas are also cropped from the top and bottom where handling occurs and where special density areas are located. The RIT113 software OD Step Calibration (Radiological Imaging Technology, Colorado Springs, CO) automatically aligns the step wedge, finds each step and extracts a uniform area in the center of each step for analysis. Typically, each extracted step has several thousand pixels that are analyzed.

Analysis of the step wedge data provides information about the short term and long term repeatability, the maximum useable optical density, the distinctness of each resolved optical step, and the noise associated with each OD level.

Since OD is defined as a transmissive measurement, the correct way to measure scanner performance is in transmissive mode. The lower cost scanners typically only have reflective mode available as this helps to keep the cost low and is more suitable to the typical buyer's needs for this type of scanner (document and photograph scanning). Wherever possible, transmissive mode was used during these tests to achieve a more correct measurement.

Scanner testing results:

In the first test, a step wedge was scanned 50 times to evaluate the noise and the short term drift**.**

The maximum useable optical density is defined to be the last monotonic step detected whose average step value is at least two scanner counts away from the average value of the previous step. This helps to ensure that the steps are distinct. Table 1 contains a summary of these scans.

Test	**Epson 1670**	**Epson 1680**	**Vidar Dos Pro**
OD step wedge maximum standard deviation	**130.48**	**83.54**	**41.3**
OD step wedge minimum standard deviation	**56.53**	**10.72**	**0.24**
OD step wedge mean standard deviation	**97.25**	**30.29**	**8.04**
Maximum detectable OD	**2.1**	**3.65**	**3.65**
Data variation begins to overlap at (OD)	**1.22**	**0.39**	**3.18**

Table 1

For each of the 32 steps in each of the 50 scans, a central region of interest was extracted that represented the most uniform area of each step. The mean of the uniform area was reported as the step value. Then, for each OD level, the maximum value, minimum value, and standard deviation across the 50 scans were calculated. The standard deviation numbers in Table 1 are the values across the 50 scans.

The average noise (standard deviation) of a step measured on the Epson 1680 is 30.29 scanner units vs. only 8 scanner units for the Dosimetry Pro. This is almost four fold increase in noise. The Epson 1670 had more than a 12 fold increase in noise over the Dosimetry Pro.

In the case of the VXR16 Dosimetry Pro, the maximum usable optical density was 3.65. For the Epson 1680, the maximum useable optical density was also 3.65. However the Epson 1670 had a maximum OD of only 2.1. Since optical density is a logarithmic scale, this is a significant difference.

The maximum and minimum values, across the 50 steps, were compared for adjacent steps. Once these values start to overlap, the scanner cannot reliably distinguish between steps. Effectively, the scanner values are being dominated by noise rather than the difference in optical density. The last row of Table 1 compares these values for the three scanners. The very poor performance of the Epson 1680 was surprising. Figures 1, 2, and 3 summarize individual step data taken from these scanners. The lowest OD values were removed from these plots to enhance the readability of the figures. Large scanner values from low optical densities were dwarfing the more significant data over 1 OD.

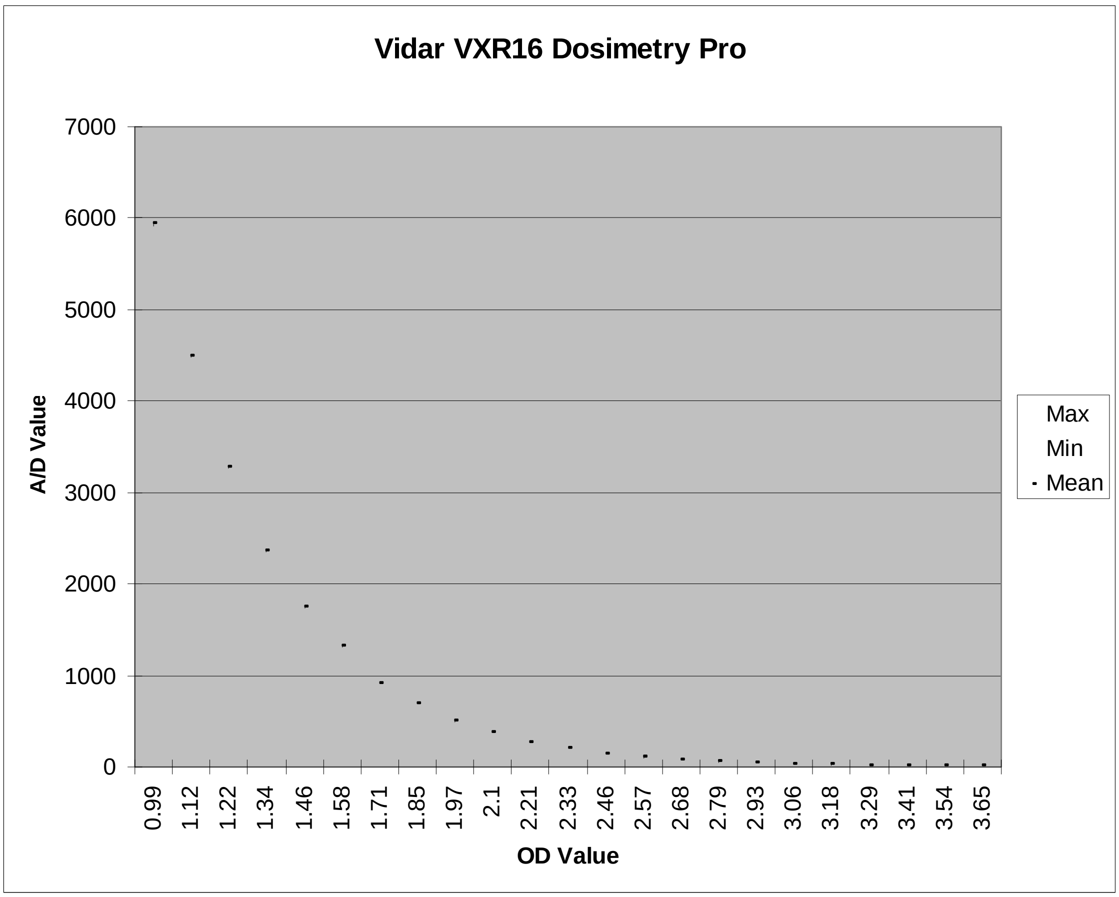

Figure 1. VXR16 Dosimetry Pro results for 50 scans
Note: the error bars are small, but they are shown on the plot.

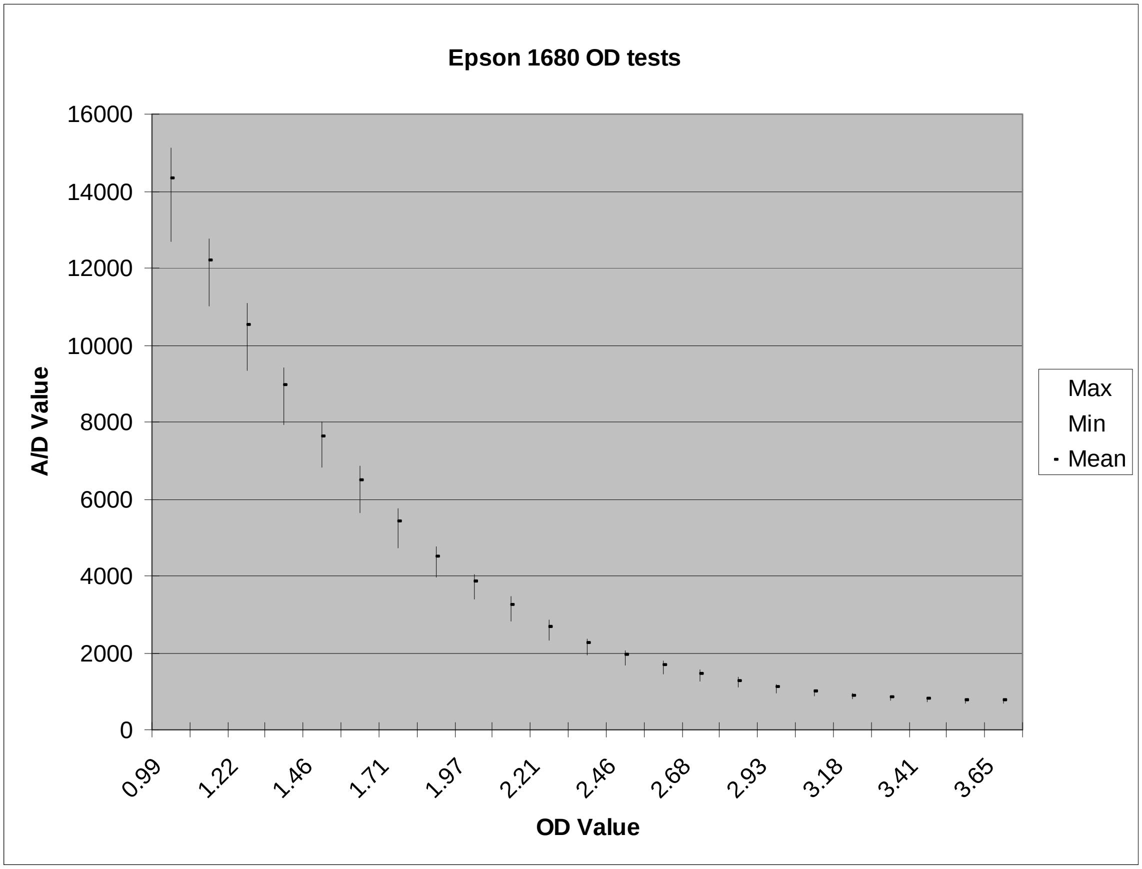

Figure 2. Epson 1680 results for 50 scans

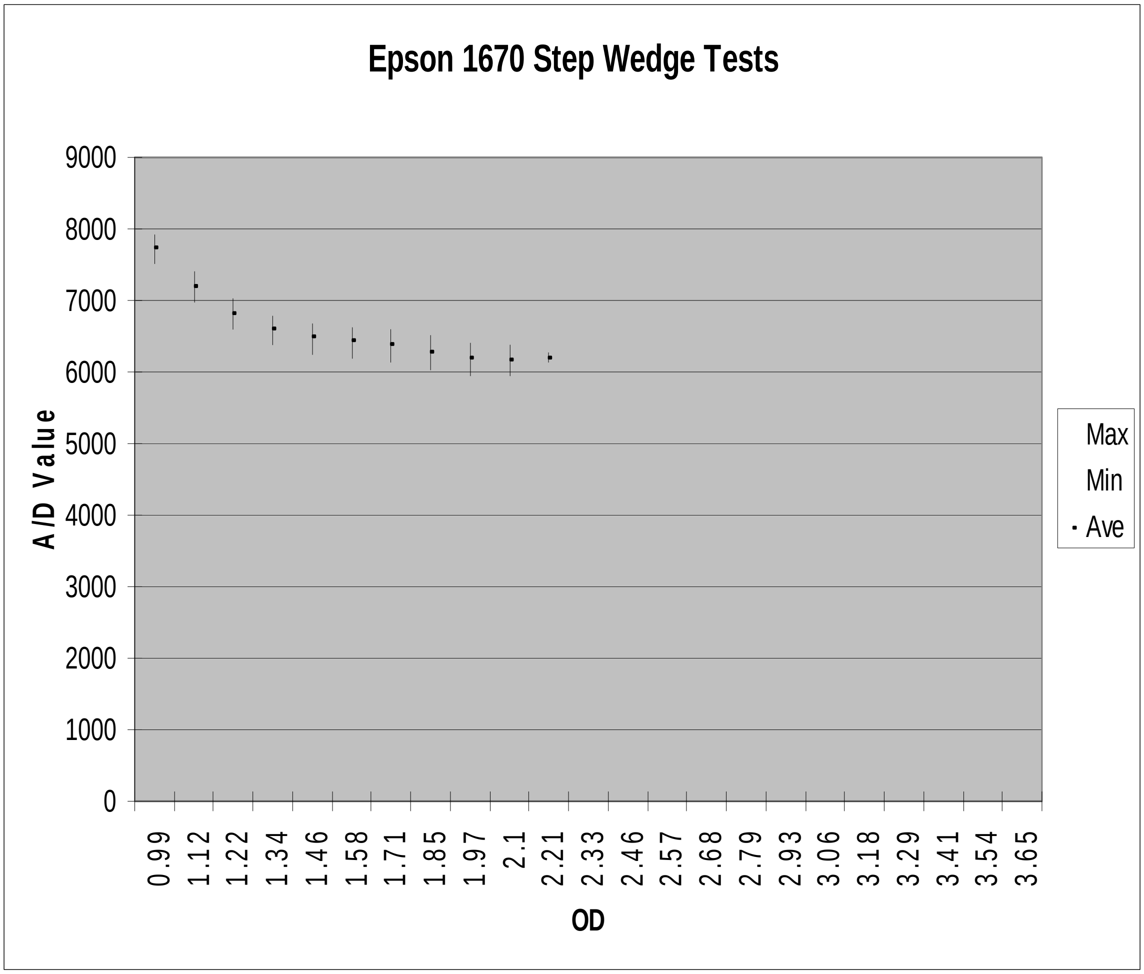

Figure 3. Epson 1670 results for 50 scans

A careful inspection of Figures 1, 2, and 3 shows that each density step resolved by the Dosimetry Pro is distinct to more than an OD of 3. However, this is not the case for the Epson 1680 after about 0.39 OD or the Epson 1670 after about 1.22 OD. An overlap in the scanner values leads to uncertainty in the dose value. Since they have a virtually identical range of scanner values, a dose calibration algorithm could not reliably distinguish between the 1.36 step and the 1.47 step (or the 1.61 step for that matter) in the Epson 1670. While this may have no importance in document scanning, it is critical in film dosimetry.

Due to the lack of FDA GMP constraints in the manufacturing process, graphics arts scanner manufacturers can substitute hardware materials (optics, light source, drive mechanics) and firmware (lookup tables, image processing, drivers) at will without notice to the system integrators, resulting in significant differences between scanners, even of the same make and model. These manufacturers are uninformed about needs of the radiation therapy physicist and would probably not have a desire to tighten manufacturing procedures to meet the rigid GMP standards for such a small segment of the marketplace, since making these changes would significantly impact the price of the product as demonstrated by the price of the Vidar Dosimetry Pro scanner.

EBT test configuration:

EBT sample films were provided by the manufacturer (International Specialty Products, ISP)[4]. ISP had exposed three films to various levels of radiation (one film with calibration pattern and two films with IMRT fields) and had provided one film as a "zero dose" film. These films were kept in the manufacturer's light tight envelopes until ready for scanning. They were scanned with an Epson 1680 document scanner that has a transparency attachment. As per ISP's recommendation [2], the red channel, from this three color CCD, was extracted (in software) and used for dosimetry testing. Similarly, a Vidar Systems Corporation VXR16 Dosimetry Pro was also used to scan these EBT films. The Dosimetry Pro is a monochrome transmissive medical quality scanner. It does not have the ability to output separate color channels, so the standard output was used. Due to the poor suitability of the Epson 1670 scanner, no EBT analysis was performed.

Over the years, there has been some confusion about the correct method of scanning EBT films. ISP currently recommends scanning them in transmissive mode [2][3]. For these tests, only transmissive measurements were used.

No colored filters were used with either scanner configuration. Some recommendations from ISP do include using a yellow filter made from a colored report cover available at office supply stores [2][3]. Colored report covers are not of sufficient optical quality and uniformity for dosimetry use. Use of these filters could add distortions to the image quality and therefore to the measured dose. Additionally, the Vidar specification sheet [7] and the Vidar Warranty [8] clearly indicate that using an additional filter would exceed the film size (thickness) specification and the single film layer requirement and will result in voiding the scanner warranty [5].

The ISP literature indicates that they have disassembled their scanner and permanently mounted a filter over the camera assembly [2]. While this may reduce some of the optical effects of using a large sheet of this film, this technique was not considered because it would void the manufacturer's warranty and invalidate the FDA 510(k) clearance for the device. These tests were limited to procedures that could be reasonably expected of a medical physicist in the field while preserving the integrity and the warranty of the scanner.

Per ISP's recommendation [2][3], great care was taken while scanning these films to preserve the correct film orientation.

EBT test results:

The RIT113 software can be used in a number of configurations to develop a calibration curve which relates scanner values to dose. Figure 4 illustrates a typical calibration curve for Kodak EDR2 film that was scanned with the Dosimetry Pro scanner.

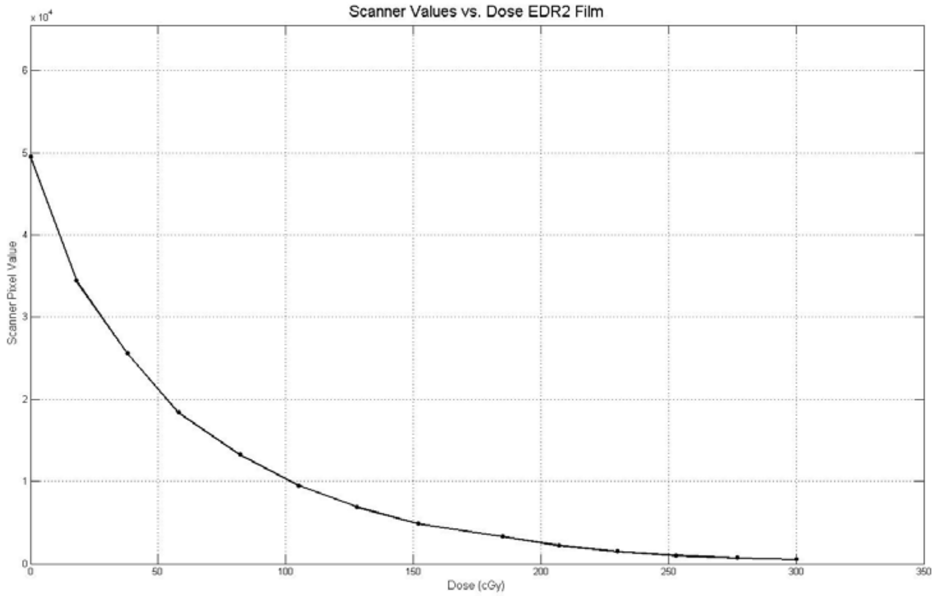

Figure 4
EDR2 typical calibration curve

The shape of this curve is typical for all types of radiographic films.

Using the exposed film and a zero dose film, provided by ISP, the calibration curve in Figure 5 was similarly developed.

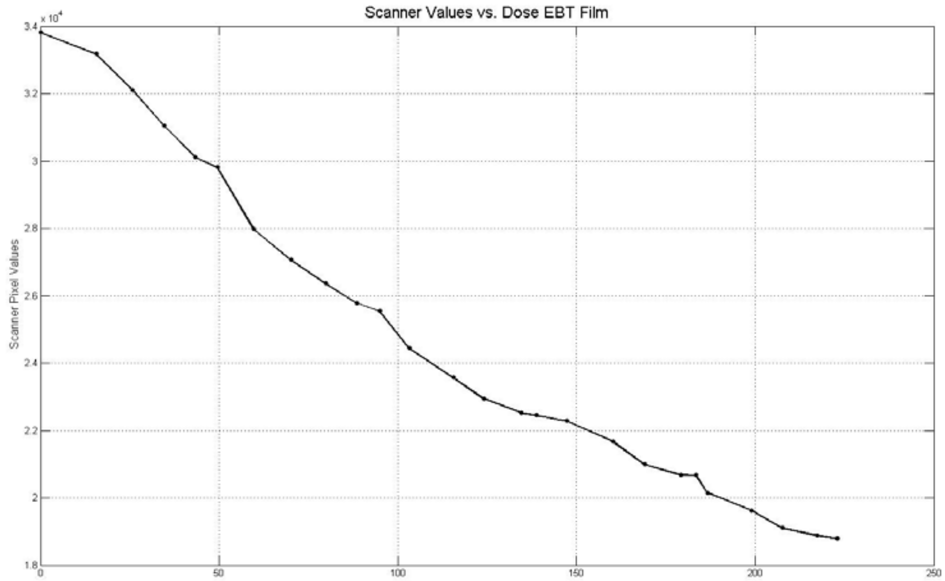

Figure 5
EBT calibration curve from the Dosimetry Pro scanner

The same calibration curve developed using an Epson 1680 scanner has similar features. Figure 6 illustrates a detailed comparison between the curves developed using these two scanners. From this figure, we can see that the curves are fairly similar. It is important to remember that the scanner values for each of these dose points are highly averaged over 1cm square regions. Many of the curve inflections happen in the same places. However, the Epson 1680 has more inflection points and the magnitude of these inflection points is larger than those calculated from the Vidar Dosimetry Pro data. Additionally, it has been reported [2] that using the red channel in the Epson increases the slope of the calibration curve and therefore is sampling where the film is more responsive. Figures 6 contradicts this finding and shows the slope of the curves from the red channel of the Epson 1680 and from the board spectrum Vidar Dosimetry Pro are nearly identical.

The inflection points and the uneven spacing between the dose points are very concerning. This curve is no where near as well behaved as the EDR2 curve in Figure 4. Because the curves are so similar using different scanners, it is concluded that the unusual aspects of the response curve are due to the EBT film itself. The shape of the curve for EBT film would lead to the conclusion that it may be difficult to accurately determine different dose levels which are close together. This would lead to some dose uncertainty in the actual delivered dose that is being measured on radiation therapy films.

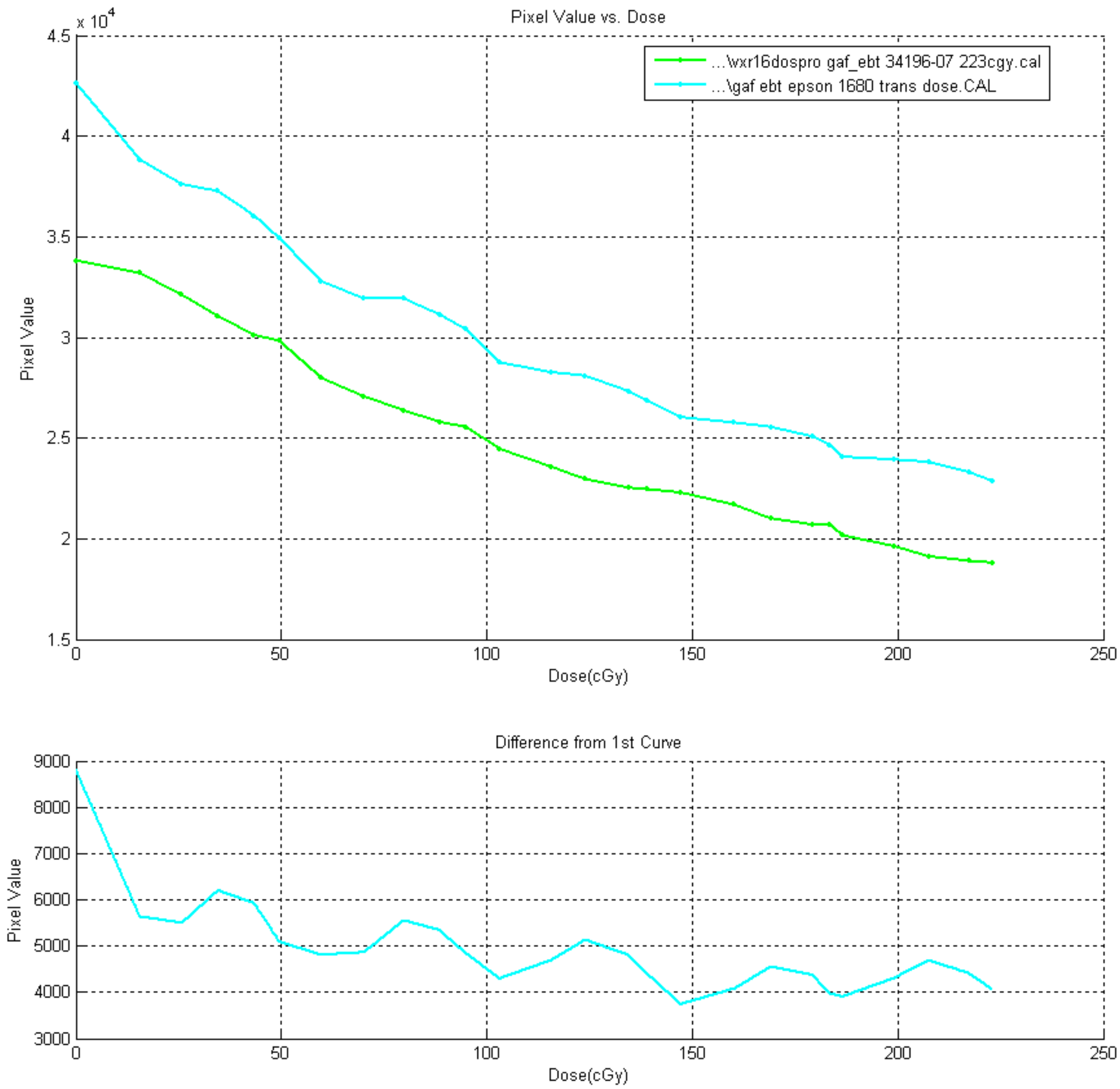

Figure 6.
Calibration curve comparison.

Finally, a direct comparison was performed on the calibration film, provided by ISP. Using the RIT113 comparison routines, the Epson scanned film was calibrated with the Epson calibration file and the Vidar scanned film was calibrated with the Vidar calibration file. Four pin pricks on the film allowed precise registration between the two images. After registration and normalization (the images were both normalized to 100 so the output profile would be displayed in dose and not percent), a profile was extracted through each film. Due to the registration process, the position of the extracted lines was identical on the two films. Figure 7 illustrates this comparison.

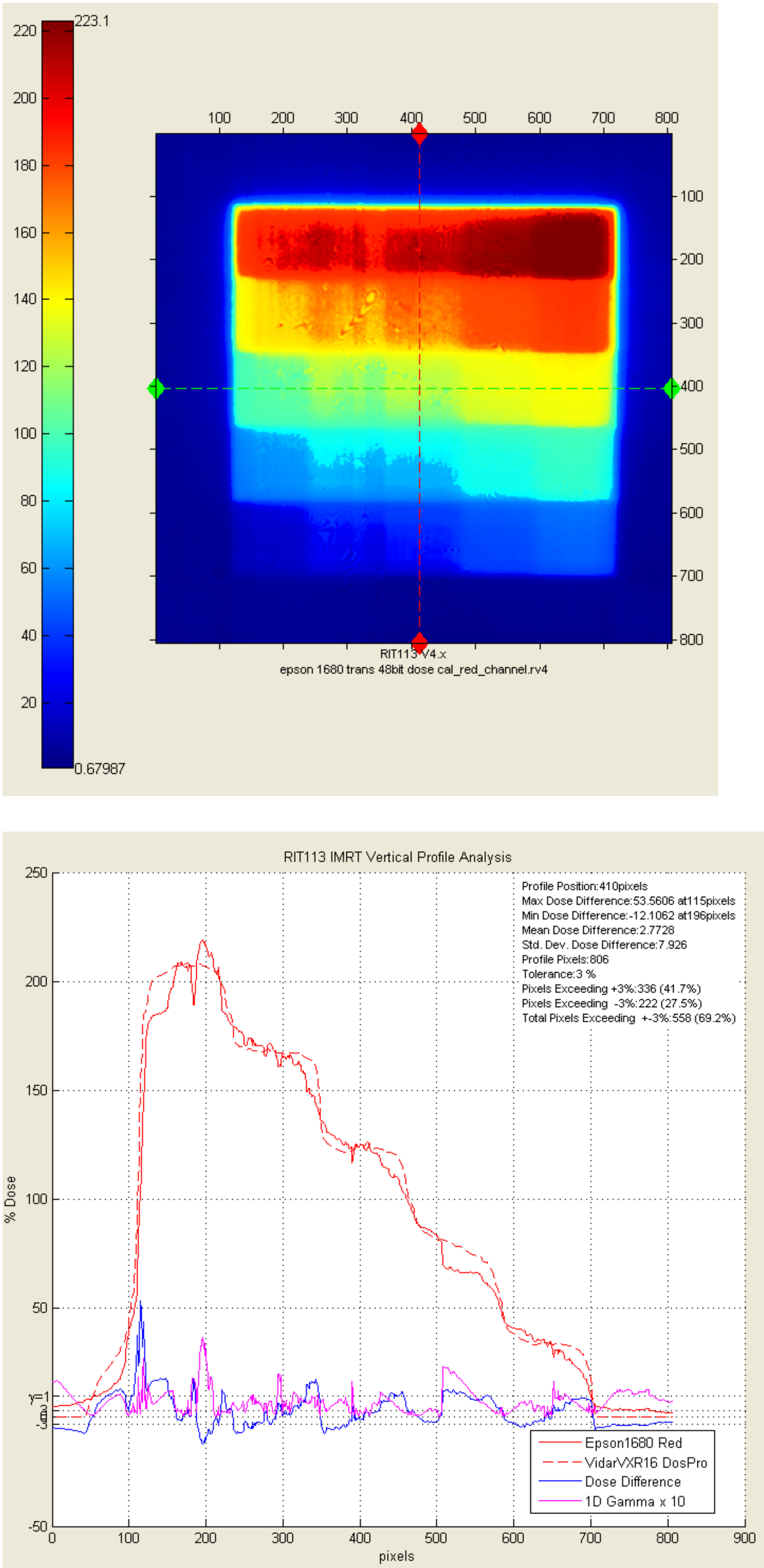

Figure 7a and b

Direct comparison of EBT film digitized with Epson and Vidar scanners

Note that the profile line for the Vidar scanner (dashed line) has well defined steps for each dose level on the film. The profile line for the Epson scanner (solid line) has much greater variation within each dose step. The conclusion is that the variation is due to the same dose uncertainty that was seen in Figure 2, since the calibration curves are very similar. Due to the similarity in scanner numbers from the Epson 1680 unit, the dose cannot be accurately determined. However dose variations as large as this are very significant in radiation therapy treatments. The variation within the highest dose level is more than 10 percent. This much variation is certainly unacceptable for radiation therapy treatments where 2 or 3 percent variation is trying to be measured.

Recent developments:

RIT has developed a set of advanced image processing corrections for EBT film in Version 5.0 of the RIT113 software. This set of algorithms corrects for fiber scatter and Vidar roller issues to achieve significantly improved images, in most cases. [15]

ISP is now suggesting improved scanning results by recommending that all EBT films be scanned in the Landscape format (as opposed to Portrait). [16]

Vidar has recently developed a Red LED version of its Vidar Dosimetry Advantage Pro scanner. It is anticipated that this unit will be available in the first quarter of 2008. ISP reports improved results when using this scanner. [17] RIT will be testing this scanner in November of 2007.

Conclusions:

These tests demonstrate that the Vidar VXR16 Dosimetry Pro is clearly superior for scanning the EBT films. The Epson 1680 performed much better than other “commercial grade” graphics art scanners that were tested. However, even the Epson 1680 scanner with the red channel separated cannot come close to the performance of the medical grade Vidar Dosimetry Pro scanner.

These tests also show the severe limitations of low cost graphic arts scanners such as the Epson 1670. The inability to accurately distinguish between dose levels at relatively low optical density proves their unsuitability for medical applications.

The characteristics of the EBT film indicate that some care must be used when trying to distinguish between similar dose levels. It is recommended that medical physicists evaluate other papers on this type of film [9 through 14] in order to determine its suitability to the measurements being made in clinical situations.

[1] Specification sheet for the Epson Expression 1680 Professional

[2] ISP, “A Protocol for IMRT QA Using Gafchromic EBT film”, August 11, 2005

[3] ISP, "Gafchromic EBT, Self-developing film for Radiotherapy Dosimetry", March 16, 2005

[4] Correspondence from Poppy Pattanayak at ISP dated September 22, 2004 containing four EBT films from Lot# 34196-07 and a list of 25 dose levels applied to one of the sample calibration films.

[5] Correspondence from Joe Barden at Vidar Systems, dated August 17, 2005

[6] Personal email to Greg Pierce from Poppy Pattanayak at ISP dated August 16, 2005.

[7] Vidar Dosimetry Pro Specification sheet.

[8] Vidar Dosimetry Pro Warranty sheet

[9] A. Kapulsky, J. Hanley, "Feasibility of a Novel GAFCHROMIC film for Routine IMRT QA", AAPM poster paper 2005, SU-FF-T-144

[10] A. Rink, A. Vitkin, D. Jaffary, "Characterization and Real-Time Measurements of Optical Density with GafChromic EBT film," AAPM Poster Paper 2006, SU-FF-T-121

[11] O. Zeidan, et. al., "Characterization and Use of EBT Radiochromic film for IMRT Dose Verification," AAPM Poster paper 2006 SU-FF-T-122

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[13] Alvarez P., et.al., "Characterization of EBT versus MD55 Gafchromic films for relative dosimetry measurements," 2006, http://rpc.mdanderson.org/RPC/home.htm (under RPC Presentations)

[14] Lynch B.D., et.al., "Important considerations for radiographic film dosimetry with flatbed CCD scanners and EBT GAFCHROMIC film," Medical Physics #33 (12), December 2006, pp. 4551-4556

[15] Harrison C. , et.al., "Comparison of Radiographic Film, Radiochromic Film and CR Plates for Intensity Modulated Radiation Therapy Quality Assurance.", AAPM 2007 Poster SU-FF-T-125

[16] Lewis, D, "New Developments in Scanning Radiochromic Film", ISP Document, Sept. 18, 2007

[17] Lewis D, "Performance of the Vidar® Red LED Dosimetry Pro Advantage™: A scanner optimized for use with GAFCHROMIC® EBT Dosimetry Film.", ISP Document, undated.