1. Introduction
The recent advances in computed tomography (CT) with the advent of multi-detector (MD) CT scanners have resulted in a significant increase in the use of CT imaging in the clinical practice. MDCT scanners are capable of acquiring multiple parallel slices, simultaneously, in a single gantry rotation with the number of slices being dependent on the detector configuration and the number of the detector channels it contains. The introduction of MDCT scanners has focused much attention on patient radiation dose issues, since it is generally believed that it is associated with higher patient doses relative to single slice scanners [1]. Reduced z-Axis geometric efficiency (GE), defined as the percentage of the x-ray beam width in the z-direction that is ‘seen’ by the detectors, is one of the main factors that contribute to the increased dose in MDCT scanners [2]. On single slice systems the entire x-ray beam, including the penumbra is utilized in the image formation. If that was the case in the image production on MDCT scanners the outer detectors would receive a less intense x-ray beam than...
the inner ones. This would lead to the images from these detectors being narrower and noisier. To overcome this, the collimation of the x-ray beam width on multi-detector systems is increased such that the penumbra lies beyond the active detectors and they are all irradiated uniformly (overbeaming). This implies that body regions lying beyond the limits of the active detectors are irradiated without being imaged (Figure 1). Beam width dose profiles (BWDP) measurements are routinely performed with either thermoluminescent dosimeters (TLD) or films to determine the extent of overbeaming. Although these dosimetric tools are suitable for these types of measurements in terms of sensitivity, they provide dose information in single points (TLD) or in only two dimensions. Gel dosimeters on the other hand provide high resolution 3D dose information, but their low sensitivity in the diagnostic energy region has limited their application in diagnostic radiology [3].

In this study we present for the first time the use of VIPAR gel dosimeters for the measurement of the BWDPs of a sixteen slice CT scanner (Siemens Sensation 16) and calculate its z-axis geometric efficiency. We give numbers of the minimum detectable dose changes recorded by this type of gel in the diagnostic CT dose energy range.

2. Materials and methods

2.1. CT scanner and MD configuration

A third generation CT scanner, the Somatom Sensation 16 multislice helical CT (Siemens AG, Forchheim, Germany), was used in the current study with a 24-channel adaptive array detector configuration. This type of detector configuration may provide up to 16 slices in a single gantry rotation. Available beam widths are 1.2, 2, 9, 10, 12, 18, and 24 mm. Beam widths are user-selected based on the mode of operation (axial or helical) and/or the required z-axis resolution. Signal from different number of detector channels (#dc) is recorded for each beam width so that the value of the product #dc times the length of each dc is equal to the nominal value of the beam width. That is, for the above beam widths detector signals from different number of dc are collected as follows: 2 x 0.6, 2 x 1, 12 x 0.75, 2 x 5, 16 x 0.75, 12 x 1.5, and 16 x 1.5, respectively.

Figure 2. a) A photograph of a 2 x 1 mm beam irradiated VIPAR gel, b) a T2 map image of a).
2.2. Gel preparation and Irradiation
The polymer N-vinylpirrolidone argon (VIPAR) gels were prepared according to the guidelines of Pappas et al [4]. After production the gel was placed in cylindrical glass vials, with 10 cm length and 12 mm internal diameter, that were pre-filled with argon and then they were stored in room temperature.

Prior to CT irradiation all gel tubes were irradiated uniformly with a boost dose of 8 Gy with a 6 MV LINAC (40 cm x 10 cm field size) to ensure a linear response throughout the delivered dose region. Fifty accumulated single axial scans were then delivered to the central portion of the gel vial using the above mentioned CT scanner. Each scan was performed with a 2 x 5 mm beam width, 120 kV and 750 mAs. Delivered dose, measured with a 100 mm long ionization chamber (MDH Industries), was 88 mGy per scan. This was repeated for 80, 90, 100, and 110 accumulated single axial scans for other gel vials to calibrate the gel reading against the number of delivered scans and consequently against dose. Three more gel vials were irradiated with the 2 x 1, 12 x 0.75, and 2 x 5 mm beam widths. Special care was taken to make sure that vials remained stationary throughout scans.

2.3. MR imaging and z-axis geometric efficiency calculation
The gel vials were scanned with a 1.5 T whole body superconducting imager (Sonata/Vision, Siemens). MR scanning consisted of a 2D PHAPS 32 Multi-Echo train sequence (TR / TE1 / TE32 / FA, 8500 ms / 25 ms / 800 ms / 180°). The applied MR scanning sequence provided 2 mm slice thickness images, with 0.3 mm in-plane spatial resolution. Pixel values were of the transverse nuclear magnetic resonance relaxation rates (R2(s⁻¹) = 1/T2) of the water protons. R2 calculations were performed on a pixel by pixel basis by applying a linear regression analysis on the pixel signal intensities measured in each of the successive temporal images of the MR sequence. z-Axis GE geometric efficiency was calculated as the percent ratio of the BWDP integrated over the area falling within active detectors to the total BWDP integral (fig.1).

3. Results and Discussion
Calibration of the gel reading against dose showed a linear relationship with a R2-dose sensitivity of 0.072 sec⁻¹Gy⁻¹ (or 0.096 Gy per scan). In figure 2, a two image panel depicts a photograph of the gel vial irradiated with a 2 x 1 mm beam a), along with a coronal, 2 mm slice thickness, T2 image map b). Figure 3 illustrates the BWDP of the 2 x 1 a), 12 x 0.75 b) and the 2 x 5 mm c) irradiated gel vials as a
function of the distance across each slice width in the coronal plane. Relaxation time (R2) values have been converted to dose values based on the calibration procedure. Calculated z-Axis GEs (green over total BWDP integral) are 78%, 70.6% and 97% for the three beam widths, respectively. Of the three, the 2 x 5 mm beam width exhibits the largest geometric efficiency. This is attributed to the fact that, in this case, the MDCT scanner behaves like a dual slice system, providing two, 5 mm each, slices per gantry rotation. As a result, the penumbra regions of the BWDP lie within the length limits of the two active detectors. The 12 x 0.75 mm beam width, on the other hand exhibits the lowest GE, since only the plateau of the BWDP matches the 12 detector array with the penumbra lying beyond their limits maximizing the proportion of ‘wasted dose’. As the proportion of the penumbra is approximately constant, regardless of the beam width, the proportion of the wasted dose is also high in the 2 x 1 mm beam, where the scanner behaves again as a dual slice system, but due to the narrow collimation, the BWDP can not be limited within the 2 mm length of the active detectors.

4. Conclusions
In conclusion, we have presented for the first time the use of VIPAR gel dosimeters for dose measurements in multi-detector CT scanners. Our results show that VIPAR gel dosimeters can be used to determine beam width dose profiles and calculate the z-axis geometric efficiency of the modern multi-detector CT scanners. Measurements of all the available beam width dose profiles can be performed as a part of the acceptance tests and the quality assurance of modern CT scanners. Further research work is required in manufacturing polymer gels with improved sensitivity in the diagnostic energy region doses.

5. References
[1] Golding S J and Shrimpton P C 2002 Radiation dose in CT: are we meeting the challenge? Br. J. Radiol. 75 1-4
[2] International Electrotechnical Commission. Medical electrical equipment-Part 2-44: Particular requirements for the safety of X-Ray equipment for computed tomography 2001 IEC International standard 60601-2-44 Ed. 2 Amended 2003
[3] Hill B, Venning A J and Baldock C 2005 A preliminary study of the novel application of normoxic polymer gel dosimeters for the measurement of CTDI on diagnostic x-ray CT scanners Med. Phys. 32 1589-1597
[4] Pappas E, Maris T, Angelopoulos A, Paparigopoulou M, Sakelliou L, Sandilos P, Voyiatzi S, Vlachos L 1999 A new polymer gel for magnetic resonance imaging (MRI) radiation dosimetry Phys. Med. Biol. 44 2677-2684