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## Is dual-energy computed tomography helpful to determinate the ferromagnetic property of bullets?

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**Faculté de Médecine & des Sciences de la Santé**

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**DIPLOME D'ETAT**

**Par**

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**IS DUAL-ENERGY COMPUTED  
TOMOGRAPHY HELPFUL TO  
DETERMINATE THE FERROMAGNETIC  
PROPERTY OF BULLETS?**

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## **Is dual-energy computed tomography helpful to determinate the ferromagnetic property of bullets?**

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**Abstract:**

*Objectives:* The goal of this ex vivo study was to determine if Dual-Energy Computed Tomography (DECT) can discriminate ferromagnetic bullets from non-ferromagnetic bullets.

*Methods:* Twelve different bullets, placed in the center of the scanner on a gelatin phantom, underwent DECT evaluation. These projectiles were both ancient bullets from the 19th century (eg. 8mm 1890 ECP) and recent bullets from the late 20th century (eg. 9mm Luger; 7.92mm Mauser; 7mm sport carabin). Two independent radiologists who were blinded to the properties of bullets performed all measurement on an external workstation with extended CT scale. Regions of interest (ROI) were placed in the core of each projectile. From these data, a dual-energy index (DEI) was calculated. A bootstrap method with a p value of less than 0.05 was used to demote statistical significance.

*Results:* Five bullets were ferromagnetic and seven were non-ferromagnetic. The DEI calculated were significantly ( $p < 0.05$ ) different between the ferromagnetic and non-ferromagnetic projectiles. There were no significant difference ( $p > 0.05$ ) for intrareader and interreader agreement analysis.

*Conclusion:* Dual-energy CT, despite several limitations, could be a valid method to differentiate ferromagnetic from non-ferromagnetic bullets in an ex-vivo environment with extended CT-scale. This approach could contribute to MR safety but further studies are necessary before using dual-energy CT as a routine technique for screening gunshots victims.

*Keywords:* Dual-energy Computed Tomography; Forensic imaging; MRI safety; Bullets injury

## **Is dual-energy computed tomography helpful to determinate the ferromagnetic property of bullets?**

### **Introduction:**

Gunshot injuries, resulting in retained bullets, are frequent (1). Because magnetic resonance imaging (MRI) can be used as a part of the damage evaluation process, it is crucial to determinate the ferromagnetic property of a retained object before any MRI procedure (2–10). Bullets are often made of non-ferromagnetic materials and will not cause patient injuries due to movement or dislodgment in tissue (10). But there are a significant number of ferromagnetic bullets (2,11–13). These ferromagnetic bullets can exhibit movement which can be regarded as dangerous for the surrounding tissue.

Conventional radiography, easily accessible, is useful to detect metallic foreign bodies but is unsuitable to discriminate ferromagnetic material (such as iron or nickel) from non-ferromagnetic material (such as lead). Dual-energy CT already proved its effectiveness for characterization of urinary calculi, measurement of contrast agent uptake or differentiation between cerebral hemorrhage and contrast (14–19). Dual-energy can discriminate elements with different atomic number (20) and therefore could be useful to distinguish ferromagnetic from non-ferromagnetic ballistic projectiles. Bullets are often made of steel (iron), lead, copper, brass (a copper-zinc alloy) and melchior (a copper-nickel-zinc alloy) (11–13). These different elements have significant difference between their atomic number: iron is 26, lead is 82, copper is 29, zinc is 30 and nickel is 28.

The goal of this ex vivo study was to determine if DECT can discriminate ferromagnetic bullets from non-ferromagnetic bullets.

### **Materials and Methods:**

#### *Bullets*

Twelve different bullets (Table 1) underwent DECT evaluation in this study. These projectiles were both ancient bullets from the 19<sup>th</sup> century and recent bullets from the late 20<sup>th</sup> century. The exact compositions of these bullets were unknown. The ferromagnetic properties of the bullets have been tested using the deflection angle and torque methods (21) used in numerous studies (5,10,22–26). The sample was attached to a stable non-ferromagnetic test fixture using a string (20-cm length; weight <1% of each bullet) which was attached to the 0° indicator of a plastic protractor. The apparatus was then placed eccentrically near the MR scanner portal. The deflection angle from the vertical position to the nearest degree was measured three times and the mean value was calculated (Table 1). Torque was assessed using a qualitative measurement technique. The bullet was attached to a string at the center of a PVC sheet. Each test samples were oriented 45° to the static magnetic field and introduced into the center of the bore where magnetic torque is the greatest. The following qualitative scale was applied: 0, no torque; +1, low torque (object shifted slightly but did not align to the magnetic field); +2, moderate torque (object aligned gradually to the magnetic field); +3, strong torque (object aligned rapidly and forcefully to the magnetic field); and +4, very strong torque (object very rapidly and very forcefully aligned to the magnetic field).

Table 1

Description of ballistic tested

Item no.	Details	Ferromagnetic property	Deflection angle	Torque
1	7.92mm Mauser (world war 2)	+	90	4+
2	8mm Lebel training (world war 1)	-	0	0
3	8mm 1890 ECP	-	0	0
4	9mm	-	0	0
5	7.65mm	-	0	0
6	.44 Winchester	-	0	0
7	7.5mm Mas 36	+	90	4+
8	.45 ACP or 11.43mm	+	90	4+
9	9mm Luger (world war 2)	+	90	4+
10	7.62mm M1 carabin (world war 2)	-	0	0
11	7mm sport carabin	+	90	4+
12	6mm Bosquet	-	0	0

#### Methods of measurement

Each bullet was placed in the center of the scanner on a gelatin phantom. Data acquisition was performed on 128-section CT scanner (SOMATOM AS +; Siemens healthcare, Munich, Germany). Each projectile undergone two acquisition at 100 kV and 140 kV using the following scanning parameters (11): slice collimation (2 x 64 x 0,6 mm), slice acquisition (2 x 128 x 0,6 mm), rotation time (0,5 seconds), pitch (0,6), CT dose index (9,8 mGy). Data reconstructions was carried out using a sharp tissue kernel (b70), a slice thickness of 1,5 mm, a slice increment of 1,0 mm and an extended Hounsfield Unit (HU) CT scale (27,28).

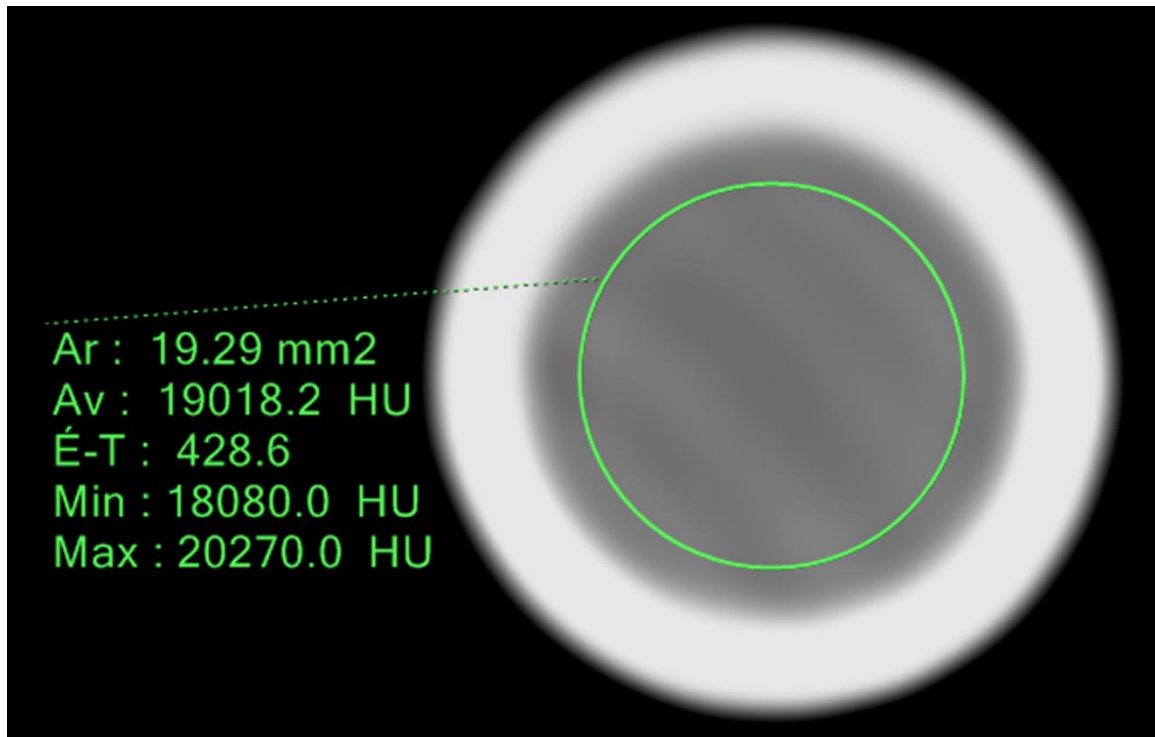
#### Outcome

Two independent radiologists (R1, a junior radiologist, with 3 years of experience; R2, a senior radiologist, with 7 years of experience) who were blinded to the properties of bullets performed all measurement on an external workstation (Philipps IntelliSpace Portal, Amsterdam, Netherlands). Each CT number measurement was performed two times by each reader on independent axial CT images at all two tube voltage. Regions of interest (ROIs)

were placed in the core of each projectile. For each bullet, placement of ROI had to be the widest possible without touching the jacket (Figure 1).

Figure 1

Example of ROI placement in bullet n°4



From these data, a dual-energy index (DEI) was calculated according to the following formula (14,20):

$$DEI = \frac{low\ kV - high\ kV}{low\ kV + high\ kV + 2000} HU$$

To identify intrareader and interreader variability, measurements were repeated after an interval of one month to avoid recall bias.

#### *Analysis*

Statistical analysis was performed using StataCorp LP data analysis (StataCorp, 4905 Lakeway Drive; College Station, Texas 77845 USA). A bootstrap method with a *p* value of less than 0.05 was used to demote statistical significance.

#### **Results:**

##### *Dual-energy analysis*

DEI were significantly (*p* < 0.05; 95% CI: -0.0110349, -0.0000267) lower in the core of ferromagnetic projectiles than those of non-ferromagnetic ones. Concerning ferromagnetic projectiles mean DEI was -0.04 (SD = 0.005; range, -0.04 to -0.03). Regarding non-ferromagnetic bullets mean DEI was -0.03 (SD = 0.006; range, -0.04 to -0.02) (Table 2 and Figure 2).

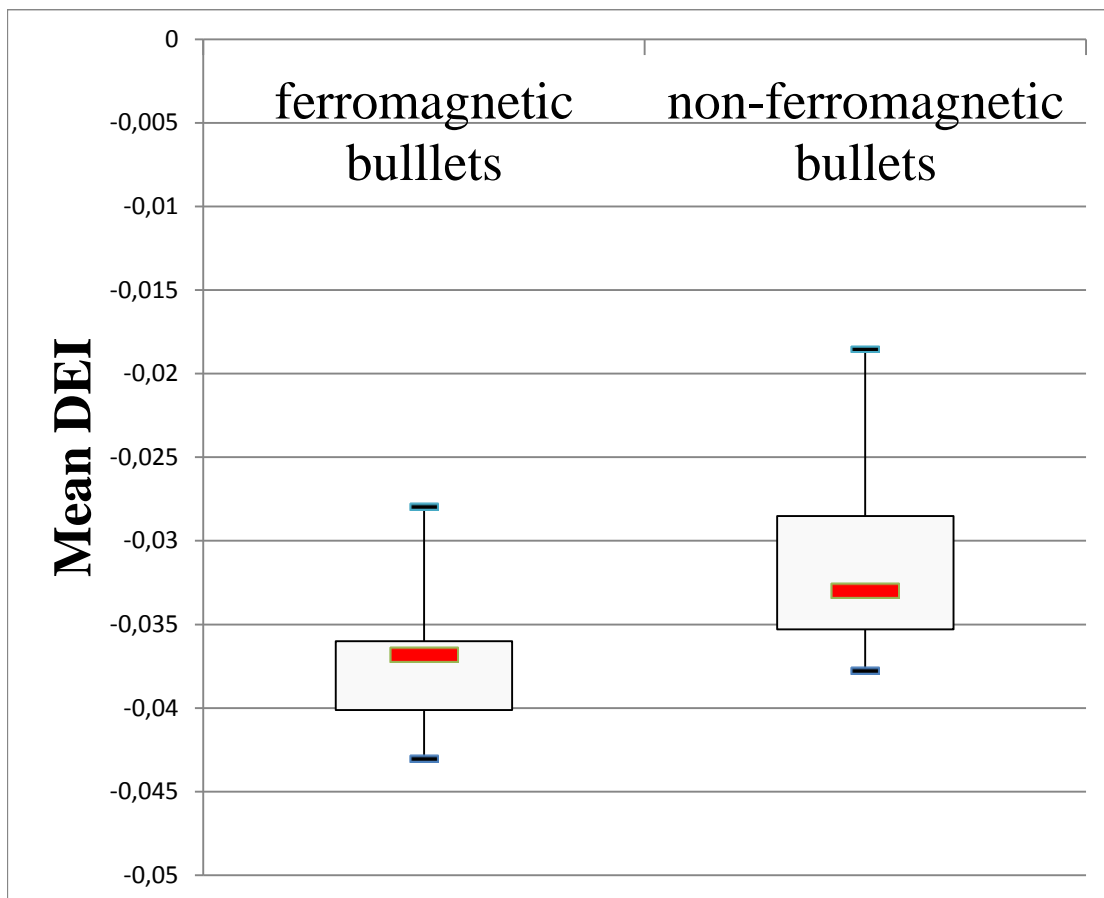
Table 2

DECT number of projectiles

	Mean DEI (SD)	Mean UH 100/140kV	Min UH 100/140kV	Max UH 100/140kV	ROI Surface 100/140kV (mm <sup>2</sup> )
<b>Ferromagnetic bullets</b>	-0.037 (0.005)	17942/19427	16880/18119	19356/21146	18.6/17,3
<b>Non-ferromagnetic bullets</b>	-0.031 (0.006)	18206/19430	17101/18353	20237/21637	18,9/18,8

Figure 2

Box plot demonstrating the DEI of ferromagnetic and non-ferromagnetic bullets ( $p < 0.05$ )

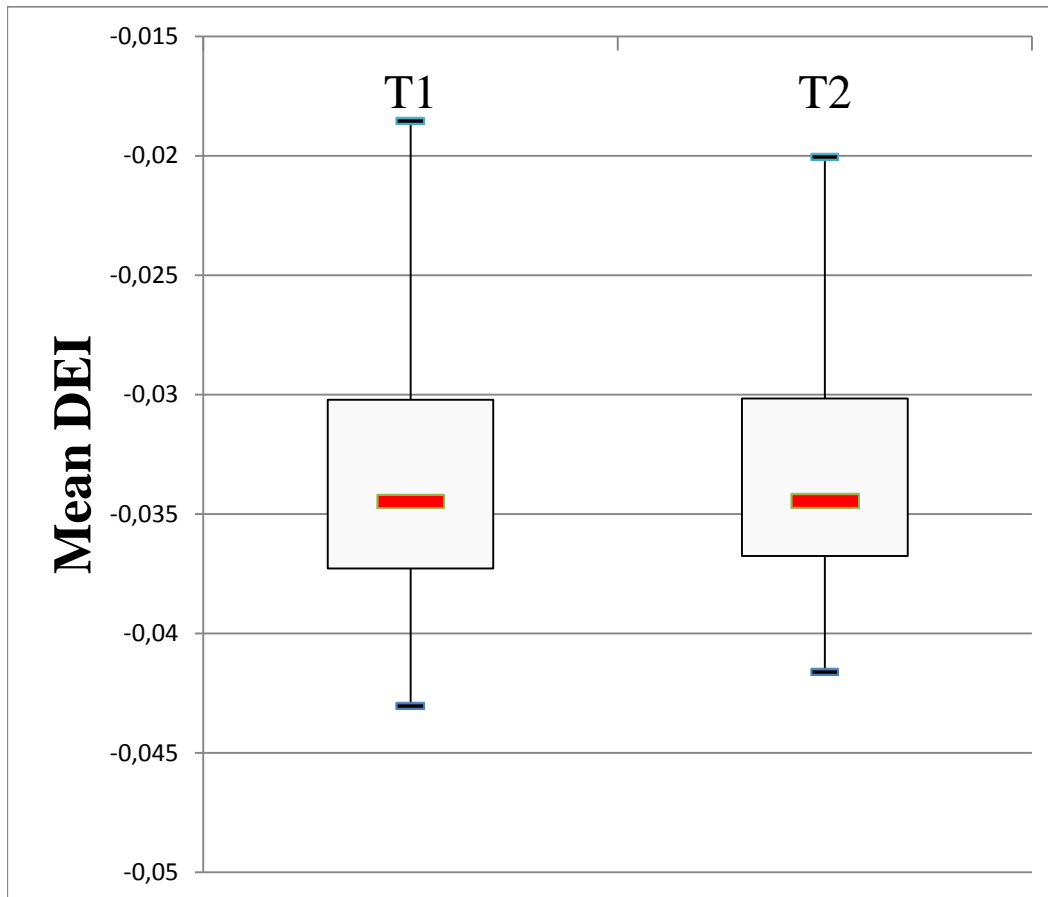


*Intrareader and interreader variability*

For intrareader agreement analysis, there were no significant differences ( $p= 0.751$ ; 95% CI: -0.0005563, 0.0007711) (Figure 3). For interreader agreement analysis, there were no significant differences ( $p= 0.785$ ; 95% CI: -0.0007593, 0.0010052) (Figure 4).

Figure 3

Box plots demonstrating mean DEI of ferromagnetic and non-ferromagnetic bullets intrareader agreement analysis ( $p=0.751$ )

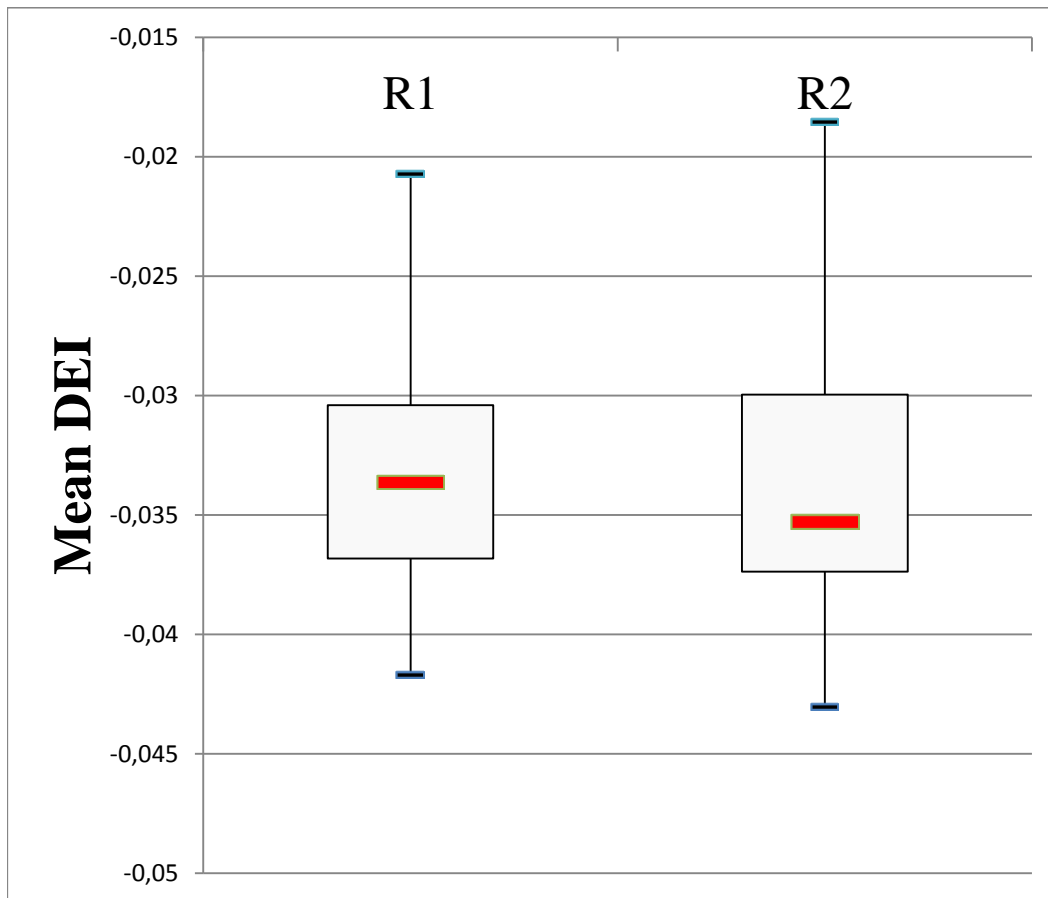


T1, first measurements ; T2, second measurements



Figure 4

Box plots demonstrating mean DEI of ferromagnetic and non-ferromagnetic bullets interreader agreement analysis ( $p=0.785$ )



R1, radiologist n°1 ; R2, radiologist n°2

### Discussion:

Our study demonstrates that DECT can distinguish ferromagnetic from non-ferromagnetic bullets at extended CT scale. These findings are consistent with the theoretical principle of DEI and the results from previous studies (11,14,15,20). Indeed, DECT acquires data using two different energy levels, it is capable of differentiating materials with different atomic numbers despite similar attenuation coefficients. As described in the literature, ROI measurements to quantify the x-ray attenuation is a reliable and a reproducible method (29). Any radiologist without specific training required can place a spherical ROI in a bullet. Only a fraction of patient who need a MRI procedure present a metallic foreign projectile in their body. Nowadays, these patients are usually disqualified from MRI. However, a large number of bullets are not ferromagnetic.

There are several limitations to our study. This ex-vivo analysis cannot yet be transposed to the living and the routine emergency radiology. The ballistics tested are undamaged projectiles analyzed in a controlled environment. Though, when a bullet enters a body, it will deform and sometimes break into small pieces. The influence of size and shape of the projectile have not been taken into account in our analysis. The same applies to the location of the foreign object in the patient's body (4). A deeply buried bullet could be more

difficult to analyze than a superficial projectile. Indeed artifacts such as beam hardening if the bullet is stuck into a hard tissue could contaminate the attenuation measurements (29). Also, we did not place a ROI on the bullet's jacket. Winklhofer and al. have shown that measurements on the jacket are unhelpful (11). In addition, some of our bullets are from the early 20<sup>th</sup> century but ancient weapons are still in use nowadays (30,31). In our study, a bullet with a lower DEI is more likely to be ferromagnetic. But despite a significant difference between ferromagnetic and non-ferromagnetic bullets, there is no cut-off DEI value to differentiate these two groups. A bullet with low DEI is more likely to be ferromagnetic but DEI values are overlapping (Figure 2). These data are in contradiction with the previous study of Winklhofer and al. (11) despite using the same scanning parameters. However, as mentioned in Winklhofer's study, the composition of a x-ray beam varies between CT manufacturers, between scanners, and on the age of the x-ray tube. The Hounsfield unit values are not necessarily reproducible on a different scanner. That is why each scanner should be calibrated with a pure sample of each metal. Furthermore, previous studies demonstrated that the CT values of high-density absorbers will vary significantly if scanned with different CT scanners despite using the same scan parameters (29). Due to this limitation, DECT cannot yet be used for screening patients in a clinical routine. Hence, it seems necessary to carry forward studies on this subject before beginning to use this technique in order to screen living patients.

## **Conclusion:**

DECT, despite several limitations, could be a valid method to differentiate ferromagnetic from non-ferromagnetic bullets in an ex-vivo environment with extended CT-scale. This approach could contribute to MR safety but further studies are necessary before using dual-energy CT as a routine technique for screening gunshots victims.

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## SERMENT D'HIPPOCRATE

Au moment d'être admis à exercer la médecine, je promets et je jure d'être fidèle aux lois de l'honneur et de la probité.

Mon premier souci sera de rétablir, de préserver ou de promouvoir la santé dans tous ses éléments, physiques et mentaux, individuels et sociaux.

Je respecterai toutes les personnes, leur autonomie et leur volonté, sans aucune discrimination selon leur état ou leurs convictions. J'interviendrai pour les protéger si elles sont affaiblies, vulnérables ou menacées dans leur intégrité ou leur dignité. Même sous la contrainte, je ne ferai pas usage de mes connaissances contre les lois de l'humanité.

J'informerai les patients des décisions envisagées, de leurs raisons et de leurs conséquences. Je ne tromperai jamais leur confiance et n'exploiterai pas le pouvoir hérité des circonstances pour forcer les consciences.

Je donnerai mes soins à l'indigent et à quiconque me le demandera. Je ne me laisserai pas influencer par la soif du gain ou la recherche de la gloire.

Admis dans l'intimité des personnes, je tairai les secrets qui me seront confiés. Reçu à l'intérieur des maisons, je respecterai les secrets des foyers et ma conduite ne servira pas à corrompre les mœurs.

Je ferai tout pour soulager les souffrances. Je ne prolongerai pas abusivement les agonies. Je ne provoquerai jamais la mort délibérément.

Je préserverai l'indépendance nécessaire à l'accomplissement de ma mission. Je n'entreprendrai rien qui dépasse mes compétences. Je les entretiendrai et les perfectionnerai pour assurer au mieux les services qui me seront demandés.

J'apporterai mon aide à mes confrères ainsi qu'à leurs familles dans l'adversité.

Que les hommes et mes confrères m'accordent leur estime si je suis fidèle à mes promesses ; que je sois déshonoré et méprisé si j'y manque.

Serment prononcé par le Docteur.....

Le .....

Pour l'Ordre national des médecins,

Le médecin

DIALLO (Idris) – Is dual-energy computed tomography helpful to determinate the ferromagnetic property of bullets? 22 f., 4 ill., 2 tabl.  
Th.: Méd.: Brest 2016

**RESUME** :

*Objectives:* The goal of this ex vivo study was to determine if Dual-Energy Computed Tomography (DECT) can discriminate ferromagnetic bullets from non-ferromagnetic bullets.

*Methods:* Twelve different bullets, placed in the center of the scanner on a gelatin phantom, underwent DECT evaluation. These projectiles were both ancient bullets from the 19Th century (eg. 8mm 1890 ECP) and recent bullets from the late 20th century (eg. 9mm Lüger; 7.92mm Mauser; 7mm sport carabin). Two independent radiologists who were blinded to the properties of bullets performed all measurement on an external workstation with extended CT scale. Regions of interest (ROI) were placed in the core of each projectile. From these data, a dual-energy index (DEI) was calculated. A bootstrap method with a p value of less than 0.05 was used to demote statistical significance.

*Results:* Five bullets were ferromagnetic and seven were non-ferromagnetic. The DEI calculated were significantly ( $p < 0.05$ ) different between the ferromagnetic and non-ferromagnetic projectiles. There were no significant difference ( $p > 0.05$ ) for intrareader and interreader agreement analysis.

*Conclusion:* Dual-energy CT, despite several limitations, could be a valid method to differentiate ferromagnetic from non-ferromagnetic bullets in an ex-vivo environment with extended CT-scale. This approach could contribute to MR safety but further studies are necessary before using dual-energy CT as a routine technique for screening gunshots victims.

**MOTS CLES** :

Dual-energy Computed Tomography; Forensic imaging; MRI safety; Bullets injury.

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