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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 19th century and recent bullets from the late 20th 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).

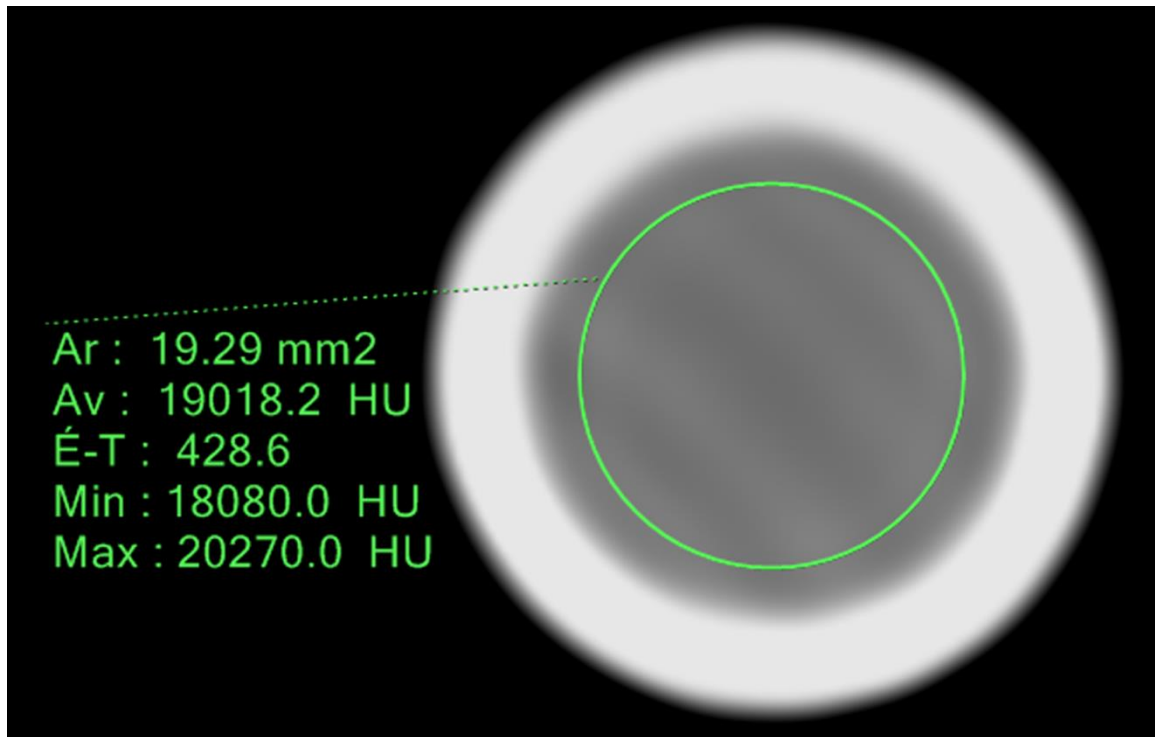
Outcome

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).

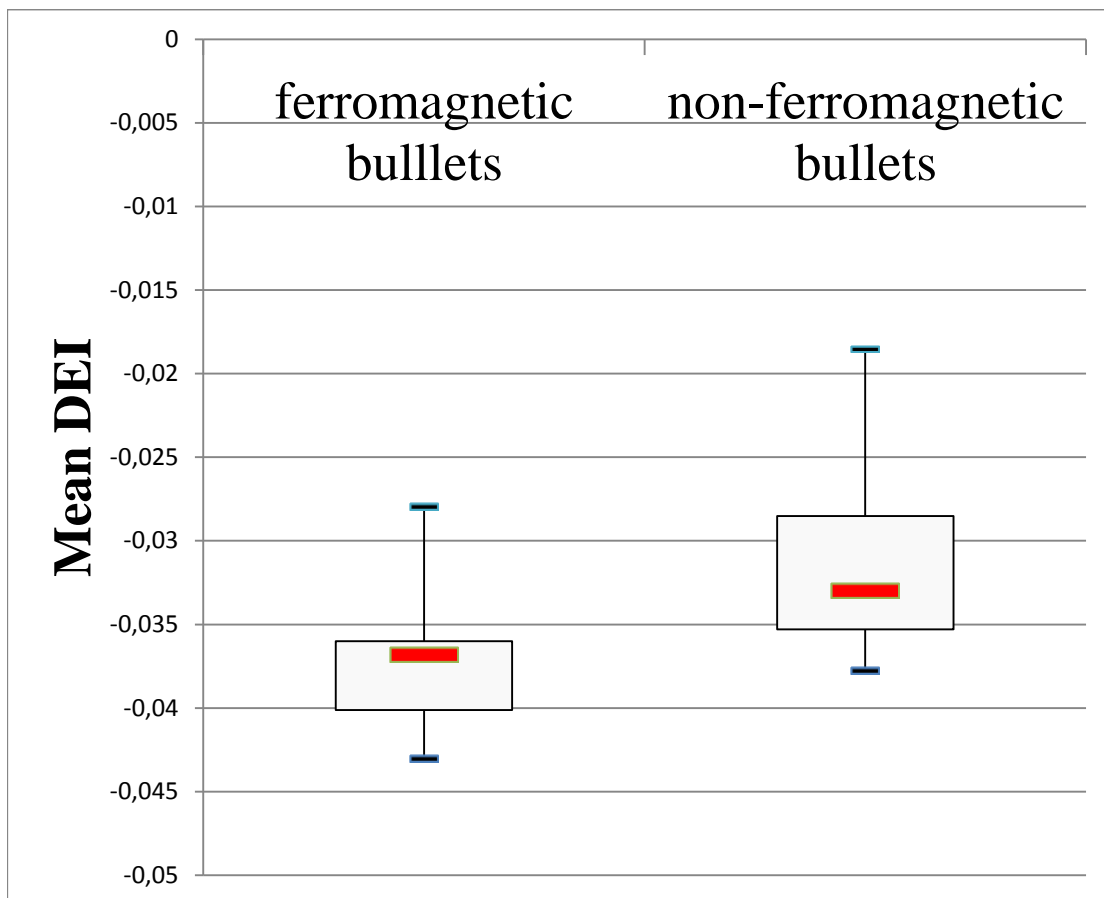
Table 2

DECT number of projectiles

	Mean DEI (SD)	Mean UH 100/140kV	Min UH 100/140kV	Max UH 100/140kV	ROI Surface 100/140kV (mm ²)
Ferromagnetic bullets	-0.037 (0.005)	17942/19427	16880/18119	19356/21146	18.6/17,3
Non-ferromagnetic bullets	-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 ($p < 0.05$)

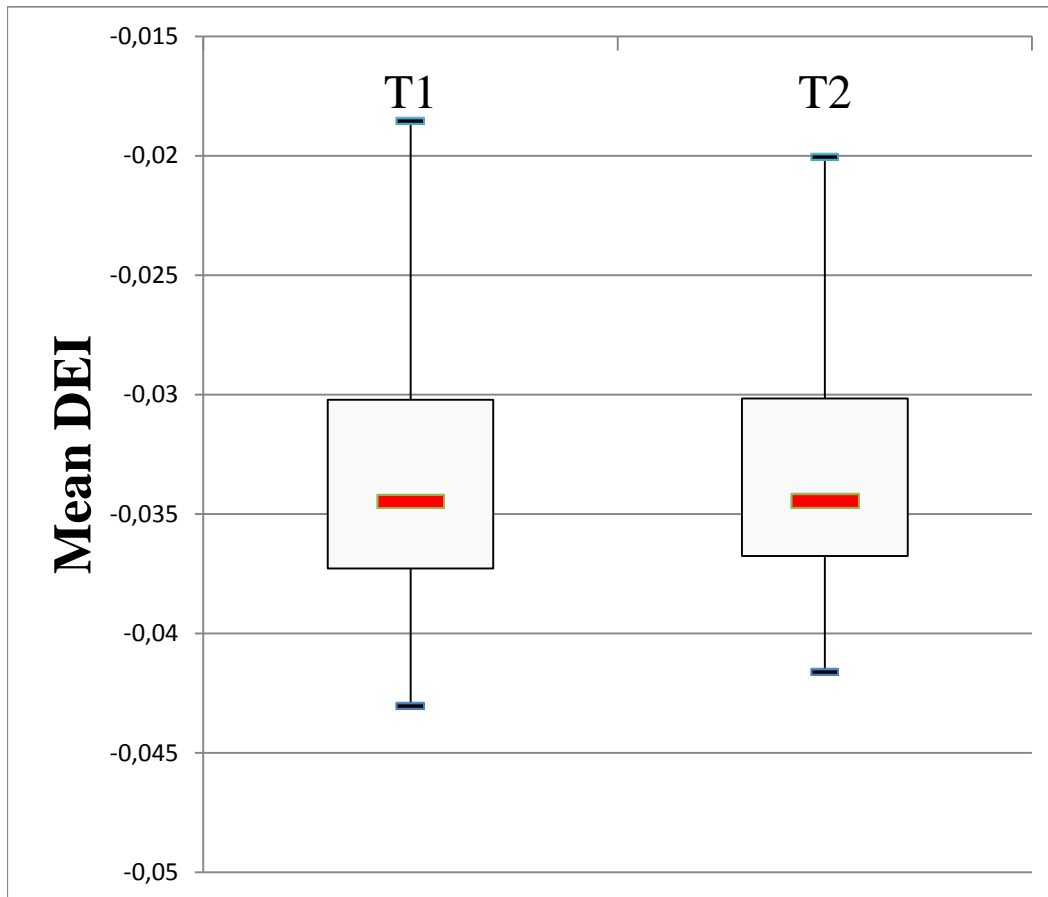


Intrareader and interreader variability

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

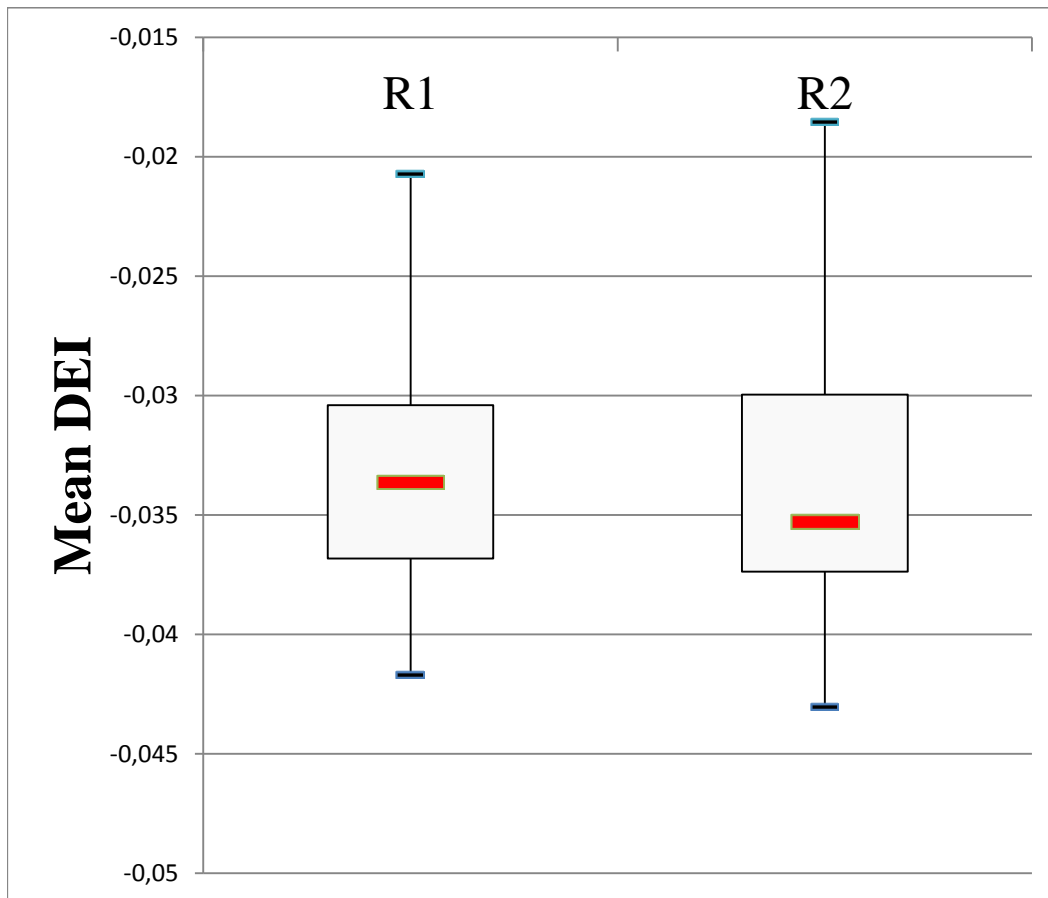
Box plots demonstrating mean DEI of ferromagnetic and non-ferromagnetic bullets intrareader agreement analysis ($p=0.751$)



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 20th 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.

References:

1. Ranney ML, Sankoff J, Newman DH, Fenton A, Mukau L, Durston WE, et al. A call to action: firearms, public health, and emergency medicine. *Ann Emerg Med.* 2013;61:700–702.
2. Eshed I, Kushnir T, Shabshin N, Konen E. Is magnetic resonance imaging safe for patients with retained metal fragments from combat and terrorist attacks? *Acta Radiol.* 2010;51(2):170-4.
3. Woods TO. Standards for medical devices in MRI: present and future. *J Magn Reson Imaging JMRI.* 2007;26(5):1186-9.
4. Shellock FG. Reference Manual for Magnetic Resonance Safety, Implants, and Devices: 2014 Edition. Los Angeles, CA, Biomedical Research Publishing Group, 2014.
5. Kumar R, Lerski RA, Gandy S, Clift BA, Abboud RJ. Safety of orthopedic implants in magnetic resonance imaging: an experimental verification. *J Orthop Res Off Publ Orthop Res Soc.* 2006;24(9):1799-802.
6. Shellock FG. MR imaging of metallic implants and materials: a compilation of the literature. *AJR Am J Roentgenol.* 1988;151(4):811-4.
7. Shellock FG. MR imaging in patients with intraspinal bullets. *J Magn Reson Imaging JMRI.* 1999;10(1):107.
8. Jourdan P, Cosnard G. MRI: projectiles, bullets and counter-indications. *J Radiol.* 1989;70(12):685-9.
9. Dedini RD, Karacozoff AM, Shellock FG, Xu D, McClellan RT, Pekmezci M. MRI issues for ballistic objects: information obtained at 1.5-, 3- and 7-Tesla. *Spine J.* 2013;13(7):815-22.
10. Teitelbaum GP, Yee CA, Van Horn DD, Kim HS, Colletti PM. Metallic ballistic fragments: MR imaging safety and artifacts. *Radiology.* 1990;175(3):855-9.
11. Winklhofer S, Stolzmann P, Meier A, Schweitzer W, Morsbach F, Flach P, et al. Added Value of Dual-Energy Computed Tomography Versus Single-Energy Computed Tomography in Assessing Ferromagnetic Properties of Ballistic Projectiles: Implications for Magnetic Resonance Imaging of Gunshot Victims. *Invest Radiol.* 2014;49(6):431–437.
12. Karacozoff AM, Pekmezci M, Shellock FG. Armor-piercing bullet: 3-T MRI findings and identification by a ferromagnetic detection system. *Mil Med.* 2013;178(3):e380-385.
13. Walker JJ, Kelly JF, McCriskin BJ, Bader JO, Schoenfeld AJ. Combat-related gunshot wounds in the United States military: 2000-2009 (cohort study). *Int J Surg Lond Engl.* 2012;10(3):140-3.

14. Graser A, Johnson TRC, Bader M, Staehler M, Haseke N, Nikolaou K, et al. Dual energy CT characterization of urinary calculi: initial in vitro and clinical experience. *Invest Radiol.* févr 2008;43(2):112-9.
15. Stolzmann P, Scheffel H, Rentsch K, Schertler T, Frauenfelder T, Leschka S, et al. Dual-energy computed tomography for the differentiation of uric acid stones: ex vivo performance evaluation. *Urol Res.* août 2008;36(3-4):133-8.
16. Gupta R, Phan CM, Leidecker C, Brady TJ, Hirsch JA, Nogueira RG, et al. Evaluation of Dual-Energy CT for Differentiating Intracerebral Hemorrhage from Iodinated Contrast Material Staining 1. *Radiology.* 2010;257(1):205-211.
17. Stolzmann P, Kozomara M, Chuck N, Müntener M, Leschka S, Scheffel H, et al. In vivo identification of uric acid stones with dual-energy CT: diagnostic performance evaluation in patients. *Abdom Imaging.* oct 2010;35(5):629-35.
18. Feuerlein S, Heye TJ, Bashir MR, Boll DT. Iodine quantification using dual-energy multidetector computed tomography imaging: phantom study assessing the impact of iterative reconstruction schemes and patient habitus on accuracy. *Invest Radiol.* nov 2012;47(11):656-61.
19. Mansouri M, Aran S, Singh A, Kambadakone AR, Sahani DV, Lev MH, et al. Dual-Energy Computed Tomography Characterization of Urinary Calculi: Basic Principles, Applications and Concerns. *Curr Probl Diagn Radiol.* nov 2015;44(6):496-500.
20. Krauss B, Schmidt B, Flohr TG. Dual source CT. In: Johnson TRC, Fink C, Schönberg SO, Reiser MF, eds. *Dual Energy CT Dual energy CT in clinical Practice.* Heidelberg, Germany: Springer, 2011:11-20.
21. American Society for Testing and Materials (ASTM). International: F2213. Standard Test Method for Measurement of Magnetically Induced Displacement Force on Medical Devices in the Magnetic Resonance Environment . In: *Annual Book of ASTM Standards, Section 13, Medical Devices and Services, Volume 13.01*, pp 1576-80. West Conshohocken, PA, ASTM International, 2001
22. Diallo I, Auffret M, Attar L, Bouvard E, Rousset J, Salem DB. Magnetic Field Interactions of Military and Law Enforcement Bullets at 1.5 and 3 Tesla. *Mil Med.* 2016. DOI: 10.7205/MILMED-D-15-00246.
23. Shellock FG. Metallic neurosurgical implants: evaluation of magnetic field interactions, heating, and artifacts at 1.5-Tesla. *J Magn Reson Imaging JMRI.* sept 2001;14(3):295-9.
24. Shellock FG, Gounis M, Wakhloo A. Detachable coil for cerebral aneurysms: in vitro evaluation of magnetic field interactions, heating, and artifacts at 3T. *AJNR Am J Neuroradiol.* févr 2005;26(2):363-6.

25. Sherlock FG, Valencerina S. In vitro evaluation of MR imaging issues at 3T for aneurysm clips made from MP35N: Findings and information applied to 155 additional aneurysm clips. *AJNR Am J Neuroradiol.* 2010;31(4):615-9.
26. Weiland JD, Faraji B, Greenberg RJ, Humayun MS, Sherlock FG. Assessment of MRI issues for the Argus II retinal prosthesis. *Magn Reson Imaging.* 2012;30(3):382-9.
27. Jackowski C, Lussi A, Classens M, Kilchoer T, Bolliger S, Aghayev E, et al. Extended CT scale overcomes restoration caused streak artifacts for dental identification in CT-3D color encoded automatic discrimination of dental restorations. *J Comput Assist Tomogr.* 2006;30(3):510-513.
28. Woisetschläger M, Lussi A, Persson A, Jackowski C. Fire victim identification by post-mortem dental CT: Radiologic evaluation of restorative materials after exposure to high temperatures. *Eur J Radiol.* 2011;80(2):432-40.
29. Ruder TD, Thali Y, Schindera ST, Torre SAD, Zech W-D, Thali MJ, et al. How reliable are Hounsfield-unit measurements in forensic radiology? *Forensic Sci Int.* 2012;220(1-3):219-23.
30. Four terror suspects found hiding in cave in southeast Turkey. In: *Yeni Safak*; March 2016. Retrieved on: <http://www.yenisafak.com/en/news/four-terror-suspects-found-hiding-in-cave-in-southeast-turkey-2435571>.
31. Alps murders: ex-policeman arrested in village near scene of al-Hilli shootings. In: *The Guardian*; February 2014. Retrieved on: <http://www.theguardian.com/world/2014/feb/18/alps-murders-former-policeman-arrested-village-shootings>

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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