

# Virtual Autopsy as a Screening Test Before Traditional Autopsy: The Verona Experience on 25 Cases

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## Abstract

**Background:** Interest has grown into the use of multidetector computed tomography (CT) and magnetic resonance imaging as an adjunct or alternative to the invasive autopsy. We sought to investigate these possibilities in postmortem CT scan using an innovative virtual autopsy approach. **Methods:** Twenty-five postmortem cases were scanned with the Philips Brilliance CT-64 and then underwent traditional autopsy. The images were interpreted by two blinded forensic pathologists assisted by a radiologist with the INFOPSY® Digital Autopsy Software System which provides three-dimensional images in Digital Imaging and Communications in Medicine format. Diagnostic validity of virtual autopsy (accuracy rate, sensitivity, specificity, and predictive values) and concordance between the two forensic pathologists (kappa intraobserver coefficients) were determined. **Results:** The causes of death at traditional autopsies were hemorrhage due to traumatic injuries ( $n = 8$ ), respiratory failure (5), asphyxia due to drowning (4), asphyxia due to hanging or strangulation (2), heart failure (2), nontraumatic hemorrhage (1), and severe burns (1). In two cases, the cause of death could not be ascertained. In 15/23 (65%) cases, the cause of death diagnosed after virtual autopsy matched the diagnosis reported after traditional autopsy. In 8/23 cases (35%), traditional autopsy was necessary to establish the cause of death. Digital data provided relevant information for inferring both cause and manner of death in nine traumatic cases. The validity of virtual autopsy as a diagnostic tool was higher for traumatic deaths than other causes of death (accuracy 84%, sensitivity 82%, and specificity 86%). The concordance between the two forensic pathologists was almost perfect ( $>0.80$ ). **Conclusions:** Our experience supports the use of virtual autopsy in postmortem investigations as an alternative diagnostic practice and does suggest a potential role as a screening test among traumatic deaths.

**Keywords:** Computed tomography, computed tomography scan, forensic sciences, postmortem investigation, traumatic deaths, virtual autopsies

## INTRODUCTION

Traditional autopsy has changed little in the past century and consists of the external examination, evisceration, dissection of major organs with identification of macroscopic pathologies and injuries, and histopathology if needed.<sup>[1]</sup> In most countries, clinical autopsies are performed with permission from the family of the deceased, and because of its invasiveness, permission to conduct a clinical autopsy is often not given. Unlike clinical autopsies, forensic (or medicolegal) autopsies may be ordered by the legal authority, which has the sole power to order this type of autopsy. Even though this examination might often seem medically desired,

it is not always indicated for medicolegal purposes and is, therefore, frequently omitted.<sup>[2]</sup> In recent times, interest has grown across the world into the possibility of the use of multidetector computed

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tomography (CT) and magnetic resonance imaging (MRI) as an adjunct or alternative to the invasive autopsy.<sup>[3]</sup> The usefulness of this technique increases almost daily as a result of technical improvements and decreasing costs.<sup>[4]</sup> Although the technology is being evaluated, cross-sectional imaging examination of corpses, CT/MRI imaging modalities, and three-dimensional (3D) body reconstruction are already providing supporting tools in forensic examinations of the skeleton, foreign bodies, the teeth and gaseous findings,<sup>[4-6]</sup> and many different institutions have implemented CT/MRI postmortem investigations on a broad scale.<sup>[7]</sup> We sought to verify the reliability of a 3D reconstruction software of CT images, known as virtual autopsy, applied to forensic cases studied at the Department of Diagnostics and Public Health, Forensic Pathology Unit, of the University Hospital of Verona.

## METHODS

### Ethics statement

This study was approved by the Institutional Review Board of the University of Verona in accordance with the seventh revision (2013) of the Helsinki Declaration of 1975.

### Data collection

This study was conducted prospectively from March 2011 to February 2015. In this period, 25 out of 445 postmortem cases as ordered by prosecutors from the Court of Verona underwent virtual autopsy and a traditional postmortem examination in succession. The data were collected at the section of Forensic Pathology of the Department of Diagnostics and Public Health, University and Hospital Trust of Verona. The bodies were first subjected to a CT scan at the Radiology Unit and then to a traditional autopsy.

### Virtual autopsy

The digital investigations were carried out using a Philips Brilliance CT-64 scanner (Eindhoven, Netherlands) with the following technical specifications: pitch, 1.173; running time, 0.5 s; length scout, 1200 cm (basic and geometric parameters); electrical voltage, 120 kV; layer thickness, 2 mm; and increase of bed, 1 mm (exposure parameters). The images acquired from the CT scan in the Digital Imaging and Communications in Medicine (DICOM) format were sent to iGene (Kuala Lumpur, Malaysia), a company specialized in digital autopsies. iGene rendered the images using their proprietary INFOPSY® iDASS™ system software. It is a comprehensive, custom built, 3D visualization application for forensic autopsy. Virtual autopsy software solution, or iDASS™, is the forensic-specific 3D visualization engine for virtual autopsy. iDASS™ enables the users to do volume rendering and real-time viewing of the digital body from the 3000–5000 DICOM slices obtained from multisliced CT after whole-body scanning, enabling the pathologist to conduct a full, noninvasive digital postmortem examination using a large, touch-screen tablet computer. The scanning process takes only a few minutes, and following the virtual autopsy process, the results are available almost immediately. The

images produced by INFOPSY® system were interpreted by two specially trained forensic pathologists who conducted the study in blind, without knowing the circumstantial data and the invasive autopsy findings.

### Traditional anatomic autopsy

The autopsies were conducted by a third forensic pathologist blinded to the radiological findings. Toxicological screening of urine and vitreous humor was carried out in every case. If screening was positive, a quantitative toxicological analysis was performed at the toxicology laboratory.

The organs were retrieved, and histopathological examination of heart, lungs, brain, kidneys, spleen, liver, and bone tissues was performed on slides stained with hematoxylin and eosin. We compared the data collected at traditional autopsy with data acquired from the CT examination, to detect concordance between the two methods.

### Statistical analysis

Data analyses were performed using the weighted Cohen  $\kappa$  test, with the calculations made using SPSS version 21.0 (IBM, Armonk, NY, USA).

The interobserver reproducibility for the radiological autopsy findings was tested using the  $k$ -statistic. Validity (accuracy, sensitivity, specificity, and positive and negative predictive value) was determined. Discordant diagnoses were reviewed.

## RESULTS

The postmortem CTs were performed out-of-hours (before 7 a.m. or after 8 p.m.). Bodies were imaged in sealed body bags in the supine position, with arms adjacent to the body. The causes of death at traditional autopsy were the following: hemorrhage due to traumatic injuries ( $n = 8$ ), respiratory failure (5), asphyxia due to drowning (4), asphyxia due to hanging or strangulation (2), heart failure (2), nontraumatic hemorrhage (1), and severe burns (1). In two cases, the cause of death could not be ascertained because of skeletal remains.

The causes of death at virtual autopsy were the following: hemorrhage due to traumatic injuries ( $n = 9$ ), respiratory failure (6), heart failure (1), asphyxia due to hanging (1), and nontraumatic hemorrhage (1). In seven cases, the cause of death could not be ascertained. All data are detailed in Table 1 and exemplified in Figures 1 and 2. Out of 23 cases for which the traditional postmortem examination found a cause of death, 15 (65%) were diagnosed correctly using virtual autopsy, these cases were considered as true positives. For one case for which the cause of death was unascertained, the same result was also obtained during the virtual autopsy. This case was considered as true negative. Overall, in 16/25 (64%) cases, virtual autopsy results matched that of the traditional autopsy. There were three false-positive and six false-negative [Tables 2 and 3] results. In 15 (65%) out of the 23 cases with an identifiable cause of death, virtual autopsy was sufficient to determine the cause of death with a crucial role in traumatic cases [Figure 3]. There are five cases of homicide (two gunshot wounds, two blunt traumas, and

**Table 1: Detailed autopsy reports with comparison between traditional and virtual findings**

<i>n</i>	Sex	Circumstance of death	State of corpse	Autopsy findings	Radiological survey data
1	Male	Road traffic collision, biker	Good	Multiple face bruises Two cuts and grazes in the occipital and right parietal scalp regions Skull fractures Subarachnoid hemorrhage CoD: Intracranial hemorrhage	Jaw fracture Skull fracture over the cranial base Subarachnoid hemorrhage CoD: Intracranial hemorrhage
2	Male	Road traffic collision, biker	Good	Severe traumatic brain injury Multiple skull fractures Cerebral intra-parenchymal hemorrhage Multiple rib fractures Hemothorax CoD: Intracranial hemorrhage	Head trauma Cerebral intra-parenchymal hemorrhage Fracture of the jaw with detachment of the superior dental arch Fracture of the right clavicle Multiple rib fractures Thorax anterior wall subcutaneous emphysema Extensive bilateral hemothorax CoD: Intracranial hemorrhage
3	Male	Accidental fall	Good	Multiple ribs fractures Wrist fracture Hemoperitoneum Splenic injury CoD: Hemorrhagic shock	Multiple rib fractures Wrist fracture Right pubic bone fracture (medial to the ischial tuberosity and lateral to the pubic tubercle) Left pubic bone fracture (medial to ischial tuberosity) Sacrum fracture (medial to the sacroiliac joint) Upper right femur spiral fracture 10th and 11th thoracic vertebral bodies mid segmental compressed fractures Splenic rupture Hemoperitoneum CoD: Hemorrhagic shock
4	Male	Homeless, body was found outdoors	Good	Pulmonary edema and congestion CoD: Respiratory failure	Intense right lung parenchymal congestion with extensive consolidation of the upper lobe CoD: Respiratory failure
5	Male	Sudden death	Good	Bilateral lung hepatization histological evidence of pneumonia CoD: Respiratory failure	Lung parenchymal congestion with ground-glass opacities and areas of consolidation CoD: Respiratory failure
6	Male	Homeless, body was found outdoors	Advanced decomposition	Mandibular fractures, both clavicles, left wrist joint dislocations CoD: Uncertained	Mandibular fractures, both clavicles, left wrist joint dislocation Internal carotid artery dissection CoD: Cerebral hemorrhage due to traumatic internal carotid artery dissection
7	Male	Worked in a steel processing mill, suspicion of occupational-related disease	Good	Bilateral pleural effusion Mild hypertrophic cardiomyopathy Histological evidence of silicosis CoD: Respiratory failure	Evidence of fluid collection in the pleural space bilaterally with anterior lungs displacement Patchy areas of consolidation in both lungs Atherosclerotic changes with calcification of the major vessels CoD: Respiratory failure
8	Male	Body found in a burned car	Advanced decomposition	Severe skin bruises Left femur fractured at its lower end CoD: Severe burns	Right foot dislocated at the ankle joint Left femur fractured at its lower end CoD: Uncertained
9	Male	Body found outdoors	Advanced decomposition	Pulmonary edema and congestion CoD: Respiratory failure	Pulmonary edema and congestion CoD: Respiratory failure

Contd...

**Table 1: Contd...**

<b>n</b>	<b>Sex</b>	<b>Circumstance of death</b>	<b>State of corpse</b>	<b>Autopsy findings</b>	<b>Radiological survey data</b>
10	Male	Suicide	Good	Ligature mark Pulmonary edema and congestion Neck soft tissue bruises CoD: Respiratory failure	Lung parenchymal congestion with ground-glass opacities and areas of consolidation  CoD: Respiratory failure
11	Male	Homicide	Early decomposition	Neck hemorrhagic infiltration CoD: Asphyxia due to manual strangulation	Gaseous pockets in liver lobes and in muscles and soft tissues CoD: Uncertained
12	Male	Sudden death	Early decomposition	Cerebral intraparenchymal hemorrhage  CoD: Intracranial hemorrhage	Cerebral intraparenchymal hemorrhage Head and neck bloating Prominence and reticular pattern of the superficial vessels of the anterior chest CoD: Intracranial Hemorrhage
13	Male	Body recovered from water	Advanced decomposition	Pulmonary edema and congestion  CoD: Asphyxia due to drowning	Gaseous pockets in the muscles layers and in the body cavities Patchy hyoid dense areas Decomposition and liquefaction of most cranial, abdominal and chest cavities organs CoD: Uncertained
14	Male	Sudden death	Good	Hypertrophic cardiomyopathy Coronary heart disease Pulmonary edema and congestion CoD: Heart failure	Presence of an in-situ external cardiac pacemaker Epigastric and umbilical bowel herniation Cardiomegaly Calcification of abdominal and thoracic aorta Parenchymal edema and congestion of both lungs CoD: Respiratory failure
15	Male	Suicide	Good	Multiple cranial bones fractures Brain injuries Stellate shaped entry wound over the front of the forehead Circular shaped exit wound over the occipital region of the scalp The path of the projectile is directed inward and straight Burst skull fractures with three comminuted fractures, one sutural fracture running radially from the entry hole and one comminuted fracture running laterally and downwards from the exit hole  CoD: Intracranial hemorrhage due to penetrating head trauma	Stellate shaped entry wound over the front of the forehead (about 3 cm to the glabella in the midline) Circular shaped exit wound over the occipital region of the scalp (about 4 cm above the cervical prominence in the midline) The path of the projectile is directed inward and straight Burst skull fractures with three comminuted fractures, one sutural fracture running radially from the entry hole and one comminuted fracture running laterally and downwards from the exit hole 1 <sup>st</sup> entry hole comminuted fracture: running downward and directed laterally over the right frontal bone extending beyond the right orbital bone 2 <sup>nd</sup> entry hole comminuted fracture: extending outward and laterally over the right parietal bone 3 <sup>rd</sup> entry hole comminuted fracture: running downwards and directed laterally over the frontal bone extending beyond the zygomatic arch Sutural entry hole fracture: running along the sagittal suture extending to the lambdoid suture with complete separation of the suture line Exit hole comminuted fracture: running laterally and downwards from the exit hole on the right side of the occipital bone up to the foramen magnum CoD: Intracranial hemorrhage due to penetrating head trauma

Contd...

**Table 1: Contd...**

<b>n</b>	<b>Sex</b>	<b>Circumstance of death</b>	<b>State of corpse</b>	<b>Autopsy findings</b>	<b>Radiological survey data</b>
16	Female	Homicide	Good	Multiple cranial bones fractures Brain Injuries Ovoid shaped breach in the left parietal bone with “punched out” margins anterior to the left parietal prominence Multiple comminuted fractures  CoD: Intracranial hemorrhage due to penetrating head trauma	Ovoid shaped breach in the left parietal bone with “punched out” margins anterior to the left parietal prominence Comminuted fracture over the right temporal bone, anterior and superior to the right mastoid process (1st fracture), extend posteriorly towards the centre of the lambdoid suture as a diastatic separation of the upper part of the right extension of the lambdoid suture and continue superiorly on the right parietal bone. Comminuted fractures over the greater wing of the right sphenoid bone, right side of the anterior cranial foss and inferior orbital plate (2nd fracture) and over the left parietal bone (3rd fracture) extend downwards and backwards over the parietal bone as linear (fissured) fractures and end over the left lower extension of the lambdoid suture as diastatic fracture and Comminuted fragments appear to be driven inside the cranium CoD: Intracranial hemorrhage due to penetrating head trauma
17	Male	Body recovered from water	Advanced decomposition	Pulmonary edema and congestion CoD: Asphyxia due drowning	Decomposition and liquefaction of most cranial, abdominal and chest cavities organs CoD: Uncertained
18	Male	Body recovered from water	Good	Pulmonary edema and congestion  CoD: Asphyxia due to drowning	Bilateral pleural effusion Lungs ground glass appearance and reticular patterned densities Left coronary artery calcification CoD: Uncertained
19	Male	Body recovered from water	Good	Pulmonary edema and congestion  CoD: Asphyxia due to drowning	Past fractures of the right 4, 5 and 7 ribs Asymmetrical pelvis probably secondary to previous fractures Presence of fluid levels in both the maxillary and sphenoid sinuses Bilateral pleural effusions Bilateral lungs vascular congestion and infection Left coronary artery and abdominal aorta calcification CoD: Uncertained
20	Male	Sudden death	Advanced Decomposition	No significant findings CoD: Uncertained	No significant findings CoD: Uncertained
21	Female	Sudden death	Advanced decomposition	Hypertrophic cardiomyopathy Pulmonary edema and congestion CoD: Heart failure	Fluid levels in the maxillary and sphenoid sinuses Bilateral pleural effusion and lung consolidation Hypertrophic cardiomyopathy CoD: Heart failure
22	Female	Homicide	Good	Haemoperitoneum Skull fractures Intracerebral hemorrhage Multiple abdominal stab wounds  CoD: Intracranial hemorrhage	Laceration over the left side of the face and over the left side of the scalp Fractures of the zygomatic and maxillary processes Two depressed fractures over the parieto-occipital bone associated with air in the cranial cavity Multiple stab wounds over the abdomen CoD: Intracranial hemorrhage

*Contd...*



**Table 1: Contd...**

<i>n</i>	Sex	Circumstance of death	State of corpse	Autopsy findings	Radiological survey data
23	Male	Homicide	Good	Traumatic subdural and subarachnoid hemorrhage Multiple bruises CoD: Intracranial hemorrhage	Subdural and subarachnoid hemorrhage  CoD: Intracranial hemorrhage
24	Male	Suicide	Good	Ligature mark Pulmonary edema and congestion  CoD: Asphyxia due to hanging	Tongue protrusion Neck skin and muscle layers indentation placed anteriorly over the hyoid bone, and laterally at the level of mastoid process (higher over the left side) Fracture on the right greater horn of hyoid bone Lungs vascular congestion Calcifications of the right and left coronary arteries CoD: Asphyxia due to hanging
25	Male	Homicide	Good	Popliteal artery rupture  CoD: Hemorrhage due to arterial rupture	Comminuted diaphyseal fracture of the distal right femur Popliteal artery rupture* CoD: Hemorrhage due to arterial rupture

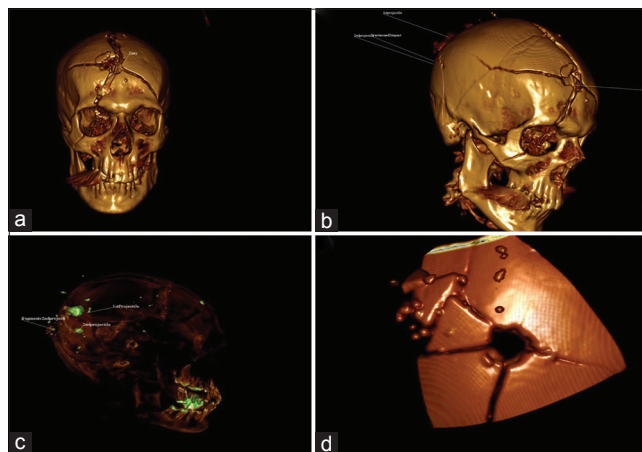
\*Detection of the arterial rupture was performed with vascular contrast. CoD: Cause of death

**Table 2: Cross-tabulation of causes of death in virtual autopsy versus classic autopsy**

Anatomic PM	Virtual PM		TOT
	CoD Found	CoD Not found	
CoD found	15	3	17
CoD not found	6	1	8
TOT	21	4	25
Sensitivity (%)		71	
Specificity (%)		25	
Accuracy (%)		64	
PPV (%)		83	
NPV (%)		14	

PM: Post-mortem examination, CoD: Cause of death, PPV: Positive predictive value, NPV: Negative predictive value, TOT: Total

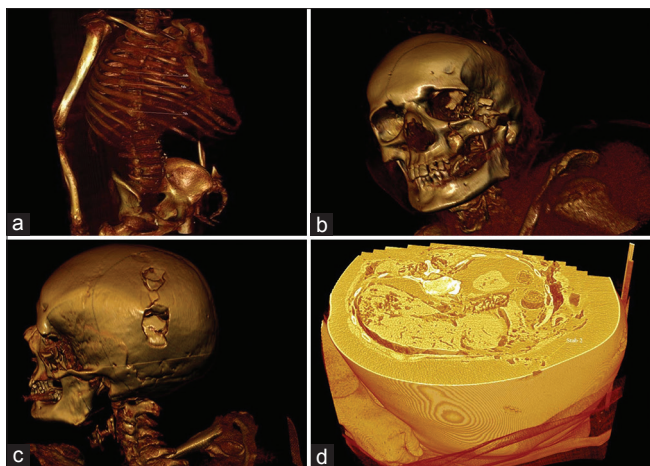
one with abdominal stab wounds), three suicides (two hangings and one gunshot wound), two road traffic collisions, and one accidental fall. The remaining cases are represented by three sudden deaths (a respiratory failure, a cerebral hemorrhage, and a heart failure), two homeless (two respiratory failures), and an occupational-related death (respiratory failure). Instead in 8/23 cases (35%), traditional autopsy was necessary to establish the cause of death [Figure 3]. These constitute four cases of drowning, one suicidal hanging, one body found outdoors, one sudden death, and one homicide through manual strangulation. Out of 11 cases for which the traditional postmortem examination found a traumatic cause of death, 9 (81%) cases were diagnosed correctly by the use of virtual autopsy, and these cases were considered as true positives [Figure 3]. For the 14 cases for which the cause of death was nontraumatic at traditional autopsy, the same result was



**Figure 1:** Case number 15, homicide, gunshot head trauma (a-d). Stellate entry wound with three comminuted and one sutural fractures (a and b); digital localization of the bullets and their fragments (c); circular-shaped exit wound, three-dimensional reconstruction (d)

obtained at the virtual autopsy. These cases were considered as true negatives. There were two cases of false-positive and two-false negatives [Tables 3 and 4] documented.

In 19 (76%) out of the 25 cases, virtual autopsy did not provide additional information in comparison to the traditional approach. In six of these cases, it gave misleading information. The forensic pathologists that analyzed the digital data overestimated the pulmonary findings. Instead, in 6 (14%) cases, virtual autopsy provided additional information, and for half of these cases, it gave relevant information for the identification of the cause of death. In addition, the overall data obtained by digital assessment were the same for each forensic pathologist, indicating very good interobserver agreement ( $\kappa > 0, 80$ ).



**Figure 2:** Case number 19, drowning: past fractures of right 4, 5, and 7 ribs and asymmetrical pelvis (a). Case number 1, road traffic collision: traumatic brain injury and jaw fracture (b) and skull fracture over the cranial base (c). Case number 22, homicide: blunt and abdominal stab wound trauma (d)

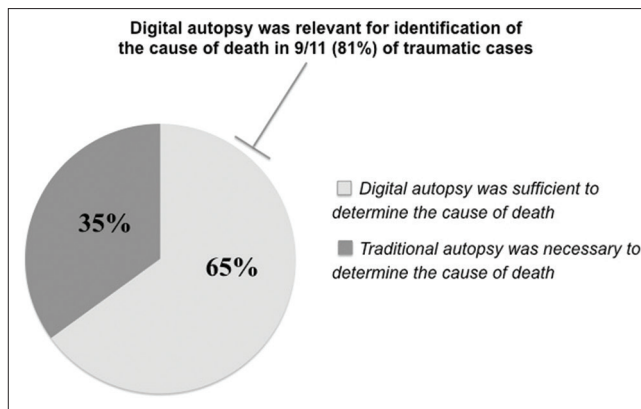
**Table 3: Discordant cases between virtual autopsy and traditional autopsy**

	Traditional autopsy CoD	Virtual autopsy CoD
False positive Case 6	Uncertained	Traumatic death
False positive Case 10	Hanging	Respiratory failure
False positive Case 14	Cardiac death	Respiratory failure
False negative Case 8	Severe burns	Uncertained
False negative Case 11	Manual strangulation	Uncertained
False negative Case 13	Drowning	Uncertained
False negative Case 17	Drowning	Uncertained
False negative Case 18	Drowning	Uncertained
False negative Case 19	Drowning	Uncertained

CoD: Cause of death

## DISCUSSION

In forensic medicine, postmortem imaging has a long tradition<sup>[8]</sup> and is now a standard practice, as an adjunct, or alternative to autopsy, in many forensic institutes worldwide.<sup>[9]</sup> We investigated the use of virtual autopsy as a screening diagnostic test before conducting a traditional autopsy. Overall, our results support a wider use of virtual autopsy as an alternative diagnostic practice to conventional autopsy and do suggest a potential role as a screening test. Among 25 cases studied at our institution, the cause of death was correctly identified during the traditional autopsy in 23 cases. The CT scan data provided relevant information for inferring



**Figure 3:** Summarized rate of cases with an identified cause of death solved with virtual autopsy and cases requiring a traditional autopsy

both cause and manner of death in traumatic cases, with an almost perfect concordance between the two forensic pathologists who were tasked to analyze the images, without any background in radiology. Moreover, the information provided by the virtual autopsy in the remaining nontraumatic deaths was important to exclude concomitant injuries. In 65% of the cases, virtual autopsy was sufficient to determine the cause of death with a key role in traumatic deaths, i.e., case number 1 concerning a biker who died after colliding with a car. The state of the corpse was good, and the diagnosis of death was traumatic brain injury. The forensic pathologist who analyzed the digital data described mandible and base of skull fractures as well as subarachnoid hemorrhages. In the traditional autopsy, the most significant findings were multiple facial bruising, two cuts and grazes in the occipital and right parietal scalp regions, and skull fracture. In this case, the virtual autopsy did not provide additional information in comparison with the traditional approach but was sufficient to determine the cause of death. The validity of virtual autopsy as a diagnostic tool is higher for traumatic deaths than other causes of death (accuracy 84%, sensitivity 82%, specificity 86%, positive predictive value 90%, and negative predictive value 86%).

In 35% of the cases [Figure 3], traditional autopsy was necessary to establish the cause of death, and in six cases, virtual autopsy gave misleading information, i.e., case number 19 concerning a man who drowned in a lake. The state of the corpse was good, and the diagnosis of death was drowning. At the virtual autopsy, the forensic pathologist described past fractures of the right 4<sup>th</sup>, 5<sup>th</sup>, and 7<sup>th</sup> ribs, pelvic asymmetry probably secondary to previous fractures, the presence of fluid levels in both the maxillary and sphenoid sinuses, bilateral pleural effusions, bilateral vascular congestion of the lungs, and infection and calcification of the left coronary artery and abdominal aorta. The presumed cause of death was bilateral bronchopneumonia. Traditional autopsy showed pulmonary edema and congestion due to drowning. In this case, the virtual autopsy provided misleading information and the traditional autopsy was necessary to determine the cause of death. In

**Table 4: Cross-tabulation of traumatic causes of death in virtual autopsy versus classic autopsy**

Anatomic PM	Virtual PM		TOT
	Traumatic CoD Found	Traumatic CoD Not found	
Traumatic CoD found	9	2	11
Traumatic CoD not found	2	12	14
TOT	11	14	25
Sensitivity (%)		82	
Specificity (%)		86	
Accuracy (%)		84	
PPV (%)		90	
NPV (%)		86	

PM: Postmortem examination, CoD: Cause of death, PPV: Positive predictive value, NPV: Negative predictive value, TOT: Total

2009, Scholing *et al.*, in a systematic review of 15 studies with 244 victims, provided inconsistent evidence as to whether virtual autopsy is a reliable alternative for autopsy in trauma victims. The authors suggested that it is a good alternative when an autopsy is refused or a good adjunct to the autopsy because it detects extra injuries.<sup>[2]</sup> In 2012, Le Blanc-Louvy *et al.* reported data from 236 digital autopsies, 63 of whom with a traumatic death and found that virtual autopsy was almost perfect in determining the cause of most traumatic deaths.<sup>[10]</sup>

In 2013, Makhoulf *et al.* studied 47 gunshot victims with virtual autopsy and reported that CT scan is important in managing gunshot victims, helping in determining the firing distance in cases of contact range.<sup>[11]</sup>

The results of our work show that virtual autopsy is helpful in the investigation of traumatic deaths, especially when more than one part of the body is involved such as in traffic accidents and falls from height or in gunshot injuries. On the other hand, virtual autopsy did not provide useful information in cases of natural death and mechanical asphyxia.

Concerning iDASS™ system, it enables the forensic pathologist to do a friendly set-up of slice stack, up to at least 2000 images with a reconstruction time of no more than 2 min to generate the digital body in 3D. Indeed, the system has forensic-specific 3D, multiplanar reformation, and two-dimensional capabilities, of which can be navigated easily using user-friendly navigation tools. In our experience, iDASS™ system showed to be user friendly for medical doctors without a background in radiology. However, it did not give any advantage in comparison to other rendering software products in data interpretation. Multidetector CT, MRI, and 3D body reconstruction have undoubted advantages over the traditional autopsy, allowing the identification of elements that would certainly not have been found at autopsy. First, the survey instrument is faster than the classic autopsy in terms of time. The duration of the examination is variable but usually ranges from 1 min to 10 min. Moreover, being noninvasive, it can be performed before the time in which

the classic autopsy is permitted (in Italy, 24 h from the time of death). In most cases, both CT and MRI provide superior views of specific anatomical regions that are difficult to reach during the invasive autopsy such as the occipital base, cervical spine, splanchnocranium, pelvis, and the four limbs. These relevant anatomical structures are important in the detailed forensic study of a corpse and should be carefully evaluated. In our series, for traumatic cases, especially in suicidal/homicidal gunshot trauma to the head, virtual autopsy provided high-quality details. For example, for cases 15 and 16 concerning suicidal and homicidal gunshots, respectively, virtual autopsy defined in an extremely precise manner, the shape of the entrance and exit wounds, the path of the projectile, and all the characteristics of the skull fractures [Table 1].

For many years, X-ray examination, in connection with forensic autopsies, has been limited to certain cases such as bullet wounds, battered child syndrome and drowning, as well as for identification purposes.<sup>[12,13]</sup> In 1985, Di Maio published a set of guidelines for the proper use of radiography in the study of deaths from firearms, which quickly became the gold standard guide for the discipline.<sup>[14]</sup> In the past few years, various institutions have implemented CT and/or MRI in postmortem forensic investigations.<sup>[7]</sup> In Switzerland, this revolution in forensic pathology started off in the mid-90s, when the Institute of Forensic Medicine of the University of Bern started a project with the Scientific Service of the City Police of Zurich. The aim was to document body and object surfaces in a 3D fashion. A few years later, the Bern Institute of Forensic Medicine started a joint research project with the Institute of Diagnostic Radiology and Neuroradiology of the University of Bern.<sup>[5]</sup> Virtual autopsy and invasive autopsy, performed in succession, have been reported to provide the same results in 59 (44%) of the published works considered.<sup>[1,10,11,15-21]</sup> Furthermore, the acquired data can be digitally reused. The findings from a virtual autopsy, in contrary to the classical approach, can be reanalyzed as many times as necessary for a complete evaluation. A further advantage of a virtual autopsy is the absence of contamination of the body. The noninvasive nature of the virtual autopsy provides an alternative to traditional autopsy for people from certain cultures and religions which prohibits the autopsy as it mutilates and damages the body. Through the radiological approach, it is also possible to assess the presence and precise location of foreign bodies, and in cases of gunshot injuries, the identification of the exact location of a bullet/bullets. A virtual autopsy conducted before a traditional autopsy helps to pinpoint the exact location of such projectiles and their fragments saving much time in its eventual recovery. Postmortem radiology is, therefore, useful to identify entry and exit bullet holes, as well as the likely trajectory taken by the bullet. The evaluation of the bullet path through the body aids in the reconstruction of the relative positions of the victim and the perpetrator during the alleged incident.



Despite the advantages of CT in identifying signs and conditions otherwise not detected by the naked eye at autopsy, it is not yet able to completely replace the conventional autopsy for the following reasons. First, a detailed external examination remains the only method of detection and characterization (the color, the shape, the exact size, location, orientation, margins, and the location in relation to anatomical landmarks) of injuries involving skin such as contusions, abrasions, and other wounds. In addition, virtual autopsy does not allow for differentiation between hypostasis and bruising as can be achieved in a standard autopsy. Moreover, it is not possible to perform molecular and toxicological studies if only virtual autopsy is carried out. To further enhance the efficacy of a virtual autopsy, combining guided biopsies of selective tissues as part of the procedure would enable molecular analysis to be performed. Conversely, even toxicological analysis may still be done in addition to a virtual autopsy after collection of relevant biological samples during the external examination of the cadaver, thus not representing an actual limitation of the procedure. The main limitation of this study was the small number of cases evaluated.

The 75% of the autopsies were conducted by our forensic pathologists at external hospitals where often radiologists were not available.

We encountered some complications also in the university hospital being forced to limit the radiological examination to the early hours of the morning due to a large number of radiological appointments involving living patients, and for the need for discretion during the transfer of the victims from the morgue across the main corridors of the hospital. Moreover, in 32 cases, there were bureaucratic problems due to the payment for the radiological services. In our opinion, taking into consideration the direct and indirect costs of the radiological approach, virtual autopsy could be used as an alternative postmortem diagnostic method or as a screening test only in selected cases where it can really provide additional relevant information with respect to the traditional postmortem investigation. Based on our experimental study, cases that correlate with the literature are mainly represented by traumatic deaths involving more than one part of the body such as traffic accidents, falls from height, or gunshot injuries.

Finally, it is necessary to remember that established diagnostic signs from clinical radiology may not always be transferrable to postmortem radiology and the recognition of normal postmortem findings and their differentiation from pathological findings is a perpetual challenge in forensic science.<sup>[22,23]</sup>

## CONCLUSIONS

To the best of our knowledge, this study represents a first evaluation of the virtual autopsy as a screening test before performing the traditional autopsy. Overall, based on our study, virtual autopsy can be recommended as an

alternative diagnostic practice when conventional autopsy is not possible and may play a role as a screening test for traumatic deaths.

Our findings should be investigated in a larger number of postmortem examinations to confirm the results.

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## Conflicts of interest

There are no conflicts of interest.

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