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Review Article

Applicability of Virtopsy in Veterinary Practice: A Short Review

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ABSTRACT

Virtopsy is a new and rapidly evolving non-invasive autopsy procedure involving the use of modern imaging modalities. It basically consists of three-dimensional body surface scanning by photogrammetry, multi-slice computed tomography (MSCT) and magnetic resonance imaging (MRI) for analysis and recording of autopsy lesions to ascertain cause and manner of death. This technique has been shown to be as effective and accurate as a conventional autopsy in the recent forensic studies. The MSCT is the most frequently used image modality for fractures, pathological gas formation and trauma, while the MRI is a good tool for soft tissue pathology. It is hoped that virtopsy will replace or serve as an indispensable adjunct to conventional autopsies in the future. Nonetheless, there is currently a paucity of information on the use of virtopsy in veterinary necropsy practice in which it could be used as a research tool and also possibly replace common procedures. The term 'virtopsy' in this article refers to the use of high throughput imaging techniques in human or animals as it may warrant. This review would look at the history, applications, prospects and limitations of virtopsy in veterinary necropsy.

Keywords: Computed tomography, magnetic resonance imaging, veterinary, virtopsy and 3D-surface scanning

INTRODUCTION

The term virtopsy was derived from virtual autopsy. Virtual was coined from the Latin word *virtus* which mean "useful, efficient and good". Autopsy derived its meaning from the Greek terminologies, *auto* meaning "self" and *opsomie,* "I will see". The team literarily removed the human subjectivity of auto to coin out "virtopsy" (Dirnhofer *et al*., 2006; Bolliger *et al*., 2008). Virtopsy currently means the application of non-invasive 3D-scanning techniques for documentation of body surface and internal organs of dead beings to determine the cause and manner of death. Virtopsy involves the use of modern imaging modalities, including photogrammetry, computed tomography and magnetic resonance imaging. The need to reduce individual subjectivity to post-mortem examinations and diagnoses, as well as reproducibility of lesions over time has been a worrying issue in the forensic arena for quite some time. It was first actualized in Bern University, Switzerland, with the sole objective of documenting radiograph and body surface scans with conventional autopsies. It was a very useful tool in the investigation of a high-profile homicide in Switzerland, where a gunshot bullet trajectory pattern to the skull was reconstructed for evidence in court (Dirnhofer *et al*., 2006). However, the idea of use of imaging tools in

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forensic investigation came to bare about four decades ago when Wullenweber (1977) reported the use of computed tomography (CT) to describe the pattern of gunshot wound to the head. This was followed by the concept of objective non-invasive documentation of body surface for forensic purposes in the nineties with the advent of three-dimensional photogrammetry.

Currently, numerous medical institutes employ radiological imaging, such as whole body CT or MRI scans, to all routine autopsies as a complimentary regime prior to conventional autopsy. Meanwhile, computed tomography has been shown to be more specific and sensitive in identifying pathological gas formation post-mortem, trauma and fractures (Dirnhofer *et al*., 2006; Thali *et al*., 2007; Bolliger *et al*., 2008). This helps the coroner to focus more on lesions of interest as observed from the CT or magnetic resonance imaging (MRI) scan. It is hoped that one day, virtopsy would totally replace invasive autopsies or become an invaluable adjunct for all autopsies.

Autopsy is usually accepted in medico-legal cases as an important procedure in determining the cause and manner of death in man and animals (Shkrum & Ramsay, 2007). However, the century-old scalpel-based technique is still used especially in veterinary necropsy (Cabana, 2008). Results obtained from such necropsy can be tendered in a court of law or used as clinical data for population/herd medicine in the prevention and control of diseases, especially those of zoonotic and economic importance.

Virtopsy of animals has been largely limited to research and rarely to confirmation of clinical diagnoses (Thali *et al*., 2004; Dirnhofer *et al*., 2006; Toklu *et al*., 2006; Aghayev *et al*., 2007; Heng *et al*., 2008). Post-mortem angiography, using imaging techniques and contrast agents, has been broadly studied using dogs as one of the models. This has been proven to be effective in the diagnosis of hemorrhages, vascular rupture and ischemia (Amundsen *et al*., 1997; Jackowski *et al*., 2005; Grabherr *et al*., 2006). Lesions of death by drowning were also studied in rat models by Toklu *et al*. (2006), revealing the ability of imaging techniques to diagnose such at post-mortem, even in small-sized animals. The X-radiographic studies of the abdomen and thorax in cats and dogs revealed an increase in postmortem gas formation over time with remarkable details and appreciation of the gas pockets (Heng *et al*., 2008; Heng *et al*., 2010a, 2010b). A study on the renal adenoma in the pet fish, Red Oscar using CT, revealed the efficacy of CT in identifying the lesion as compared to necropsy (Gumpenberger *et al*., 2004).

Of recent, some universities have adopted digital photography into necropsy routines for the sole purpose of teaching and record keeping. It has become an invaluable method in the digital representation of actual cases and lesions to students. This aside there is no available literature on the use of 2D- or 3D-imaging techniques as an aid to post-mortem examinations in animals. This is a great drawback in this era of sophisticated technology, emerging and re-emerging diseases.

VIRTOPSY: TOOLS

Virtopsy basically consists of two principles revolving around three basic tools (Dirnhofer *et al*., 2006; Bolliger *et al*., 2008), namely:

a. Body volume documentation and analysis with the aid of computed tomography (CT), magnetic resonance imaging (MRI) and microradiology.

b. 3D body surface documentation using photogrammetry and optical scanning.

The Bern virtopsy team have compared post-mortem imaging diagnoses using these tools to invasive autopsy in over 200 cases and found it as effective as, or even better than conventional methods (Farkash *et al*., 2000; Dirnhofer *et al*., 2006; Thali *et al*., 2007; Bolliger *et al*., 2008). These imaging tools carry great prospects for the way veterinary necropsy is practiced today, especially on small animals. Meanwhile, time, efforts and resources can be saved with a rapid CT or MRI scan of carcasses to detect common gross lesions, such as hematoma, abscess, organ size changes, gas formation (especially in parenchymatous organs), as well as fractures and traumatic injuries. Nevertheless, in view of the current demand, the usage of such technique will ensure an "intact" acceptable carcass prior to last respect before burial or cremation.

The most important record of the use of virtopsy in veterinary forensics was reported by Thali *et al*. (2008), where MRI and CT scans were used to remodel the bullet injury pattern in a lynx helping to determine the type of weapon used and narrowing investigations to such weapon owners.

3D Photogrammetry-based Optical Scanning

This entails the compensation for the 2D resolution of classical photography with the use two digital cameras to obtain photographs of body surface from different angles from a central projection unit. The generated pictures are then fed into a computer and with the aid of the TRITOP/ATOS III (GOM, Braunsweig, Germany), software are converted to appreciable 3D images. Meanwhile, TRITOP gives colour to picture while ATOS calculates the 3D coordinates (Dirnhofer *et al*., 2006; Thali *et al*., 2007; Bolliger *et al*., 2008). It is thus valuable in the assessment of whole body surfaces to document injuries and gross lesions with dimensional precisions. In fact, it has been widely used in computer remodelling of automobile accidents by relating surface injuries with damages on the automobile. Data generated can be analyzed by a third party and even tendered in a legal proceeding. The use of this particular tool in veterinary necropsy may not be that relevant save for requests for detailed forensic investigations on cases of animal cruelty or poaching of endangered species. Here, photographic reconstruction of lesions on body surface may give a clue to the nature of handling or capturing.

Multi-slice Computed Tomography (MSCT)

The 2D- and 3D-documentations of fractures, pathological gas formation and gross tissue trauma are better analyzed with MSCT (Dirnhofer *et al*., 2006). Most medical institutions now use it for routine pre-invasive autopsy whole body scans of cadavers (Thali *et al*., 2007; Bolliger *et al*., 2008). Computed tomography operates with the same principle of photon energy attenuation as X-ray, except that in CT, the photons are emitted in a rotating manner to give sectional slice images of tissues. It creates a gray-scale attenuation map according to the rate of absorption of photons by the body tissues. This is fed into a computer to reconstruct 3D images using mathematical algorithms (Donchin, 1994; Oliver *et al*., 1995; Douglas, 2002; Hayakawa *et al*., 2006; Thrall, 2007). Moreover, it is fast to operate and allows a quick whole body scan in 10-20 minutes. Osseous lesions, foreign bodies, pathological gas formation and organ trauma have been diagnosed with MSCT revealing more precise and accurate results over conventional autopsies (Farkash *et al*., 2000; Dirnhofer *et al*., 2006; Thali *et al*., 2007; Bolliger *et al*., 2008). Such lesions can also be easily diagnosed in veterinary necropsies with the MSCT, thereby stressing its value in this field for whole body scans. The adoption of the MSCT in veterinary post-mortem examinations, however, requires a variety of adjustable machines to accommodate the range of animal sizes and shapes since those used for imaging of cats and dogs may not be suitable for cattle and horses.

Magnetic Resonance Imaging

Body tissues and fluid contain chemicals made up of atoms. Each atom has a positively charged proton which has magnetic properties. MRI harnesses this magnetic property of protons and generates images by introducing high-powered magnetic field to the tissues to cause excitation and misalignment of protons, the magnetic field is then put off to receive signals from the tissues as the protons begin to realign to their former state. This process is called precession and electrical signals generated from this are sent via coils to computers to generate images (Oliver *et al*., 1995; Douglas, 2002; Hayakawa *et al*., 2006; Thrall, 2007). As soft tissues and body fluid contain more chemicals, and hence protons, the

MRI offers an excellent choice for soft tissue imaging ante- and post-mortem. In fact, MR was rated higher than CT in demonstrating soft tissue injury, neurological and non-neurological organ trauma and non-traumatic pathology (Thali *et al*., 2007). Soft tissue pathologies such as trauma, organ size changes, abscesses, edema, and hemorrhages may be diagnosed in veterinary necropsy using MRI.

Current Trends in Virtopsy

Limitations of the MSCT and MRI in virtopsy have been recognized and they have been studied in the effort to improve their efficiency. In particular, the lack of colour can now be tackled by using colour-encoded software to analyze images from the instruments. Meanwhile, size resolution can be improved using micro-radiology (CT and MR) to as small as micro-millimeters (Aghayev *et al*., 2006). The combination of micro-spectroscopy and micro-MR has been suggested to assess ante-mortem and post-mortem metabolite concentrations in tissues (Jackowski *et al*., 2005). This could help differentiate post-mortem from ante-mortem lesions and possibly establish time since death. Rapid advances in imaging technology may play an important role in reducing the cost of imaging instruments and procedures in the future, thereby translating into more clients of veterinarians requesting necropsy. The virtopsy teams plan to develop a robotic version for ease, called “virtobot”, which entails every procedure of autopsy in a non-invasive hi-tech approach. A mobile virtobot is also proposed to cater for outstation on-the-scene investigations called “virtomobile” (Dirnhofer *et al*., 2006).

The MSCT and MRI are practically the backbone of virtopsy; it has been suggested that micro-radiology using these two techniques (micro-CT and micro-MRI) would usher in a new perspective of virtual histology, where coroners would be saved the time-consuming histological procedures. In addition, CT guided tissue sampling has also been reported to be accurate (Aghayev *et al*., 2007) and sensitive. Its use in veterinary medicine should be weighed against ultrasound guided tissue sampling for cost, handling and logistics.

Applications of Virtopsy to Veterinary Necropsy Practice

Currently, there is a gap in information on non-invasive necropsies in veterinary medical practice, though animals have been used for research in virtopsy in the areas of post-mortem angiography, post-mortem abdominal and thoracic gas formation, drowning, pulmonary embolism and other related areas (Amundsen *et al*., 1997; Thali *et al*., 2004; Jackowski *et al*., 2005; Grabherr *et al*., 2006; Aghayev *et al*., 2007; Thali *et al*., 2007; Heng *et al*, 2008; Heng *et al*., 2010a, 2010b). Literature on comparative studies, between 2D and/or 3D postmortem imaging procedure and conventional necropsies, are very rare, and most literature deal with correlating clinical radiological findings with necropsy results (Thali *et al*., 2004; Aghayev *et al*., 2007) or directly interpreting post-mortem imaging results (Heng *et al*., 2008; Heng *et al*., 2010a, 2010b). This signifies the relative slow pace of technological development in veterinary necropsy/forensics when compared with medical forensics.

Despite the expensive nature of the MRI and CT machines, some veterinary hospitals especially in the developed countries acquire them for routine clinical procedures (Marta *et al*., 2007); none however has employed them in necropsy. On the contrary, veterinary practice is unique, as a clinician requires a sound judgment for the need and use of certain procedures on his patients. A balance is usually struck between procedures to be done, clients’ ability to pay and the salvage value of the animals. This factor, as well as awareness and willingness of owners, has largely limited advanced diagnostic procedures to small animals and pets. Necropsies are carried out on every case ending with death in veterinary establishments that are capable, usually on the request and/or approval of owners. Requests for large animal, reptilian and amphibian necropsies are often prompted by disease control, insurance claim or forensics.

Zoonoses are very important in veterinary practice, where all preventive measures must be rigorously followed. There is still, however, a high risk of veterinarians (specifically pathologists) contracting the zoonoses from carcasses they handle. The principal techniques of necropsy involve visual inspection, palpation and tissue incision (Cabana, 2008) that entail potential risks of disease contraction by veterinary pathologists and students. The problems posed by emerging diseases, as well as the re-emergence of those formally eradicated only stresses the dire need for a review of the ways veterinarians handle animals and dead tissues so as to reduce hazards in veterinary and medical practices. The much desired non-invasive approach presented by virtopsy as well as its superb appreciation of lesions provides a much better method for performance of necropsies. It ensures minimal contact with carcasses and its tissue fluids and blood, thereby reducing risk of infection.

The prospects of virtopsy being applied to veterinary post-mortem investigation are very high taking into cognizance the ease of the procedure, reduction in disease contraction risk, reproducibility, and possibility of third opinion and the convenient storage of data for future reference. Customs and beliefs (Mittleman, *et al*., 1992) would not be limiting factors in the advancement of virtopsy as they are to autopsy. It will also be a vibrant research tool for advancement of veterinary pathologists in an attempt to reduce the arduous nature of conventional necropsies, especially of large animals. Virtopsy is already an important compliment to autopsy and in the authors' opinion, it would be a matter of time for it to be adopted by veterinary pathologists for necropsies.

Appreciation of lesions and acceptance of results from virtopsy would definitely take some time since there is that urgent need for an in-depth research into its use and system of reporting. It is because the available information from virtopsy can be extrapolated for use in veterinary necropsy and may serve as a guide to veterinary pathologists. Ante-mortem clinical finding, imaging and necropsy results of a wide range of diseases and lesions need be compared to generate appreciable information to advance the use of these imaging technologies in veterinary necropsy.

The 3D-photogrammetry may not be readily used in veterinary virtopsy, except if strongly indicated for legal forensic cases requiring surface scanning and reconstruction of events. This may be an avenue for further research and possible application to necropsy.

Most necropsies in veterinary practice are done far and away from established institutions with standard facilities. The use of imaging tools in this scene would demand their handiness and mobility. Proposals by the Bern Virtopsy team are on the way for mobile virtopsy units (Dirnhofer *et al*., 2006).

ADVANTAGES AND DISADVANTAGES OF VIRTOPSY

Advantages

Time saving: A veterinary necropsy procedure takes a time range of thirty minutes to two hours, depending on the size of the animal, and periods are shorter for small-sized animals. This means valuable time is bound to be saved if a rapid MRI, MSCT or even 2D-Xray scan is carried out on all carcasses to pinpoint areas of pathological interests observable through these means, as discussed earlier. For example, a rapid X-ray scan of the thoracic area revealing leafing of the right lung as well as radiolucency in the thoracic cavity would suggest pneumothorax (gas not observable in conventional necropsy). The pathologists' attention would now be focused on this till further lesions provide contradicting evidence.

Non-invasiveness: Tissue destruction is an inevitable part of conventional scalpel-based necropsies which renders the old technique irreproducible and complete destruction of evidence in forensic cases. Virtopsy offers minimal or no tissue destruction as well as preservation of hard forensic evidence for future referrals such as in cases of poaching endangered species (Bolliger *et al*., 2008; Cabana, 2008).

Lesser risk of disease contraction: Risk of disease contraction is the most important drawback to conventional necropsy methods due to its invasiveness and a higher probability of accidental body injuries and contracting the examiners body parts and even mucos membranes (through spills or splashes) with contaminated fluids and secretions. Such zoonotic diseases contraction could be avoided during animal necropsies by the use of imaging techniques. This is a very vital area of concern to veterinary academic institutions for the safety of students during necropsy rounds.

Excellent storage and retrieval system: Electronic and digital storage of lesions and necropsy results is one of the main objectives of virtopsy. Such storage methods are not possible by conventional scalpel-based necropsy and therefore, data transferability is quite difficult. Results of virtopsy can be transferred electronically to another party for multiple opinions with appropriate digital representation of lesions to inform such opinions (Dirnhofer *et al.*, 2006). Necropsy cases of diseases of global interests, such as emerging and re-emerging disease, may be stored and transferred internationally amongst veterinarians and policy makers to evolve epidemiological measures, particularly in incubatory stages of such diseases.

Disadvantages

Major limitations to the adoption of virtopsy to veterinary necropsy practice involve cost and technical matters.

Cost

Magnetic resonance imaging and CT machines are very expensive even for veterinary clinical use, where the justifications for their purchase would normally be well thought of based on economics, service quality and research output. This lone factor is the most important limitation to their use of in veterinary necropsy since necropsies do not contribute much to the income of most veterinary institutions. If put in place for necropsies, the next question is how much does a client need to pay?

Technical Limitations

Despite the overwhelming positive values of non-invasive autopsy, there are still technical areas regarding appreciation and interpretation of lesions that need to be researched upon and answered even in the human field. Lesions obtained from such image results may be ambiguous, specifically whenno database is available to support such. Monochromatism (Patowary, 2005) is a single technical hitch that may render the objectives of virtopsy unobtainable as MSCT and MRI records images in the shade of grey, though research is on the way in the areas of colour rendering of images for better appreciation.

Furthermore, minute lesions, such as sporadic or multiple petechial hemorrhages on adipose tissues as well as pustules or minute necrotic foci on organs, such as the liver or kidney, may not be appreciated by either MSCT or MRI. However, more research into virtual histology may alleviate such trouble, particularly if it is buttressed with the colour encoding technique.

The hazard of personnel and environmental exposure to radiation (Thrall, 2007) is there, specifically for veterinary establishments that own and employ X-radiography in necropsy. This is so true, owing to the fact that all necropsy rooms are practically not built with radiation protection in mind.

CONCLUSION

Virtopsy is becoming an indispensable adjunct to autopsy/necropsy with the potentials of replacing the invasive procedure in the future. It holds a bright prospect for applications in veterinary pathology. Though it is expensive to run and faced with technical limitations of colour appreciation, lesion timing and radiological hazards, it reduces the risk of disease contraction by veterinary pathologists and students. Moreover, it is easy to use, preserves valuable organ lesions since it is non-invasive, saves valuable time and efforts and gives the possibility of obtaining a second and third opinion on cases. It is also easily archived and retrieved. In order to prove its usefulness in veterinary practice, intensive research into different case scenarios for a wide range of species and lesions are therefore required. Only time and research hinder its complete adoption in veterinary necropsy.

REFERENCES

Aghayev, E., Sonnenschein, M., Jackowski, C., Thali, M., Buck, U., Yen, K., Bolliger, S., Dirnhofer, R., & Vock, P. (2006). Postmortem Radiology of Fatal Hemorrhage: Measurements of Cross-Sectional Areas of Major Blood Vessels and Volumes of Aorta and Spleen on MDCT and Volumes of Heart Chambers on MRI. *American Journal of Roentgenology, 187*(1), 209-215.

Aghayev, E., Thali, M. J., Sonnenschein, M., Jackowski, C., Dirnhofer, R., & Vock, P. (2007). Post-mortem tissue sampling using computed tomography guidance. *Forensic Science International, 166*, 199-203.

Albert, L. B. (2008). *Encyclopedia of diagnostic imaging*. New York: Springer.

Amundsen, T., Kvaerness, J., Jones, R. A., Waage, A., Bjermer, L., Nilsen, G., & Haraldseth, O. (1997). Pulmonary embolism: detection with MR perfusion imaging of lung--a feasibility study. *Radiology, 203*(1), 181-185.

Bolliger, S. A., Thali, M. J., Ross, S., Buck, U., Naether, S., & Vock, P. (2008). Virtual autopsy using imaging: bridging radiologic and forensic sciences. A review of the virtopsy and similar projects. *European Radiology, 18*, 273-282.

Brogdon B. G. (1998). *Forensic radiology*. United States of America: CRC Press.

Cabana, J. E., & Cooper, M. E. (2008). *Veterinary necropsy procedures* (p. 22-25). Philippines: CLSU Alumni Association Inc.

Cooper, J. E., & Cooper, M. E. (2008). Forensic veterinary medicine: a rapidly evolving discipline. *Forensic Science Medical Pathology, 4*, 75-82.

Dirnhofer, R., Jackowski, C., Vock, P., Potter, K., & Thali, M. J. (2006). VIRTOPSY: Minimally invasive, imaging-guided virtual autopsy. *Radiographics, 26*, 1305-1333.

Donchin, Y., Rivkind, A. I., Bar-Ziv, J., Hiss, J., Almog, J., & Drescher, M. (1994). Utility of Postmortem Computed Tomography in Trauma Victims. *The Journal of Trauma, 37*(4), 552-556.

Douglas, P. B. (2002). *Radiology source book*. New Jersey: Humana Press.

Farkash, U., Scope, A., Lynn, M., Kugel, C., Maor, R., Abargel, A., & Eldad, A. (2000). Preliminary Experience with Postmortem Computed Tomography in Military Penetrating Trauma. *The Journal of Trauma, 48*(2), 303-309.

Grabherr, S., Djonov, V., Friess, A., Thali, M. J., Ranner, G., Vock, P., & Dirnhofer, R. (2006). Postmortem Angiography After Vascular Perfusion with Diesel Oil and a Lipophilic Contrast Agent. *American Journal of Roentgenology, 187*(5), W515-W523.

Gumpenberger, M., Hochwartner, O., & Loupal, G. (2004). Diagnostic imaging of a renal adenoma in a red oscar (*Astronotus ocellatus* Cuvier, 1829). *Veterinary Radiology and Ultrasound, 45*, 139-142.

Hayakawa, M., Yamamoto, S., Motani, H., Yajima, D., Sato, Y., & Iwase, H. (2006). Does imaging technology overcome problems of conventional postmortem examination? A trial of computed tomography imaging for postmortem examination. *International Journal of Legal Medicine*, *120*, 24-26.

Heng, H. G., Teoh, W. T., & Sheikh-Omar, A. R. (2008). Postmortem abdominal radiographic findings in feline cadavers. *Veterinary Radiology and Ultrasound, 49*, 26-29.

Heng, H. G., Selvarajah, G. T., Lim, H. T., Ong, J.S., Lim, J., & Ooi, J. T. (2009a). Serial postmortem thoracic radiographic findings in canine cadavers. *Forensic Science International, 188*, 119-124.

Heng, H. G., Selvarajah, G. T., Lim, H. T., Ong, J. S., Lim, J., & Ooi, J. T. (2009b). Serial postmortem abdominal radiographic findings in canine cadavers. *Forensic Science International, 192,* 43-47.

Jackowski, C., Sonnenschein, M., Thali, M. J., Aghayev, E., von Allmen, G., Yen, K., Dirnhofer, R., & Vock, P. (2005). Virtopsy: postmortem minimally invasive angiography using cross section techniques-implementation and preliminary results. *Journal of Forensic Science, 50*, 1175-1186.

Kleinman, P. K. (1990). *Diagnostic imaging of child abuse*. London, England: Mosby.

Marta, S., Jose, M., Rafael, L., Eliseo, B., Maria, J. R., & Amalia, A. (2007). Ultrasonographic, computed tomographic and magnetic resonance imaging anatomy of the normal canine stifle joint. *The Veterinary Journal*, *174*, 351-361.

Mittleman, R. E., Davis, J. H., Kaszil, W., & Graves, W. M. (1992). Practical approach to investigative ethics and religious objections to the autopsy. Journal of Forensic Science, 37(3), 824-829.

Oliver, W. R., Chancellor, A. S., Soltys, M., Symon, J., Cullip, T., Rosenman, J., Hellman, R., Boxwala, A., Gormley, W. (1995). Three-dimensional reconstruction of a bullet path: validation by computed radiography. *Journal of Forensic Science, 40*, 321-324.

Patowary, A. J. (2005). Virtopsy: One step forward in the field of forensic medicine- A review. *Journal of Indian Forensic Medicine, 30,* 32-36.

Pinheiro, J. (2006). *Introduction to Forensic Medicine and Pathology*. In Schmitt, A., Cunha, E. and Pinheiro, J. (Eds.), Forensic Anthropology and Medicine (p. 13-37). New Jersey: Humana Press.

Schumacher, M., Oehmichen, M., König, H. G., & Einighammer, H. (1983). Intravital and postmortal CT examinations in cerebral gunshot injuries [in German]. *Fortschr Röntgenstr, 139*(07), 58,62.

Shkrum, M. J., & Ramsay, D.A. (2007). *Forensic Pathology of Trauma: Common Problems for the Pathologist*. New Jersey: Humana Press.

Swift, B., & Rutty, G. N. (2004). Recent advances in postmortem forensic radiology. *Forensic Pathology Reviews, 4*, 355-404.

Thali, M. J., Dirnhofer, R., Becker, R., Oliver, W., & Potter, K. (2004). Is 'virtual histology' the next step after 'virtual autopsy'? Magnetic resonance microscopy in forensic medicine. *Magnetic Resonance Imaging, 22*, 1131-1138.

Thali, M. J., Jackowski, C., Oesterhelweg, L., Ross, S. G., & Dirnhofer, R. (2007). VIRTOPSY - The Swiss virtual autopsy approach. *Legal Medicine, 9*, 100-104.

Thali, M. J., Kneubuehl, B. P., Bolliger, S. A., Christe, A., Koenigsdorfer, U., Ozdoba, C., Spielvogel, E., & Dirnhofer, R. (2007). Forensic veterinary radiology: Ballistic-radiological 3D computertomographic reconstruction of an illegal lynx shooting in Switzerland. *Forensic Science International, 171*(1), 63-66.

Thrall, D. E. (2007). *Textbook of Veterinary Diagnostic Radiology*. United States of America: Saunders Elsevier.

Toklu, A. S., Alkan, N., Gürel, A., Cimsit, M., Haktanır, D., Körpınar, S., & Purisa, S. (2006). Comparison of pulmonary autopsy findings of the rats drowned at surface and 50 ft depth. *Forensic Science International, 164*(2-3), 122-125.

Wullenweber, R., Schneider, V., & Grumme, T. (1977). A computed-tomographical examination of cranial bullet wounds (in German). *Zeitschrift fur Rechtsmedizin, 80*, 227-246.