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Use of post-mortem computed tomography during the COVID-19 pandemic

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Abstract

Post mortem computed tomography (PMCT) is widely used in England and Wales to supplement or replace traditional invasive Coroner's autopsy. Using PMCT and coronary angiography, the cause of death can be determined without invasive examination in approximately 70% of cases, assuming a typical Coroner's autopsy case mix. Coroner's autopsy services continued during the COVID-19 pandemic and have identified deaths resulting from COVID-19 undiagnosed in life. In some areas of England, PMCT was used to replace traditional autopsy due to concerns over infection risk to mortuary staff associated with invasive autopsy. Health and safety concerns also resulted in changes to post mortem scanning protocols. PMCT has been used to identify potential COVID-19 deaths and assist in the selection of cases for viral studies. There is typically bilateral ground-glass opacities and consolidation within the lungs on CT; although these changes are not specific for COVID-19, the diagnosis can be confirmed with post mortem nose and throat swabs.

Keywords coroner's autopsy; COVID-19; digital autopsy; post mortem CT

Introduction

PMCT is increasingly used in adult autopsy practice, to investigate traumatic deaths and to reduce the requirement for an invasive examination in the diagnosis of deaths from natural disease. A digital autopsy (DA) is one in which the primary modality of investigation is cross-sectional imaging, supplemented by other techniques as required. PMCT is the technique of choice in the investigation of adult deaths.^{1,2} In the UK, access to PMCT services is varied. Most adult autopsies in England and Wales are carried out on the instruction of a Coroner for the investigation of sudden deaths of unknown cause or suspected unnatural deaths. In many regions, mainly across the North of

England and Midlands, PMCT is the first line of investigation for all coronial autopsy requests, with an invasive procedure carried out only when imaging does not identify the cause of death. In these areas, the cost of imaging is met by the Coroner's service, funded by the Local Authority, and the largest provider of DA services is iGene Digital Autopsy. In other areas, including the South of England and Wales, DA services are not provided locally, nor funded by the Coroner. Oxford provides a supra-regional DA service for London, the South of England and Wales for cases in which the family have expressed an objection to invasive autopsy. In this article we present an overview of the Oxford DA service and discuss how this and other post mortem imaging services in England have operated during the COVID-19 pandemic. We describe the changes to DA protocols in response to COVID-19, and discuss how PMCT can be utilized in order to reduce the requirement for invasive autopsy to diagnose COVID-19 deaths.

The Oxford digital autopsy service

The Oxford DA service is based on evidence and experience gained by the authors over a 12-year period of research into post mortem imaging, including a Department of Health funded validation study of post mortem CT (PMCT) and MRI in adult deaths, from 2006-10.¹ Protocols and techniques developed during this study were applied to a trial DA service for HM Coroner Oxfordshire, 2010-12.³ In 2013, the service was opened up to other Coroners' Areas across England and Wales. Currently, 30 Coroners' Areas use the service with approximately 200 DA requests annually. The service is provided using NHS facilities and staff, and administered by a limited company, Oxford Radcliffe Medicolegal Imaging Service (ORAMIS Digital Autopsy Limited).

Coronial referrals to the DA service are received when a family expresses an objection to traditional invasive Coroner's autopsy and requests a less invasive alternative. Most referrals are therefore from the Moslem and Jewish communities who have religious objections to invasive autopsy. These communities also require the funeral to take place as soon as possible after death and we therefore endeavour to carry out the DA as soon as possible after the referral is received, typically the same day. The cost of post mortem imaging (£500) is paid for by the family or their religious organization. The Coroner pays the standard pathologist's fee (£96.80) and mortuary costs (£100).

PMCT scans are carried out in the NHS CT unit at the Churchill Hospital (1.5 miles from the Oxfordshire public mortuary at the John Radcliffe Hospital). The CT unit is used for living NHS patients during the day; access for the DA service is therefore limited to before 7 am or after 6 pm. ORAMIS provides a "one stop" service in which the family's funeral director brings the body to Oxford for CT scan ± angiography. If these do not identify the cause of death then the body is transferred immediately to the mortuary for invasive examination, limited and directed by the imaging findings. The examination is usually complete in <1 hour, after which the cause of death and summary of the findings is emailed to the Coroner, and the body is released back to the family's funeral director.

There is a stepwise decision-making process that aims to avoid or minimize any invasive procedure (Figure 1). The

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1. Full body CT + external examination → issue report & cause of death

↓
no definitive cause of death

2. CT coronary angiography → issue report & cause of death

↓
no definitive cause of death

3. Conventional invasive autopsy, limited according to the imaging findings

Figure 1 A stepwise approach to the diagnosis of cause of death in the Oxford DA service. This approach minimises the invasive procedures carried out. Other minimally invasive investigations are performed as indicated, including aspiration of fluids for toxicology and biochemistry, and biopsy of tumours identified at imaging.

imaging is reported by a consultant radiologist; a consultant pathologist makes the decisions regarding what procedures are required following discussions with the radiologist. Over 90% of cases are carried out by the authors, each with personal experience of >1500 DAs. The pathologist is usually present in the CT control room, viewing and discussing the imaging findings with the radiologist. The pathologist carries out external examination of the body in the CT unit. Coronary angiography for most cases is carried out by the pathologist using a method developed in Oxford.⁴ Initial findings from a trial service indicated that 35% of unselected Coroners' autopsy referrals could be diagnosed with PMCT alone, increasing to 70% with the inclusion of coronary angiography. The Oxford DA service includes an initial selection of cases; requests for PMCT are declined for those cases in which it is clear on the basis of the history and circumstances of the death that invasive autopsy is highly likely to be required. As a consequence, audit of the first 300 cases in the Oxford DA service demonstrated that in 82%, cause of death was provided on the basis of CT ± angiography (Figure 2). The remainder required an invasive procedure that was limited in all cases.

Impact of COVID-19 on digital autopsy services

COVID-19 had an impact on all autopsy services in the UK but the response to the pandemic has varied between units. The major concern has been health and safety for mortuary staff, as standard invasive autopsy is associated with a risk of exposure to the virus. This has led to changes in referral patterns, types of examination and personal protective equipment (PPE). In some Coroner's Areas autopsies virtually ceased whilst in others there was an increase in autopsy requests; in some areas with access to PMCT services all coronial autopsies became digital.

Those DA units with mortuary-based CT scanners continued to provide a service during the COVID-19 pandemic but with changes in local protocols. For example, workload at the iGene unit in the West Midlands (Sandwell) increased as all autopsies in the region became digital. Initially, sourcing PPE was challenging as supplies during the first national lockdown (an 8-week period starting 23rd March 2020) were diverted to the NHS. As a result, PMCT continued but angiography, which requires opening of the body bag and a minimally invasive procedure, was suspended. Once appropriate PPE was secured, angiography was re-introduced but only for those cases in which there were no COVID-19 symptoms prior to death and PMCT showed no

changes suggestive of COVID-19 within the lungs. Access to the DA facility was suspended for funeral directors and other visitors. Paper continuity of evidence forms were replaced by electronic records and administration staff worked from home. Similarly, workload at the iGene DA unit in the North Midlands (Stoke-on-Trent) increased at the onset of the COVID-19 pandemic as there was an increase in referrals from other regions with the aim of reducing requirements for invasive Coroners' autopsies.

In Oxford, the standard autopsy service for HM Coroner Oxfordshire continued during the first national lockdown but with amended protocols. There was a reduced number of coronial referrals for post mortem examination, largely due to a reduction in requests for non-suspicious out-of-hospital deaths in the elderly when the Coroner was more likely to accept a suggested cause of death from the patient's general practitioner. This led to a 36% reduction in Coroner's autopsy requests compared to the same period in 2018, with a significant reduction in diagnoses of sudden natural deaths at autopsy.⁵ Those autopsies performed during the first lockdown were more likely to be in younger adults with a higher proportion of unnatural deaths. The Coroner authorized the taking of post mortem nose and throat swabs for all cases in which the history was consistent with COVID-19. If the swab was positive for SARS-CoV-2 RNA, and the history indicated death from COVID-19, then the Coroner

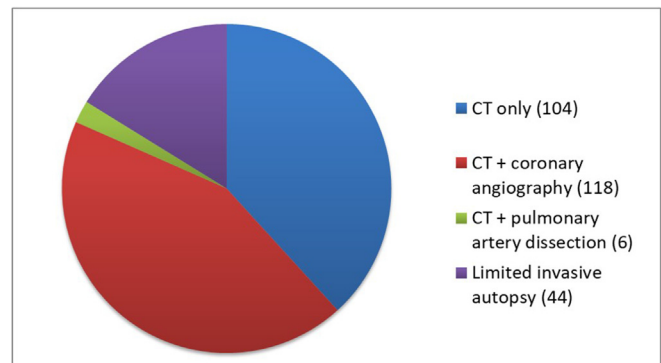


Figure 2 Audit of diagnostic modalities required in the first 300 digital autopsies of the Oxford DA service. 82% required only CT ± coronary angiography. 28 digital autopsies carried out on the request of the police for the investigation of traumatic deaths/suspected homicide were excluded from the analysis.

accepted a cause of death with only external examination of the body. From March 2020, mortuary staff and pathologists were required to wear enhanced PPE, including powered air-purifying respirators, for all adult autopsies. The PPE provided was based on guidance provided by the Royal College of Pathologists guidelines⁶ and international recommendations.^{7,8}

At the onset of the COVID-19 pandemic, the concern for the Oxford DA service was exposure of staff and living patients attending the NHS CT unit to the virus coming from deceased patients and funeral directors. A high proportion of the referrals for the Oxford DA service come from London Coroners, and London was the major UK focus of COVID-19 infections at the start of the pandemic. As a result of these concerns, the Oxford DA service was suspended for out-of-region referrals during the first national lockdown, re-starting on 22nd May 2020. The service then continued as normal until the start of the Tier 4 restrictions in London and South East England in December 2020, followed by the third national lockdown on 6th January 2021. After this, the DA service continued but with amended protocols that were in place until 5th March 2021. The protocols, aiming to minimize risk to radiology staff and patients, were that deceased patients referred for DA were initially taken to the John Radcliffe Hospital mortuary; external examination and COVID-19 swabs were carried out in the post-mortem room. The body was then transferred to the Churchill Hospital radiology department in a sealed body bag; the bag was not opened in the CT unit and therefore coronary angiography could not be performed. This resulted in a significant increase in the proportion of DAs proceeding to an invasive examination; 29% of DAs carried out between 1st January and March 5th 2021 required an invasive

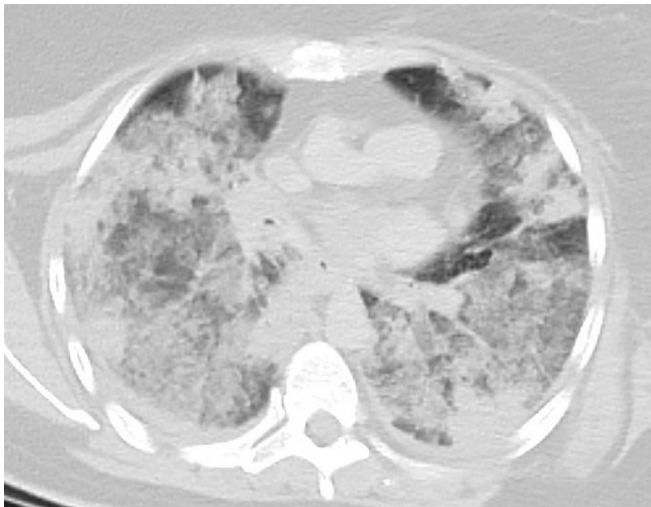


Figure 3 Case 1. Axial CT image of the chest (lung windows) showing bilateral, predominantly peripheral ground-glass opacities and consolidation. There are tiny, bilateral pleural effusions. Case history: A 70 year-old woman was found dead in her living room. She suffered from diabetes mellitus and ischaemic heart disease, and had a recent fever and cough. There were no notable findings on external examination. Additional PMCT findings were a small pericardial effusion and left ventricular hypertrophy. Coronary arteries showed minor calcification. There was no acute intracranial or intra-abdominal pathology and no fractures. Nose and throat swabs taken at the time of digital autopsy were positive for SARS-CoV-2 RNA. Cause of death: Ia COVID-19; II Diabetes mellitus.

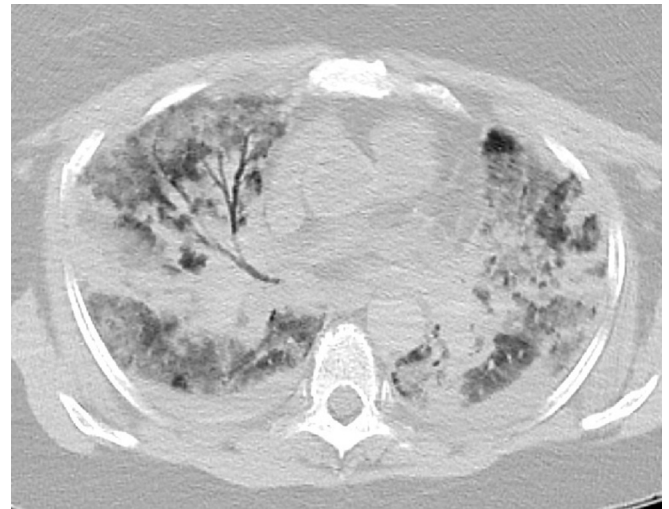


Figure 4 Case 2. Axial CT image of the chest (lung windows) showing bilateral ground-glass opacities and consolidation with bronchial dilatation within involved lung on the right. There are small, bilateral pleural effusions. Case history: A 63 year-old woman was found unresponsive and collapsed at home. She had a history of asthma, lethargy and breathlessness. On external examination she was found to be obese. Additional PMCT findings: Coronary arteries showed minor calcification. The heart appeared normal. There was no acute intracranial pathology. There were CPR-related injuries with bilateral anterior rib fractures, a sternal fracture, and haemorrhage around the liver and spleen. Nose and throat swabs taken at the time of digital autopsy were positive for SARS-CoV-2 RNA. Cause of death: Ia COVID-19; II Asthma, obesity.

procedure, compared to 9% between 1st November and 31st December 2020, $p = 0.05$. The invasive procedures were carried out in the John Radcliffe Hospital post-mortem room with staff wearing full PPE.

Use of PMCT to diagnose COVID-19 deaths

During the first year of the COVID-19 pandemic, starting 1st April 2020, the Oxford autopsy service diagnosed COVID-19 as the cause of death in 27 patients (4% of all adult Coroner's autopsies). The diagnoses were made on the basis of positive COVID-19 nose and throat swabs, taken post-mortem or immediately ante-mortem, together with external examination only (12 cases), full invasive autopsy \pm histology (8 cases) or PMCT scan (7 cases).

Typical chest CT features of COVID-19 infection in the living are of bilateral, peripheral, basal predominant, ground-glass opacities (defined as hazy opacities with preservation of vascular and bronchial markings) and vascular enlargement. These are often associated with consolidation (a homogeneous increase in pulmonary attenuation that obscures the margins of vessels and airway walls), particularly in the later stages of the infection. Ground-glass opacities may be of rounded morphology, and there may be associated thickened interlobular septa and intralobular lines (the "crazy paving" pattern), air bronchograms, halo sign and bronchiectasis.^{9,10} It is unusual to see lobar or segmental consolidation without ground-glass opacities, lung cavities, discrete small nodules and pleural effusions and these findings in isolation should prompt consideration of alternative diagnoses. Development of fibrosis may be manifest by the appearance of traction bronchiectasis, parenchymal bands and architectural distortion.

Chest CT appearances are rarely completely normal in PMCT, even in those with normal antemortem lungs. The most common abnormality is a diffuse, ground-glass pattern of opacification with a dependent distribution due to post-mortem hypostasis. Familiarity with post-mortem CT decomposition artefact is essential in the accurate assessment of the likelihood of COVID-19 infection based on the PMCT appearances, as is consideration of the pre-test probability of the disease, which will depend on the prevalence of COVID-19 infection in the community. Several reports suggest that PMCT findings in patients who have died of COVID-19 pneumonia are similar to those in the living, although unsurprisingly, more diffuse, suggesting more severe infection.^{11,12} Diagnosis of COVID-19 pneumonia in the living and after death may be made more difficult due to the presence of pre-existing lung conditions or complications of COVID-19 infection such as pulmonary embolic disease, superimposed bacterial or fungal infection or heart failure.

The non-specific nature of even the typical chest CT findings in patients with COVID-19¹³ means that the diagnosis of this infection as the cause of death will also require a history consistent with the diagnosis and positive post mortem COVID-19 swabs. The practical consequences of this for the DA service is that when the PMCT findings and history suggest COVID-19 pneumonia, the body is released to the family for funeral, but a final cause of death is not provided to the Coroner until the viral swab results are available (usually the following day). If COVID-19 is suspected on the basis of PMCT changes in the lungs, but the swabs are negative, then a cause of death of pneumonia is provided. Two cases from the Oxford DA service in which COVID-19 was diagnosed are illustrated in Figures 3 and 4.

In summary, PMCT has been used to reduce the need for invasive Coroner's autopsy during the COVID-19 pandemic. The PMCT changes within the lungs in COVID-19 are similar to those described in living patients, although are generally more severe, and must be interpreted in the context of "normal" post mortem imaging changes. When COVID-19 is suspected on the basis of the imaging, the diagnosis should be confirmed with viral swabs. ♦

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