MODERN RADIOLOGY eBook

# Sustainable Imaging

# 可持续成像

EUROPEAN SOCIETY OF RADIOLOGY

# Preface

*Modern Radiology* is a free educational resource for radiology published online by the European Society of Radiology (ESR). The title of this second, rebranded version reflects the novel didactic concept of the ***ESR eBook*** with its unique blend of text, images, and schematics in the form of succinct pages, supplemented by clinical imaging cases, Q&A sections and hyperlinks allowing to switch quickly between the different sections of organ-based and more technical chapters, summaries and references.

Its chapters are based on the contributions of over 100 recognised European experts, referring to both general technical and organ-based clinical imaging topics. The new graphical look showing Asklepios with fashionable glasses, symbolises the combination of classical medical teaching with contemporary style education.

Although the initial version of the ***ESR eBook*** was created to provide basic knowledge for medical students and teachers of undergraduate courses, it has gradually expanded its scope to include more advanced knowledge for readers who wish to 'dig deeper'. As a result, *Modern Radiology* covers also topics of the postgraduate levels of the *European Training Curriculum for Radiology*, thus addressing postgraduate educational needs of residents. In addition, it reflects feedback from medical professionals worldwide who wish to update their knowledge in specific areas of medical imaging and who have already appreciated the depth and clarity of the ***ESR eBook*** across the basic and more advanced educational levels.

I would like to express my heartfelt thanks to all authors who contributed their time and expertise to this voluntary, non-profit endeavour as well as Carlo Catalano, Andrea Laghi and András Palkó, who had the initial idea to create an ***ESR eBook***, and - finally - to the ESR Office for their technical and administrative support.

*Modern Radiology* embodies a collaborative spirit and unwavering commitment to this fascinating medical discipline which is indispensable for modern patient care. I hope that this ***educational*** tool may encourage curiosity and critical thinking, contributing to the appreciation of the art and science of radiology across Europe and beyond.

**Minerva Becker**, Editor
Professor of Radiology, University of Geneva, Switzerland

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**章节大纲：**



# 前言

*《现代放射学》*是由欧洲放射学协会 (European Society of Radiology, ESR) 在线发布的免费放射学教育资源。第二版（更名版）标题反映了 ***ESR 电子书***新颖的教学概念，它以简洁页面的形式巧妙地融合文本、图像和示意图，并辅以临床影像学案例、问答部分和内容超链接，使读者能够在各基于器官的部分、更具技术性的章节、摘要以及参考文献之间快速切换浏览。

其章节以 100 多名公认欧洲专家的优秀稿件为根基，涉及各类一般技术和基于器官的临床影像学主题。同时采用了全新的图形外观，展示了佩戴时尚眼镜的 Asklepios，象征着传统医学教学与现代风格教育的结合。

虽然初版 ***ESR 电子书***旨在为医学生和本科生教师提供医学基础知识，但现已逐渐扩充其知识领域，为希望“深入挖掘”的读者提供了更多高阶技术知识。因此，*《现代放射学》*还涵盖了*欧洲放射学培训课程*研究生水平的各类主题，旨在解决住院医师的研究生教育需求。此外，书中还囊括了全球医疗专业人士的反馈，他们希望更新自己在医学影像特定领域的知识，并对 ***ESR 电子书***在基础和高等教育水平上的深度和清晰度表示高度赞赏。

我要衷心感谢所有为这项非营利活动自愿贡献时间和专业知识的作者，以及最初提出创作 ***ESR 电子书***的 Carlo Catalano、Andrea Laghi 和 András Palkó，最后还要感谢 ESR 办公室所提供的技术和行政支持。

*《现代放射学》*充分体现了医者的协作精神和对这门热门医学学科坚定不移的承诺，这是现代患者护理必须具备的优秀精神品质。我希望这款***教育***工具能够激励各位始终保持好奇心和批判性思维，从而促进整个欧洲乃至欧洲以外地区对放射学艺术和科学的认识。

**Minerva Becker，编辑**
**瑞士日内瓦大学放射学教授**

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# Translation Credits

This is a translation of the Chapter of the **Modern Radiology eBook.**

**ORIGINAL TITLE:**
Sustainable Imaging

**TRANSLATED BY:**
Prof. Peijun Wang, Tongji Hospital of Tongji University
Prof. Yan Zhou, Renji Hospital, Shanghai Jiao Tong University School of Medicine

**COORDINATED BY:**
Prof. Shiyuan Liu, Shanghai Changzheng Hospital
Prof. Yi Xiao, Shanghai Changzheng Hospital

**ENDORSED BY:**
Chinese Society of Radiology

**NOTE FROM THE COORDINATORS:**
Thank you to Chinese radiology experts for bridging languages and open the world-class English resource by ESR to every Mandarin-speaking student, fueling global radiology talent with a single click

**<↑> HYPERLINK**

tongjipjwang@vip.sina.com
clare1475@hotmail.com

## Sustainable Imaging

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# 翻译致谢

本章节为《现代放射学电子书》的部分译文。

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**翻译：**
王培军教授，同济大学附属同济医院
周滟教授，上海仁济医院

**联合翻译：**
刘士远教授，长征医院
萧毅教授，长征医院

**审定：**
中华医学会放射学分会

**译者寄语：**
感谢中国放射学专家们的倾力奉献！你们跨越了语言的鸿沟，将欧洲放射学会 (ESR) 的世界级学术宝库呈献给广大中文学子。如今，前沿智慧一键即达，为全球放射学人才的蓬勃发展注入了强劲动力。

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**章节大纲：**



**<↑> 超链接**

tongjipjwang@vip.sina.com
clare1475@hotmail.com

# / Signage

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<!> ATTENTION

<↑> HYPERLINKS

>▪< FURTHER KNOWLEDGE

>|< COMPARE

<∞> REFERENCES

<?> QUESTIONS



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>▪< 进阶知识

>|< 比较

<∞> 参考文献

<?> 问题

MODERN RADIOLOGY eBook

Based on the ESR Curriculum for Radiological Education

# Sustainable Imaging


**AUTHORS**

Michael Jackson

Royal Hospital for Children and Young People, Edinburgh, United Kingdom

**AFFILIATION**

European Society Radiology (ESR) subcommittee on sustainable imaging

<↑> HYPERLINK

michael.jackson@nhs.scot




## Sustainable Imaging

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**章节大纲：**



基于 ESR 课程的放射学教育

# 可持续成像


**作者**

Michael Jackson

英国爱丁堡皇家儿童与青少年医院（Royal Hospital for Children and Young People, Edinburgh, United Kingdom）

**所属机构**

欧洲放射学会 (ESR) 可持续医学影像分会 (European Society Radiology [ESR] subcommittee on sustainable imaging)

<↑> 超链接

michael.jackson@nhs.scot

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  - Magnetic Resonance Imaging (MRI) and Nuclear Medicine
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## Sustainable Imaging

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  - 避免灾难性的恶性循环
- 核心要点
- 知识测试
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# Introduction

# 简介



## Sustainable Imaging

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章节大纲：

# / Introduction

The Climate Emergency is one of the largest threats to human health and wellbeing, a global health crisis of greater severity than the Covid-19 pandemic.

Healthcare in general, and medical imaging in particular, is an energy intensive activity with a substantial environmental impact. In recent years it has become increasingly clear than this environmental impact can lead to loss of human lives and livelihoods.

This chapter will examine the carbon cost of imaging together with additional associated environmental pollutants, looking at several specific imaging modalities, consumables and other related energy use such as transport.

We will consider modifications to current practice which can help reduce the impact of imaging but will also contemplate broader questions related to how healthcare is delivered. Is the current model of energy intensive downstream treatment one that can continue when some diseases are potentially preventable?

Although focusing on imaging, the content and themes of this chapter are applicable to most other areas of medicine. As healthcare providers we have an ethical responsibility to ensure that the care we deliver is not only safe and appropriate for the patient in front of us, but also sustainable and justifiable.

## / Sustainable Imaging

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# / 简介

气候危机是对人类健康与福祉最严重的威胁之一，是一场比新冠疫情更为严峻的全球健康危机。

总体而言，医疗保健，尤其是医学影像，属于高能耗活动，会对环境产生重大影响。近年来愈发明显的是，这种环境影响可能导致人类生命与生计的损失。

本章将探讨影像检查的碳排放，以及伴随产生的其他环境污染物，具体探讨几种特定的成像方式、耗材，以及诸如交通出行等其他相关能源使用情况。

我们将思考对当前实践的改进，以帮助减轻成像检查对环境的影响，同时也会思考与医疗服务提供方式相关的更广泛问题。当某些疾病有可能通过预防避免的情况下，当前这种高能耗的下游环节治疗模式还能持续下去吗？

尽管本章聚焦于医学成像，但其中的内容和主题同样适用于医学的大多数其他领域。我们作为医疗服务提供者，肩负着伦理责任：要确保我们所提供的医疗服务，不仅对眼前的患者而言安全适当，同时也应具备可持续性和公平性。

# Background

# 背景



## Sustainable Imaging

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# / Background

The Climate Emergency is one of the largest threats to human health and wellbeing.

Climate change is directly contributing to humanitarian emergencies from heatwaves, wildfires, floods, tropical storms and hurricanes and they are increasing in scale, frequency and intensity.

37% of heat-related deaths are attributed to human-induced climate change. Heat-related deaths among those over 65 have risen by 70% in two decades. In 2020, 98 million more experienced food insecurity compared to the 1981–2010 average. The WHO conservatively projects 250 000 additional yearly deaths by the 2030s due to climate change impacts on diseases like malaria, undernutrition, diarrhoea and coastal flooding. [ref 1]

In 2017, the World Bank, in collaboration with Health Care Without Harm, published an estimated calculation which found that the health care sector generated 2.6 billion out of the 52 billion metric tons of $CO_2$ globally emitted in 2011 — or 5% of global $CO_2$ emissions.[ref 2]

The health sectors of the United States, Australia, England, and Canada emit a combined 748 million metric tons of carbon dioxide annually. If the health sectors of these countries were a single independent nation, they would rank seventh in the world for greenhouse gas emissions. [ref 3]

While healthcare can undoubtedly deliver great benefits, it is increasingly clear that the environmental impact of healthcare-related emissions is also contributary to loss of human lives and livelihoods. Healthcare professionals and the public alike are ever more aware of the need to address sustainability in all healthcare activities and decisions.

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Ref 2:: Climate-Smart Healthcare: Low-carbon and Resilience Strategies for the Health Sector. World Bank 2017
Ref 3: Sustainability in Health Care. Howard Hu, Gary Cohen, Bhavna Sharma, Hao Yin, Rob McConnell. Annual Review of Environment and Resources 2022 47:1, 173-196. https://www.annualreviews.org/content/journals/10.1146/annurev-environ-112320-095157



# / Sustainable Imaging

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**章节大纲：**



# / 背景

气候危机是对人类健康与福祉最严重的威胁之一。

气候变化正直接导致由热浪、山火、洪水、热带风暴和飓风引发的人道主义危机，且这些危机的规模、发生频率和强度都在不断增加。

37% 与高温相关的死亡归因于人类活动导致的气候变化。在过去二十年里，65 岁以上人群中与高温相关的死亡人数增加了 70% 。2020 年，面临粮食不安全问题的人数比 1981-2010 年的平均水平多出 9800 万。世界卫生组织（World Health Organization，WHO）保守估计，到 2030 年代，由于气候变化对疟疾、营养不良、腹泻等疾病的影响以及沿海洪灾，每年将额外导致约 25 万人死亡。[参考文献 1]

2017 年，世界银行与健康无害医疗组织 (Health Care Without Harm) 合作发布了一项估算结果。该结果显示，在 2011 年全球排放的 520 亿吨二氧化碳 ($CO_2$) 中，医疗保健行业产生了 26 亿吨，占全球 $CO_2$ 排放量的 5%。[参考文献 2]

美国、澳大利亚、英国和加拿大的医疗保健行业每年二氧化碳排放总量达 7.48 亿吨。倘若这些国家的医疗部门视为一个独立国家，其温室气体排放量将位居世界第七。[参考文献 3]

医疗保健无疑能带来诸多益处，但医疗保健相关的排放对环境造成的影响，以及导致人类生命和生计的损失也日益明显。医疗专业人员和普通公众都愈发意识到，必须在所有医疗活动与决策中解决可持续性问题。

**<∞> 参考文献**

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参考文献 3：Sustainability in Health Care. Howard Hu, Gary Cohen, Bhavna Sharma, Hao Yin, Rob McConnell. Annual Review of Environment and Resources 2022 47:1, 173-196. https://www.annualreviews.org/content/journals/10.1146/annurev-environ-112320-095157

# The Climate Crisis is a Health Crisis.

The diagram on the right demonstrates how the multifactorial impacts of global heating can combine to impact health:

## Impact of climate change on human health

(Source: U.S. Centers for Disease Control and Prevention)

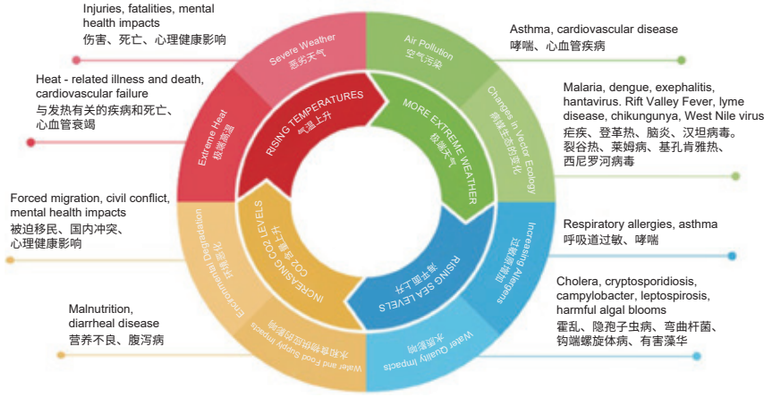


Diagram from: Duindam, D. Transitioning to Sustainable Healthcare: Decarbonising Healthcare Clinics, a Literature Review. Challenges 2022, 13, 68.

https://doi.org/10.3390/challe13020068



# Sustainable Imaging

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**章节大纲：**



## 气候危机即健康危机。

右图展示了全球变暖如何从多方面对健康造成影响：

## 气候变化对人类健康的影响

（资料来源：美国疾病控制和预防中心）

图表源自：Duindam, D. Transitioning to Sustainable Healthcare: Decarbonising Healthcare Clinics, a Literature Review. Challenges 2022, 13, 68.

https://doi.org/10.3390/challe13020068

# Sustainable Imaging

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Within healthcare, medical imaging represents a significant proportion of carbon-based emissions, and also produces additional environmental pollution.

Estimates vary, but imaging is thought to account for approximately 10% of health-care related emissions [ref 1], which would equate to around 0.5% of global emissions.

In 2016, $CO_2$ emissions from magnetic resonance imaging and computed tomography, calculated in 120 countries, accounted for 0.77% of total global emissions [ref 1].

Another estimate puts this proportion higher still at 1% [ref 2].

Whilst there is some variation amongst these figures, it is clear that medical imaging makes a significant contribution to greenhouse gas emissions. Recent research estimates that fossil fuel emissions causes 8.34 million premature deaths related to air pollution per year [ref 3]. Using the lower estimate of 0.5%, medical imaging would be responsible for 41,700 premature deaths every year on this basis or using the higher estimate of 1% some 83,400 deaths per annum.

Although some countries which have a high imaging-related energy use will utilise sustainably generated electricity, when we remember that these estimated air pollution related premature deaths do not factor in the additional premature deaths WHO anticipates as the result of global heating, the figures remain highly concerning.

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Ref 1 Picano E, Mangia C, D'Andrea A. Climate Change, Carbon Dioxide Emissions, and Medical Imaging Contribution. J Clin Med. 2022 Dec 27;12(1):215. doi: 10.3390/jcm12010215. PMID: 36615016; PMCID: PMC9820937
Ref 2 The Lancet Digital Health. Curbing the carbon footprint of health care. Lancet Digit Health. 2023 Dec;5(12):e848. doi: 10.1016/S2589-7500(23)00229-7. PMID: 38000867
Ref 3 Lelieveld J, Haines A, Burnett R, Tonne C, KlingmÃ¼ller K, MÃ¼nzel T et al. Air pollution deaths attributable to fossil fuels: observational and modelling study BMJ 2023; 383 :e077784 doi:10.1136/bmj-2023-077784



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章节大纲：



在医疗保健领域，医学成像在碳排放中占比颇高，还会造成其他环境污染。

尽管估算数值存在差异，但一般认为医学成像约占医疗相关排放量的 10% [参考文献 1]，这相当于全球排放量的 0.5% 左右。

2016 年，对 120 个国家的磁共振成像和计算机断层扫描的$CO_2$ 排放量估算表明，其占当年全球总排放量的 0.77% [参考文献 1]。

另有一项估算得出的比例更高，达到 1% [参考文献 2]。

尽管这些数据有一定差异，但很明显医学成像在温室气体排放中占了相当比重。最新研究估计，化石燃料排放每年导致 834 万人因空气污染而过早死亡 [参考文献 3]。按最低估值 0.5% 计算，医学成像每年因此造成的过早死亡人数约为 41,700 例；若按最高估值 1% 计算，则每年约 83,400 例。

尽管一些成像能源使用量高的国家会利用可持续发电，但我们要知道，这些与空气污染相关的过早死亡估算值，并未计算在 WHO 预计的因全球变暖导致的额外过早死亡人数之内，因此这些数据仍令人十分担忧。

<∞> 参考文献

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# Four Principles of Sustainable Health Care



## Sustainable Imaging

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**章节大纲：**



# 可持续医疗保健的四项原则

# / Four Principles of Sustainable Healthcare

Within healthcare, medical imaging represents a significant proportion of carbon-based emissions, and also produces additional environmental pollution. In considering how to deliver less harmful imaging services it is useful to recall the four principles of sustainable healthcare [Mortimer F, 2010]:

1. Prevention
   / Promoting health and preventing disease by tackling the causes of illnesses and inequalities.
2. Patient Self-Care
   / Empowering patients to take a greater role in managing their own health and healthcare.
3. Lean Service
   / Streamlining care systems to minimise wasteful activities.
4. Low Carbon
   / Prioritising treatments and technologies with a lower environmental impact.

<∞> REFERENCE

Mortimer F. The sustainable physician. Clin Med (Lond). 2010 Apr;10(2):110-1. doi: 10.7861/clinmedicine.10-2-110. PMID: 20437974; PMCID: PMC4952075



/ **Sustainable** Imaging

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章节大纲：



# / 可持续医疗保健的四项原则

在医疗保健领域，医学成像在碳排放中占比颇高，还会造成其他环境污染。在考虑如何提供更环保的影像服务时，回顾可持续医疗保健的四项原则大有裨益 [Mortimer F, 2010]：

1. 预防
   / 通过消除疾病与不公正的原因，促进健康并预防疾病。
2. 患者自我护理
   / 使患者能够在自身健康与医疗管理中发挥更大作用。
3. 精益服务
   / 精简医疗系统，最大限度减少浪费。
4. 低碳
   / 优先考虑对环境影响较小的治疗方案和技术。

<∞> 参考文献

Mortimer F. The sustainable physician. Clin Med (Lond). 2010 Apr;10(2):110-1. doi: 10.7861/clinmedicine.10-2-110. PMID: 20437974; PMCID: PMC4952075

# Imaging Modalities



## Sustainable Imaging

**CHAPTER OUTLINE:**



## 可持续成像

**章节大纲：**





# 影像学检查方法

# / Imaging Modalities

Medical Imaging or radiology utilises several different examination techniques or modalities, covered in detail elsewhere in the eBook for Undergraduate Education in Radiology.

Each modality has particular advantages and disadvantages in relation to demonstrating different body regions and pathologies, but there is also variation in the carbon footprint of each modality.

While radiology departments endeavour to use resources judiciously regardless of sustainability issues, examination of the relative carbon cost of different imaging techniques may be helpful in planning imaging departments of the future, and working out how imaging can best serve patients more broadly.

## / Sustainable Imaging

**CHAPTER OUTLINE:**







# / 影像学检查方法

## / 可持续成像

**章节大纲：**



医学成像（或放射学）采用多种不同的检查技术或成像方式，本电子书《放射学本科教育》章节对此有详细介绍。

每种成像方式在显示不同身体部位和病变方面各有优劣，而且每种成像方式的碳足迹也存在差异。

尽管放射科无论是否考虑可持续性问题，都会努力合理使用资源，但研究不同成像技术的相对碳成本，或许有助于规划未来的影像科，并更全面地探索如何使影像检查最有效地服务患者。

# / Ultrasound

The use of sulphur hexafluoride microbubbles as contrast agent for ultrasound examinations increases the environmental impact (see Consumables: Ultrasound Microbubbles).

Ultrasound does have some technical limitations, with visibility of the chest and abdomen partly limited by the ribs and bowel gas respectively and is known to be operator dependent, meaning reliability of findings is more variable compared to CT or MRI. However, image quality continues to improve with developing technology and in view of the relatively low carbon footprint ultrasound may become increasingly useful in settings where cross-sectional imaging resources are limited.

**<!> ATTENTION**

**In most situations ultrasound has the lowest greenhouse gas emissions, particularly compared to cross-sectional imaging. An abdominal ultrasound is estimated to produce 0.5 Kg $CO_2$e, compared to 9.2 kg for an abdominal CT scan and 17.5kg for and abdominal MRI.**



## / Sustainable Imaging

**CHAPTER OUTLINE:**







## / 可持续成像

**章节大纲：**



# / 超声

在超声检查中使用六氟化硫微泡作为对比剂会加剧对环境的影响（详见消耗品：超声微泡）。

超声检查确实存在一些技术局限：胸部视野部分受肋骨遮挡，腹部视野则受肠气干扰，同时其结果高度依赖操作者，这意味着与 CT 或 MRI 相比，其检查结果的可靠性波动更大。但随着技术的不断发展，超声图像质量持续提升。鉴于超声检查的碳足迹相对较低，在断层成像资源受限的情况下，其应用可能会越来越广泛。

**<!> 注意**

**在大多数情况下，超声检查产生的温室气体排放量最低，与断层成像相比尤其如此。据估算，一次腹部超声检查产生 0.5 Kg $CO_2$e（千克二氧化碳当量），而一次腹部 CT 扫描产生 9.2 kg，一次腹部 MRI 检查产生 17.5 kg。**

# / Computed Tomography (CT)

While an abdominal scan is estimated to produce 9.2 Kg $CO_2$e, whole body scans or multi-phase acquisitions can result in some examinations exceeding 30Kg $CO_2$e.

Schöckel L et al [2020] estimated 350million CT examinations are performed globally each year. Assuming a $CO_2$e of 9.2Kg per examination, CT scans would contribute some 3.2 million tonnes of $CO_2$ globally each year.

<∞> REFERENCE

Schöckel L, Jost G, Seidensticker P, Lengsfeld P, Palkowitsch P, Pietsch H. Developments in X-Ray Contrast Media and the Potential Impact on Computed Tomography. Invest Radiol. 2020 Sep;55(9):592-597. doi: 10.1097/RLI.0000000000000696. PMID: 32701620



## / Sustainable Imaging

CHAPTER OUTLINE:







## / 可持续成像

章节大纲：



# / 计算机断层扫描 (CT)

虽然一次腹部扫描估计产生 9.2 Kg $CO_2$e，但全身扫描或多期采集会使某些检查产生的二氧化碳当量超过 30 Kg $CO_2$e。

Schöckel 等人 [2020] 估计，全球每年约进行 3.5 亿次 CT 检查。假设每次检查产生 9.2 Kg $CO_2$e，那么全球每年的 CT 扫描将产生约 320 万吨 $CO_2$。

<∞> 参考文献

Schöckel L, Jost G, Seidensticker P, Lengsfeld P, Palkowitsch P, Pietsch H. Developments in X-Ray Contrast Media and the Potential Impact on Computed Tomography. Invest Radiol. 2020 Sep;55(9):592-597. doi: 10.1097/RLI.0000000000000696.PMID: 32701620

# / Magnetic Resonance Imaging (MRI)

MRI requires a very strong magnetic field to operate (most clinical scanners using field strength of 1.5 or 3 Tesla) > **see eBook chapter on MRI.**

The carbon cost of installing and maintaining superconducting magnets is substantial (see also MRI: Helium).

MRI often delivers information that is not readily provided by other imaging modalities, but this high energy consumption is prompting radiology departments to examine how to perform examinations in a more sustainable fashion.

For example, implementation of power-save mode for 12 hours overnight instead of off mode on all outpatient MRI units in the United States could save U.S. health care 58 863.2–76 288.2 MW-hours, $8.2–$10.7 million, and 41 606.4–54 088.3 metric tons of $CO_2e$ [Wollen SA et al 2023].

**<!> ATTENTION**

**An estimate of carbon footprint suggests an abdominal MRI scan produces 17.5Kg $CO_2e$, approximately double that of an abdominal CT scan and some 35 times the carbon cost of an abdominal ultrasound scan. [McAlister S, et al 2022]**



## / Sustainable Imaging

**CHAPTER OUTLINE:**







## / 可持续成像

**章节大纲：**



# / 磁共振成像 (MRI)

MRI 运行需要非常强的磁场（大多数临床扫描仪使用 1.5 或 3T 的场强），**详见本电子书《磁共振成像 (MRI)》章节。**

安装和维护超导磁体的碳成本相当高（详见《磁共振成像 (MRI)》章节：氦气）。

MRI 常常能提供其他成像方式不易获取的信息，但这种高能耗促使放射科研究如何以更可持续的方式进行检查。

例如，若美国所有门诊 MRI 设备在夜间 12 小时开启节能模式而非关机模式，可为美国医疗保健系统节省 58863.2~76288.2 兆瓦时的电量、820 万~1070 万美元的电费，并减少 41606.4~54088.3 公吨的 $CO_2e$ [Wollen SA et al 2023]。

**<!> 注意**

**一项关于碳足迹的估算表明，一次腹部 MRI 扫描产生 17.5 Kg $CO_2e$，约为腹部 CT 扫描的两倍，大约是腹部超声扫描的 35 倍。[McAlister S, et al 2022]**

# / Nuclear Medicine

Energy costs related to nuclear medicine imaging techniques including gamma cameras, SPECT and PET scanners are also likely to be substantial, although relatively little published literature exists currently.


**<∞> REFERENCE**

McAlister S, McGain F, Petersen M, Story D, Charlesworth K, Ison G, Barratt A. The carbon footprint of hospital diagnostic imaging in Australia. Lancet Reg Health West Pac. 2022 May 3;24:100459. doi: 10.1016/j.lanwpc.2022.100459. PMID: 35538935; PMCID: PMC9079346

Woolen SA, Becker AE, Martin AJ, Knoerl R, Lam V, Folsom J, Eusemann C, Hess CP, Deshpande V. Ecodesign and Operational Strategies to Reduce the Carbon Footprint of MRI for Energy Cost Savings. Radiology. 2023 May;307(4):e230441. doi: 10.1148/radiol.230441. Epub 2023 Apr 25. Erratum in: Radiology. 2023 Jul;308(1):e239020. PMID: 37097133




# / Sustainable Imaging

**CHAPTER OUTLINE:**







# / 可持续成像

**章节大纲：**



# / 核医学

核医学成像技术（包括伽马相机、SPECT 和 PET 扫描仪）的能源成本可能也相当高，尽管目前公开发表的相关文献相对较少。


**<∞> 参考文献**

McAlister S, McGain F, Petersen M, Story D, Charlesworth K, Ison G, Barratt A. The carbon footprint of hospital diagnostic imaging in Australia. Lancet Reg Health West Pac. 2022 May 3;24:100459. doi: 10.1016/j.lanwpc.2022.100459. PMID: 35538935; PMCID: PMC9079346

Woolen SA, Becker AE, Martin AJ, Knoerl R, Lam V, Folsom J, Eusemann C, Hess CP, Deshpande V. Ecodesign and Operational Strategies to Reduce the Carbon Footprint of MRI for Energy Cost Savings. Radiology. 2023 May;307(4):e230441. doi: 10.1148/radiol.230441. Epub 2023 Apr 25. Erratum in: Radiology. 2023 Jul;308(1):e239020. PMID: 37097133

# Additional Energy Costs



## Sustainable Imaging

## 可持续成像

CHAPTER OUTLINE:



章节大纲：





# 额外能源成本

# / Transport

In the UK, patient and staff transport is thought to account for approximately 10% of the National Health Service (NHS) carbon footprint.

In England alone there are over 9.5bn NHS related road miles per year, accounting for around 3.5% of all road travel.[ref 1]

While transport logistics are largely beyond the control of radiology departments, there is scope to modify working practice to reduce unnecessary travel:

- ”hub and spoke” service delivery where subspecialist radiologists attend district general hospitals to deliver examination lists closer to the local community, reducing travel to the tertiary centre
- Portable CT scanners and mammography units located at convenient sites within the community
- Modify working practice to utilise teleradiology or off-site systems to reduce unnecessary staff commuting

Image created by M. Jackson using Image Creator via Copilot App

<∞> REFERENCE

Ref 1: The NHS: Carbon Footprint
Faculty of Public Health Special Interest Group document 2020
https://www.fph.org.uk/media/3126/k9-fph-sig-nhs-carbon-footprint-final.pdf



## / Sustainable Imaging

CHAPTER OUTLINE:







## / 可持续成像

章节大纲：



# / 交通出行

在英国，患者和医护人员的交通出行约占国民医疗服务体系（National Health Service，NHS）碳足迹的 10%。

仅英格兰，每年与 NHS 相关的公路里程就超过 95 亿英里，约占所有公路出行的 3.5% [参考文献 1]

虽然交通出行在很大程度上已超出放射科的可控范围，但仍可通过调整工作流程来减少不必要的出行：

- “中心辐射式 (hub and spoke)”服务模式，让亚专科放射科医生定期前往地区综合医院出诊，在更靠近社区的地点完成检查项目，减少患者远赴三级中心的需求
- 在社区便利地点设置便携式 CT 扫描仪和乳腺 X 线摄影设备
- 调整工作模式，运用远程放射学或异地系统，减少工作人员不必要的通勤

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<∞> 参考文献

参考文献 1：The NHS: Carbon Footprint
Faculty of Public Health Special Interest Group document 2020
https://www.fph.org.uk/media/3126/k9-fph-sig-nhs-carbon-footprint-final.pdf

Educational meetings have traditionally been in-person events and most people find such events more engaging and stimulating than on-line learning, particularly for events that last a few hours or even days. The social opportunities that such events provide between formal sessions are also known to be vital in forging professional relationships and friendships that often lead to productive collaborations and innovative new practice.

However, the carbon cost of national and particularly international conferences and meetings is substantial, requiring scrutiny in the context of the climate emergency.

Yakar and Kwee calculated the carbon footprint of the RSNA 2017 annual meeting (the largest radiology conference hosted in Chicago every year). Airplane travel from 24,000 attendees (around half from USA, half from other countries) equated to 40,000 tonnes of CO2e. When good quality electronic learning resources are available can we justify intercontinental travel for the purposes of Continuing Professional Development (CPD)?

<∞> REFERENCE

Yakar D, Kwee TC. Carbon footprint of air travel to international radiology conferences: FOMO? Eur Radiol. 2020 Nov;30(11):6293-6294. doi: 10.1007/s00330-020-06988-2. Epub 2020 Jun 10. PMID: 32518990; PMCID: PMC7283036



# / Sustainable Imaging

CHAPTER OUTLINE:







# / 可持续成像

章节大纲：



学术教育会议传统上都在线下举办，大多数人觉得线下活动比线上学习更有吸引力、更能激发兴趣，尤其是持续数小时甚至数天的活动。此类活动正式议程之外的社交机会，对于建立职业联系和友谊十分难得，往往能促成富有成效的合作并催生创新实践。

然而，国内尤其是国际会议的碳排放成本相当高，在当前气候危机的大背景下，必须重新审视这一问题。

亚卡尔 (Yakar) 和奎伊 (Kwee) 计算了 2017 年北美放射学会（Radiological Society of North America，RSNA）年会（每年在芝加哥举办的最大规模放射学会议）的碳足迹。24000 名参会者（约半数来自美国，半数来自其他国家）乘坐飞机出行，相当于产生了 40000 吨 CO2 排放。在高质量电子学习资源已触手可及的时代中，为了持续专业发展（Continuing Professional Development，CPD），我们进行洲际旅行还合理吗？

<∞> 参考文献

Yakar D, Kwee TC. Carbon footprint of air travel to international radiology conferences: FOMO? Eur Radiol. 2020 Nov;30(11):6293-6294. doi: 10.1007/s00330-020-06988-2. Epub 2020 Jun 10. PMID: 32518990; PMCID: PMC7283036

# / Artificial Intelligence

It is hoped that AI algorithms and machine learning will offer improved diagnostic accuracy and efficiency in relation to medical imaging going forwards. Advanced computing may offer new solutions which ultimately lead to a reduction in energy cost and greenhouse gas emissions. However, for the time being artificial intelligence is a high energy undertaking.

Recent research suggests that NVIDIA, a market leader in AI computing, will see its servers consume more than 85.4 terawatt-hours annually by 2027, exceeding the energy usage of countries such as Sweden and Argentina [de Vries, 2023]. In 2020, information-and-communication-technology infrastructure and devices consumed around 5 % of global electricity use [UK Parliament 2022]. In 2022, Google reported that machine learning had accounted for 15 per cent of its energy usage over the previous three years [Patterson, 2022].

**<∞> REFERENCES**

de Vries, The growing energy footprint of artificial intelligence, Joule (2023), https://doi.org/10.1016/ j.joule.2023.09.004
Energy consumption of ICT. UK Parliament Research Briefing (2022)
POSTNOTE Number 677, September 2022
David Patterson Google Research February 15, 2022 Good News About the Carbon Footprint of Machine Learning Training (research.google)

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**<!> ATTENTION**

**Energy costs related to AI are predicted to decrease as technology improves, but at present the use of AI algorithms in imaging analysis adds yet more carbon footprint to an already energy-hungry endeavour.**



## / Sustainable Imaging

**CHAPTER OUTLINE:**







## / 可持续成像

**章节大纲：**



# / 人工智能

人们期望人工智能算法和机器学习未来能够提高医学影像诊断的准确性和效率。先进的计算技术或许能提供新的解决方案，最终降低能源成本并减少温室气体排放。但就目前而言，人工智能是一项高能耗的活动。

近期研究表明，人工智能 (AI) 计算市场的领军者英伟达 (NVIDIA)，到 2027 年其服务器每年耗电量将超过 85.4 太瓦时，超过瑞典和阿根廷等国家的用电量 [de Vries, 2023]。2020 年，信息与通信技术基础设施及设备的耗电量约占全球用电量的 5%[英国议会，2022]。2022 年，谷歌报告称，在过去三年里，机器学习占其能源消耗的 15% [Patterson, 2022]。

图片由 M. Jackson 采用 Copilot 应用程序中的 Image Creator 生成

**<!> 注意**

**尽管随着技术进步，与人工智能相关的能源成本预计会降低，但目前在影像分析中使用人工智能算法，给这项本就能耗巨大的工作又增添了更多的碳足迹。**

**<∞> 参考文献**

de Vries, The growing energy footprint of artificial intelligence, Joule (2023), https://doi.org/10.1016/ j.joule.2023.09.004
Energy consumption of ICT. UK Parliament Research Briefing (2022)
POSTNOTE Number 677, September 2022
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# Consumables

# 消耗品



## Sustainable Imaging

## 可持续成像

**CHAPTER OUTLINE:**



**章节大纲：**

# / Personal Protective Equipment (PPE)

Vast quantities of single use personal protective equipment were utilised during the Covid-19 pandemic, prompting questions about the environmental impact of items such as disposable face masks, gloves and aprons.[refs 1,2] The World Health Organization estimated that some 89 million medical masks, 76 million examination gloves, and 1.6 million pairs of goggles were required worldwide in each month of the pandemic [ref 3].

While the use of such items has reduced post-pandemic, and the imaging department typically uses less PPE compared to other specialties, the collective impact on a global basis remains concerning.

Infection control measures are vital to protect both patients and staff but must be judicious and follow evidence-based practice to reduce unnecessary waste.

Image created by M. Jackson using Image Creator via Copilot App


**<∞> REFERENCES**

Ref 1: Rizan C, Reed M, Bhutta MF. Environmental impact of personal protective equipment distributed for use by health and social care services in England in the first six months of the COVID-19 pandemic. J R Soc Med. 2021 May;114(5):250-263. doi: 10.1177/01410768211001583. Epub 2021 Mar 16. PMID: 33726611; PMCID: PMC8150566

Ref. 2: Bennett R, Maraka J. Healthcare should not cost us the Earth BMJ 2020; 371 :m4289 doi:10.1136/bmj.m4289

Ref 3: WHO News Release, 3 March 2020 https://www.who.int/news/item/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide




## / Sustainable Imaging

**CHAPTER OUTLINE:**







## / 可持续成像

**章节大纲：**



# / 个人防护装备 (PPE)

在新冠疫情期间，大量使用了一次性个人防护装备（personal protective equipment，PPE），这引发了人们对一次性口罩、手套和围裙等物品对环境影响的质疑 [参考文献 1，2]。世界卫生组织估计，在疫情期间，全球每月约需要 8900 万个医用口罩、7600 万只检查手套和 160 万副护目镜 [参考文献 3]。

虽然疫情过后此类物品的使用有所减少，而且影像科与其他科室相比，PPE 的使用量通常较少，但从全球范围来看，其总体影响仍令人担忧。

感染控制措施对于保护患者和医护人员至关重要，但必须谨慎采用，并遵循循证实践的原则，减少不必要的浪费。

图片由 M. Jackson 采用 Copilot 应用程序中的 Image Creator 生成


**<∞> 参考文献**

参考文献 1：Rizan C, Reed M, Bhutta MF. Environmental impact of personal protective equipment distributed for use by health and social care services in England in the first six months of the COVID-19 pandemic. J R Soc Med. 2021 May;114(5):250-263. doi: 10.1177/01410768211001583. Epub 2021 Mar 16. PMID: 33726611; PMCID: PMC8150566

参考文献 2：Bennett R, Maraka J. Healthcare should not cost us the Earth BMJ 2020; 371 :m4289 doi:10.1136/bmj.m4289

参考文献 3：WHO News Release, 3 March 2020 https://www.who.int/news/item/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide

# / Contrast Agents

Iodinated contrast media (ICM) are used in a number of x-ray based imaging techniques, but most commonly in the setting of CT.

Millions of litres of ICM are used globally each year, with a recent estimate of over 10 million litres per annum [ref 1].

Following IV use, these agents are excreted in urine and enter the water supply system. Iodinated contrast media have been found in sewage water, surface water and drinking water at multiple sites across the world. A study conducted at the river Rhine (crossing the border between Germany and the Netherlands) calculated some 71 tonnes of ICM flowed from Germany into the Netherlands in 2020.

Whilst the ICM themselves are considered safe, they can react with commonly used disinfectants, such as chlorine in the presence of organic matter and the resulting breakdown products are more toxic than standard disinfection products [ref. 2]. Existing treatment technologies are not yet capable of removing ICM and their transformation products  from wastewater.

Image created by M. Jackson using Image Creator via Copilot App

<∞> REFERENCES

Ref. 1: Dekker HM, Stroomberg GJ, Prokop M. Tackling the increasing contamination of the water supply by iodinated contrast media. Insights Imaging. 2022 Feb 24;13(1):30. doi: 10.1186/s13244-022-01175-x. PMID: 35201493; PMCID: PMC8873335

Ref. 2: Sengar A, Vijayanandan A (2021) Comprehensive review on iodinated X-ray contrast media: complete fate, occurrence, and formation of disinfection byproducts. Sci Total Environ 769:144846. https://doi.org/10. 1016/j.scitotenv.2020.144846



## / Sustainable Imaging

CHAPTER OUTLINE:







## / 可持续成像

章节大纲：



# / 对比剂

碘对比剂（Iodinated contrast media，ICM）用于多种基于 X 线的成像技术，但最常见于 CT 检查。

全球每年使用数百万升碘对比剂 (ICM)，近期一项估算显示每年使用量超过 1000 万升 [参考文献 1]。

经静脉注射使用后，这些对比剂会通过尿液排出，进而进入供水系统。在全球多个地点的污水、地表水和饮用水中都发现了碘对比剂的踪迹。一项在莱茵河（流经德国与荷兰边境）开展的研究计算得出，2020 年约有 71 吨碘对比剂 (ICM) 从德国流入荷兰。

虽然碘对比剂 (ICM) 本身是安全的，但它们会与常用消毒剂发生反应，比如在有机物存在的情况下与氯发生反应，所产生的分解产物比普通消毒产品的毒性更强 [参考文献 2]。现有的处理技术尚无法从废水中去除碘对比剂 (ICM) 及其转化产物。

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<∞> 参考文献

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# / Iodinated Contrast Agents

**<!> ATTENTION**

## Strategies to address ICM entering the water supply include:

- / Specific processing of hospital wastewater prior to discharge into the sewage system.
- / Collection of urine in disposable bags for outpatient scans.
- / Eliminate use of contrast when not required.
- / Collect and recycle opened contrast that has not been administered.
- / Rationalise the volumes of contrast bottles utilised during a radiology examination list to reduce waste.

Reducing unnecessary use and wastage of ICM is also beneficial in reducing non-water-related environmental impact as substantial energy costs etc are incurred in the manufacture of these agents.



## / Sustainable Imaging

**CHAPTER OUTLINE:**







## / 可持续成像

**章节大纲：**



# / 碘对比剂

减少碘对比剂 (ICM) 的不必要使用和浪费，也有助于降低除了水之外的环境影响，因为生产对比剂会消耗大量的能源成本等。

**<!> 注意**

## 解决碘对比剂 (ICM) 流入供水系统问题的策略包括：

- / 医院废水在排入污水系统之前进行专门处理。
- / 为门诊扫描患者提供一次性尿液收集袋。
- / 在无需使用对比剂时，避免使用。
- / 收集并回收未使用但已开封的对比剂。
- / 在放射检查流程中，合理规划所用瓶装对比剂的容量，以减少浪费。

# / Gadolinium-based Contrast Agents

Gadolinium is a heavy metal used as an intravenous contrast agent in MRI examinations. Some types of tumours and infective processes are only readily visualised by administering gadolinium-based contrast agents (GBCAs). However, there is growing concern over gadolinium entering the water supply. World consumption of gadolinium oxide is estimated at approximately 1000 tons per year, with no effective means of removal or recycling at present. GBCAs are almost completely excreted in the urine within 30hrs of injection. GBCAs have been found in drinking water of several European cities. [ref 1]

GBCAs appear to be stable molecules which limits the toxicity of gadolinium. However, research on the embryos and larvae of the sea urchin *Paracentrotus lividus* suggests that gadolinium pollution poses a risk to marine life [ref 2]. Given that GBCAs have only been in use since 1988, the long-term effects of thousands of tons accumulating within the ocean remains to be seen.

In addition to concerns related to water pollution, extraction of gadolinium also has a significant environmental impact.

Image created by M. Jackson using Image Creator via Copilot App

<∞> REFERENCES

Ref. 1: Ognard J, Barrat JA, Cotton F, Mian A, Kremer S, Sitoh YY, Verclytte S, Loffroy R, Tripier R, Alavi Z, Ben Salem D. A roadmap towards pollution prevention and sustainable development of Gadolinium. J Neuroradiol. 2021 Nov;48(6):409-411. doi: 10.1016/j.neurad.2021.08.002. Epub 2021 Sep 8. PMID: 34506855
Ref. 2: Martino C, Byrne M, Roccheri MC, Chiarelli R. Interactive effects of increased temperature and gadolinium pollution in Paracentrotus lividus sea urchin embryos: a climate change perspective. Aquat Toxicol. 2021 Jan 21;232:105750. doi: 10.1016/j.aquatox.2021.105750. Epub ahead of print. PMID: 33529976



## / Sustainable Imaging

CHAPTER OUTLINE:







## / 可持续成像

章节大纲：



# / 钆对比剂

钆 (Gadolinium) 是一种重金属，在 MRI 检查中用作静脉对比剂。一些类型的肿瘤和感染性病变，只有通过使用钆对比剂（gadolinium-based contrast agents，GBCA）才能清晰显影。然而，人们越来越担心钆进入供水系统。据估计，全球每年氧化钆的消耗量约为 1000 吨，目前尚无有效的去除或回收方法。钆对比剂 (GBCA) 在注射后 30 小时内几乎完全通过尿液排出。在欧洲多个城市的饮用水中都发现了钆对比剂 (GBCA)。[参考文献 1]

钆对比剂 (GBCA) 似乎是稳定分子，限制了钆的毒性。然而，对紫球海胆（*Paracentrotus lividus*）胚胎和幼虫的研究表明，钆污染会对海洋生物构成风险 [参考文献 2]。鉴于钆对比剂 (GBCA) 从 1988 年才开始使用，数千吨此类物质在海洋中积累所产生的长期影响仍有待观察。

除了对水污染的担忧之外，钆的开采也会对环境造成重大影响。

图片由 M. Jackson 采用 Copilot 应用程序中的 Image Creator 生成

<∞> 参考文献

参考文献 1：Ognard J, Barrat JA, Cotton F, Mian A, Kremer S, Sitoh YY, Verclytte S, Loffroy R, Tripier R, Alavi Z, Ben Salem D. A roadmap towards pollution prevention and sustainable development of Gadolinium. J Neuroradiol. 2021 Nov;48(6):409-411. doi: 10.1016/j.neurad.2021.08.002. Epub 2021 Sep 8. PMID: 34506855
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# / Helium

Helium is used in various industries, from space research to weather forecasting, but hospitals are the largest users, accounting for 32% of the global market in 2021.

A typical MRI unit requires approximately 2,000 litres of liquid helium to keep the superconducting magnets cool enough to operate. Additional top-ups may be required over the lifetime of the unit to replace helium that boils off and escapes into the atmosphere.

Helium is not a greenhouse gas, but it is one of the earth's rarest elements, produced by the natural radioactive decay of uranium or thorium present in the earth's crust. This process is very slow, meaning the earth's helium supply is finite and irreplaceable [ref 1].

Some scanners are equipped with a unit to help capture and re-use lost helium, but this is not universal.

Manufacturers are developing low helium use scanners (the first UK machine of this type was installed at King's College, London in 2022, using less than one litre of helium).

There is also promising research in low field MRI systems (operating with a magnetic field strength of 0.25 – 1.0 T, compared to typical scanners at 1.5 T and 3.0 T). These systems do not require helium, use substantially less energy and are much easier to install compared to conventional scanners. Currently images are of lower quality, but it is hoped such machines may provide cross-sectional solutions in more remote communities [ref 2]. If image quality continues to improve, the reduced environmental impact may accelerate the adoption of such systems.

Image created by M. Jackson using Image Creator via Copilot App

**<∞> REFERENCES**

Ref 1: Mary Henderson Keeping an eye on the potential shortage of helium for MRIs. RSNA News January 25,2023 https://www.rsna.org/news/2023/january/helium-shortage-for-MRI
Ref. 2: Hori M, Hagiwara A, Goto M, Wada A, Aoki S. Low-Field Magnetic Resonance Imaging: Its History and Renaissance. Invest Radiol. 2021 Nov 1;56(11):669-679. doi: 10.1097/RLI.0000000000000810. PMID: 34292257; PMCID: PMC8505165.



# / Sustainable Imaging

**CHAPTER OUTLINE:**







# / 可持续成像

**章节大纲：**



# / 氦气

氦气应用于从太空研究到天气预报等各行各业，但医院是最大的使用方，2021 年占全球市场的 32%。

一台普通的 MRI 设备大约需要 2000 升液氦，才能将超导磁体冷却到足以正常运行的温度。在设备使用期间，可能还需要额外补充氦气，以弥补因沸腾而逸散到大气中的部分。

氦气并非温室气体，但它是地球上最稀有的元素之一，由地壳中铀或钍的自然放射性衰变产生。这一过程极为缓慢，也就是说地球上的氦储量有限且无法替代 [参考文献 1]。

一些扫描仪配备了收集和重新利用散失氦气的装置，但并未普遍采用。

制造商们正在研发低氦用量的扫描仪（2022 年，英国首台此类设备安装在伦敦国王学院 [King's College]，其氦气使用量不到一升）。

在低场强 MRI 系统方面也有前景可观的研究（这类系统的磁场强度为 0.25 - 1.0 T，而典型扫描仪的磁场强度为 1.5 T 和 3.0 T）。与传统扫描仪相比，这些系统无需使用氦气，能耗大幅降低，安装也更为简便。目前，此类设备生成的图像质量较低，但人们希望它们能为较偏远的社区提供断层成像解决方案 [参考文献 2]。如果图像质量持续提升，对环境影响较小的这一优势，可能会促使它们更快地广泛采用。

图片由 M. Jackson 采用 Copilot 应用程序中的 Image Creator 生成

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参考文献 1：Mary Henderson Keeping an eye on the potential shortage of helium for MRIs. RSNA News January 25,2023 https://www.rsna.org/news/2023/january/helium-shortage-for-MRI
参考文献 2：Hori M, Hagiwara A, Goto M, Wada A, Aoki S. Low-Field Magnetic Resonance Imaging: Its History and Renaissance. Invest Radiol. 2021 Nov 1;56(11):669-679. doi: 10.1097/RLI.0000000000000810.PMID: 34292257; PMCID: PMC8505165.

# / Ultrasound Microbubbles

Sulphur hexafluoride (SF6) is used as a contrast agent in ultrasound examinations in a variety of settings including liver lesion characterisation, trauma imaging and assessment of VUR in children.

This agent has a good patient safety profile and may help provide valuable clinical information.

Ultrasound examinations typically use very small quantities.

However, SF6 is one of the most potent greenhouse gases, estimated to be 23,500 times more effective at trapping infrared radiation than CO2.

Cumulative effect from global use in this context is a growing concern. In industry the main (and growing) use of SF6 is as an electrical insulating agent, reminding us that even if electricity used to power healthcare comes from renewable sources, the environmental impact of electrical infrastructure may still be substantial.

Image created by M. Jackson using Image Creator via Copilot App



## / Sustainable Imaging

CHAPTER OUTLINE:







## / 可持续成像

# / 超声微泡

章节大纲：



六氟化硫（Sulphur hexafluoride，SF6）在多种超声检查中用作对比剂，包括肝脏病变的鉴别诊断、创伤成像以及儿童膀胱输尿管反流（vesicoureteral reflux，VUR）的评估。

这种对比剂的患者安全性很好，可有助于提供有价值的临床信息。

通常在超声检查中的用量极少。

但六氟化硫 (SF6) 是最强效的温室气体之一。据估计，其捕获红外辐射的能力是 CO2 的 23,500 倍。

在这种情况下，全球使用六氟化硫所产生的累积效应日益令人担忧。在工业领域，六氟化硫 (SF6) 主要（且越来越多地）用作电气绝缘剂。这提醒我们，即便医疗保健所使用的电力来自可再生能源，电力基础设施对环境的影响可能依然不容小觑。

图片由 M. Jackson 采用 Copilot 应用程序中的 Image Creator 生成

# / Miscellaneous

Many hospitals continue to produce “hard-copy” radiology reports on paper. Estimates of the carbon cost of an A4 sheet of paper vary between 4.5g – 60g. [ref 1, ref 2]. If all radiology examinations performed in England (43.3 million) were accompanied by a one sheet report this would equate to between 195,000 Kg and 2,598,000 Kg $CO_2$e.

While electronic reporting eliminates this cost, data storage of reports and images remains a substantial energy cost.

Single-use interventional equipment is costly both in relation to manufacture and disposal.

Reporting equipment including reporting stations, laptops, dictaphones, monitors, meeting room projectors etc may not require replacement on a daily basis, but do not last forever and also incur both manufacturing and disposal carbon costs.

<∞> REFERENCES

Ref. 1: Dias AC, Arroja L. Comparison of methodologies for estimating the carbon footprint – case study of office paper. Journal of Cleaner Production 24 (2012): 30-35

Ref. 2: Carbon Footprint of Paper vs Plastic vs Glass vs Cardboard (Calculator) (8billiontrees.com) https://8billiontrees.com/carbon-offsets-credits/carbon-ecological-footprint-calculators/carbon-footprint-of-paper-vs-plastic/



# / Sustainable Imaging

CHAPTER OUTLINE:







# / 可持续成像

# / 其他

章节大纲：



许多医院仍在打印纸质的放射学报告。据估算，一张 A4 纸产生的碳排放量在 4.5 g~60 g 之间。[参考文献 1，参考文献 2]。如果在英格兰进行的所有放射学检查（4330 万次）都附带一张纸的报告，那么这将产生 195,000~2,598,000 Kg $CO_2$e。

虽然电子报告消除了该碳排放，但报告和图像的数据存储仍需消耗大量能源。

一次性介入设备在制造和处理方面成本高昂。

报告设备，包括报告工作站、笔记本电脑、录音笔、显示器、会议室投影仪等，虽无需每日更换，但使用寿命有限，其制造和处理同样会产生碳排放成本。

<∞> 参考文献

参考文献 1：Dias AC, Arroja L. Comparison of methodologies for estimating the carbon footprint – case study of office paper. Journal of Cleaner Production 24 (2012): 30-35

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# Ethical Considerations



## Sustainable Imaging

## 可持续成像

**CHAPTER OUTLINE:**



**章节大纲：**





# 伦理学考量

# / Ethical Considerations

The Four Principles (or Pillars) of Medical Ethics are:

| | | | |
|---|---|---|---|
| **1. Beneficence** doing good | **2. Non-maleficence** to do no harm | **3. Autonomy** giving the patient the freedom to choose freely, where they are able | **4. Justice** ensuring fairness |

While historically these have largely been applied to consider specific case-by-case ethical conundrums, in the era of the climate crisis, we must utilise these principles more broadly to guide our practice and work towards limiting the impact of medical imaging on climate change.

Regarding issues of sustainability and climate justice, principles 2. (Non-maleficence) and 4. (Justice) are of relevance. As pointed out by some authors, climate change is not only an ethical and justice issue, but it can also be considered a human rights challenge because it affects disproportionally poor and vulnerable individuals both in low- and high-income countries [ref 1, ref 2]. Promoting climate change literacy, helping medical institutions to reduce their environmental impact and ensuring that campaigns promoting a healthy lifestyle to prevent diseases reach all members of a society are challenging tasks awaiting all of us.

<∞> REFERENCES

Ref. 1: Chapman AR, Ahmed AK. Climate Justice, Humans Rights, and the Case for Reparations. Health Hum Rights. 2021 Dec;23(2):81-94. PMID: 34966227; PMCID: PMC8694300

Ref. 2: Churchill LR, Henderson GE, King NMP. Why Climate Literacy Is Health Literacy. AMA J Ethics. 2024 Feb 1;26(2):E147-152. doi: 10.1001/amajethics.2024.147. PMID: 38306204.



## / Sustainable Imaging

CHAPTER OUTLINE:







## / 可持续成像

章节大纲：



# / 伦理学考量

医学伦理的四大原则（或支柱）为：

| | | | |
|---|---|---|---|
| **1. 行善原则** 行善 | **2. 不伤害原则** 不造成伤害 | **3. 自主原则** 在患者有能力的情况下，给予他们自由选择的权利 | **4. 公正原则** 确保公平 |

从历史上看，这些原则大多用于考量具体案例中的伦理难题。但在气候危机时代，我们必须更广泛地运用这些原则来指导实践，努力降低医学成像对气候变化的影响。

就可持续性和气候公平问题而言，原则 2（不伤害原则）与原则 4（公正原则）与之相关。正如一些作者所指出的，气候变化不仅是一个伦理和公平的问题，还可被视为对人权的挑战，因为无论是在低收入国家还是高收入国家，它对贫困和弱势群体的影响尤为严重 [参考文献 1，参考文献 2]。提升气候变化认知、助力医疗机构减轻其对环境的影响，以及确保推广健康生活方式以预防疾病的宣传活动覆盖社会全体成员，这些都是摆在我们所有人面前的艰巨任务。

<∞> 参考文献

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# / Preventable Disease

According to the World Health Organisation 80% of premature heart attacks and strokes are preventable.

Healthy diet, regular physical activity and not using tobacco products are key to prevention.

WHO estimates 30-50% of all cancer cases are preventable, key risk factors being:

- Tobacco
- Alcohol
- Poor diet
- Physical inactivity
- Infections such as hepatitis and human papilloma virus
- Environmental pollution
- Occupational carcinogens
- Radiation (most commonly solar ultra-violet radiation)

When we know what is causing such a large proportion of the disease burden, it is more important than ever to focus on large scale prevention campaigns to reach all individuals in a society.

In addition, decarbonising medical practice without compromising patient care is a major challenge for the decades ahead and will require some “big picture” thinking alongside the more modest carbon-cutting changes to imaging practice currently underway.



## / Sustainable Imaging

**CHAPTER OUTLINE:**







## / 可持续成像

# / 可预防的疾病

**章节大纲：**



根据世界卫生组织 (WHO) 的数据，80% 过早发生的心脏病发作和卒中是可以预防的。

健康饮食、定期体育锻炼以及不使用烟草制品是预防的关键。

WHO 估计，所有癌症病例中有 30%~50% 是可以预防的，主要风险因素如下：

- 吸烟
- 饮酒
- 不良饮食
- 缺乏身体活动
- 感染，如肝炎和人乳头瘤病毒感染
- 环境污染
- 职业致癌物
- 辐射（最常见的是太阳紫外线辐射）

当我们了解导致如此大比例疾病负担的原因后，开展大规模预防活动以覆盖社会全体成员，就比以往任何时候都更为重要。

此外，在不影响患者治疗的前提下实现医疗实践的脱碳，是未来几十年面临的一项重大挑战。这不仅需要我们在当前对成像实践做出相对有限的低碳改进，还需具备一些着眼于全局的思考。

# / Imaging Begets Imaging

Medical imaging examinations can create more imaging examinations. One examination may provide an inconclusive result with the recommendation for an alternative scan for further characterisation. An otherwise normal scan may reveal an incidental finding unrelated to the clinical presentation for which further imaging is suggested. Antenatal imaging has revealed multiple congenital lesions which previously may never have bothered the patient, but which now typically get multiple follow-up examinations.

Imaging protocols have historically been based on defensive medicolegal considerations – it is considered "safer" to arrange a follow-up scan (or multiple scans) to ensure an equivocal lesion is not malignant.

In the context of imaging contributing to the climate emergency, is it time to eliminate the "reassurogram"?

The unfortunate, if catchy, acronym VOMIT (Victim of Medical Imaging Technology) was coined in 2003 to describe individuals who are over investigated based on spurious or incidental findings on scans, particularly cross-sectional imaging such as CT and MRI. In the era of the climate crisis, we should also consider VOMITING (Victims of Medical Imaging Technology – International / Global), those suffering from air pollution or the effects of global heating, even if located in a distant country to where the imaging was performed.

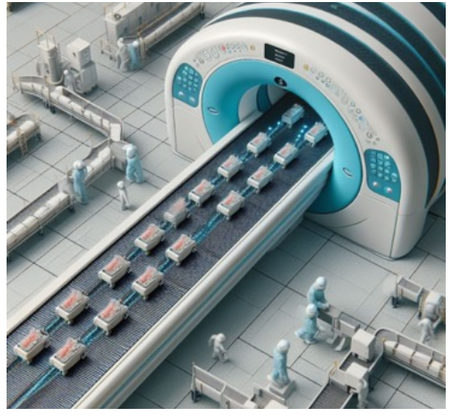

Image created by M. Jackson using Image Creator via Copilot App



## / Sustainable Imaging

**CHAPTER OUTLINE:**







## / 可持续成像

**章节大纲：**



# / 影像检查引发后续更多影像检查

医学成像检查可能会连锁引起一系列成像检查。一次检查可能得不出确定的结果，建议再次进行扫描，明确疾病特征。原本看似正常的扫描可能会偶然发现与临床表现无关的情况，从而建议进行更多成像检查。产前成像已发现多种先天性病变，这些病变过去可能从未给患者带来困扰，但如今通常会引发多次后续检查。

从历史上看，成像方案是基于"防范医疗纠纷风险"的考量制定的 —— 安排一次（或多次）后续扫描，以确保性质不明的病变并非恶性，这种做法被认为"更为稳妥"。

鉴于成像检查对气候危机的影响，现在是不是到了摒弃"安心扫描"的时候呢？

2003 年，有人创造了"VOMIT"这个虽朗朗上口却令人遗憾的缩写词，即"医学成像技术受害者"（Victim of Medical Imaging Technology，VOMIT），用于描述那些因扫描（尤其是像 CT 和 MRI 等断层成像）中的"假阳性或偶然检出"而接受过度检查的人。在气候危机时代，我们还应考虑"VOMITING"—— 即"国际/全球医学成像技术受害者"（Victims of Medical Imaging Technology – International / Global，VOMITING），也就是那些即便身处与进行成像检查之地相隔甚远的国家，但仍要遭受空气污染或全球变暖影响的人们。

图片由 M. Jackson 采用 Copilot 应用程序中的 Image Creator 生成

# / Avoiding an Apocalyptic Death Spiral

The seemingly relentless growth in high resource medical imaging alongside artificial intelligence and high precision health data analysis is a concerning trend from the environmental and health costs perspectives. More and more imaging is performed but in some cases along a trajectory of diminishing returns.

It is time to consider whether healthcare resources need to be reallocated to promote heath and prevent disease rather than mainly rely on high-energy scanners to image disease processes in extraordinary detail.

As healthcare professionals at an early stage of your career, you will be instrumental in shaping how care is delivered in the years to come. Will you participate in shaping these discussions? Can we find solutions to ensure that remarkable imaging technology can deliver genuine patient benefit without contributing to environmental catastrophe?

Image created by M. Jackson using Image Creator via Copilot App

CHAPTER OUTLINE:









# / 避免灾难性的恶性循环

从环境成本和健康成本的角度来看，高资源消耗的医学成像技术与人工智能以及高精度健康数据分析技术看似无休止地发展，这一趋势令人担忧。越来越多的成像检查在进行，但在某些情况下，受益却呈递减趋势。

是时候思考是否需要重新分配医疗资源，将重点更多地放在促进健康和预防疾病上，而非主要依赖高能耗的扫描仪去极其细致地对疾病过程进行成像。

作为处于职业生涯早期的医疗专业人员，您们将在塑造未来医疗服务模式方面发挥重要作用。您会参与到这些讨论中来吗？我们能否找到解决方案，确保出色的成像技术既能真正惠及患者，又不会导致环境灾难呢？

章节大纲：



图片由 M. Jackson 采用 Copilot 应用程序中的 Image Creator 生成

# / Take-Home Messages

/ Medical imaging has an environmental impact due to substantial energy consumption and a considerable amount of waste, particularly through the disposal of contrast agents, consumables and equipment. Therefore, medical imaging also contributes to the climate crisis.

/ As healthcare professionals we have an ethical duty to ensure that our practice is safe, that we responsibly use resources, and that we minimise the environmental impact of medical imaging while ensuring - at the same time - optimal patient outcomes.

/ Radiology departments are in the process of reviewing and modifying practice to help reduce waste and eliminate unnecessary imaging. Furthermore, the introduction of new imaging techniques hold promise at improving sustainability while providing accurate diagnostic information.

/ There also needs to be a broader discussion within medicine and society concerning the manner in which healthcare is delivered. Tackling the causes of preventable disease must take priority over downstream high resource interventions. The next generation of healthcare professionals will need to help drive this transition.



## / Sustainable Imaging

CHAPTER OUTLINE:







## / 可持续成像

章节大纲：



# / 核心要点

/ 医学成像由于大量的能源消耗以及产生相当数量的废弃物，对环境造成影响，尤其是在处理对比剂、消耗品和设备时。因此，医学成像也是造成气候危机的因素之一。

/ 作为医疗专业人员，我们负有伦理责任，要确保诊疗操作的安全性，合理使用资源，在保证患者获得最佳治疗效果的同时，尽量降低医学成像对环境的影响。

/ 放射科正在对诊疗操作进行审查和调整，以减少废弃物的产生，并避免不必要的成像检查。此外，新成像技术的引入有望在提高可持续性的同时，提供准确的诊断信息。

/ 医学界和全社会还需要就医疗服务的提供方式展开更广泛的讨论。解决可预防疾病的病因，必须优先于那些高资源消耗的下游干预措施。下一代医疗专业人员将需要助力推动这一转变。

# Test Your Knowledge



## Sustainable Imaging

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## 可持续成像

**章节大纲：**



# 知识测试

# / Test Your Knowledge

<?> QUESTION

1 Approximately how many premature deaths can be attributed to pollution related to medical imaging on a worldwide basis each year?

- ☐ 60
- ☐ 6000
- ☐ 60,000
- ☐ 60,000,000



## / Sustainable Imaging

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# / 知识测试

<?> 问题

1 全球范围内，每年大约有多少过早死亡可归因于与医学成像相关的污染？

- ☐ 60
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- ☐ 60,000,000

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<?> ANSWER

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# Test Your Knowledge

<?> QUESTION

2 According to a recent study how much iodinated contrast flowed into the Netherlands from Germany along the river Rhine in 2020?

- ☐ 7.1 kg
- ☐ 710 kg
- ☐ 7.1 tonnes
- ☐ 71 tonnes



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- ☐ 7.1 千克
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- ☐ 71 吨

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# / Test Your Knowledge

<?> QUESTION

## 3 Which of these imaging modalities typically has the highest carbon footprint per examination?

- ☐ Plain Radiograph
- ☐ Ultrasound
- ☐ CT
- ☐ MRI



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# / 知识测试

<?> 问题

## 3 以下这些成像方式中，每次检查碳足迹最高的是哪一种？

- ☐ X 线平片
- ☐ 超声
- ☐ CT
- ☐ MRI

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# / Test Your Knowledge

<?> QUESTION

4 Sulphur Hexafluoride is a powerful greenhouse gas used as a contrast agent in ultrasound. Compared to carbon dioxide how powerful is its greenhouse effect?

- ☐ 23 times
- ☐ 230 times
- ☐ 2300 times
- ☐ 23000 times



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# / 知识测试

<?> 问题

4 六氟化硫是一种强效温室气体，用作超声检查中的对比剂。与二氧化碳相比，它的温室效应有多强？

- ☐ 23 倍
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- ☐ 2300 倍
- ■ 23000 倍

# Test Your Knowledge

<?> QUESTION

## 5 What are the four principles of sustainable healthcare

- ☐ Prevarication, Patient self-care, Lean Service, Low Carbon
- ☐ Prevention, Patient self-care, Lean Service, Low Carbon
- ☐ Prevention, Patient self-harm, Lean Service, Low Carbon
- ☐ Prevention, Patient self-care, Late Service, Low Car use



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<?> 问题

## 5 可持续医疗保健的四项原则是什么？

- ☐ 推诿敷衍、患者自我护理、精益服务、低碳
- ☐ 预防、患者自我护理、精益服务、低碳
- ☐ 预防、患者自我伤害、精益服务、低碳
- ☐ 预防、患者自我护理、延迟服务、减少汽车使用

# / Test Your Knowledge

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- ☐ 预防、患者自我伤害、精益服务、低碳
- ☐ 预防、患者自我护理、延迟服务、减少汽车使用

# / Test Your Knowledge

<?> QUESTION

## 6 Which principles of medical ethics are of particular relevance to the climate crisis?

- ☐ Philanthropy and benefaction
- ☐ Wisdom and austerity
- ☐ Justice and non-malificence
- ☐ Pride and prejudice



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# / 知识测试

<?> 问题

## 6 哪些医学伦理原则与气候危机特别相关？

- ☐ 慈善原则与行善原则
- ☐ 智慧原则与节俭原则
- ☐ 公正原则与不伤害原则
- ☐ 傲慢原则与偏见原则

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- ☐ 傲慢原则与偏见原则

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# Sustainable Imaging

**CHAPTER OUTLINE:**





# 可持续成像

**章节大纲：**



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