

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

VOLKSWAGEN GROUP OF AMERICA, INC.,
Petitioner,

v.

LONGHORN AUTOMOTIVE GROUP LLC,
Patent Owner.

IPR2025-01064
U.S. Patent 8,265,353

Declaration of Shauna L. Wiest

I, Shauna L. Wiest, state and declare as follows:

I. Introduction

1. I have prepared this Declaration in connection with the Petition for *Inter Partes* Review of U.S. Patent No. 8,265,353, which I understand will be filed concurrently with this Declaration.

2. I am currently a Senior Research Analyst with the Research & Information Services team at Finnegan, Henderson, Farabow, Garrett & Dunner, LLP located at 3300 Hillview Avenue, Palo Alto, CA 94304.

3. I am over eighteen years of age, and I am competent to make this Declaration. I make this Declaration based upon my own personal knowledge, and my professional knowledge of library science practices.

4. I earned a Master of Science in Library Science degree from the University of North Carolina at Chapel Hill in 1999, and a Bachelor of Arts in Political Science degree from the University of California at San Diego in 1989. I have worked as a law librarian for twenty years. I have been employed at Finnegan, Henderson, Farabow, Garrett & Dunner, LLP since 2021. Before that, from 2000-2015, I was employed as a Law Librarian at Stoel Rives LLP, and from 2015-2016, I was employed as a Competitive Intelligence Specialist for Nossaman LLP. Additionally, as a graduate student at the University of North Carolina at Chapel Hill, I served as an intern at the Environmental

Protection Agency at Research Triangle Park (“EPA-RTP”) where one of my rotations included original cataloging for EPA technical documents, state agency reports and documents, international organization documents, dissertations, and, on occasion, monographs. In this role, I accessed OCLC, MARC records, and the EPA National Library Catalog on a daily basis.

II. Standard Library Practice for Receiving, Cataloging, and Making Materials, including Serial Publications, Publicly Available and Accessible

5. I have knowledge of and experience with standard library practices regarding the receipt, cataloging, shelving, and making materials, including serial publications, available and accessible to the public. I have knowledge of and experience with the Machine-Readable Cataloging (MARC) system, an industry-wide standard that libraries use to catalog materials.

6. Based on standard library practice, when a library receives an item, the cataloguer or cataloguer’s assistant will examine the item and stamp and/or affix a label to the item with the library name and/or barcode with the date it was received. Next, the library will catalog the item within a few days of receiving it. As a general practice, cataloguing is centralized and performed by a cataloguing department within a library or university setting.

7. Normally, after an item is cataloged, the public may access the item by searching a library catalog, browsing the library shelves, and/or

requesting the item from the library. Standard library practice is to make the item available to the public within several days of cataloging it. If an item requires original cataloging, the item will be made available to the public up to and including one week from the date of receipt.

III. Ownership and Date-Stamp

8. Libraries have different policies on whether or not to date stamp publications. It is becoming increasingly common for libraries to no longer date stamp the publications they receive. In the past, it was standard practice to affix an ownership stamp somewhere within the publication, usually on the cover page, verso of the cover page, or a designated page within the publication. The timing of when an ownership stamp is entered on the monograph or periodical can vary from one library to another. It could occur when the item is received in acquisitions after shipment to the library, or at the time of cataloging. Therefore, it is possible for there to be instances when the date of receipt precedes the cataloging date or vice versa.

IV. MARC Records

9. The MARC system was developed during the 1960s to standardize bibliographic catalog records so they could be read by computers and shared among libraries. By the mid-1970s, MARC had become the international standard for cataloging bibliographic materials and is still used today. Many libraries

provide public access to their MARC records via their electronic cataloging systems at the library. In a MARC record, each field provides specific information about the cataloged item, including how materials are held and when they were made available to the public.

10. The MARC record system uses a specific three-digit numeric code (“field tags”) (from 001-999) to identify each field in a catalog record. For example, field tag 008 provides the six-digit date an item was catalogued (*Date entered on file*). The first six characters of field tag 008 are always in the “**YYMMDD**” format. Descriptions and definitions of all of the character positions of field tag 008 are outlined here:

<https://www.loc.gov/marc/bibliographic/bd008a.html>.

11. As is relevant to this Declaration, MARC field tag 022 sets forth the International Standard Serial Number (“ISSN”), a unique identification assigned to every serial publication. MARC field tag 310 sets forth the current publication frequency of an item. MARC field Tag 362 sets forth the dates of publication and/or sequential date designation for a work.

V. Cataloguing Treatment of Serials

12. A serial publication, also known as a “journal,” “periodical,” “newspaper,” or “magazine,” is a resource that is issued in successive parts and has no predetermined conclusion. These successive parts are commonly

referred to as “issues,” and each issue is usually chronologically numbered, bears a unique date, and is received on an expected, ongoing basis. The presence of enumeration, years of coverage, regular receipt, and/or other chronological information, also indicates a serial publication.

13. There are differences between cataloging finite resources (books/monographs) and continuing resources (serials). For serials, the catalog record provides information about the serial as a whole, including the first or earliest available issue. It also provides information as to holdings – the breadth of volumes and issues received, checked in, and held by a library, including the public availability of those holdings. In serials cataloging, there are identifying characteristics unique to serials that are slightly different from monographs (books). The issue date for a serial publication, for example, generally appears on the cover (front or back), the masthead page, the title page (if any), the table of contents page(s), or on the pages of the individual articles contained within the issue. More information regarding the unique aspects of cataloging serials can be found at this link:

<https://www.loc.gov/aba/pcc/conser/scctppt/Basic-2014/Basic-Trainee-Mannual.pdf>.

VI. Public Availability and Accessibility of *Beyer* and *Osman*

14. Section VI of this Declaration relates to the date of receipt and public availability/accessibility for the following references: Beyer, T., Antoch, G., Blodgett, T. *et al. Dual-modality PET/CT imaging: the effect of respiratory motion on combined image quality in clinical oncology. Eur. J. Nucl. Med. Mol. Imaging* Vol. 30, No. 4, pages 588–596 (April 2003) (“*Beyer*”). I understand that *Beyer* has been submitted as **Exhibit Ex-1016** in this proceeding. This reference is appended to my Declaration as **Appendix A**.

15. Section VI of this Declaration also relates to the date of receipt and public availability/accessibility for Osman, M.M., Cohade, C., Nakamoto, Y. *et al. Respiratory motion artifacts on PET emission images obtained using CT attenuation correction on PET-CT. Eur. J. Nucl. Med. Mol. Imaging* Vol. 30, No. 4, pages 603–606 (April 2003) (“*Osman*”). I understand that *Osman* has been submitted as **Exhibit Ex-1015** in this proceeding. This reference is appended to my Declaration as **Appendix A**.

16. As detailed below, I have reviewed the print *Beyer and Osman* references, which were supplied to me by Wisconsin Tech Search (a service of the University of Wisconsin - Madison) on May 15, 2025, the University of Wisconsin public holdings information and MARC record for *Beyer* and *Osman* to determine the date of public availability for these references. **Note:** These two references

were published in the same journal volume, issue, and date: Eur. J. Nucl. Med. Mol. Imaging Vol. 30, No. 4 (April 2003).

17. **Appendix A** to this Declaration is a true and accurate copy of the cover, front matter, table of contents, and date stamp for the print issue of European Journal of Nuclear Medicine containing *Beyer* and *Osman* held by the Health Sciences Library at the University of Wisconsin - Madison. **Appendix A** includes pages 588-596, which comprise the reference *Beyer*, and pages 603-606, which comprise the reference *Osman*. **Appendix A** includes date-stamps on PDF pages 1 and 2 indicating that the issue of European Journal of Nuclear Medicine and Molecular Imaging containing *Beyer* and *Osman* was received by the University of Wisconsin Health Sciences Library on May 19, 2003. **Appendix A** also sets for the ISSN for the print journal as 1619-7070 on PDF page 5.

18. **Appendix B** to this Declaration is a true and accurate copy of the University of Wisconsin - Madison Library public catalog record for its copy of European Journal of Nuclear Medicine and Molecular Imaging containing *Beyer* and *Osman*, which was downloaded from <https://search.library.wisc.edu/catalog/999932262702121> on May 22, 2025.

19. The University of Wisconsin - Madison Library public catalog record (**Appendix B**) sets forth the publication and holding details for its copy of containing *Beyer* and *Osman*. The public catalog record indicates that the

Middleton Shelving Facility holds print Volume 29 No. 1 (2002) through Volume 33 Supplement 2 (2006) of the print serial publication European Journal of Nuclear Medicine and Molecular Imaging. **Appendix B** also sets forth the ISSN number as 1619-7089 (print).

20. **Appendix C** to this Declaration sets forth the individual holdings and onsite location information for members of the public seeking the print issue of European Journal of Nuclear Medicine and Molecular Imaging containing *Beyer* and *Osman*, which was downloaded from <https://search.library.wisc.edu/catalog/999932262702121/holdings?from=locations> on May 22, 2025. **Appendix C** indicates that the print issue of European Journal of Nuclear Medicine and Molecular Imaging containing *Beyer* and *Osman* is held at the Middleton Shelving Facility and is available upon request at Call Number Q 7EU46461 (34-V-6).

21. **Appendix D** to this Declaration is a true and accurate copy of the University of Wisconsin Library MARC record for its holdings of the journal European Journal of Nuclear Medicine and Molecular Imaging, which was downloaded from <https://search.library.wisc.edu/catalog/999932262702121> (Click on “Library Staff Details” and then “Staff View”) on May 22, 2025.

22. **Appendix D** confirms the fixed data elements of MARC field tag 008 as 020320c20029999gw mr p 0 0eng c. As discussed above, the first six characters

“020320” are in typical “YYMMDD” format and indicate that the print journal European Journal of Nuclear Medicine and Molecular Imaging was first catalogued by the University of Wisconsin - Madison Library on March 20, 2002 and that the journal began publication in 2002 and is a continuing resource currently published with no end date noted.

23. The University of Wisconsin - Madison Library MARC record (**Appendix D**) field tag 310 sets forth the publication frequency of European Journal of Nuclear Medicine and Molecular Imaging as monthly. MARC field tag 022 sets forth the print ISSN number as 1619-7070, which matches the ISSN in **Appendix A** and **Appendix B**. MARC field tag 362 denotes the dates of publication and/or sequential date designation for the European Journal of Nuclear Medicine and Molecular Imaging as Vol. 29, no. 1 (Jan. 2002).

24. Based on the information set forth in **Appendices A, B, C, and D** attached to this Declaration, standard library practices, and my experience as a librarian, the issue of European Journal of Nuclear Medicine and Molecular Imaging containing *Beyer* and *Osman* was received by the University of Wisconsin Health Sciences Library staff on May 19, 2003.

25. Accordingly, the issue of European Journal of Nuclear Medicine and Molecular Imaging containing *Beyer* and *Osman* would have been checked-in and catalogued by the University of Wisconsin Health Sciences Library within a few

days of May 19, 2003, and would have subsequently been made available to the public within a few days of being checked-in and catalogued. The general public could have accessed the issue of European Journal of Nuclear Medicine and Molecular Imaging containing *Beyer* and *Osman* by (i) searching the University of Wisconsin at Madison Library catalog; (ii) visiting the library; or (iii) by asking a Library staff member and requesting the print issue available at the Middleton Shelving Facility at Call Number Q 7EU46461 (34-V-6) on or before May 25, 2003.

VII. Conclusion

26. In signing this Declaration, I understand it will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I understand I may be subject to cross-examination in this case and that cross-examination will take place within the United States. If cross-examination is required of me, I will appear for cross-examination within the United States during the time allotted for cross-examination.

27. I declare that all statements made herein of my knowledge are true, that all statements made on information and belief are believed to be true, and that these statements were made with the knowledge that willful false statements and

Declaration of Shauna L. Wiest

the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Executed on May 29, 2025.

A handwritten signature in black ink, appearing to read "Shauna L. Wiest", written over a horizontal blue line.

Shauna L. Wiest

20612

Volume 30 • Number 4 • April 2003

European Journal of

Nuclear Medicine and Molecular Imaging



HEALTH SCIENCES LIBRARY
UNIVERSITY OF WISCONSIN

MAY 19 2003

1305 Linden Drive
Madison, WI 53706

European Journal of Nuclear Medicine and Molecular Imaging

Official Journal of the European Association of Nuclear Medicine (EANM)

Editor-in-Chief

P.J. Ell, London

Section Editors

S.S. Gambhir, Los Angeles
(Molecular Imaging)
M. Schwaiger, München (Controversies)
H.W. Strauss, New York (Reviews)
I. Carrió, Barcelona (Blue pages)
W.H. Knapp, Hannover (News & Views)
D.C. Costa, London (Image of the month)

Honorary Editor

F.H.M. Corstens, Nijmegen

Editorial Board

M. Aas, Oslo
H.M. Abdel Dayem, New York
P.D. Acton, Philadelphia
H. Amaral, Santiago
S. Askienazy, Paris
W.H. Bakker, Rotterdam
T.M. Behr, Marburg
H. Bergmann, Vienna
K.A. Bergstroem, Helsinki
H. Biersack, Bonn
A. Bischof Delaloye, Lausanne
J.A.K. Blokland, Leiden
B.D. Bok, Paris
E. Bombardieri, Milano
M.H. Bourguignon, Paris
F.J.H.N. Braga, Sao Paulo
A. Britten, London
U. Buell, Aachen
E.E. Camargo, Campinas
B.E. Caner, Ankara
J.M. Carril, Santander
J.F. Chatal, Nantes
J.-K. Chung, Seoul
A.J. Coakley, Canterbury
G. Cook, Sutton
R.A. Dierckx, Gent
A.A. Driedger, London/Ontario
H. Durak, Izmir
M. Eisenhut, Heidelberg

K. Endo, Gumna
M. Fischer, Kassel
A. Fischer Thom, Sao Paulo
G. Flux, Sutton
J.S. Fleming, Southampton
I. Fogelman, London
L.M. Freeman, New York
I. Gordon, London
U. Haberkorn, Heidelberg
C. Halldin, Stockholm
L.K. Harding, Birmingham
D. Hastings, Manchester
R. Hicks, Melbourne
D.J. Hnatowich, Worcester
C. Hoefnagel, Amsterdam
L. Højgaard, Copenhagen
B. Hutton, Sydney
R.B. Innis, Bethesda
M.P. Iturralde, Pretoria
A. Jacobs, Cologne
P. Jarritt, Belfast
L. Johansson, Umea
A.G. Jones, Boston
M. Kelly, Victoria
E.E. Kim, Houston
J. Konishi, Kyoto
R.N. Krasikova, St. Petersburg
D.J. Kwekkeboom, Rotterdam
A.A. Lammertsma, Amsterdam
S.A. Larsson, Stockholm
M. Lassmann, Würzburg
V. Lele, Bombay
C. Le Rest, Brest
G.S. Limouris, Athens
P. Lind, Klagenfurt
A. Lingford-Hughes, Bristol
J. Links, Baltimore
R.-S. Liu, Taipei
X.-J. Liu, Beijing
G. Lucignani, Milano
H.R. Maecke, Basle
M. Maisey, London
J. Malamitsi, Athens
G. Mariani, Pisa
P.Y. Marie, Nancy
J. Martin-Comin, Barcelona
J.S. Masjbur, Bandung
S.J. Mather, London

V.R. McCready, Sutton
A.J.B. McEwan, Edmonton
J.A. Melin, Brussels
J.L. Moretti, Paris
P.J. Mountford, Staffordshire
D.L. Munz, Berlin
N. Nair, Bombay
A. Notghi, Birmingham
M.J. O'Doherty, London
A. Otte, Freiburg
W. Oyen, Nijmegen
E.K.J. Pauwels, Leiden
A.C. Perkins, Nottingham
M. Peters, Cambridge
A. Piepsz, Brussels
V.W. Pike, Bethesda
L.S. Pilowsky, London
C. Reiners, Würzburg
M.D. Rutland, Auckland
M. Salvatore, Naples
M.P. Sandler, Nashville
Y. Sasaki, Chiba
H.B. Sayman, Istanbul
O. Schillaci, Rome
K. Schmidt, Bethesda
O. Schober, Muenster
P.A. Schubiger, Villigen
G. von Schulthess, Zurich
A.M. Scott, Heidelberg, Victoria
J.P. Seibyl, New Haven
H. Sinzinger, Vienna
F.X. Sundram, Singapore
Y. Suzuki, Isehara
J. Szilvasi, Budapest
N. Tamaki, Sapporo
S. Tanada, Chiba
A. Tarkowska, Lublin
M.L. Thakur, Philadelphia
T. Treves, Boston
T. Turkington, Durham, NC
J. Turner, Christ Church
M. Ünü, Ankara
R. Underwood, London
H. van der Wall, Sidney
A. Verbruggen, Leuven
S.-C. Wang, Beijing
F. Wolf, Erlangen
R.E. Zimmerman, Boston



Springer

HEALTH SCIENCES LIBRARY
UNIVERSITY OF WISCONSIN

MAY 19 2003

1305 Linden Drive
Madison, WI 53706

European Journal of Nuclear Medicine and Molecular Imaging

Online First
Immediately Online
<http://link.springer.de>
link.springer-ny.com

Faster publication!

Official Journal of the European Association of Nuclear Medicine (EANM)

Volume 30 Number 4 April 2003

Editorial

Bergmann H

The need for independent physics advice 491

Original articles

Hoffend J, Linke G, Mohammed A, Tiefenbacher CP, Eisenhut M, Haberkorn U

$^{99m}\text{TcO}(\text{BAT-NI})$, a novel nitroimidazole tracer: in vivo uptake studies in ischaemic myocardium 494

Belhaj-Tayeb H, Briane D, Vergote J, Kothan S, Léger G, Bendada S-E, Tofighi M, Tamgac F, Cao A, Moretti J-L

In vitro and in vivo study of ^{99m}Tc -MIBI encapsulated in PEG-liposomes: a promising radiotracer for tumour imaging 502

Jamar F, Barone R, Mathieu I, Walrand S, Labar D, Carlier P, De Camps J, Schran H, Chen T, Smith MC, Bouterfa H, Valkema R, Krenning EP, Kvols LK, Pauwels S

^{86}Y -DOTA⁰-D-Phe¹-Tyr³-octreotide (SMT487) – a phase 1 clinical study: pharmacokinetics, biodistribution and renal protective effect of different regimens of amino acid co-infusion 510

Pauleit D, Floeth F, Herzog H, Hamacher K, Tellmann L, Müller H-W, Coenen HH, Langen K-J

Whole-body distribution and dosimetry of O -(2-[^{18}F]fluoroethyl)-L-thyrosine 519

Isselt JW van, Klerk JMH de, Rijk PP van, Gils APG van, Polman LJ, Kamphuis C, Meijer R, Beekman FJ

Comparison of methods for thyroid volume estimation in patients with Graves' disease 525

Vlajković M, Ilić S, Bogičević M, Rajić M, Ristić L, Petronijević V, Golubović E, Stefanović V, Artiko V

Radionuclide voiding patterns in children with vesicoureteral reflux 532

Maza S, Valencia R, Geworski L, Sandrock D, Zander A, Audring H, Dräger E, Winter H, Sterry W, Munz DL

Influence of fast lymphatic drainage on metastatic spread in cutaneous malignant melanoma: a prospective feasibility study 538

Schaefer WM, Lipke CSA, Nowak B, Kaiser HJ, Buecker A, Krombach GA, Buell U, Köhl HP

Validation of an evaluation routine for left ventricular volumes, ejection fraction and wall motion from gated cardiac FDG PET: a comparison with cardiac magnetic resonance imaging 545

Monsieurs MA, Bacher K, Brans B, Vral A, De Ridder L, Dierckx RA, Thierens HM

Patient dosimetry for ^{131}I -lipiodol therapy 554

Goerres GW, Mosna-Firlejczyk K, Steurer J, Schulthess GK von, Bachmann LM

Assessment of clinical utility of ^{18}F -FDG PET in patients with head and neck cancer: a probability analysis 562

Treyer V, Jobin M, Burger C, Teneggi V, Buck A

Quantitative cerebral H_2^{15}O perfusion PET without arterial blood sampling, a method based on washout rate 572

Choi JY, Kim SJ, Hong SB, Seo DW, Hong SC, Kim B-T, Kim SE

Extratemporal hypometabolism on FDG PET in temporal lobe epilepsy as a predictor of seizure outcome after temporal lobectomy 581

Beyer T, Antoch G, Blodgett T, Freudenberg LF, Akhurst T, Mueller S

Dual-modality PET/CT imaging: the effect of respiratory motion on combined image quality in clinical oncology 588

Nakamoto Y, Tatsumi M, Cohade C, Osman M, Marshall LT, Wahl RL
Accuracy of image fusion of normal upper abdominal organs visualized with PET/CT 597

Short communications

Osman MM, Cohade C, Nakamoto Y, Wahl RL
Respiratory motion artifacts on PET emission images obtained using CT attenuation correction on PET-CT 603

Fricke E, Machtens S, Hofmann M, Hoff J van den, Bergh S, Brunkhorst T, Meyer GJ, Karstens JH, Knapp WH, Boerner AR
Positron emission tomography with ^{11}C -acetate and ^{18}F -FDG in prostate cancer patients 607

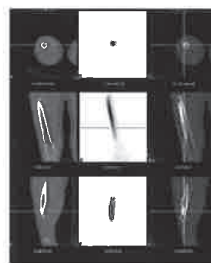
Yamamoto Y, Nishiyama Y, Monden T, Satoh K, Ohkawa M
A study of the acute effect of smoking on cerebral blood flow using $^{99\text{m}}\text{Tc}$ -ECD SPET 612

Review article

Flotats A, Carrió I
Non-invasive in vivo imaging of myocardial apoptosis and necrosis 615

News & Views 631

Image of the month



Horger M, Pfannenberger C, Claussen CD, Bares R, Eschmann SM
Combined transmission and emission tomography in a vastus intermedius muscle stress syndrome 636

Forthcoming articles in print

published online and citeable with the DOI (Digital Object Identifier) can be found under <http://link.springer.de/link/service/journals/00259/contents/tfirst.htm> or subscribe to Alert service <http://link.springer.de/alert> or <http://link.springer-ny.com/alert/>

Indexed in/abstracted by *Current Contents*, *Index Medicus* and *EMBASE*
Printed on acid free paper



Springer



1619-7070(200304)30:4;1-#

European Journal of Nuclear Medicine and Molecular Imaging

Official Journal of the European Association of Nuclear Medicine (EANM)

1 Aims and Scope

The aim of the *European Journal of Nuclear Medicine and Molecular Imaging* is to provide a forum for the exchange of clinical and scientific information for the nuclear medicine community and allied professions involved in the functional, metabolic and molecular investigation of disease. The *European Journal of Nuclear Medicine and Molecular Imaging* will remain of primary interest to those practising the field of nuclear medicine but will also report on original works relating to physics, dosimetry, radiation biology, computer science, radiochemistry and pharmacy. The Journal will welcome original material reflecting the growing field of molecular imaging probes, reporter gene assays, cell trafficking, targeting of endogenous gene expression and antisense methodologies.

The Journal will continue to publish in depth Reviews of topical interest, Occasional surveys, Short communications and Letters to the editor. A section on Controversies is also a new feature. Case reports are not published.

2 Copyright

Submission of a manuscript implies: that the work described has not been published before (except in form of an abstract or as part of a published lecture, review or thesis); that it is not under consideration for publication elsewhere; that its publication has been approved by all co-authors, if any, as well as – tacitly or explicitly – by the responsible authorities at the institution where the work was carried out. Transfer of copyright to Springer-Verlag becomes effective if and when the article is accepted for publication. The copyright covers the exclusive right (for U.S. government employees: to the extent transferable) to reproduce and distribute the article, including reprints, translations, photographic reproductions, microform, electronic form (offline, online) or other reproductions of similar nature.

All articles published in this journal are protected by copyright, which covers the exclusive rights to reproduce and distribute the article (e.g., as offprints), as well as all translation rights. No material published in this journal may be reproduced photographically or stored on microfilm, in electronic data bases, video disks, etc., without first obtaining written permission from the publisher. The use of general descriptive names, trade names, trademarks, etc., in this publication, even if not specifically identified, does not imply that these names are not protected by the relevant laws and regulations.

An author may make an article published by Springer-Verlag available on his/her personal home page, provided the source of the published article is cited and Springer-Verlag is mentioned as the copyright owner. Authors are requested to create a link to the published article in Springer's internet service. The link must be accompanied by the following text: "The original publication is available at <http://link.springer.de> or at <http://link.springer-nj.com>".

Please use the appropriate URL and/or DOI for the article. Articles disseminated via SpringerLink are indexed, abstracted and referenced by many abstracting and information services, bibliographic networks, subscription agencies, library networks, and consortia.

While the advice and information in this journal is believed to be true and accurate at the date of its publication, neither the authors, the editors, nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Special regulations for photocopies in the USA: Photocopies may be made for personal or in-house use beyond the limitations stipulated under Section 107 or 108 of U.S. Copyright Law, provided a fee is paid. All fees should be paid to the Copyright Clearance Center, Inc., 21 Congress Street, Salem, MA 01970, USA, stating the ISSN 0340-6997, the volume, and the first and last page numbers of each article copied. The copyright owner's consent does not include copying for general distribution, promotion, new works, or resale. In these cases, specific written permission must first be obtained from the publisher.

The Canada Institute for Scientific and Technical Information (CISTI) provides a comprehensive, world-wide document delivery service for all Springer-Verlag journals. For more information, or to place an order for a copyright-cleared Springer-Verlag document, please contact Client Assistant, Document Delivery, CISTI, Ottawa K1A 0S2, Canada Tel. +1-613-9939251; Fax +1-613-9528243; e-mail: cisti.docdel@nrc.ca

3 Subscription Information

ISSN print edition 1619-7070
ISSN electronic edition 1619-7089

Volume 30 (12 issues) will appear in 2003.

European Journal of Nuclear Medicine and Molecular Imaging appears monthly. It is published by Springer-Verlag Berlin, Heidelberger Platz 3, 14197 Berlin, Germany. Periodicals postage paid at New York, NY, and additional mailing offices. Springer-Verlag New York, Inc., 175 Fifth Avenue, New York, NY 10010, USA are our Mailing Agents.

Postmaster send all address changes to: European Journal of Nuclear Medicine and Molecular Imaging, Springer-Verlag New York Inc., Journal Fulfillment, P.O. Box 2485, Secaucus, NJ 07096-2485, USA.

North and South America

Please ask for the appropriate price list in US \$.

Please mail orders and inquiries to:

Springer-Verlag New York Inc. Journal Fulfillment, P.O. Box 2485 Secaucus, NJ 07096-2485, USA
Tel.: +1-800-SPRINGER (7746443)
or +1-212-4601500, Fax: +1-201-3484505
e-mail: journals@springer-nj.com

All Countries except North and South America

Recommended annual subscription rate incl. basic online license: € 1,100.00 (Prices are net-prices subject to local VAT) plus carriage charges: (Germany: € 28.10 other countries: € 48.20). Single issue price available upon request. SAL delivery (surface airmail lifted) is mandatory to Japan, North & South East Asia, India, Australia and New Zealand. Custom-

ers should ask for the appropriate price list. Airmail delivery to all other countries is available upon request.

Orders or claims can either be placed via a bookseller or sent directly to: Springer-Verlag, Customer Service Journals, Haberstrasse 7, 69126 Heidelberg, Germany, Tel.: +49-6221-345-0, Fax: +49-6221-3454229, e-mail: subscriptions@springer.de

Cancellations must be received by September 30 to take effect at the end of the same year.

Changes of address: Allow six weeks for all change to become effective. All communications should include both old and new addresses (with postal codes) and should be accompanied by a mailing label from a recent issue.

According to §4 Sect. 3 of the German Postal Service Data Protection Regulations if subscriber's address changes, the German Federal Post Office can inform the publisher of the new address even if the subscriber has not submitted a formal application for mail to be forwarded. Subscribers not in agreement with this procedure may send a written complaint to Customer Service Journals, Karin Tiks, within 14 days of publication of this issue.

Back volumes: Prices are available on request.

Microform editions are available from:

ProQuest. Further information available with: <http://www.proquest.com/umi/>

4 Electronic edition

An electronic edition of this journal is available via Springer-Verlag's online journal service at <http://link.springer.de> or at <http://link.springer-nj.com>.

Alert Service: Would you like to automatically receive via e-mail news of newly published articles listed in the journal's table of contents with direct links to the respective abstracts? Then take advantage of our free Alert service. To register and obtain further information, go to <http://link.springer.de/alert/> or <http://link.springer-nj.com/alert/>.

Online First articles are published in electronic form weeks before distribution of the printed journal. An Online Publication date is published in each Online First article and its print version. Authors should be aware that after electronic publication they cannot withdraw an article or change its content. Any corrections have to be made in an Erratum which will be hyperlinked to the article. Online First articles can be cited using their Digital Object Identifier (DOI), a unique and consistent identification code included in both the print and the electronic versions.

5 Responsible for advertisements

Springer-Verlag,
Edda Lückermann and Noëla Krischer
Heidelberger Platz 3, 14197 Berlin, Germany
Tel. +49-30-827875739, Fax +49-30-827875300
e-mail: krischer@springer.de,
www.wikom.springer.de

6 Production

Springer-Verlag, Anneliese Sand
Journal Production Medicine
Postfach 105280, 69042 Heidelberg, Germany
Tel.: +49-6221-4878901, Fax +49-6221-4878200
e-mail: sand@springer.de

Address for courier, express and registered mail:
Tiergartenstrasse 17, 69121 Heidelberg, Germany

Printers: Stürtz AG, Würzburg, Germany
Printed on acid-free paper

Springer-Verlag Berlin Heidelberg New York
a member of BertelsmannSpringer
Science+Business Media GmbH
<http://www.springer.de>
Ownership and Copyright
© Springer-Verlag Berlin Heidelberg 2003
Printed in Germany

Dual-modality PET/CT imaging: the effect of respiratory motion on combined image quality in clinical oncology

Thomas Beyer^{1,2}, Gerald Antoch¹, Todd Blodgett³, Lutz F. Freudenberg², Tim Akhurst⁴, Stephan Mueller²

¹ Department of Diagnostic and Interventional Radiology, University Hospital Essen, Essen, Germany

² Department of Nuclear Medicine, University Hospital Essen, Essen, Germany

³ PET Facility, University of Pittsburgh Medical Center, Pittsburgh, USA

⁴ Memorial Sloan Kettering Cancer Center, New York, USA

Received: 7 October 2002 / Accepted: 18 November 2002 / Published online: 12 February 2003

© Springer-Verlag 2003

Abstract. To reduce potential mis-registration from differences in the breathing pattern between two complementary PET and CT data sets, patients are generally allowed to breathe quietly during a dual-modality scan using a combined PET/CT tomograph. Frequently, however, local mis-registration between the CT and the PET is observed. We have evaluated the appearance, magnitude, and frequency of respiration-induced artefacts in CT images of dual-modality PET/CT studies of 62 patients. Combined PET/CT scans during normal respiration were acquired in 43 subjects using single- or dual-slice CT. Nineteen patients were scanned with a special breathing protocol (limited breath-hold technique) on a single-slice PET/CT tomograph. All subjects were injected with ~370 MBq of FDG, and PET/CT scanning commenced 1 h post injection. The CT images were reconstructed and, after appropriate scaling, used for on-line attenuation correction of the PET emission data. We found that respiration artefacts can occur in the majority of cases if no respiration protocol is used. When applying the limited breath-hold technique, the frequency of severe artefacts in the area of the diaphragm was reduced by half, and the spatial extent of respiration-induced artefacts was reduced by at least 40% compared with the acquisition protocols without any breathing instructions. In conclusion, special breathing protocols are effective and should be used for CT scans as part of combined imaging protocols using a dual-modality PET/CT tomograph. The results of this study can also be applied to multi-slice CT to potentially reduce further breathing artefacts in PET/CT imaging and to improve overall image quality.

Keywords: PET/CT imaging – Dual-modality tomography – Oncology – Respiration protocols

Eur J Nucl Med Mol Imaging (2003) 30:588–596

DOI 10.1007/s00259-002-1097-6

Introduction

Oncologic disease is typically detected by anatomical imaging techniques, such as computed tomography (CT), which is often considered the method of choice for cancer imaging. In recent years positron emission tomography (PET), as a functional imaging technique, has gained widespread acceptance in clinical oncology for the detection of metabolic and functional abnormalities at an early stage of disease. In general, PET has a higher sensitivity and specificity than CT for the detection and staging of cancer [1]. However, the combination of PET and CT promises to be more accurate than either modality alone in the initial diagnosis and for therapy management [2].

A straightforward approach to using PET and CT together is to align the two image sets retrospectively [3]. Several computer-based algorithms have been described and research is ongoing to improve and automate these alignment techniques. So far, retrospective registration of complementary image sets works well for the brain [4], but often requires interaction with an operator to achieve an acceptable level of registration accuracy [5]. Another approach to using complementary PET and CT information is to combine the hardware into a single, dual-modality PET/CT tomograph [6].

The basic concept of combined PET/CT tomography is to examine the patient in both PET and CT mode without moving the patient off the table between examinations. Thus any potential misalignment between the two data sets is minimised, patient comfort is increased and

Thomas Beyer (✉)
Department of Diagnostic and Interventional Radiology,
University Hospital Essen, Hufelandstrasse 55,
45147 Essen, Germany
e-mail: Thomas.Beyer@uni-essen.de
Tel.: +49-201-7231528, Fax: +49-201-9597756

logistical issues with patient referral are potentially minimised [7].

In addition to providing accurately aligned functional and anatomical information, combined PET/CT offers the benefit of routine CT-based attenuation correction of the emission data [8, 9]. When using CT-based attenuation correction transmission times can be shortened to less than a minute for a whole-body scan, and transmission scans can be performed post injection without the need to correct for the bias from emission contamination.

Nevertheless, a number of issues need to be addressed in the context of complementary PET/CT imaging. Most issues pertain to the effect of methodological differences in scanning a patient with PET and CT when, at the same time, using the available CT transmission images for attenuation correction of the emission data. CT scans, for example, are typically (95%) performed in full-inspiration breath-hold with the arms up to reduce both attenuation artefacts and motion artefacts outside the heart. Current CT technology allows high-quality CT scans of the thorax or the abdomen to be completed in 20 s. In contrast, the scan time for a number of PET emission scans to cover a similar axial imaging range is in the order of several minutes. Due to the longer scan time needed, dedicated PET scans are acquired with the arms down and during normal respiration [10]. Ideally, in a combined tomograph, both CT and PET data should be acquired during the same respiratory (and cardiac) cycle. However, this is impractical in current generations of PET/CT systems, which have CT components that do not allow for efficient cardiac and respiratory gating [11] and do not routinely offer gating options for the emission acquisition. Therefore alternative solutions have to be found to best match the spatial extent of the transmission information to the average spatial distribution of the tracer activity in the emission data. This is of importance not only in matching the reconstructed anatomical and functional information but also in limiting any propagation of mis-registered CT and PET information during CT-based attenuation correction.

Goerres and colleagues showed that CT-based attenuation maps match most closely the tracer activity distribution during the emission scan when the CT is performed in end-expiration [12]. However, to ask the patient to hold his or her breath for the duration of the entire CT scan, which often extends from the lower jaw to the upper thighs, would require a very fast, multi-ring CT scanner. In addition, some cancer patients may not tolerate holding their breath in expiration or end-expiration for the duration of a whole-body CT examination. Taking into account the availability of single-slice and dual-slice CT systems and in order to minimise the stress on the patient, we suggest a limited breath-hold protocol which requires patients to hold their breath only for a limited time during the CT part of the combined PET/CT examination.

Materials and methods

Patient population. PET/CT data sets from 62 patients from three clinical sites were collected as part of this study. All patients were part of clinical protocols and had been referred for a PET/CT study by their oncology physician.

PET/CT system. The PET/CT tomograph used in this study is a BGO-based biograph (biograph BGO, Siemens Medical Solutions, Hoffman Estates, USA). The biograph BGO [11] combines a PET tomograph based on the ECAT EXACT HR+ and a Somatom Emotion CT scanner in a single, compact gantry. The CT components are available as single-slice or dual-slice CT. The transverse field of view of the CT and PET are 50 cm and 58.5 cm, respectively. The axial field of view of the PET is 15.5 cm with 63 image planes per bed position (2.4 mm slice spacing). The centres of the field of view of the CT and the PET are separated by 90 cm in the axial direction. A common patient handling system is installed at the front of the combined gantry and assures accurate positioning of patients up to 204 kg for both the CT and the PET examination.

PET/CT scanning and data processing. All patients fasted for at least 4 h prior to the PET/CT examination. An average activity of 370 MBq of fluorine-18 fluorodeoxyglucose (FDG) was injected 60 min $\pm$ 10 min before the examination. Patients were positioned head-first supine, and were moved to just above the first scanning position on the CT. A topogram (or scout scan) was acquired to define the axial imaging range, which for a whole-body PET/CT examination typically extended from the lower jaw to the upper thighs. A single, continuous spiral CT scan was defined on the topogram, with the total extent of the spiral being automatically matched to the closest integer number of PET bed positions. This was done to ensure sufficient CT data for CT-based attenuation correction of the PET emission data, as will be described below.

CT scan parameters were 130 kVp, 5-mm slice width, pitch 1.6, and a reconstruction increment of 2.4 mm to match the axial sampling of the reconstructed emission images. Note that the pitch was defined as the table feed per rotation divided by the nominal slice width. When necessary, the patients were given oral and/or intravenous contrast agents prior to the spiral CT scan. Depending on the axial imaging range and the number of CT detector rows, the CT transmission scan took between 40 s and 75 s. Once the CT had been completed, the table moved automatically to position the patient in the field of view of the PET. Emission scanning commenced in the caudocranial direction with the pelvis scanned first to limit artefacts in the bladder resulting from FDG excretion into the urine. Emission scan duration was 4 min to 8 min per bed position depending on the size of the patient and the preferences at each of the three sites. Typically whole-body PET/CT scans did not exceed eight bed positions (95 cm).

The CT images were reconstructed on-line and were available for CT-based attenuation correction (CT-AC) of the emission data. First the CT images were segmented into bone and non-bone using a threshold of 300 HU. The segmented images were transformed into maps of attenuation coefficients at the effective CT energy, E_{CT} . A non-bone scale factor was applied to the pixel values in the non-bone class, and a bone scale factor was applied to the pixel values in the bone class. Both scale factors were derived from the ratio of the mass attenuation coefficient of water and bone, respectively, at 511 keV and E_{CT} [8]. The presence of intravenous contrast and oral contrast agents in CT images in the context of the CT-AC described above has been discussed in [13] and [14].

Fig. 1a–c. Three variants of CT scan acquisitions as part of the PET/CT acquisition protocols described in this study. **a** Single-slice CT during tidal breathing (TB-SS). **b** Single-slice CT and limited breath-hold (LBH-SS) technique, whereby patients were asked to hold their breath during normal respiration for as long as the spiral CT covered the lower thorax and the liver. **c** Dual-slice CT during tidal breathing (TB-DS)

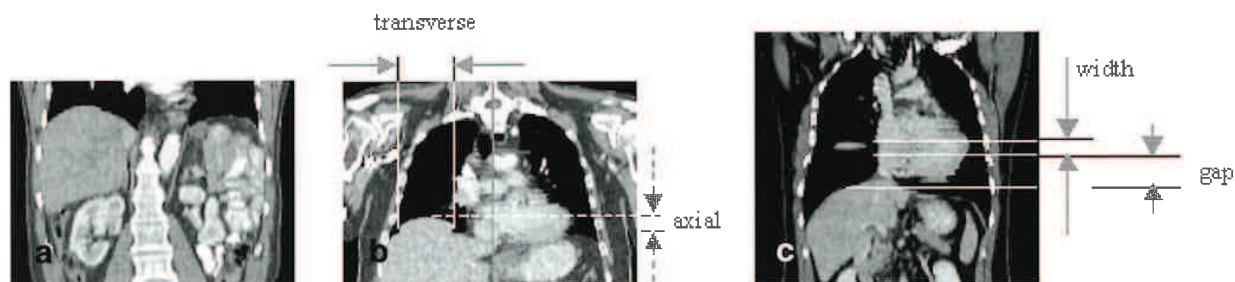
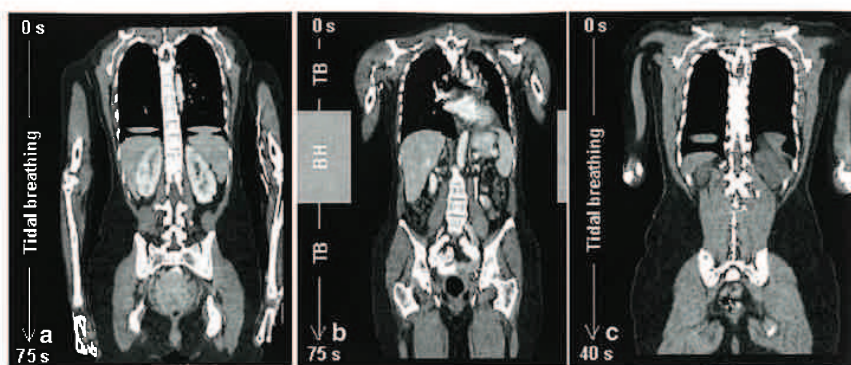


Fig. 2a–c. NMS classification scheme for CT artefacts during spiral CT scanning as part of the PET/CT imaging protocol. **a** No artefact; the surface of the liver appears smooth. **b** Mild artefacts; the liver surface appears slightly ragged and small soft tissue extensions into the lower lung can be seen. **c** Significant artefacts; artificial soft tissue densities appear detached in the mid-thorax

Table 1. Details of respiration protocols used (total no. of patients =62)

Respiration protocol	Respiration	CT	No. of patients
TB-SS	Tidal breathing	Single-slice	24
LBH-SS	Limited breath-hold	Single-slice	19
TB-DS	Tidal breathing	Dual-slice	19

Respiration protocols. All 62 patients were separated into three groups (Table 1) depending on the CT scanner and the breathing protocol: 43/62 patients were scanned on the biograph BGO with a single-slice CT, and 19/62 patients were scanned on the biograph BGO with a dual-slice CT. Of the 43 patients scanned on the single-slice CT version, 24 were instructed to breathe shallowly during the CT and the PET examination (TB-SS) while 19 were scanned with a limited breath-hold technique (LBH-SS). The 19 patients scanned on the biograph BGO with dual-slice CT were allowed to breathe shallowly during both the CT and the PET examination (TB-DS).

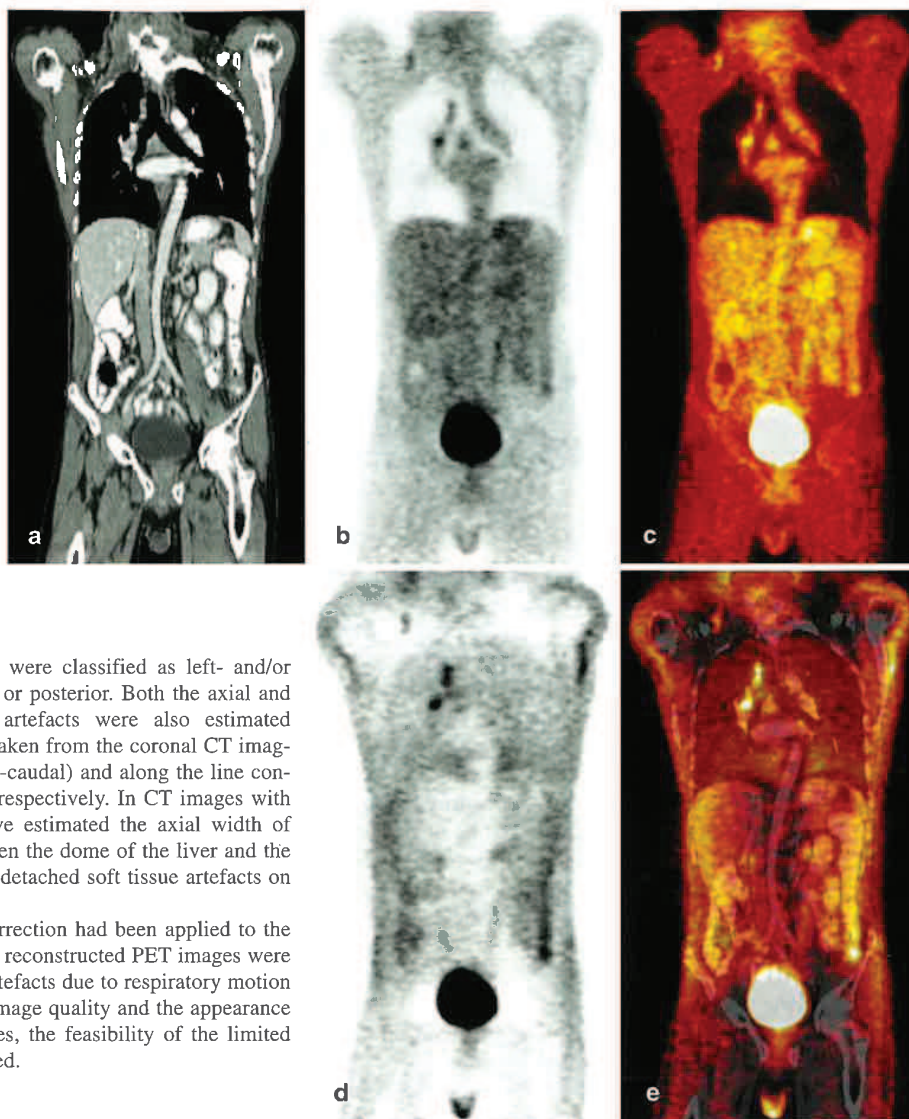
The respiration protocols in all three groups are illustrated in Fig. 1. The CT scan consisted of a single, continuous spiral covering an axial range from the neck to the thighs depending on the clinical indication and subsequently the number of PET bed positions. Patients following the TB-SS protocol were allowed to

breathe throughout the CT scan, which took about 75 s. Patients participating in the LBH-SS protocol were asked to breathe quietly during the initial part of the CT scan starting cranially. As the field of view of the CT approached the lower mediastinum, patients were asked to expire and to hold their breath until the active field of view passed the liver (as seen on the topogram view), at which time the patients were allowed to breathe shallowly again. As with TB-SS, the total scan time for the CT was about 75 s, during which the patients held their breath for about 20 s – the time needed to cover the area of the lower mediastinum and the liver. The breathing procedure for the LBH-SS protocol was practised with the patients before the scan was started.

During the TB-DS protocol no breathing instructions were given and all subjects were scanned during tidal breathing even though the entire CT examination time could be as short as 40 s because of the faster scanning option with a dual-slice CT.

Data analysis and image evaluation. Although respiratory motion affects the thorax and the abdomen, we focussed on artefacts in the area of the diaphragm, which of all regions is affected most by respiration. For each set of PET/CT images from a single patient the whole-body CT images were evaluated for the appearance of motion artefacts between mid-thorax and mid-abdomen. Our subjective approach to the classification of the CT images (referred to here as the NMS classification) is based on three categories: no artefacts, mild artefacts and significant artefacts (Fig. 2). The CT images were considered free of artefacts when the liver appeared uniform and the boundary between the liver and the lungs appeared smooth in all views (Fig. 2a). The CT images were deemed to be mildly affected by respiration if the dome of the liver extended asymmetrically into the lower lungs but these artificial soft tissue densities were still attached to the liver (Fig. 2b). If the soft tissue densities appeared completely detached from the liver and were without any morphological correlate in the mid-thorax, they were considered significant artefacts (Fig. 2c).

Fig. 3a–e. Example of a whole-body PET/CT study acquired with the LBH-SS protocol. The coronal CT (a), corrected PET (b) and fused PET/CT images (c) demonstrate the absence of respiration-induced artefacts in the vicinity of the diaphragm. For comparison, the emission data prior to attenuation correction are shown in d and in e when fused with the CT (a)



Mild and significant artefacts were classified as left- and/or right-sided in addition to anterior or posterior. Both the axial and the transverse extent of these artefacts were also estimated (Fig. 2b, c). Measurements were taken from the coronal CT images along the main axis (i.e. cranio-caudal) and along the line connecting the arms (i.e. left-right), respectively. In CT images with significant respiration artefacts we estimated the axial width of these artefacts, and the gap between the dome of the liver and the lower boundary of the artificially detached soft tissue artefacts on the coronal CT images (Fig. 2c).

After CT-based attenuation correction had been applied to the complementary emission data, the reconstructed PET images were evaluated for the appearance of artefacts due to respiratory motion during the CT. Based on the CT image quality and the appearance of the artefacts in the PET images, the feasibility of the limited breath-hold technique was reviewed.

Results

Figure 3 shows a PET/CT case study with no respiration artefacts in the vicinity of the diaphragm and the liver. The study was acquired using the single-slice CT and limited breath-hold (LBH-SS) protocol described above. Throughout our patient population we occasionally observed a residual discrepancy in the position of the liver on CT compared with the mean axial liver position in the emission scan, which is acquired over a large number of respiration cycles.

The number of studies with CT images free from apparent respiratory motion artefacts varied with the scan protocol. With the single-slice CT and tidal breathing (TB-SS) protocol only 1/24 studies was free of respiration artefacts, compared with 5/19 (26%) studies when applying the LBH-SS technique. Interestingly none of the patients scanned following the dual-

slice CT and tidal breathing (TB-DS) protocol was free of artefacts.

Throughout our patient population, mild respiration-induced artefacts were the most frequently observed. This was true for 11/19 (58%) and 14/19 (74%) patients examined with the LBH-SS and the TB-DS protocol, respectively. An example of a patient study with mild artefacts in the right liver is shown in Fig. 4. The coronal CT image (Fig. 4a) illustrates a typical mild respiration artefact as previously described by Goerres et al. [12]. Mild artefacts were observed mostly on the patients' right side, and translated from the CT to the corrected PET images after CT-based attenuation correction. In our experience the spatial extent of these artefacts seen in the corrected PET images (Fig. 4b) was less than on the corresponding CT images.

Fig. 4a–e. Mild respiration artefact seen on the coronal CT image (a) of a patient scanned during tidal breathing. The artefact on the PET image after CT-based attenuation correction (b) and on the fused image (c) is not as sharply delineated as on the CT image. No artefact is seen on the non-corrected emission image (d). Image fusion of the CT and non-corrected PET image (e) reveals no corresponding artefacts



Significant artefacts were observed predominantly on the right side (63%) of the thorax and posteriorly (50%). Figure 5 shows an example of a study with a significant breathing artefact. Significant breathing artefacts were considered present when fully detached soft tissue densities were visible in the CT images of the lower or mid-thorax. Such apparent detachments are generated by the CT reconstruction if the same organ (i.e. liver) is scanned during different phases of one or more respiratory cycles, which leads to visible excursions of the organ into the actual field of view of the CT. Frequently, however, the corresponding PET images after application of CT-based attenuation correction reveal only semi-detached artefacts, as seen in Fig. 5b.

Respiration artefacts were observed with varying frequencies among the three acquisition protocols. Figure 6 illustrates the frequency of mild and significant artefacts in the CT images of the 62 patients studied.

Significant artefacts occurred most frequently (16/24) when employing single-slice CT without a specific breathing protocol (TB-SS). Such artefacts were much reduced (5/19) by using a dual-slice CT system (TB-DS), and even more so by applying a limited breath-hold technique using single-slice CT (LBH-SS) (3/19). Mild artefacts were predominantly observed when using the TB-DS and LBH-SS protocols. It can be assumed that most of the significant artefacts were reduced to mild artefacts by use of the limited breath-hold technique or by use of dual-slice CT.

In all three patient groups the spatial extent of respiration-induced artefacts in the CT images varied widely. This is illustrated in Fig. 7, which compares the average axial and coronal extent of the artefacts. When applying the tidal breathing technique to single- or dual-slice CT (TB-SS or TB-DS), the average axial extent of the artefacts on CT was very similar: 21 ± 11 mm and 22 ± 7 mm, respectively (Fig. 7a). By using the limited breath-hold technique (LBH-SS), the axial extent was reduced to

Table 2. Average axial extent $\pm$ standard deviation of mild and significant artefacts with all three breathing protocols. The axial extent was averaged over all patients (N), and over patients with either mild (N_m) or significant (N_s) artefacts

	Respiration protocol		
	TB-SS	LBH-SS	TB-DS
N	24	19	19
All artefacts (mm)	21 ± 11	9 ± 8	22 ± 7
N_m	7	11	14
Mild artefacts (mm)	16 ± 5	9 ± 4	22 ± 7
N_s	16	3	5
Significant artefacts (mm)	24 ± 11	20 ± 13	29 ± 19

9 ± 8 mm on average. The average extent of mild and significant artefacts in the axial direction (Fig. 2a) is summarised in Table 2.

The coronal extent (Fig. 2b) of all respiration artefacts was also estimated (Fig. 7b). Similar to our observations on the axial extent of respiration-induced

Fig. 5a–e. Example of a significant respiration artefact as seen on the coronal CT image (a). The corresponding corrected PET image (b) shows a semi-detached artefact in the region of the right liver. Image fusion of a and b in c illustrates the extent of the artefacts with each modality. The lung-liver boundary appears normal on the uncorrected emission (d) and fused emission (e) CT images

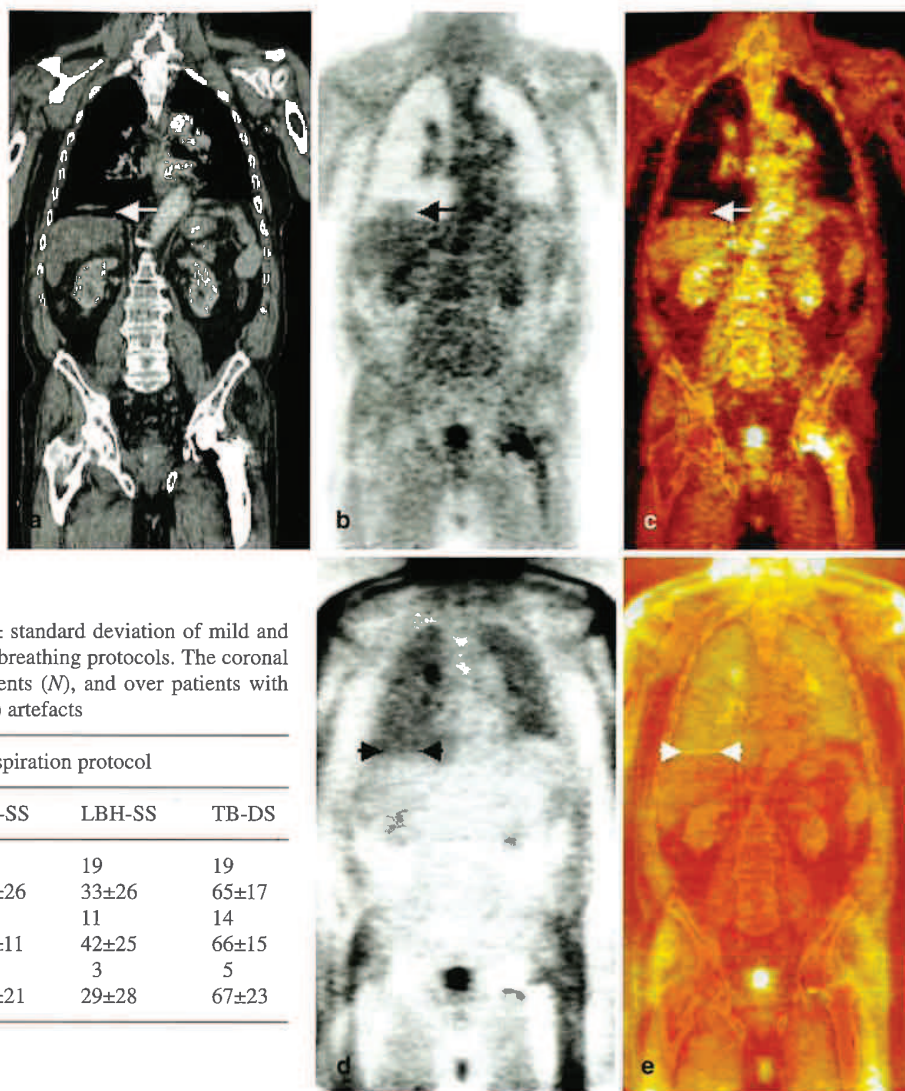


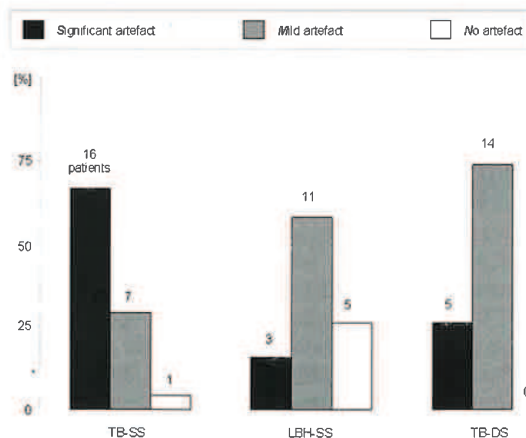
Table 3. Average coronal extent $\pm$ standard deviation of mild and significant artefacts with all three breathing protocols. The coronal extent was averaged over all patients (N), and over patients with either mild (N_m) or significant (N_s) artefacts

	Respiration protocol		
	TB-SS	LBH-SS	TB-DS
N	24	19	19
All artefacts (mm)	69 $\pm$ 26	33 $\pm$ 26	65 $\pm$ 17
N_m	7	11	14
Mild artefacts (mm)	56 $\pm$ 11	42 $\pm$ 25	66 $\pm$ 15
N_s	16	3	5
Severe artefacts (mm)	78 $\pm$ 21	29 $\pm$ 28	67 $\pm$ 23

artefacts, the use of the limited breath-hold technique (LBH-SS) again reduced the extent by a factor of 2 compared with the tidal breathing technique (TB-SS and TB-DS). Differences between single-slice and dual-slice CT were small as long as no respiration protocol was used. However, with all three respiration protocols the coronal extent of the artefacts was more variable than the axial extent (compare Table 2 and Table 3).

Figure 8 illustrates the axial width of significant artefacts. Here the width refers to the distance between the upper and lower boundaries of the fully detached soft tissue

Fig. 6. Frequency (%) of respiration artefacts in 62 patients examined with dual-modality PET/CT, according to the acquisition protocols used (Table 1): TB-SS, LBH-SS or TB-DS. CT images were classified into three classes: no artefacts, mild artefacts and significant artefacts. Using a respiration protocol on a single-slice CT or using a dual-slice CT reduces the frequency of significant artefacts due to respiration on CT images



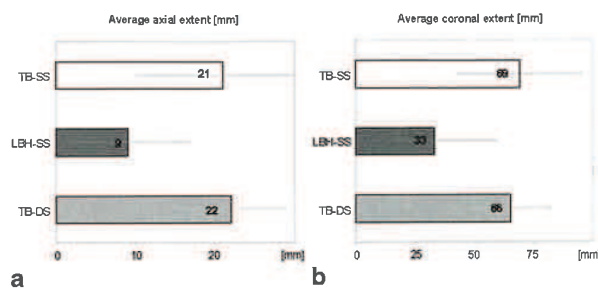


Fig. 7a, b. Average spatial extent (**a** axial, **b** coronal) of respiration artefacts in CT images of 62 patients, according to the acquisition protocol used

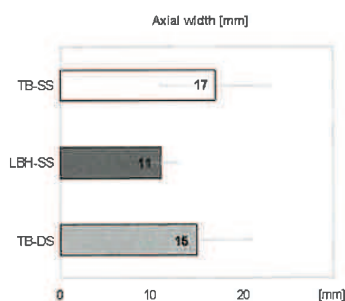


Fig. 8. Mean axial width of significant artefacts in CT images of 62 patients, according to the acquisition protocol used. The width is defined as the maximum distance between the upper and lower boundaries of fully detached soft tissue artefacts in the thorax

artefacts in the coronal CT images (Fig. 2c). If no respiration protocol was used, the maximum extent of significant artefacts was estimated to be 17 ± 6 mm on single-slice CT (TB-SS) and 15 ± 6 mm on dual-slice CT (TB-DS). When the limited breath-hold technique was applied to single-slice CT (LBH-SS), the width was reduced by up to 40% to 11 ± 2 mm. The mean distance between the lower boundary of the soft tissue detachment and the diaphragm was about 13 ± 8 mm, and ranged from as little as 4 mm to as much as 4 cm, depending on the respiration frequency.

Discussion

We found that respiration artefacts (mild and significant) occurred in 98% of all cases (42/43 patients) when no respiration technique was used (Fig. 6). The frequency of significant and mild artefacts, as well as the spatial extent of these artefacts, was reduced far more by use of the limited breath-hold technique than by use of dual-slice CT. This suggests that the introduction of a special breathing protocol is important, regardless of the number of CT detector rows available.

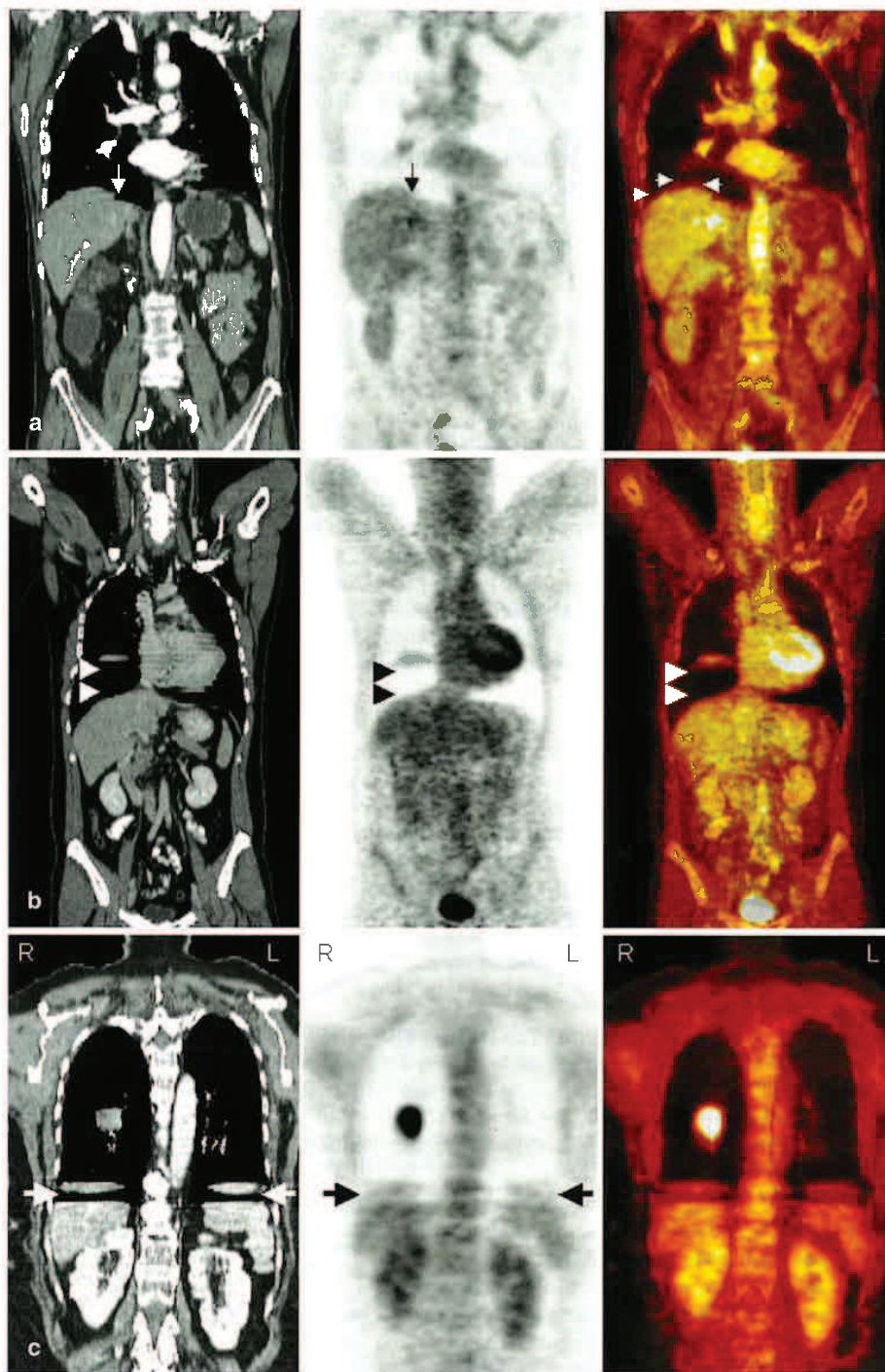
In the absence of respiratory gating mechanisms for routine clinical use in both CT and PET imaging, combi-

nation of CT respiration protocols and multi-slice CT seems an optimal means of reducing the frequency and magnitude of PET/CT image artefacts arising from involuntary patient motion. Nevertheless, use of the limited breath-hold technique, or any other respiration protocol, requires cooperative patients, and such a technique sometimes may be inapplicable in situations with (voluntarily or involuntarily) uncooperative patients. In our study, for example, we observed severe respiration artefacts on CT images of an extremely anxious patient, which extended up to 63 mm in the axial direction. On the other hand, the shorter scan times possible with multi-slice CT technology may help in achieving the required patient cooperation when breathing instructions are given.

Combined PET/CT image quality depends not only on the image quality of the CT and the PET but also on the processing of the available CT images for attenuation correction of the complementary emission data. To limit quantitative bias and artefacts in the corrected emission images, available transmission data need to be processed appropriately. For example, artefacts will be introduced in the corrected emission images if the spatial resolution of the transmission and the emission data is different [15]. Therefore a rebinning and filtering step is required in CT-based attenuation correction to match the spatial resolution of the CT data used for attenuation correction and the emission data. By degrading the spatial resolution of the CT by a factor of, typically, 5, large amounts of the intrinsic spatial detail information are lost. Thereby the propagation of artefacts from the CT may be reduced. This is illustrated in Fig. 9.

In our experience the appearance of mild and significant artefacts affects the image quality of PET/CT data differently. Mild respiration-induced artefacts on CT images tend to mask the reconstructed and corrected emission activity (Fig. 9a). This is the case when the CT image represents the morphology of a patient at a time in the respiratory cycle that closely matches the average tracer distribution, as measured over many respiration cycles during a PET examination. In contrast, significant respiration-induced artefacts are created by parts of the morphology captured on CT during remote excursion of the diaphragm and upper liver from their average movement during tidal respiration. If artefacts are distant from the diaphragm, they tend to create focally increased uptake patterns on the corrected emission images (Fig. 9b). If these artefacts are closer to the diaphragm, the PET activity distribution appears continuous between the liver and the apparent detachment, and no locally independent uptake patterns can be seen (Fig. 9c). In our study, artefacts were mostly observed in the vicinity of the diaphragm with 13 ± 8 mm average distance between the upper boundary of the liver and the lower boundary of the artefact. In significant but not in mild respiration artefacts, emission activity is seen not only in the physiological variants and in the soft tis-

Fig. 9a–c. The appearance of mild (a) and significant (b, c) artefacts in CT and corresponding PET images after CT-based attenuation correction. Mild artefacts (arrow in a) tended to "mask" the tracer uptake pattern in the corrected PET images (a, middle). Frequently the reconstructed activity exceeded the boundary of the liver (arrowheads in a, right). Significant artefacts distant from the diaphragm led to the creation of separate areas of focal uptake (b) without intermittent tracer uptake. Artefacts closer to the diaphragm (c) did not translate into the corrected emission images accordingly, and the tracer distribution extended through the gap (arrows)



sue artefact but also in the space between the artefact and the normal liver (Fig. 9c). In other words, due to the periodic motion of the diaphragm during the emission scan, tracer uptake appears smeared. This may impair quantitative assessment of lesions close to the diaphragm.

As shown by other authors, respiratory motion during CT may lead to locoregional mis-registration of the CT and PET data [16, 17]. However, by viewing complementary CT and PET images acquired as part of the same dual-modality examination in fused mode, respiration-induced artefacts on CT images can be directly correlated

with artificial uptake patterns in corrected PET images (Fig. 9). Some authors recommend viewing the emission images before attenuation correction is applied in order to exclude respiration-induced bias [18]. We feel that this might be necessary in the case of lesions in the vicinity of the diaphragm. For most clinical scenarios today, however, a combined PET/CT acquisition protocol involving a carefully designed respiration technique, like the limited breath-hold protocol described here, seems sufficient.

Conclusion

In conclusion, an appropriate respiration protocol is the main determinant of artefact-free PET/CT images of the lower thorax and upper abdomen. We have shown that application of a limited breath-hold technique when acquiring the CT part of a combined PET/CT examination significantly reduces the frequency and extent of respiration-induced artefacts in the lower thorax.

Acknowledgements. The authors like to thank Paulina Khersonskaya, Sam Hsiao, Bärbel Terschüren, Sandra Pabst, and Ruth Hall for their help with the data acquisition. This paper benefited from helpful discussions with David Townsend, Jeffrey Yap, and Thomas Bruckbauer.

References

- Gambhir SS, Czernin J, Schwimmer J, Silverman DHS, Coleman EE, Phelps ME. A tabulated summary of the FDG PET literature. *J Nucl Med* 2001; 42 (5 Suppl):1S–93S.
- Vansteenkiste JF, Stroobants SG, Dupont PJ, Leyn PRD, Wever WF, Verbeken EK, Nuyts JL, Maes FP, Bogaert JG. FDG-PET scan in potentially operable non-small cell lung cancer: Do anatomometabolic PET-CT fusion images improve the localisation of regional lymph node metastasis? *Eur J Nucl Med* 1998; 25:1495–1501.
- Hutton BF, Braun M, Thurfjell L, Lau DYH. Image registration: an essential tool for nuclear medicine. *Eur J Nucl Med* 2002; 29:559–577.
- Woods RP, Grafton ST, Holmes CJ, Cherry SR, Mazziotta JC. Automated image registration. I. General methods and intra-subject, intramodality validation. *J Comput Assist Tomogr* 1998; 22:139–152.
- Yu JN, Fahey FH, Gage HD, Eades CG, Harkness BA, Pelizzari CA, Keys JW Jr. Intermodality, retrospective image registration in the thorax. *J Nucl Med* 1995; 36:2333–2338.
- Townsend DW, Cherry S. Combining anatomy and function: the path to true image fusion. *Eur Radiol* 2001; 11:1968–1974.
- Beyer T, Townsend DW, Brun T, Kinahan PE, Charron M, Roddy R, Jerin J, Young J, Nutt R, Byars LG. A combined PET/CT tomograph for clinical oncology. *J Nucl Med* 2000; 41:1369–1379.
- Kinahan PE, Townsend DW, Beyer T, Sashin D. Attenuation correction for a combined 3D PET/CT scanner. *Med Phys* 1998; 25:2046–2053.
- von Schulthess GK. Cost considerations regarding an integrated CT-PET system. *Eur Radiol* 2000; 10 (Suppl 3):S377–S380.
- Hoh CK, Hawkins RA, Glaspy JA, Dahlbom M, Tse NY, Hoffman EJ, Schiepers C, Choi Y, Rege S, Nitzsche E, Maddahi J, Phelps ME. Cancer detection with whole-body PET using 2-[¹⁸F]fluoro-2-deoxy-d-glucose. *J Comput Assist Tomogr* 1993; 17:582–589.
- Beyer T, Townsend D, Blodgett T. Dual-modality PET/CT tomography for clinical oncology. *Q J Nucl Med* 2002; 46:24–34.
- Goerres GW, Kamel E, Heidelberg T-NH, Schwitter MR, Burger C, von Schulthess GK. PET-CT image co-registration in the thorax: influence of respiration. *Eur J Nucl Med* 2002; 29:351–360.
- Beyer T, Townsend D. Dual-modality PET/CT imaging: CT-based attenuation correction in the presence of CT contrast agents. *J Nucl Med* 2001; 42:56P.
- Carney J, Beyer T, Brasse D, Yap J, Townsend D. Clinical PET/CT scanning using oral CT contrast agents. *J Nucl Med* 2002; 43:57P.
- Meikle SR, Dahlbom M, Cherry SR. Attenuation correction using count-limited transmission data in positron emission tomography. *J Nucl Med* 1993; 34:143–150.
- Cohade C, Osman M, Wahl RL. Accuracy of PET and CT spatial registration of lung lesions with PET-CT. *J Nucl Med* 2002; 43:14P–15P.
- Nakamoto Y, Cohade C, Osman M, Tatsumi M, Traughber BJ, Marshall LT, Wahl RL. Comparison of size and location of normal upper abdominal organs on PET and CT using PET/CT. *J Nucl Med* 2002; 43:14P.
- Osman MM, Cohade C, Nakamoto Y, Wahl RL. Clinically significant inaccurate localization of lesions with PET-CT: frequency in 275 patients. *J Nucl Med* 2002; 43:32P.

Respiratory motion artifacts on PET emission images obtained using CT attenuation correction on PET-CT

Medhat M. Osman², Christian Cohade¹, Yuji Nakamoto¹, Richard L. Wahl¹

¹ Department of Radiology, Division of Nuclear Medicine, The Johns Hopkins University School of Medicine, Baltimore, USA

² Department of Internal Medicine, Division of Nuclear Medicine, Saint Louis University, St. Louis, USA

Received: 7 May 2002 / Accepted: 16 September 2002 / Published online: 21 January 2003

© Springer-Verlag 2003

Abstract. PET-CT scanners allow generation of transmission maps from CT. The use of CT attenuation correction (CTAC) instead of germanium-68 attenuation correction (Ge AC) might be expected to cause artifacts on reconstructed emission images if differences in respiratory status exist between the two methods of attenuation correction. The aim of this study was to evaluate for possible respiratory motion artifacts (RMA) in PET images attenuation corrected with CT from PET-CT in clinical patients. PET-CT scans were performed using a Discovery LS PET-CT system in 50 consecutive patients (23 males, 27 females; mean age 58.2 years) with known or suspected malignancy. Both CTAC and Ge AC transmission data obtained during free tidal breathing were used to correct PET emission images. Cold artifacts at the interface of the lungs and diaphragm, believed to be due to respiratory motion (RMA), that were seen on CTAC images but not on the Ge AC images were evaluated qualitatively on a four-point scale (0, no artifact; 1, mild artifact; 2, moderate artifact; 3, severe artifact). RMA was also measured for height. Curvilinear cold artifacts paralleling the dome of the diaphragm at the lung/diaphragm interface were noted on 84% of PET-CT image acquisitions and were not seen on the ⁶⁸Ge-corrected images; however, these artifacts were infrequently severe. In conclusion, RMA of varying magnitude were noted in most of our patients as a curvilinear cold area at the lung/diaphragm interface, but were not diagnostically problematic in these patients.

Keywords: PET/CT – Image fusion – Artifact – Respiratory motion

Eur J Nucl Med Mol Imaging (2003) 30:603–606

DOI 10.1007/s00259-002-1024-x

Introduction

Positron emission tomography (PET) provides unique information regarding tumor biology, but the lack of anatomical landmarks on PET can make precise lesion localization challenging. Software image fusion can be applied to address this problem but is often logistically challenging owing to differences in the patient's positioning between studies. PET-CT systems can acquire anatomical and functional information in the same examination in very close temporal proximity [1]. In such systems, CT data can be used for PET attenuation correction (AC) instead of the traditionally used germanium-68 and is much faster [2].

Artifacts originating from the use of CT data for AC, rather than ⁶⁸Ge transmission data, are not yet well characterized. While translation of the patient's body between PET and CT is a possible source of misalignment, physiological activities like breathing might also result in artifacts. Artifacts might be expected if differences in respiratory status were to exist between the PET and CT images. For example, if the lungs were to be more inflated on CT than on PET, an attenuation value derived from the lung (which has low attenuation) might be applied to the upper liver, resulting in underestimation of the upper liver's true radioactivity level. The purpose of this study in clinical patients was twofold: (a) to evaluate whether respiratory motion artifacts (RMA) exist at the level of the interface of the diaphragm and lung in PET images that have been attenuation corrected with CT from PET-CT and (b) to compare these images with images attenuation corrected using ⁶⁸Ge transmission images, the historical standard.

Richard L. Wahl (✉)

Department of Radiology, Division of Nuclear Medicine,
The Johns Hopkins University School of Medicine,
601 N. Caroline St., Rm 3223A, Baltimore, MD 21287-0817 USA
e-mail: wahl@jhmi.edu
Tel.: +1-410-6143764, Fax: +1-443-2872933

Materials and methods

Patients. Images from 50 (23 males, 27 females; mean age 58.2 years) sequential clinical patients who underwent PET-CT scans (GE Discovery LS PET-CT system) in our institution for known or suspected cancer were assessed.

PET-CT scanning. After 4 h of fasting, approximately 555 MBq of fluorine-18 fluorodeoxyglucose (FDG) was injected intravenously, followed by an approximately 55-min uptake phase. Patients were given no specific breathing instructions during the image acquisition (tidal breathing expected).

CT scanning. Parameters were as follows for 5–7 bed acquisitions: 140 kV, 80 mA, 0.8 s per CT rotation, pitch of 6, 22.5 mm/s table speed, 722.5–1011.5 mm coverage, 31.9–37 s acquisition time. CT acquisition was performed before emission acquisition. Five-millimeter-thick sections were re-sliced to 4.25 mm in thickness. CT data were resized from 512×512 matrix to a 128×128 matrix to match PET data in order to fuse images and generate CT transmission maps.

PET scanning and image processing. Emission data were acquired for 5–7 bed positions, typically from the base of the skull through the mid-thigh (722.5–1011.5 mm coverage, identical to the CT protocol). Emission data were acquired for 5 min for each bed position (35 scanning planes, 14.6 cm longitudinal field of view, one slice overlap). Images were reconstructed with an 8-mm Gaussian filter using a 128×128 matrix. PET images were reconstructed using CT (CTAC) with OSEM iterative reconstruction algorithm (2 iterations, 28 subsets). Emission data were also reconstructed with segmented ^{68}Ge AC (3 min/level transmission data).

Image analysis. Both CTAC and Ge AC images were independently evaluated for the presence of RMA, a cold curvilinear defect at the interface of the lower lung and diaphragm. RMA was qualitatively rated on a four-point scale (0, no artifact; 1, mild artifact; 2, moderate artifact; 3, severe artifact) by one observer (M.O.). RMA was also quantified as the vertical distance between the top and bottom of the cold artifact (located at the apparent interface of the lower lung and diaphragm) in the right lung (anterior, middle, posterior) and the left lung (posterior only owing to the heart). To quantify the RMA, the mid-plane of the chest was visually located on the relevant coronal PET views and measurements were made on the sagittal views (Fig. 1). Upper and lower regions of interest were placed to define the extent of the artifact, and the cranial caudal extent of the cold defect was measured.

Results

Curvilinear cold artifacts paralleling the dome of the diaphragm at the apparent lung/diaphragm interface were commonly noted on PET-CT image acquisitions but were not seen on the ^{68}Ge -corrected acquisitions (Fig. 1). In the right lung, 8 patients (16%) had no RMA, 33

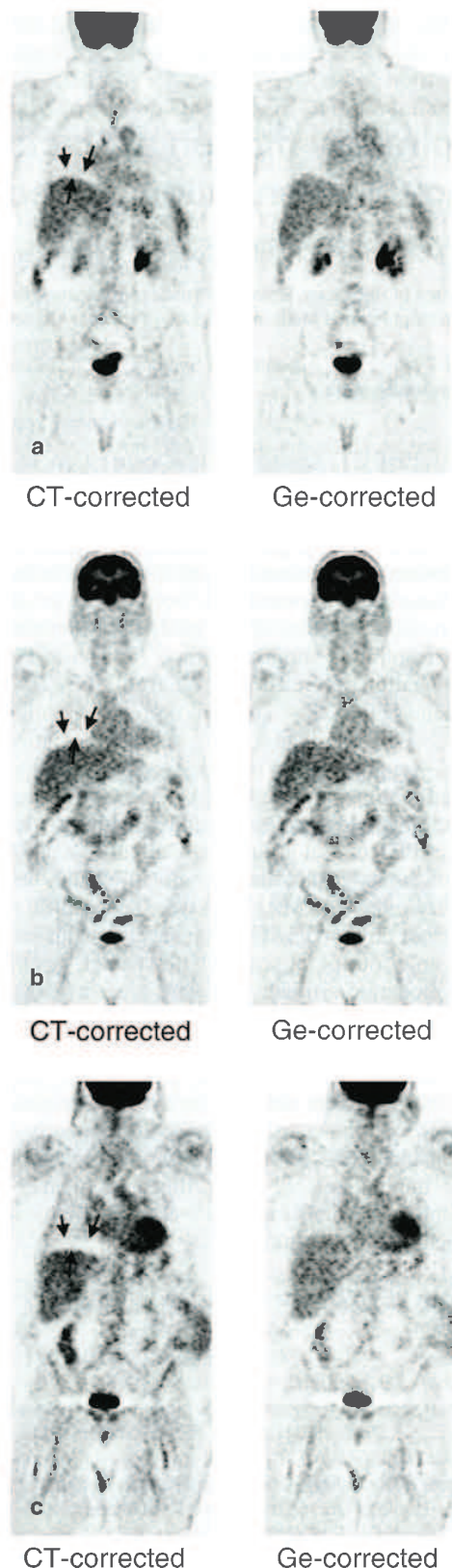


Fig. 1a–c. Examples of mild (a), moderate (b), and severe (c) RMA on CT-corrected emission FDG-PET images and comparative ^{68}Ge -corrected images of the same patients

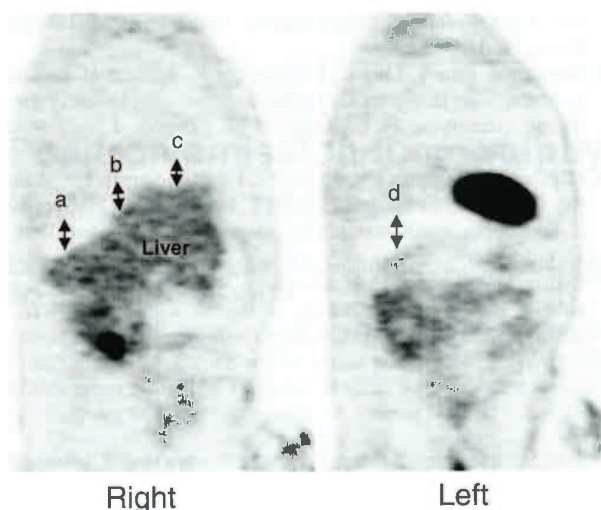


Fig. 2. Examples of quantitative assessment of RMA. In the right lung: a, posterior; b, middle; c, anterior; in the left lung: d, posterior

Table 1. Qualitative assessment of RMA using a three-point scale

Extent of RMA	Right lung	Left lung
Absent (0)	8 pts (16%)	8 pts (16%)
Mild (1)	33 pts (66%)	31 pts (62%)
Moderate (2)	8 pts (16%)	6 pts (12%)
Severe (3)	1 pt (2%)	5 pts (10%)

Table 2. Quantitative assessment of RMA

Site of RMA measurement	Right lung	Left lung
Anterior	16.4±10.5 mm	Not measured
Middle	14.3±7.6 mm	Not measured
Posterior	13.6±8.6 mm	17.8±10.8 mm

(66%) had mild RMA, 8 (16%) had moderate RMA, and one (2%) had severe RMA. In the left lung, 8 patients (16%) had no RMA, 31 (62%) had mild RMA, 6 (12%) had moderate RMA, and 5 (10%) had severe RMA (Table 1). Figure 1 shows examples of mild (a), moderate (b), and severe (c) RMA and comparative ^{68}Ge -corrected images for the same patients.

RMA was quantified on the sagittal view (Fig. 2). RMA was 16.4 ± 10.5 mm at the anterior, 14.3 ± 7.6 mm at the middle, and 13.6 ± 8.6 mm at the posterior aspect of the right lung base and 17.8 ± 10.8 mm at the posterior aspect of the left lung base (Table 2). RMA could not be evaluated immediately adjoining the heart as myocardial uptake of FDG masks a large portion of the anterior aspect of the left lung.

None of the patients included in this study had an FDG-avid lesion in the region of the respiratory artifact. Thus, RMA in this study did not interfere with interpretation of CTAC PET images.

Discussion

We demonstrated that curvilinear cold artifacts (RMA) paralleling the dome of the diaphragm at the lung bases were frequently present on PET images obtained at free tidal breathing using CTAC. The RMA was mild in severity in most patients and was more noticeable in the right lung than in the left lung. RMA was not present in Ge AC images. The "cold" defect is likely due to an inaccurate correction for photon attenuation at the interface of the lung base and diaphragm owing to inconsistencies in the position of the interface between PET and CT acquisitions. The most likely source of the artifact is under-attenuation correction for the upper liver imaged at PET owing to larger lung volumes on the CT (single breath) than on the emission PET (free breathing with the expiratory phase predominant) [1, 2, 3].

Goerres has reported that the normal expiration provides excellent co-registration between PET and CT [4]. However, many cancer patients may not be able to tolerate a long breath hold. Thus, the breath-holding approach may not be practical in day-to-day clinical practice in all patients. It is probable that our tidal breathing approach may entail a smaller lung volume on PET than on CT (as expiration is longer than inspiration). This may account for inconsistencies in the AC map and the RMA that we observed.

Expiratory imaging or respiratory gating approaches should be studied to determine whether they reduce the frequency of RMA [4, 5, 6]. In the absence of careful study of those approaches, it is important to be familiar with the cold RMA. While RMA was commonly present using the free tidal breathing acquisition protocol that we find clinically practicable, RMA did not result in diagnostic challenges in the studied population. However, in a separate larger study, RMA resulted in infrequent (2%) but potentially serious localization errors [7].

Conclusion

RMA of some degree was visualized at the lung/diaphragm interface in most (84%) of our patients on CTAC PET images, likely due to differing positions of the liver and lung between CT and the subsequent PET images. Marked RMA was seen in only 10% of patients. It is important to be aware of RMA as a source of commonly seen cold artifacts at the lung/diaphragm interface in PET-CT images. RMA was not clinically problematic in the current study but warrants further study in patients with lesions located in the upper liver or lower lung fields as well as systematic approaches to minimize the artifact.

References

1. Beyer T, Townsend DW, Brun T, Kinahan PE, Charron M, Roddy R, Jerin J, Young J, Byars L, Nutt R. A combined PET/CT scanner for clinical oncology. *J Nucl Med* 2000; 41:1369–1379.
2. Kinahan PE, Townsend DW, Beyer T, Sashin D. Attenuation correction of a combined 3D PET/CT scanner. *Med Phys* 1998; 25:2046–2053.
3. Akhurst T, Chisin R. Hybrid PET/CT machines: optimized PET machines for the new millennium? *J Nucl Med* 2000; 41:961–962.
4. Goerres GW, Kamel E, Heidelberg T-NH, Schwitter MR, Burger C, von Schulthess GK. PET-CT image co-registration in the thorax: influence of respiration. *Eur J Nucl Med* 2002; 29:351–360.
5. Nehmeh S, Erdi Y, Ling C, Rosenzweig K, Schoder H, Larson S, Macapinlac H, Squire O, Humm J. Effect of respiratory gating on quantifying PET images of lung cancer. *J Nucl Med* 2002; 43:876–881.
6. Miyauchi T, Raylman RR, Kison PV, Paberzs, Shreve PD, Wahl RL. Can respiratory gated FDG-PET improve quality in thoracic and upper abdominal tumor imaging? *J Nucl Med* 1996; 35:135 Suppl.
7. Osman MM, Cohade C, Nakamoto Y, Wahl RL. Clinically significant inaccurate localization of lesions with PET-CT: frequency in 275 patients. *J Nucl Med* 2003 (in press)



Journals, Magazines, Newspapers

European journal of nuclear medicine and molecular imaging

AVAILABLE AS

Online

Physical



[View Online](#)



[Available Issues / Request a Copy](#)

[Citation](#)

Details

Physical Locations



Multiple items exist. Use [Available Issues / Request a Copy](#) to see what's on the shelf.

Middleton Shelving Facility

by request only

Q 7EU46461 (34-V-6)

This Location Has

v.29(2002)-v.31(2004)

v.32:no.1(2005)-v.32:no.3(2005)

v.32:no.5(2005)

v.32:no.7(2005)-v.32:no.12(2005)

v.33(2006)

Supplements

v.29:suppl.1(2002)-v.29:suppl.2(2002)

v.30:suppl.1(2003)-v.30:suppl.2(2003)

v.31:suppl.1(2004)-v.31:suppl.2(2004)

v.32:suppl.2(2005)

v.33:suppl.1(2006)-v.33:suppl.2(2006)

Publication Details**OTHER TITLE**

European journal of nuclear medicine

FORMAT

Journals, Magazines, Newspapers

LANGUAGE

English

CONTRIBUTORS[European Association of Nuclear Medicine](#)

PUBLICATION

Heidelberg, Germany : Springer-Verlag, c2001-

PUBLICATION DATES

Vol. 29, no. 1 (Jan. 2002)-

PHYSICAL DETAILS

volumes : illustrations ; 28 cm

ISSNS

1619-7089, 1619-7070

OCLC

ocm49348061, ocm51876601

PRECEDING TITLES

[European journal of nuclear medicine](#)

Notes

Title from cover.
Chemical abstracts
Index medicus v29n1, Jan. 2002-
MEDLINE v29n1, Jan. 2002-
PubMed v29n1, Jan. 2002-
Available also online.

Subjects

[Nuclear Medicine -- periodicals.](#)

Medical Subject Heading

[Radioisotopes -- therapeutic use -- periodicals.](#)

Medical Subject Heading

[Diagnostic Imaging -- periodicals.](#)

Medical Subject Heading

[Diagnostic Techniques, Radioisotope -- periodicals.](#)

Medical Subject Heading

Content Types

[periodicals](#)

Additional Information

Library Staff Details



The Library has...

Viewing the library holdings for: [European journal of nuclear medicine and molecular imaging](#)

Middleton Shelving Facility

NUMBER OF ITEMS
30 items

Details

LOCATION
by request only

CALL NUMBER
Q 7EU46461 (34-V-6)

COUNT
30 items

This Location Has

v.29(2002)-v.31(2004)

v.32:no.1(2005)-v.32:no.3(2005)

v.32:no.5(2005)

v.32:no.7(2005)-v.32:no.12(2005)

v.33(2006)

Supplements

v.29:suppl.1(2002)-v.29:suppl.2(2002)

v.30:suppl.1(2003)-v.30:suppl.2(2003)

<https://search.library.wisc.edu/catalog/999932262702121/holdings?from=locations>

1/3

Volkswagen Exhibit 1025, Page 35 of 43

v.31:suppl.1(2004)-v.31:suppl.2(2004)

v.32:suppl.2(2005)

v.33:suppl.1(2006)-v.33:suppl.2(2006)

Materials

✓ v. 33, suppl. 1-2 2006

Issue

✓ v. 33, no. 10-12 2006

Issue

✓ v. 33, no. 7-9 2006

Issue

✓ v. 33, no. 4-6 2006

Issue

✓ v. 33, no. 1-3 2006

Issue

✓ v. 32, suppl. 2 2005

Issue

✓ v. 32, no. 11-12 2005

Issue

✓ v. 32, no. 9-10 2005

Issue

✓ v. 32, no. 7-8 2005

Issue

✓ v. 32, no. 5 2005

Issue

✓ v. 32, no. 1-3 2005

Issue

✓ v. 31, suppl. 2 2004

Issue

✓ v. 31, no. 12 & suppl. 1 2004

Issue

✓ v. 31, no. 9-11 2004

Issue

 v. 31, no. 7-8 2004

Issue

 v. 31, no. 5-6 2004

Issue

 v. 31, no. 3-4 2004

Issue

 v. 31, no. 1-2 2004

Issue

 v. 30, suppl. 1-2 2003

Issue

 v. 30, no. 11-12 2003

Issue

 v. 30, no. 9-10 2003

Issue

 v. 30, no. 7-8 2003

Issue

 v. 30, no. 5-6 2003

Issue

 v. 30, no. 3-4 2003

Issue

 v. 30, no. 1-2 2003

Issue

 v. 29, suppl. 1-2 2002

Issue

 v. 29, no. 10-12 2002

Issue

 v. 29, no. 7-9 2002

Issue

 v. 29, no. 4-6 2002

Issue

 v. 29, no. 1-3 2002

Issue

Diagnostic Techniques, Radioisotope -- periodicals.
Medical Subject Heading

Content Types

periodicals

Additional Information

Library Staff Details

^

MARC Bibliographic Record

LEADER	01783cas a2200493 a 4500		
001	9957280323602122		
005	20150313114213.0		
008	020320c20029999gw mr p 0 0eng c		
010		\$a 2002252212	
016	7_	\$a101140988\$2DNLM	
022		\$a1619-7070\$y0340-6997	
030		\$aEJNMA6	
032		\$a10949\$bUSPS	
035		\$a(0CoLC)ocm49348061	
035		\$a5728032	

035		\$a(WU)5728032-uwmadisondb
035		\$a(EXLNZ-01UWI_NETWORK)999932262702121
040		\$aWAU\$beng\$cWAU\$dNLM\$dNSD\$dCAS
042		\$alcd
060	00	\$aW1\$bEU72DJ
210	10	\$aEur J Nucl Med Mol Imaging\$2dnlm
245	00	\$aEuropean journal of nuclear medicine and molecular imaging.
246	17	\$aEuropean journal of nuclear medicine
246	3_	\$aEuropean journal of nuclear medicine & molecular imaging
260		\$aHeidelberg, Germany :\$bSpringer-Verlag,\$cc2001-
300		\$avolumes :\$billustrations ;\$c28 cm
310		\$aMonthly
336		\$atext\$btxt\$2rdacontent
337		\$aunmediated\$bn\$2rdamedia
338		\$avolume\$bnc\$2rdacarrier
362	0_	\$aVol. 29, no. 1 (Jan. 2002)-
500		\$aTitle from cover.
510	0_	\$aChemical abstracts\$x0009-2258
510	1_	\$aIndex medicus\$x0019-3879\$bv29n1, Jan. 2002-
510	1_	\$aMEDLINE\$bv29n1, Jan. 2002-
510	1_	\$aPubMed\$bv29n1, Jan. 2002-

530		\$aAvailable also online.
550		\$aOfficial journal of the European Association of Nuclear Medicine (EANM).
650	12	\$aNuclear Medicine\$vperiodicals.
650	22	\$aRadioisotopes\$xtherapeutic use\$vperiodicals.
650	22	\$aDiagnostic Imaging\$vperiodicals.
650	22	\$aDiagnostic Techniques, Radioisotope\$vperiodicals.
710	2_	\$aEuropean Association of Nuclear Medicine.
780	00	\$tEuropean journal of nuclear medicine\$x0340-6997\$w(DLC)sn 82004503\$w(OCOLC)02502280
997		\$aMARCIVE
LEADER	02432nas--2200661-a-4500	
001	991021972777702122	
005	20250121180436.0	
006	m-----o--d-----	
007	cr-unu	
008	030318c20029999gw-mr-pso-----0---a0eng-c	
010		\$a 2008233049
016	7_	\$a013089518\$2Uk
022		\$a1619-7089
035		\$a(DE-599)ZDB1459062-1
035		\$a(OCOLC)51876601
035		\$a(CKB)111025029846004

035		\$a(CONSER)--2008233049
035		\$a(EXLCZ)99111025029846004
042		\$apcc
050	00	\$aR895.A1
060	00	\$aW1\$bEU72DJ
082	04	\$a616.07575
130	0_	\$aEuropean journal of nuclear medicine and molecular imaging (Online)
210		\$aEUR J NUCL MED MOL IMAGING
210		\$aEUROPEAN JOURNAL OF NUCLEAR MEDICINE & MOLECULAR IMAGING
210		\$aEUR. J. NUCL. MED. MOL. IMAGING
210		\$aEUR J NUCL MED MOL I
245	10	\$aEuropean journal of nuclear medicine and molecular imaging.
246	13	\$aEuropean journal of nuclear medicine
260		\$aBerlin :\$bSpringer-Verlag
310		\$aMonthly
336		\$atext\$btxt\$2rdacontent
337		\$acomputer\$bc\$2rdamedia
338		\$aonline resource\$bcr\$2rdacarrier
362	1_	\$aVol. 29, issue 1 (Jan. 2002)-
500		\$aRefereed/Peer-reviewed

525		\$aSupplements accompany some issues.
538		\$aMode of access: World Wide Web.
550		\$aOfficial journal of the European Association of Nuclear Medicine (EANM).
588	0_	\$aFirst issue; title from journal home page (SpringerLink, viewed Jan. 14, 2008).
588	1_	\$aVol. 46, issue 1 (Jan. 2018) (viewed Dec. 13, 2018).
650	_0	\$aNuclear medicine\$vPeriodicals.
650	_0	\$aDiagnostic imaging\$vPeriodicals.
650	12	\$aNuclear Medicine.
650	22	\$aDiagnostic Imaging.
650	22	\$aDiagnostic Techniques, Radioisotope.
650	22	\$aRadioisotopes\$xtherapeutic use.
650	_7	\$aNuclear Medicine.\$2ebps
650	_7	\$aMolecular Imaging.\$2ebps
650	_7	\$aDiagnostic imaging.\$2fast\$0(OCOLC)fst00892354
650	_7	\$aNuclear medicine.\$2fast\$0(OCOLC)fst01040348
655	_7	\$aPeriodicals.\$2fast\$0(OCOLC)fst01411641
655	_7	\$aPeriodicals.\$2lcgft
650	_7	\$aMedicina nuclear\$2thub
655	_7	\$aRevistes electròniques\$2thub
780	00	\$tEuropean Journal of Nuclear Medicine\$w(CKB)954925519624\$w(DLC)sn82004503\$x1432-

		105X
776	08	\$x1619-7070
710	2_	\$aEuropean Association of Nuclear Medicine,\$eissuing body.
906		\$aJOURNAL

MMS IDs**Document ID:** 999932262702121**Network Electronic IDs:** 9911030212602121**Network Physical IDs:** 999932262702121**mms_mad_ids:** 9957280323602122, 991021972777702122**mms_ec_ids:** 99925243318802134**mms_gb_ids:** 991006761691102123**mms_lc_ids:** 991016450659402125**mms_ml_ids:** 991012378487302124**mms_osh_ids:** 991004567788402126**mms_pl_ids:** 99901303943802127**mms_plt_ids:** 991013466417902128**mms_rf_ids:** 991013780026202129**mms_sf_ids:** 991014911017002130**mms_st_ids:** 991013503869602131**mms_sup_ids:** 99916320805902132**mms_ww_ids:** 991015504155402133